Energy Efficiency as a Means to Redress the Energy Security Challenge in India: An Assessment

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Anushree Mistry declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy in the School of Information, Systems and Modelling in the Faculty of Engineering and Information Technology at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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List of Abbreviations

APEC	Asia-Pacific Economic Cooperation
ASI	Annual Survey of Industries
AT&C	Aggregated Technical and Commercial
BAU	Business-as-Usual
BCM	Billion Cubic Metres
BEE	Bureau of Energy Efficiency
BLY	Bachat Lamp Yojana
BRIC	Brazil, Russia, India and China
CAGR	Compound Annual Growth Rate
CBM	Coal Bed Methane
CCS	Carbon Capture and Sequestration
CCUS	Carbon Capture, Utilisation and Storage
CEA	Central Electricity Agency
CES	Constant Elasticity of Substitution
CFEP	Carbon Free Energy Portfolio
CFL	Compact Fluorescent Lamps
CGE	Computable General Equilibrium
CIL	Coal India Limited
CIS	Change in Stocks
CLD	Causal Loop Diagram
CNG	Compressed Natural Gas
CP	Country Policy
CSO	Central Statistics Office of India
DGCI&S	Directorate General of Commercial Intelligence and Statistics
DISCOMS	Distribution Companies
DRI	Direct Reduced Iron

DSM	Demand-Side Management
EAF	Electric Arc Furnace
ECBC	Energy Conservation Building Code
EEFP	Energy Efficiency Financing Platform
EEZ	Exclusive Economic Zone
EGEAS	Electric Generation Expansion Analysis System
EIA	Energy Information Administration
ESC	Energy Saving Certificates
ESCO	Energy Service Companies
ETSAP	Energy Technology Systems Analysis Programme
FDI	Foreign Direct Investment
FEEED	Framework for Energy Efficiency Economic Development
GAMS	General Algebraic Modelling System
GDP	Gross Domestic Product
GFCE	Government Final Consumption Expenditure
GFCF	Gross Fixed Capital Formation
GHG	Greenhouse Gases
GTAP	Global Trade Analysis Project
GVA	Gross Value Added
HHI	Herfindahl-Hirschman Index
HT	Historical Trends
ICL	Incandescent Lamp
IEA	International Energy Agency
IEF	International Energy Forum
IEG	Institute of Economic Growth
IGCC	Integrated Gasification Combined Cycle
IPCC	Intergovernmental Panel on Climate Change

IREDA	Indian Renewable Energy Development Agency
LED	Light Emitting Diode
LNG	Liquid Natural Gas
LPG	Liquified Petroleum Gas
MARKAL	MARKet Allocation
MOSPI	Ministry of Statistics and Programme Implementation
MRTS	Mass Rapid Transit System
MTEE	Market Transformation for Energy Efficiency
NAPCC	National Action Plan on Climate Change
NAS	National Account Statistics
NEP	National Energy Policy
NIC	National Industrial Classification
NITI	National Institution for Transforming India
NMEEE	National Mission for Enhanced Energy Efficiency
NR	Natural Resources
NSS	National Sample Survey
ORS	Other Renewable Sources
PAT	Perform-Achieve-Trade
PFCE	Private Final Consumption Expenditure
PLDV	Passenger Light-Duty Vehicles
RBI	Reserve Bank of India
REC	Renewable Energy Certificates
RET	Renewable Energy Targets
RPO	Renewable Purchase Obligation
S&L	Standards and Labelling
SAM	Social Accounting Matrix
SCD	Systematic Country Diagnostic

SDG	Sustainable Development Goals
SDS	Sustainable Development Scenario
SFD	Stock-Flow Diagrams
SIDBI	Small Industries Development Bank of India
SLNP	Street Light National Programme
T&D	Transmission and Distribution
TEEESE	TERI Energy Economy Environment Simulation Evaluation
TERI	The Energy and Resource Institute
TFC	Total Final Consumption
UCG	Underground Coal Gasification

Abstract

Prompted by the concerns about the impending energy security challenge for India, this research examines the role of energy efficiency as a means to redress this challenge. This is achieved in this research by estimating (for the period 2015-2050) the energy security and socio-economic impacts of three alternative scenarios - by employing an energy-augmented input-output-based-model, developed specifically for this research. The three scenarios are: Business-as-Usual Historic Trends (BAU-HT), Country Policy (CP) and Sustainable Futures (SF). The scenarios represent alternative future policy pathways - each characterized by different sets of economic, technological, energy and environmental considerations - that India could adopt to achieve its socio-economic aspirations. The BAU-HT scenario reflects a continuation of the current energy and economic policy trends while the CP and SF scenarios represent higher levels of commitment to promoting energy efficiency. The CP and SF scenarios broadly align with India's draft National Energy Policy 2017, and Sustainable Development Scenario in The IEA's World Energy Outlook 2017, respectively. The analysis suggests that if current policy trends continue (i.e. BAU-HT scenario), by 2050, India is likely to experience considerably worsened energy security, with a five-fold increase (compared to 2015) in primary energy requirements and GHG emissions, and high fossil fuel and energy import dependency (70 and 17%, respectively). The severity of these impacts can be considerably reduced – and, energy security improved – in the CP and SF scenarios - marked by increased emphasis on promoting energy efficiency. In the CP and SF scenarios, for example, the primary energy requirements will increase three-fold and two-fold, respectively – as compared to five-fold increase in the BAU-HT scenario. Further, the GHG emissions in the CP and SF scenarios will be 45 and 84% lower, and, energy diversity, energy import dependency, trade balance and employment, considerably better – in comparison with the BAU-HT scenario. The analysis also suggests that the macro (national) and micro (sectoral) level impacts of various scenarios could vary considerably. For instance, capital investment and employment rates in the CP and SF scenarios generally increase at the national level, whereas at the sectoral level they increase only in the non-energy sectors, and decline in the energy sectors. Insights into these impacts and associated trade-offs, it is contended, presents the Indian policymakers with a robust platform to consider the role energy efficiency can play in promoting energy security.

Chapter 1 : Introduction

It is time for a sustainable energy policy which puts consumers, the environment, human health, and peace first.

– Dennis Kucinich

1.1. Background

Externally-derived energy is essential for sustaining human life and to make life easier. We need energy for everything – to power homes, drive cars, use technology and even to feed and clothe ourselves. Energy underpins modern life – the internet, the phone system, every appliance, air conditioning and heating, everything in our offices, and our homes. We consume energy 24 hours a day and are continuously dependent on some form of energy in one way or another. Even the availability of food is made possible only by the use of energy; food is planted, harvested, processed, packaged, transported, retailed, bought and then cooked with the help of energy. Our energy production is intertwined with many other aspects of modern life, such as water consumption, economic growth, population growth and land use. On the negative side, our production and consumption of energy (mainly fossil fuels) also contribute to climate change.

The remainder of this section considers factors such as rising population, increased energy demands, improved lifestyle practices and dependence on fossil fuel sources to portray the criticality of energy to modern-day lifestyle, while at the same time highlighting the potential for declining energy security to support such lifestyle.

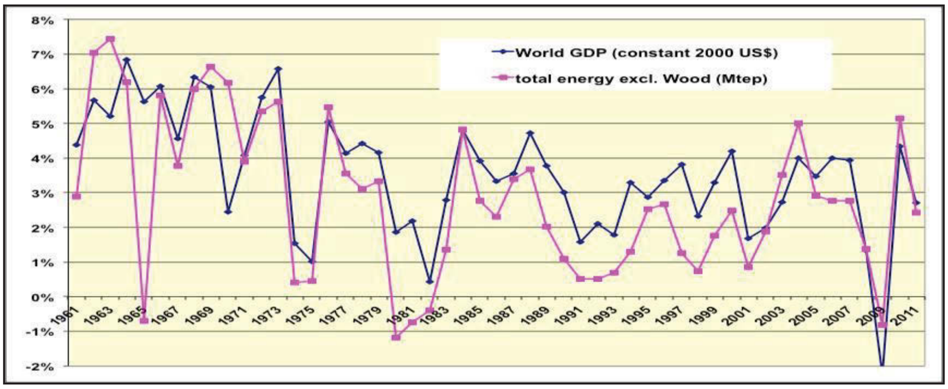


Figure 1-1: World Total Energy Consumption and Real GDP, 1980 – 2012

Source: BP (2014)

Global energy consumption has increased over time in line with growing GDP. Figure 1-1 shows how the two variables are closely entwined. It can be observed that as the world's GDP rises and falls, total global energy consumption follows a similar path. Conversely, energy consumption dropped during the 2008 recession accompanying the Global Financial Crisis, which suggests that there is a close relationship between energy demand and the economy.

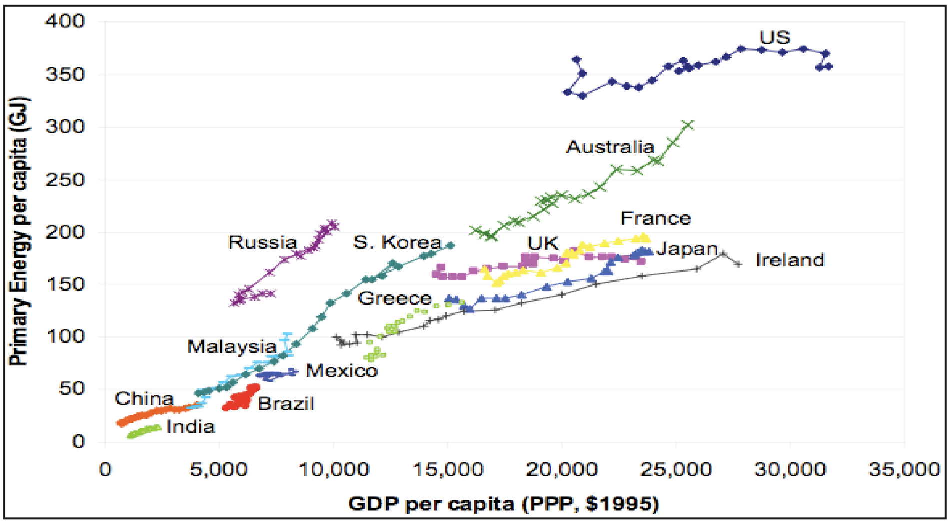


Figure 1-2: Energy Demand and GDP per capita, 1980-2002

Source: Scottish-Sceptic (2013)

Figure 1-2 shows the rising trend in energy consumption in both the developed and developing world from 1980 to 2002, in line again with rising GDP. With rapid industrialisation and growth in developing countries we see an increase in their energy use.

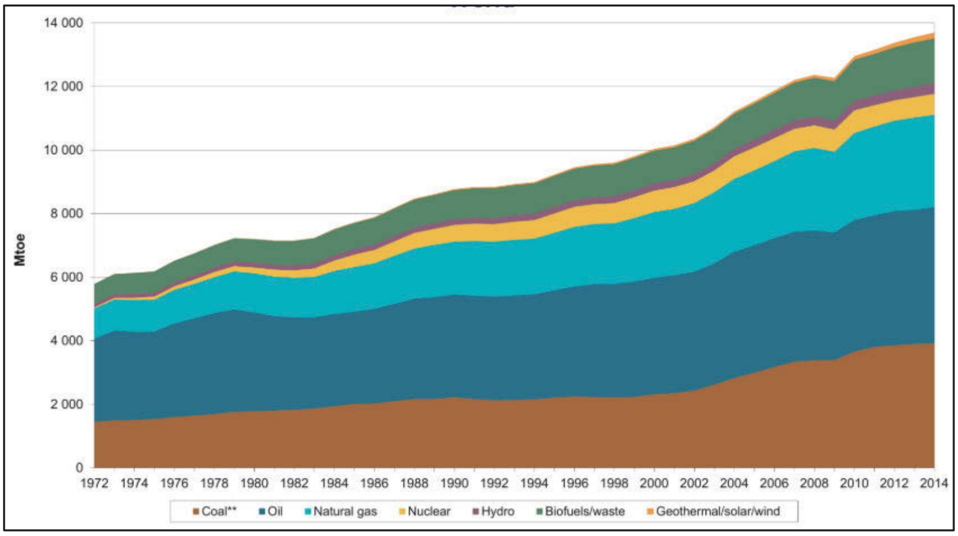


Figure 1-3: Total Primary Energy Supply in Mtoe, 1970 – 2012

Source: IEA (2014)

Improved lifestyle conditions accompanied by a growing global population have resulted in more and more people migrating from rural villages to urban cities. To meet the energy demands of this increasingly urbanised population, there has been a growing trend in energy supply of the various primary energy resources, as can be observed in Figure 1-3, with the total primary energy supply increasing from 6,106 Mtoe in 1973 to 13,371 Mtoe in 2012 (IEA, 2014).

The global population is projected to reach 8 billion by 2028, 9 billion by 2054 and stabilise at just above 10 billion after 2200 and the population of India is projected to reach 1.38 billion by 2020, 1.5 billion by 2030 and 1.7 billion by 2050. Forecasts predict that the growth in population will be accompanied by considerable growth in the energy demand in the coming decades, particularly in developing countries (United Nations Population Division, 1999).

Every year our population is rising exponentially but the natural energy resources on which we are dependent to sustain our lives remain finite. In many parts of the world, the population growth is at rates that cannot be sustained by indigenous resources and exceed any expectations of improvements in housing, health care or energy supplies (Arriaga,2004). If projections are accurate, energy will continue to be a prerequisite to fulfilling our growing demands.

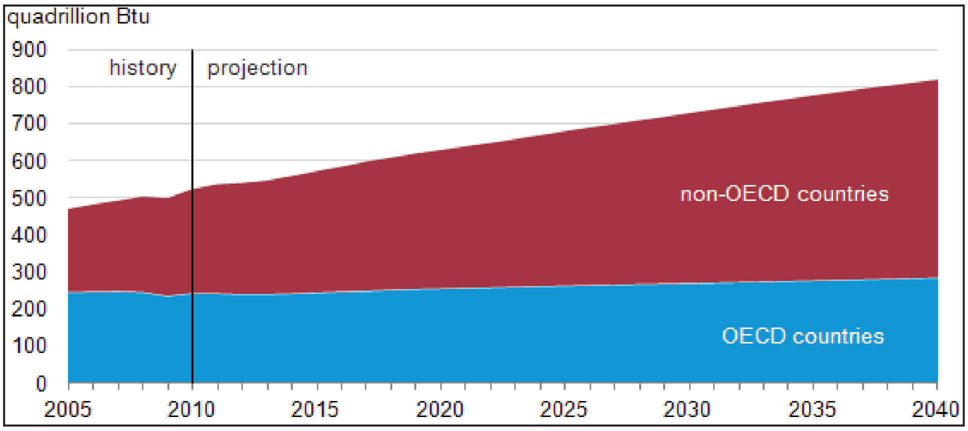


Figure 1-4: Projected World Primary Energy Consumption, 2005 – 2040

Source: EIA (2013)

Region	2010	2015	2020	2025	2030	2035	2040	Average annual percent change 2010-2040
OECD	**242**	**244**	**255**	**263**	**269**	**276**	**285**	**0.5**
Americas	120	121	126	130	133	137	144	0.6
Europe	82	82	85	89	91	93	95	0.5
Asia	40	41	43	44	45	46	46	0.5
Non-OECD	**282**	**328**	**375**	**418**	**460**	**501**	**535**	**2.2**
Europe and Eurasia	47	50	53	57	61	65	67	1.2
Asia	159	194	230	262	290	317	337	2.5
Middle East	28	33	37	39	43	46	49	1.9
Africa	19	20	22	24	27	31	35	2.1
Central and South America	29	31	33	35	39	42	47	1.6
World	**524**	**572**	**630**	**680**	**729**	**777**	**820**	**1.5**

Table 1-1: World Energy Consumption by country grouping, 2010-2040 (quadrillion Btu)

Source: US Energy Information Agency (2013)

According to the Energy Information Administration's (EIA) *International Energy Outlook, 2013*, the world's primary energy consumption is projected to increase and a large proportion of this increase will be from developing nations in the non-OECD region, as seen in Figure 1-4 and Table 1-1. These show that while the energy patterns for the OECD countries are predicted to be relatively stable between 2010 and 2040, most of this new demand will come from the new emerging economies of India and China, which by 2035 will account for more than 90% of the net energy demand growth (IEA, 2013). These rising energy demands engendered by economic progress and improved standard of living are likely to add to the pressures on energy supplies, increasing the dependence of those countries on imported energy supplies and non-renewable energy sources.

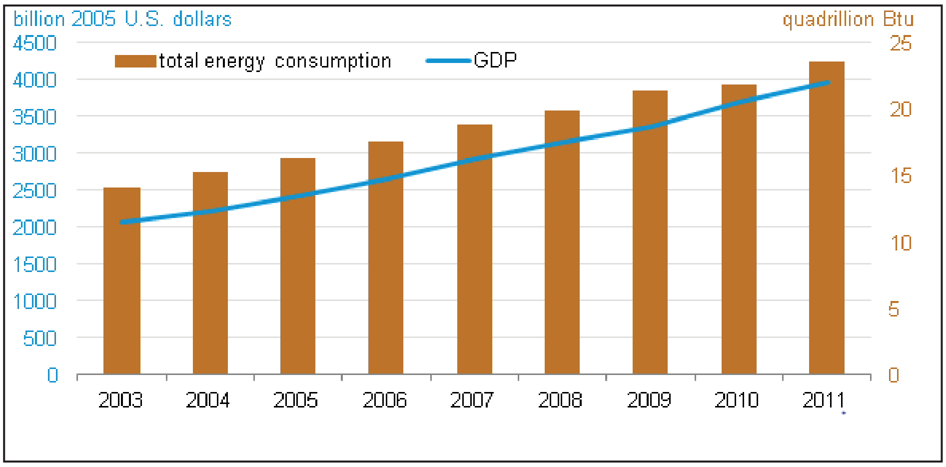


Figure 1-5: India's Total Energy Consumption and Real GDP, 2000 – 2012

Source: US Energy Information Administration, (2013)

India, the focus of this research, is ranked as the second most populated, third largest economy and the fourth largest consumer of energy in the world. As shown in Figure 1-5, according to the EIA statistics of 2012, India's real GDP growth was accompanied by even greater growth in energy consumption.

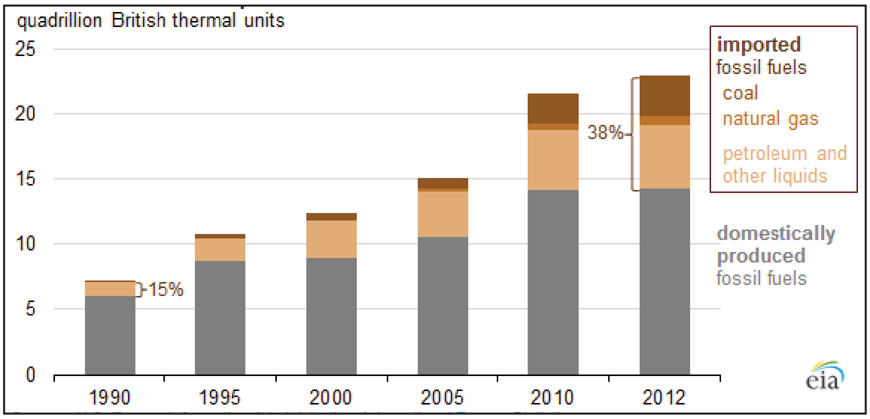


Figure 1-6: India's Fossil Fuel Consumption, 1990-2012

Source: Dunn (2014)

As can be observed in Figure 1-6, India's dependence on imported fossil fuels rose to 38% in 2012. As the country's economic development gathers pace, there is an increased demand for the availability of more reliable sources of energy.

The above discussion shows that energy and economy are closely related. Rising GDP means people can afford to buy more and more goods and services. These goods require energy to be produced and manufactured, and that energy globally is currently sourced mainly from fossil fuels.

Most global energy policies are formulated on the basis of Say's Law, '*Supply creates its own demand*.' This epigram seems to suggest that huge investments in expanding the capacity of existing power plants along with building new power plants, trade agreements between nations to provide for energy resources and the implementation of new and improved technologies, creates new demand in terms of buying coal to fuel the power plants, purchasing steel, cement and other raw materials required to construct new power plants.

Traditionally the world, including India, has dealt with supply-side approaches to energy because they are politically appealing and encourage investment in new projects, which in turn enhances growth and helps to create new employment opportunities.

However, these supply-side options have their own disadvantages, an example being that investing in infrastructure development requires funding. According to the IEA's *World Energy Investment Outlook 2014*, almost US$1,000 billion of the current global supply investment was in the primary supply of oil and natural gas and an additional US$650 billion was in electricity sector worldwide. Much of this investment was needed just to maintain current energy levels and it is estimated that to continue to meet the world's energy needs an annual spend of US$2,000 billion will be required, bringing the global energy supply investment figure to about US$40 trillion over the period to 2035.

Additionally, a growing number of economies are becoming dependent on fuel imports dominated by fossil fuel energy resources, which is leading to increased geopolitical tensions (International Renewable Energy Agency (IRENA), 2019). All these factors often contribute to rising energy prices, which is counter to the global principal energy policy of *affordability*.

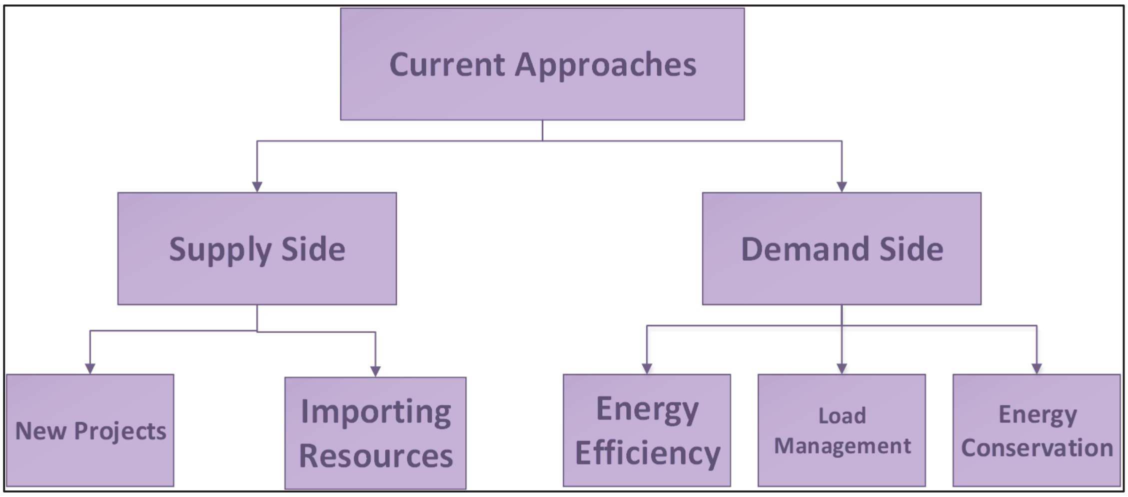


Figure 1-7: Current Management Approaches

Source: Author's compilation

Though supply-side management is the traditional mindset to show progress and growth, the importance of demand-side management is increasing. Demand-side management looks at the other end of the equation, as can be seen in Figure 1-7, whereby instead of adding more generation to the system, users are compensated for reducing their consumption. These regulated initiatives by governments include steps towards energy efficiency, energy conservation and load management. The challenge with demand-side approaches is that they have not received that much appreciation and have little political appeal. For instance, in India, the distribution companies (DISCOMs) and state regulators do not believe that DSM can have large-scale impacts the main reasons being the lack of ownership and the availability of skilled labour to encourage energy efficiency and DSM. Also, the lack of availability of information in the public domain on the monitoring and evaluation processes and lack of communication between the authorities together result in very little political visibility of DSM (Chunekar, Kelkar and Dixit, 2014).

Taking into consideration the current global energy policy objectives for emissions reduction, energy security and affordability, Peter Warren (Warren, 2014), defined demand-side management (DSM) as:

… technologies, actions, and programs on the demand-side of energy metres that seek to manage or decrease energy consumption, in order to reduce total energy system expenditures or contribute to the achievement of policy objectives such as emissions reduction or balancing supply and demand.

DSM has globally been one of the most effective programs for stimulating investment in energy-efficient technologies. It involves influencing consumer load shape and magnitude of demand to meet long-term planning objectives. Many economies globally have been promoting energy-efficient DSM programs with a view to adopting energy-saving technologies and practices.

Energy efficiency plays a key role in a government's strategic planning and it is the focus of this research to contribute to delivering energy security in India. Efforts at energy conservation and load management, though important, are not included in the scope of this thesis.

The IEA defines energy efficiency as 'a way of managing and restraining the growth in energy consumption. Something is more energy efficient if it delivers more services for the same energy input or the same services for less energy input.'

Energy efficiency – doing more with less energy – is the key focus of this research. A report titled *The Total Cost Saving Electricity Though Customer-Funded Energy Efficiency Programs: Estimates at the National, State, Sector and Program Level 2015,* by the Lawrence Berkeley National Laboratory (LBNL) (a US Department of Energy Office Science laboratory managed by the University of California) states that investing in energy efficiency costs an average of just $0.046 per kWh, which is below the average retail cost per kilowatt hour in the US (Hoffman et al., 2015). According to the IEA's *Energy Efficiency Market Report 2014*, the estimated investment in demand-side energy efficiency markets worldwide in 2012 was between US$310 billion and US$360 billion, which was larger than supply-side investment in renewable electricity or in coal, oil and gas electricity generation in that same year. Energy efficiency resulted in energy savings of 1,337 Mtoe in 2011in the 11 IEA member countries, which was equal to 80% of the total final consumption (TFC) of China and 87% of the TFC of the US in that same year. Energy efficiency has moved from a niche market to an established financial market segment with large amounts of finance committed to energy efficiency. For example, Germany's public investment bank, The German Development Bank, The Kreditanstalt für Wiederaufbau (KfW), committed €16 billion towards energy efficiency in Germany in 2013. The European Investment Bank provided €2.1 billion to the European Union towards energy efficiency improvements across several EU countries. The UK Green Investment Bank provided €181 million to energy efficiency in 2012. Energy efficiency markets of the IEA member countries documented more than €30 billion in dedicated spending towards energy efficiency in 2012 (IEA, 2014a).

Many diverse energy-efficient markets are being established around the world. India, for example, implemented a nationwide market-based Light Emitting Diode (LED) bulbs roll-out scheme in 2016-17, which reduced the electricity demand by over 50 billion kWh every year and reduced consumer bills by over €3.1 billion. Another example is the Japan energy efficiency market where the sales of LED bulbs constituted 30% of all Japanese bulbs sold in 2013. In Thailand, the share of LED bulbs has grown from 8% in 2011 to 12% in 2013 of the total lighting market accounting for an increase in sales value from US$15 million in 2011 to US$ 38 million in 2013 (IEA, 2014a).

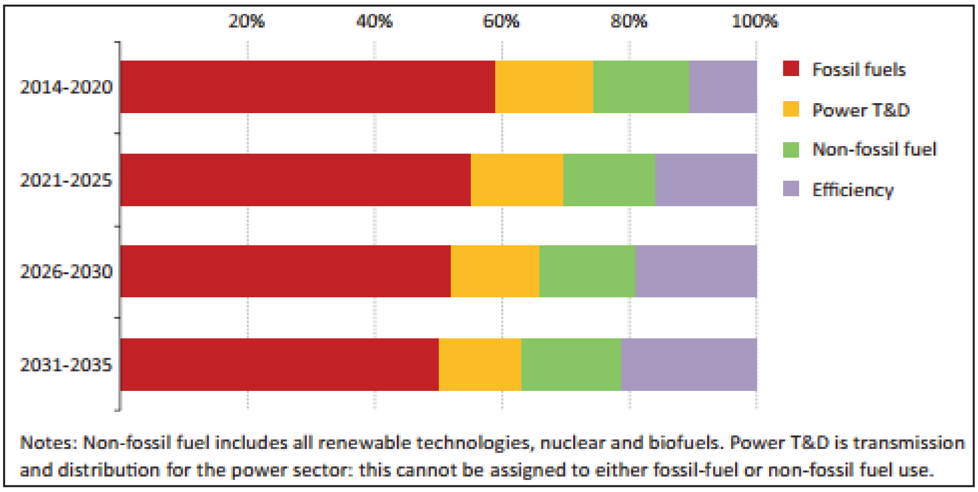


Figure 1-8: Distribution of total global average energy investment, 2014 – 2035

Source: (IEA, 2014c)

The overall global scenario in energy investment can be seen in Figure 1-8, which shows a decline in fossil fuel investment by 60% primarily due to the increased spending in energy efficiency over the period from year 2014 to 2035.

In the United States, implementation of appliance standards has saved Americans an estimated US$50 billion from 1987 through 2000. Further, in the state of Vermont, the gains from energy efficiency are offsetting projected increases in electricity consumption (Granade et al., 2009). In Australia, *Kildonan's Energy Efficiency Program* aims to assist households with energy and financial savings. A preliminary analysis of a sample of 32 participants for the year 2009-2010, helped to provide households an average savings of 1,542kWh of electricity which translated to a reduction of AUD$53.50 in the electricity bill for the participating households (UnitingCare, 2010). In India, the New Delhi Municipal Council worked on a pilot project in 2001with Energy Service Companies (ESCO) on high-efficiency electrical lighting, which continues to save 252,000 kWh annually and 149 million tonnes of avoided CO_2 emissions per year. In the State of Gujarat, 12,000 tube lights were replaced at Sachivalaya Complex for the Government of Gujarat, which reduced the lighting load by 64% without sacrificing illumination levels in 2001 (Singh, 2009). Energy efficiency programs currently focus only on the energy savings they deliver and in particular technology efficiency. The notion has been that promoting efficient technologies in buildings, appliances, transport and industry will reduce the growth in electricity consumption that would have taken place had the technologies been less energy efficient. Improving energy efficiency also contributes to lower greenhouse gas emissions and other pollutants.

The current approaches for addressing the energy security challenge with the help of the energy efficiency improvement measures is vastly technocratic in nature. Energy policies of the major economies focus on the technological aspects and how improving technology to be more efficient can help fight the challenge of improved energy security and such environmental concerns as mitigating greenhouse gas emissions.

Energy efficiency has been an issue on the global political agenda for many years and the IEA's World Energy Outlook 2012 emphasised the need for greater political support for energy efficiency. Though popular with governments, the current energy policies have dominantly ignored the key economic impacts of energy efficiency enhancements. Existing studies mainly focus on evaluating the impact of demand-side efficiency improvements, such as energy-efficient appliances and vehicles and building code star ratings. Current research typically emphasises the technological aspects, focusing on micro assessments, or developing costs and/or benefit estimates of specific measures to improve efficiency. As stated by James Sweeney, Director at Stanford University's Precourt Energy Efficiency Center, 'Most of those who control energy research dollars are fundamentally hostile to any area but technology.' (Golden, 2012) Many analysts believe that energy efficiency offers a ‘win-win’ opportunity through aggressive energy conservation policies which encourage reduced consumption of those fossil fuels that contribute to climate change, which negatively affects plant and animal life and the environment. As James C. Davis, an executive with Chevron Group said in 2012, ‘Energy efficiency is the cheapest and most readily available source of alternative energy there is.’ (Golden, 2012) Though useful, such a statement excludes an understanding of such macroeconomic impacts as policy trade-offs, trade balances, environmental impacts, rebound effect, energy intensity and energy security.

These macroeconomic factors are important because a successful political approach will only come about if policymakers find socio-economic impacts acceptable. The concern of policymakers is to ensure they can get public support to retain their power. Successful implementation of energy policies will only be possible if they can contribute to the socio-economic concerns of the society such as generation of employment, reduction of GHG emissions and improving the overall standard of living for the citizens.

Existing practices to achieve energy efficiency are focused single-mindedly on a technology-efficient approach, and they ignore the broader macroeconomic and socio-economic impacts that need to be considered if energy-efficient policies are to be successfully implemented.

1.2. Research Objectives

Against the above background, the main objective of this research is ***to examine the role energy efficiency can play in redressing the energy security challenge in the context of India.*** In order to achieve this objective, four sub-objectives have been set in this research.

1.2.1. Sub-objectives

a. Contextualise the energy security challenge for India, to establish its importance in the Indian context.

b. Review existing energy policies to redress the energy security challenge, with a view to delineating the role of energy efficiency in this process.

c. Develop an analytical framework for assessing the macroeconomic impacts of energy efficiency.

d. Determine the macroeconomic impacts of energy efficiency in a set of alternative medium-term and long-term scenarios for India and assess the level of energy security achieved in each scenario.

1.3. Research Framework

The framework developed for this research is as shown in Figure 1-9. The framework shows a combination of methodologies applied. The methodologies include a historical review, input-output modelling, scenario analysis and development of energy security composite indices. A summary of each of the methodologies is discussed in this section. A detailed description of each methodology is provided in the relevant chapters of this thesis.

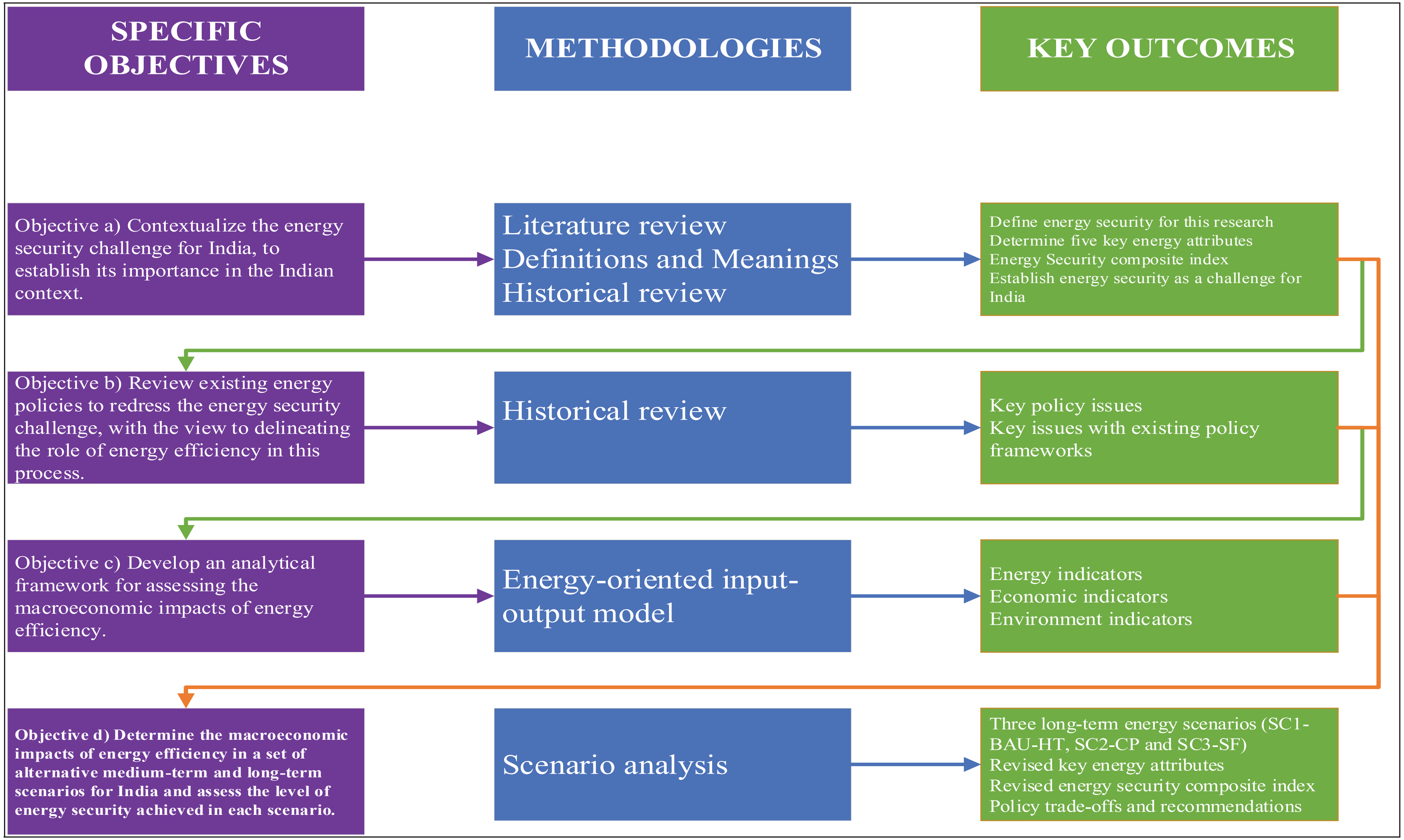


Figure 1-9: Research Framework

Source: Author's compilation

- **Review of existing energy security definitions.**

The first objective in this research is to contextualise the energy security challenge in India. This is developed by reviewing the existing definitions of energy security in general and for India. Based on this review, the five key energy attributes of accessibility, affordability, availability, reliability and sustainability are determined. A comprehensive and concise definition of energy security is arrived at in the context of this research based on these key energy security attributes. A composite index for energy security is developed based on historical data from 1970 to 2014.

- **Review of existing energy policies.**

The second objective is to review existing policies and current research frameworks used by energy studies on India. Based on a review of the policy strategies adopted by the Government of India as embedded in its five-year plans, the role of energy efficiency within these policies is questioned and the models used for forecasting to meet the demand and supply sides in the context of India is identified. The purpose of the literature review is to develop a comprehensive profile of the energy security issue from the point of view of energy efficiency. A list of questions is developed to facilitate the literature review.

The purposes of the review are:

i. to assess the appropriateness of existing energy efficiency policies in addressing the challenges facing the energy sector of India

ii. to develop an understanding of the strengths and weaknesses of the current energy efficiency frameworks used by energy studies on India.

- **Energy-oriented Input-Output analysis.**

This is a quantitative modelling framework that identifies the interdependencies between the various sectors of the economy and helps in the study of the complex interrelationships between energy, the economy, and the environment. This modelling framework helps the study of the various direct and indirect linkages across the various economic sectors. This model also allows study at the macro level and the disaggregated sectoral levels, enabling a detailed study of both the energy and economic sectors. The detailed description of the development of the modelling framework is given in Chapter 4.

- **Development of Scenarios.**

This research develops three long-term energy scenarios for India over the study period from 2015-2050, namely, Business-as-Usual (SC1-BAU-HT), Country Policy (SC2-CP) and Sustainable Futures (SC3-SF). The scenario analysis method considers five key variables that have the potential to influence the development of India's future energy sector. These variables are: (1) diversity of energy supply mix, (2) energy import dependency, (3) technological advancement, (4) socio-economic factors and (5) GHG emissions. In each of the scenarios, the level of influence of energy efficiency on these variables is from low to high. A detailed explanation of each of the scenarios is discussed in Chapter 5.

- **Assessment of Energy Security in the future.**

The results of the scenario analysis provide insights into the impact that energy efficiency improvement measures have on the energy system, the economy and the environment. From the scenario results, each of the five key energy security attributes is revised for the future and a revised composite index of energy security for India under each of the scenarios is determined for the study period of 2015-2050. This composite index of the future is compared with the historic composite index determined in Chapter 2, to show the role of energy efficiency in addressing the energy security challenge in India. Based on this analysis, some policy recommendations are put forth for more integrated energy-economy-environment policies and, in particular, key policy trade-offs that may ensue. This research will demonstrate the effects of energy efficiency improvement measures on macroeconomic impacts through a study of key energy-consuming sectors.

Overall, the indicators adopted, and the methodology implemented for this research will be cross-thematic to help policy decisions that attract political interests in the energy, economy and the environment of the country by considering the key policy indicators including trade balances, energy intensity, GHG emissions, employment.

1.4. Scope of Research

The scope of this research is dependent on the specific objectives and the availability of data.

Objective a: to incorporate published findings and other activities relevant to energy security, review existing issues related to energy security and undertake a comparative study on the measures and practices to address these issues in India.

Objective b: to focus on energy security in the context of India by reviewing past and present policies and measures, to study the historical trends and current practices for energy efficiency in India and highlight the limitations of these approaches in existing policy-making actions. This objective will also include a review of the existing research frameworks to carry out energy policy analysis in India.

Objective c: to use the model framework to look at the energy efficiency issues from a broader point of view by performing an assessment of the key macroeconomic impacts. The basis of the framework is an energy-oriented input-output analysis adapted from the Global Trade Analysis Project (GTAP) databases for a quantitative analysis of the energy efficiency policy issues affecting India. The GTAP databases, which provide a consistent representation of the economy, consist of input-output tables, trade and macroeconomic data from several sources. Together these consistent sets of economic facts facilitate the creation of reliable economic simulation models. Further sources, such as the World Bank, the UN and the IEA collectively provide information on energy production, consumption, trade and the technology used for electricity generation in India.

Objective d: to develop a long-term scenario analysis for alternative energy efficiency measures. It is proposed to use the findings and insights gained from Objectives A, B and C to assess the implications of the constraints imposed by energy efficiency on the future energy security of India.

Overall, this research will demonstrate the role energy efficiency plays in addressing the energy security challenge. It will do this by considering various sectors of the economy such as residential, agriculture, industry, transport and commercial services and by looking at such key macroeconomic indicators as GDP, trade balance, import dependency, employment, GHG emissions and so on. This research incorporates published research findings, a comparative study on historical trends and current practices to the energy security issues and highlights any limitations of these approaches. It focuses on India and covers the period from 2015 to 2050, the latter date being the latest for which current data and forecasts are available.

The model framework will provide a broader point of view from which to assess impacts, while the long-term scenarios will help to develop alternative energy efficiency improvement measures. Based on this research, it will be possible to draw out policy recommendations to better assess the macroeconomic impacts of energy efficiency improvements on India's future energy security.

1.5. Data Considerations

This research requires a diverse range of data on energy, the economy and the environment. These data are collected from various published sources. The data consideration for each of the objectives are shown in Table 1-2 below:

Sub-Objective	Data Requirements	Data Sources
a	- Energy security definitions in general - Energy security definitions for India - Energy attributes that comprise of key energy indicators	Books, journal articles, reports, legislation, policy papers and annual reports. MOSPI, Central Statistics Office of India, CEA, NITI Aayog, IEA, EIA
b	- Existing energy policies for India - Existing energy studies for India	Books, journal articles, reports, legislation and policy papers. NITI Aayog, IEA, EIA
c	- Input-output tables for India - Electricity generation by technology - GDP, population and labour productivity	Books, journal articles, reports, legislation, policy papers, and annual reports. MOSPI, Central Statistics Office of India, CEA, NITI Aayog, IEA, EIA, WB, UN
d	- Energy demand forecasts and efficiency improvements - Population growth forecasts - GDP and sectoral growth forecasts	Books, journal articles, reports, legislation policy papers and annual reports. MOSPI, Central Statistics Office of India, CEA, NITI Aayog, IEA, EIA

Table 1-2: Data consideration for each sub-objective

Source: Author's compilation

For Objective a, this research explores the various definitions of energy security through an extensive review of the literature from sources such as books, journal articles and policy papers.

For Objective b, this research explores existing energy policies and energy studies in India through a review of the literature from sources such as policy papers and legislation published by the Government of India.

For Objective c, the basic input-output tables were obtained from the GTAP databases and India's Ministry of Statistics and Program Implementation. These tables are further modified by incorporating data from the IEA, the World Bank and the United Nations for disaggregated representation of energy production and consumption at the sectoral level as well as electricity generation using different technologies. The data on energy resources were obtained from the annual Energy Statistics published by the Central Statistics Office of India. Data on the electricity sector came from the CEA. The estimates of GDP, population growth and labour productivity were obtained from World Bank datasets.

For Objective d, in the case of each of the scenarios, the premise of the assumptions was based on available published data. For the SC1-BAU-HT scenario, the assumptions were based on historical trends. For the SC2-CP scenario, the assumptions are aligned with the objectives of India's draft NEP 2017; and for the SC3-SF scenario, the assumptions align with the objective of the Sustainable Development Scenario designed by the IEA and published in its World Energy Outlook 2017.

1.6. The Significance of This Research

Energy, economic and climate change policies are being developed at a rapid rate and there appears to be little understanding of the wider impacts of energy efficiency on the efficacy of such policies. This research makes a significant contribution by assessing the energy efficiency improvement measures needed to address the energy security challenge for India in the future.

- **Energy Security definition and scope:** The existing literature on energy security indicates there is no one definition of energy security. This research develops a comprehensive and concise definition of energy security in the context of India by considering the key energy security dimensions and includes the context of the energy-economy-environment relationship. Further, this research analyses energy security by developing a composite index by giving different weights to the key energy security attributes of energy accessibility, affordability, availability, reliability and sustainability for the historic period from 1970 to 2014 and, based on the results derived from the scenario analysis, for the future period from 2015 to 2050.

- **Focus on India's energy sector:** A significant element of this research is that it assesses alternative long-term scenarios driven by factors of immediate concern to contemporary energy-related issues in India. These scenarios consider the current challenges faced by the energy sector in India and the various alternative pathways that may be available in the future to address these challenges. For instance, a need to reduce GHG emissions from energy use is one of the key driving forces in the scenarios of this research.

- **Research Framework:** A major contribution of this research is the development of a modelling framework that consists of a scenario-based approach and an energy-oriented input-output model to analyse those scenarios. The significance of this framework is that it examines the energy and economic sectors at disaggregated sectoral levels. This framework allows both the direct and indirect interrelationships across the economic sectors to be quantified, as well as the details of the energy system on both the demand and supply sides.

In this way, this research analyses quantitatively both the energy and economic impacts in great depth and assesses these impacts on the overall energy security of India for the future.

➢ **Research outcomes:** This research provides an assessment of three long-term energy scenarios for India in terms of how energy requirements in the country are likely to be met in the next 35 years (2015-2050) and the potential impact of those scenarios on the energy system, the economy and the environment. The scenario outcomes provide important information for the future in terms of primary and final energy requirements, the generation technology mix, GHG emissions and intensities, the energy diversity mix, energy rebound effect and information on economy-wide impacts such as economic growth, total industry output, employment and trade balance. A comparison of the results across the scenarios provides important insights for policy decision-making. The scenario results suggest that if the current trends continue into the future, by 2050, India could experience a 5-fold increase in primary energy requirements and GHG emissions compared to the base year levels of 2015, and its dependency on oil imports would increase significantly, potentially leading to energy insecurity for India. The research analysis suggests that promoting energy efficiency improvement measures through the alternative scenarios of CP and SF have the potential to reduce the consumption of fossil fuels and limit GHG emissions in the future. It shows a need for a fundamental shift in the energy sector from the dominant coal- and oil-based systems to one that is diverse in its energy resources and uses efficient technologies, thereby leading to significant energy savings in the future.

Potential Beneficiaries:

- **Policy makers** will be able to make more informed decisions, by knowing the nature of the energy efficiency issue and its limitations towards providing for energy security

- **Policy analysts** will have a framework to study the impact of energy efficiency improvement measures on energy, economy, and environment which will help to conduct future energy policy research

- The results will provide insights into the true cost of the different energy resources and thus will have immense **educational value**. Some of the information can be used in educational tools to increase public awareness

- The research will generate huge data sets for energy that can be further used by the **research community** to develop/refine methodologies

- **Governments** restructuring energy industries will be able to draw upon the insights and findings of the relationship between energy and the economy to plan better future reform initiatives.

1.7. The Organisation of the Thesis

This thesis consists of nine chapters.

Chapter 2 establishes a definition of energy security and its key attributes in the context of India. A detailed review of the existing definitions of energy security in general and in the context of India is conducted. Based on this review, energy security in the context if this research is established by carrying out historical trend analysis and establishing future projections of key energy-economy indicators.

Chapter 3 provides a review of the existing energy policies and frameworks in India. This chapter aims to address the appropriateness of the existing energy policies in addressing the challenges faced by India's energy sector and develops an understanding of the strengths and weaknesses of the existing research frameworks for energy policy analysis. It also proposes an appropriate research framework for this research.

Chapter 4 develops an energy-oriented input-output framework to assess the economy-wide impacts of energy efficiency.

Chapter 5 provides an overview of the importance of scenarios and discusses the key scenario analysis methodologies. Based on this review, three long-term energy scenarios are developed for this research. It takes into account five key scenario variables that have the potential to shape India's energy sector.

Chapter 6 assesses the energy, economy and environment impacts of the three long-term energy scenarios from a policy perspective.

Chapter 7 assesses future energy security based on the revised indices determined for the indicators that comprise each of the key attributes. This assessment helps to examine the role of energy efficiency in addressing India's energy security challenge.

Chapter 8 discusses the policy trade-offs between key energy and economic factors to provide a more complete policy perspective.

Chapter 9 presents the main conclusions of this research, the limitations of this research and provides some recommendations for future research.

Chapter 2 : Energy Security in the Context of this Research

2.1 Introduction

This chapter discusses how energy security is a context-dependent concept and why it is considered to be a multi-faceted challenge for India. The objective of this chapter is to establish a foundation for this research by defining energy security and its key attributes in the context of India.

A detailed review of the existing definitions is used in this chapter to establish the various themes of energy security. This discussion highlights the fact that though extensive research has been conducted in this field, there is, as yet, no widely accepted definition of energy security. Based on this review, a definition of energy security is developed in the context of this research, incorporating the key attributes of energy accessibility, affordability, availability, reliability and sustainability.

A detailed discussion of each of these attributes, using their key indicators, establishes energy security as a challenge for India which will, unless addressed, exacerbate with time. This discussion establishes that the growing population of India will stimulate rising energy demands to achieve better standards of living and economic prosperity. The challenge for India is that this prosperity will need to be achieved in cognizance and avoidance of possible environmental impacts.

This chapter is organised as follows: Section 2.2 uses the literature to review the definitions of energy security in general, and in the context of India. This section finishes by establishing a definition of energy security and explaining the key attributes of accessibility, affordability, availability, reliability and sustainability in the context of this research. Section 2.3 establishes energy security as a challenge for India. This is achieved by carrying out a historical trend analysis and establishing future projections in terms of growing demand, increased investment and dependence on imports and examining what impact these measures will have on the growing population. The chapter concludes with a summary of the key findings in Section 2.4.

2.2 Energy Security Definitions

This section reviews the key definitions of energy security, focusing on both supply and demand. It also discusses how energy security is defined in the context of India. Further, it defines the key attributes that are considered for this research. Towards the end of this section, the definition of energy security in the context of this research is developed based on the identified key energy security attributes.

Author	Focus of Study	Definition	Remarks
United Nations Development Programme, 2000	To analyse the social, economic, environmental and security issues linked to energy supply and to assess and use options for sustainable development.	*'the availability of energy at all times in various forms, in sufficient quantities and at affordable prices, without unacceptable or irreversible impact on the environment.'*	Relationship of energy to sustainable development, poverty alleviation, environmental impacts, improvement of women's lives, available energy resources and technology improvements. **Attributes:** accessibility, affordability, availability, reliability and sustainability.
Bielecki, 2002	The issues of the security of oil supply.	'*a public good which is not properly valued by the market*	Focus on external supply sources. High energy prices will

Author	**Focus of Study**	**Definition**	**Remarks**
		and the benefits of which are available equally to those who pay for it and to those who do not. Consequently, the market may tend to produce a level of energy security that is less than optimal.'	result in energy shortages and hence the economic loss. **Attributes:** affordability, availability and reliability.
Lieb-Dóczy, Börner & MacKerron, 2003	Risk of private investment in the European gas and electricity markets.	*'Security of supply is fundamentally about risk.'*	Risk – generation of electricity, bad weather conditions, poor maintenance, failures in the supply of primary fuel and faults. **Attributes:** accessibility, availability and reliability.
Lesbirel, 2004	Energy security as an insurance mechanism against disruptions to energy import markets in the	*'an insurance against risks.'*	Risk – energy import disruptions. Ensure adequate access to energy sources to

Author	Focus of Study	Definition	Remarks
	context of the Japanese energy imports from 1970 to 1999.		sustain acceptable levels of social and economic welfare. **Attributes:** accessibility and reliability.
Yergin, 2006	Energy security will remain a challenge for US policy due to the changing concept of energy security. Diversify supply sources and integrate into a global energy consumption system.	*'Safety and certainty of oil lie in variety and variety alone.'*	Winston Churchill directed Royal Navy ships to switch from secure coal to more insecure oil resources from Persia to make the fleet more powerful than the fellow Germans. **Attributes:** accessibility and reliability.
Grubb, Butler & Twomey, 2006	The relationship between low-carbon objectives and the security of the UK electricity system.	*'A system's ability to provide a flow of energy to meet demand in an economy in a manner and price that does not disrupt the course of the economy.'*	The diversity of fuel mix: types, sources and technological knowledge.

Author	Focus of Study	Definition	Remarks
			Attributes: affordability and reliability.
IAEA, 2007	Seven national case studies to develop energy indicators for sustainable development for the period from 2002 to 2005. How these indicators were developed and how they could be used to assess national energy systems and hence the effectiveness of the policies. Brazil, Cuba, Lithuania, Mexico, Russia, Slovakia and Thailand.	'*The provision of adequate and reliable energy services at an affordable cost, in a secure and environmentally benign manner and in conformity with social and economic development needs, is an essential element of sustainable development.*'	To address key energy-related issues and to assess in effective energy policies for sustainable development. **Attributes:** affordability, availability, reliability and sustainability.
Asia Pacific Energy Research Centre, 2007	To provide APEC economies with options for enhancement of energy security and sustainable development.	*'The ability of an economy to guarantee the availability of energy resource supply in a sustainable and timely manner with the energy price being at a level that will not adversely*	Acceptability – risk of GHG emissions linked to fossil fuel consumption. Environmental impacts. Accessibility to these energy sources. In addition, human

Author	Focus of Study	Definition	Remarks
		affect the economic performance of the economy.'	resources in the energy industrial sectors. Affordability – investment costs in infrastructure development and technology advancement. Availability of energy sources – oil, natural gas, coal, nuclear and renewable energy, hydro and biofuels. **Attributes:** accessibility, affordability, availability, reliability and sustainability.
Kemmler & Spreng, 2007	Poverty is linked to energy use and energy poverty indicators are used to assess poverty. A case study on India.	*'Promoting energy efficiency and reducing energy intensity thus reducing pollution and protecting the environment and contributing to a better quality of life.'*	Sustainability in developed countries is focused on environmental topics while in developing countries the issues of poverty and equity are important. Energy indicators

Author	Focus of Study	Definition	Remarks
			are not restricted to environmental and economic issues but also to social issues, such as the measure of poverty. **Attributes:** accessibility, affordability, availability, reliability and sustainability.
Nuttall & Manz, 2008	The impact of climate change on the future and the transition to cleaner energy technologies.	'*Energy security has been framed primarily around availability and access to fossil fuels.*'	Considers all countries and, for each country, examines the national security policies to consider energy security and new energy technologies for the future. **Attributes:** accessibility and availability.
Florini, 2008	Global governance to move on a sustainable path to provide	*'Reliable and affordable access to energy supplies.'*	Need for rapid energy technology improvements and

Author	Focus of Study	Definition	Remarks
	appropriate, reliable and affordable energy services.		innovation, keeping in mind the environmental impacts. **Attributes:** accessibility, affordability, availability and reliability.
UNESCAP, 2008	Energy security and sustainable development in the Asia-Pacific.	*'Encourage raising energy conservation and energy efficiency measures along with diversifying energy supplies.'*	Raising energy conservation and efficiency, rationalising pricing and taxation systems, improving energy sector governance, diversifying energy supplies and using alternative fuels. **Attributes:** accessibility, affordability, availability, reliability and sustainability.
Kleber, 2009	The role of energy security in formulating US national security policies.	*'The capacity to avoid adverse impact of energy disruptions caused either by natural,*	Surety – access to energy and fuel sources

Author	Focus of Study	Definition	Remarks
		accidental or intentional events affecting energy and utility supply and distribution systems.'	Survivability – energy and fuel sources are resilient and durable Supply – identified and available source of energy Sufficiency – adequate quantity of fuel from a variety of sources Sustainability – reduce waste and use alternative energy sources. **Attributes:** accessibility, availability, reliability and sustainability.
Hughes, 2009	A methodology that can be used to explain energy security, its importance and implications and how it can be improved.	'*Review: understanding the problem; Reduce: using less energy which can be accomplished through energy conservation or energy efficiency, or both; Replace:*	Review of existing sources, sectors and a variety of secure supply sources.

Author	Focus of Study	Definition	Remarks
		shifting to secure sources which include diversifying energy supplies, changing infrastructure or allow alternative energy source; Restrict: limiting new demand to secure sources.'	Reduce – energy conservation, energy efficiency, lowering energy intensity. Replace – diversify energy supplies, change in infrastructure, alternative energy sources. Restrict – limit new demand to secure sources and infrastructure. **Attributes:** accessibility, affordability, availability and sustainability.
Nuclear Energy Agency, 2010	The security of power supply and the role nuclear energy can play in reducing the supply risk.	*'Security of energy supply is the resilience of the energy system to unique and unforeseeable events that threaten the physical integrity of energy flows or that*	Supply of electricity affects the wellbeing of individuals and society. Risk – geopolitical (external) and technical,

Author	Focus of Study	Definition	Remarks
		lead to discontinuous energy price rises, independent of economic fundamentals.'	financial and economic issues (internal). **Attributes:** affordability and availability.
Sovacool & Mukherjee, 2011	Provides a synthesised framework for analysing national energy security policies and performances. Review carried out through research interviews, surveys and focus group workshops.	*'Equitably provide available, affordable, reliable, efficient, environmentally benign, properly governed and socially acceptable energy services.'*	Dimensions – affordability, availability, technology development, sustainability and regulation. Dimensions are disaggregated to 20 components which are further broken down into 320 simple indicators and 52 complex indicators. **Attributes:** accessibility, affordability, availability, reliability and sustainability.

Author	Focus of Study	Definition	Remarks
Martchamadol and Kumar, 2012	Assessment of energy security of Thailand using 19 indicators from 1986 to 2030.	'*A resilient energy system and securing the amount of energy required for people's life, economic, and social activities, defense and other purposes at acceptable prices.*'	Dimensions – energy demand, availability of energy sources, environmental impacts, energy markets and risks and energy price. **Attributes:** affordability, availability and sustainability.

Table 2-1: Energy Security Definitions

2.2.1 Energy security definitions for India

Author	Focus of Study	Definition	Remarks
Kalam, 2005	India's Independence Day speech to the nation by the President of India. To achieve energy independence or an economy with total freedom from oil, coal and gas imports by 2030 in the electricity generation and transport infrastructure sectors.	*'Energy security as a transition to total energy independence. Ensuring that our country can supply lifeline energy to all its citizens, at affordable costs at all times.'*	To use the least amount of energy and cut down energy losses and to secure access to all sources of energy including coal, oil and gas supplies. Access technologies to provide reliable, affordable and sustainable energy to all. **Attributes:** accessibility, affordability, availability, reliability and sustainability.
Planning Commission of India, 2006	An integrated energy policy linked with sustainable development that covers all sources of energy and addresses all aspects of energy use and supply.	'*The country is energy secure when we can supply lifeline energy to all our citizens as well as meet their effective demand for safe and convenient energy to satisfy various needs at*	Reliably meet the energy demands of all sectors at competitive prices through safe, clean and convenient energy sources with efficient

Author	Focus of Study	Definition	Remarks
		affordable costs at all times with a prescribed confidence level considering shocks and disruptions that can be reasonably expected.'	technology in a sustainable manner. **Attributes:** accessibility, affordability, availability, reliability and sustainability.
Verma, 2007	Geopolitics of the Iran-Pakistan-India gas pipeline. The importance of Iran as a gas supplier and the India-Pakistan relationship.	*'Safeguarding and sustaining the country's developmental and global power aspirations.'*	Diversification of supply, resilience in the energy system to withstand shocks and supply disruptions, integrated energy system (one global oil market) and flow of information about world markets and energy prospects. **Attributes:** accessibility, availability and reliability.

Author	Focus of Study	Definition	Remarks
Sethi, 2009	Challenges of India to meet the Millennium Development Goals and raise its Human Development Index.	*'The effective energy demand of all sectors for different needs is reliably met with safe, convenient and competitive energy in a sustainable manner. Lifeline energy needs of all households are met with clean and safe commercial fuels where necessary, with transparent and targeted subsidies. All forms of available and emerging energy sources and energy technologies are adapted in a sustainable manner.'*	Strong overtones of equity and a moral responsibility towards our global commons. **Attributes:** accessibility, affordability, availability, reliability and sustainability.
Ahmad, 2009	Importance of West and Central Asia in the context of global demand for oil and natural gas. India's strategies to enhance energy security.	*'An assured access to energy resources, at affordable prices, to obtain sustainable economic growth rates and economic development.'*	Geopolitical tensions such as political instability in Iraq. Energy security is part of national development and national security. Energy security cannot be attained

Author	Focus of Study	Definition	Remarks
			purely on a national basis but through cooperation with other countries. **Attributes:** accessibility, affordability, availability and sustainability.
Raja Mohan, 2009	To explore the conceptual challenges that Indian foreign policy must confront in ensuring energy security for the nation.	*'The successful assurance of reliable supplies of energy and related technologies at reasonable prices.'*	Energy security is a matter of national security. **Attributes:** accessibility, affordability, availability and reliability.

Table 2-2: Energy Security Definitions for India

The review of energy security definitions, largely qualitative in nature, shows most of the studies consider availability and affordability as key dimensions of energy security, while others base it on reliable supply and access to energy and energy technologies. The definitions also consider the environmental impacts of energy and ensure the use of energy sources and related technology development are carried out in a sustainable manner.

For India, recent events highlight a sense of urgency in dealing with energy security threats facing its society. In July 2012, for example, India made history with the largest blackout in history, which left nearly 700 million people without power and brought the country to a near standstill. The blackout raised concerns about India's energy infrastructure and its ability to meet growing energy demands while aspiring to be an economic superpower (Yardley and Harris, 2012). Further, in 2013, India had a total trade deficit of US$126 billion, of which US$41.7 billion was with its the two largest oil suppliers, Saudi Arabia and Iraq, resulting from its need to increase oil imports to meet growing demand. Given India's inadequate domestic coal reserves to meet its needs, its fuel import bills are expected to continue to rise in the coming years (Raghavan, 2015). In 2017, India ranked 75th in the environmental impact survey report (Hassen, 2017), with carbon emissions rising by almost 5% in 2016, making it a key contributor to the future global emissions and adding to the pressures of keeping the global temperature rise below the 2°C limit. Growing population and increased infrastructure developments mean that even a small increase in per capita emissions will add up to an amount of GHG emissions that will likely make India the world's biggest polluter (Carrington and Safi, 2017).

These anecdotes reveal the energy security concerns within the country. As a result of this review of definitions, this research will consider the five key attributes of energy security, namely, accessibility, affordability, availability, reliability and sustainability in the context of India. A detailed discussion explaining the indicators that comprise each of these attributes is given below.

2.2.1.1 Energy Availability

Energy availability is defined as the amount of physical reserves of energy resources available. Availability is measured in terms of the domestic production of the primary energy resources and electricity, and the level of imports of these resources to meet the energy demands of the economy from 1970 to 2015.

Production Per Capita

The domestic production of primary energy sources in India shows a trend of continuous growth because of the increased consumption due to the country's growing population over the years. Coal continues to be the dominant source of energy for India.

The production of coal has increased exponentially over the years. As can be seen in Figure 2-1, total production increased from a mere 72.95 MT in 1970-71 to 539.94 MT in 2011-13 and to 639.23 MT in 2015-16 - a compound annual growth rate (CAGR) of 4.02% (Central Statistics Office, 2012-2017).

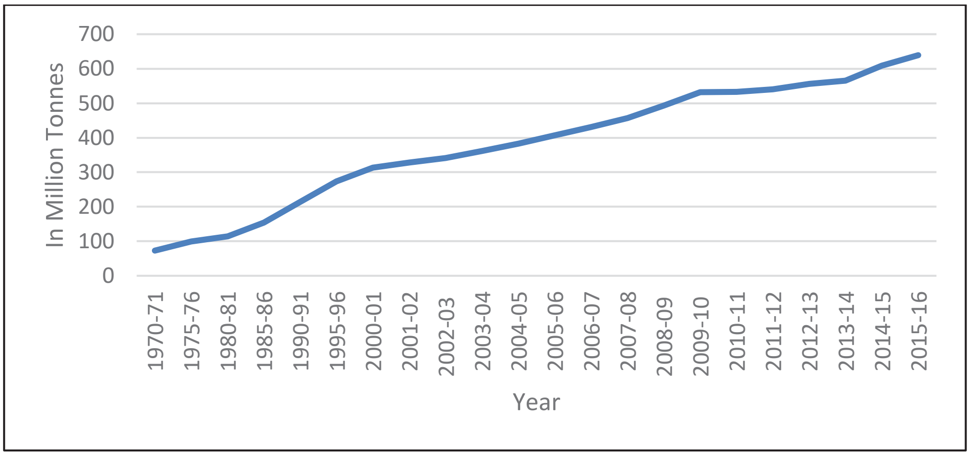


Figure 2-1: Production of Coal, 1970 - 2015

Source: Central Statistics Office (2012-2017)

Lignite production has increased over the years, from 3.39 MT in 1970-71 to 43.84 MT in 2015-16, with a CAGR of 4.7%, as seen in Figure 2-2 (Central Statistics Office, 2012-2017).

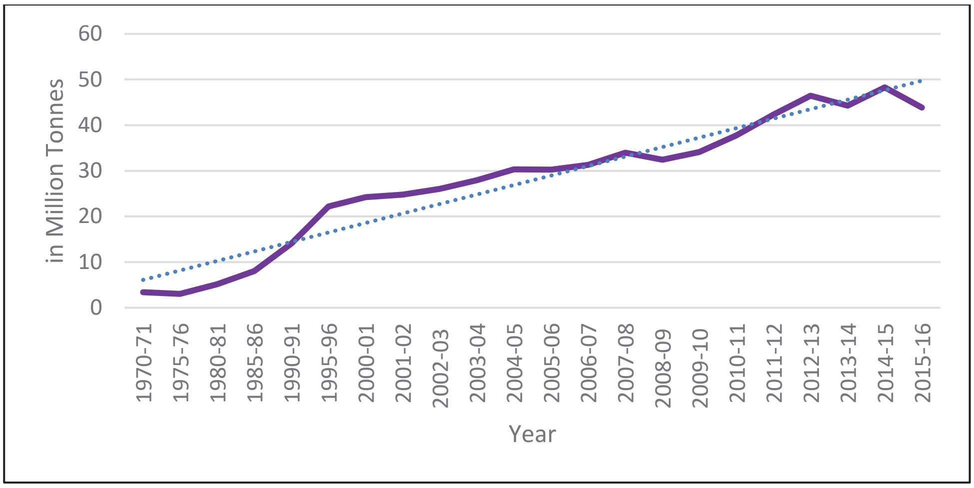


Figure 2-2: Production of Lignite, 1970 - 2015

Source: Central Statistics Office (2012-2017)

The production of crude petroleum products has gradually increased over the years; it rose from 17.11MT in 1970-71 to 32.43MT in 2000-01, was relatively constant for the years 2004 to 2010 and showed a slight increase to 37.71 MT in 2010-11. Since then, production has been steady with a total production of 36.95 MT in 2015-16, as can be seen in Figure 2-3 (Central Statistics Office, 2012- 2017).

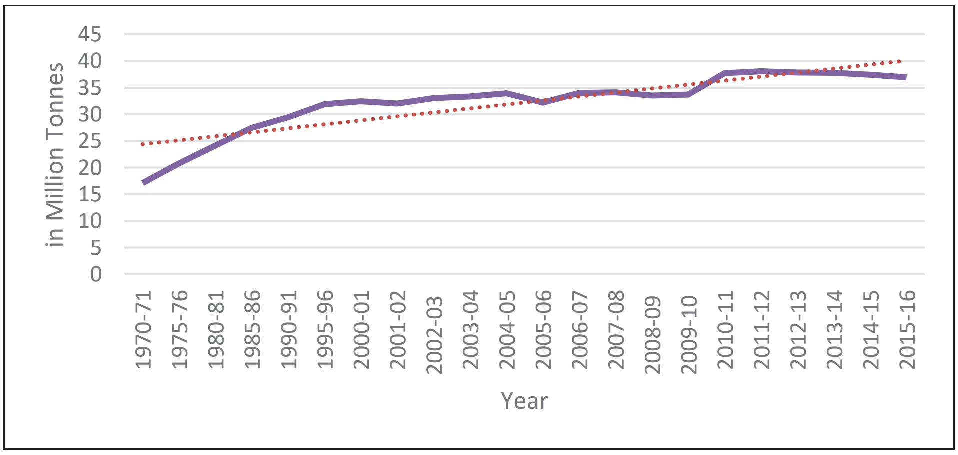


Figure 2-3: Production of Crude Petroleum, 1970 - 2015

Source: Central Statistics Office (2012-2017)

Overall production showed an increasing trend over the years, with a particularly rapid increase during the period of 1985-2000, as shown in Figure 2-4. After that, production plateaued to around 32 Billion Cubic Metres (BCM) till 2009, peaked at 51.25 BCM in 2010-11 and decreased exponentially to a low of 25.46 BCM in 2015-16 (Central Statistics Office, 2012-2017).

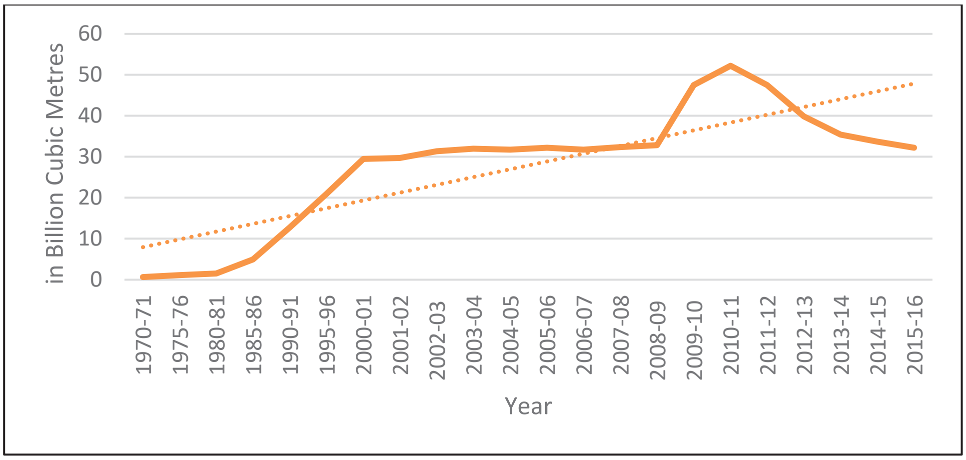


Figure 2-4: Production of Natural Gas, 1970 - 2015

Source: Central Statistics Office (2012-2017)

Electricity in India is produced from utilities and non-utilities that comprise thermal, hydro, nuclear and other renewable sources (ORS). Over the years, electricity generation has increased from 61,212 GWh in 1970-71 to 5,60,842 GWh in 2000-01 and 13,35,956 GWh in 2015-16, with an annual growth rate of about 4%, as can be seen from the graph in Figure 2-5 (Central Statistics Office, 2012-2017).

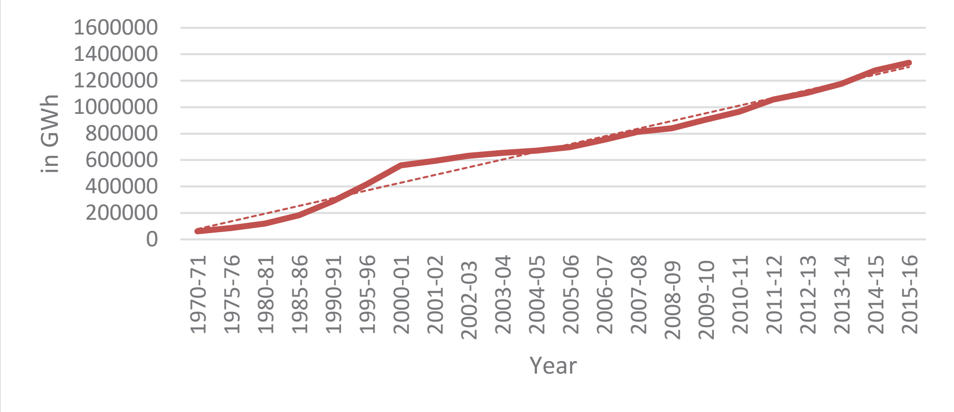


Figure 2-5: Production of Electricity, 1970 - 2015

Source: Central Statistics Office (2012-2017)

The aggregate production per capita of these primary energy resources and electricity shows an exponential increase until the 1990s; from then until 2005 per capita production fell, a contributing factor being a plateau in the production of crude oil and natural gas along with a decrease in the rate of production of other primary sources. More recently, there has been an increase in the production of coal and electricity, which has been offset by a decline in natural gas and lignite production and a continued steady state production of crude oil. Thus, the overall production per capita is increasing, but at a slower rate than in the early 1970s and 1980s, as can be seen in Figure 2-6, which is the author's compilation based on Figure 2-1: Production of Coal, 1970 - 2015Figure 2-1 to Figure 2-5.

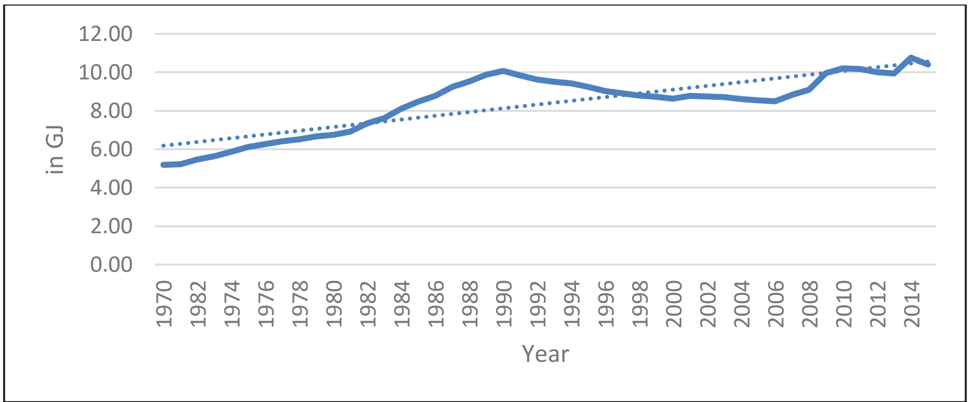


Figure 2-6: Production per capita, 1970 - 2015

Source: Author's compilation

Import Dependency

As the population continues to increase, the domestic production falls short of demand. Hence, India is increasingly dependent on imports of primary resources from energy-rich nations to bridge the energy demand gap.

The domestic coal reserves in the country are not of very high quality, which increases the pressure on imports to meet the demand. The import of coal is rising, as can be seen in Figure 2-7, increasing gradually from 20.93 MT in 2000-01 to 73.26 MT in 2009-10, followed by a steep rise to 217.78 MT in 2014-15 (Central Statistics Office, 2012-2017).

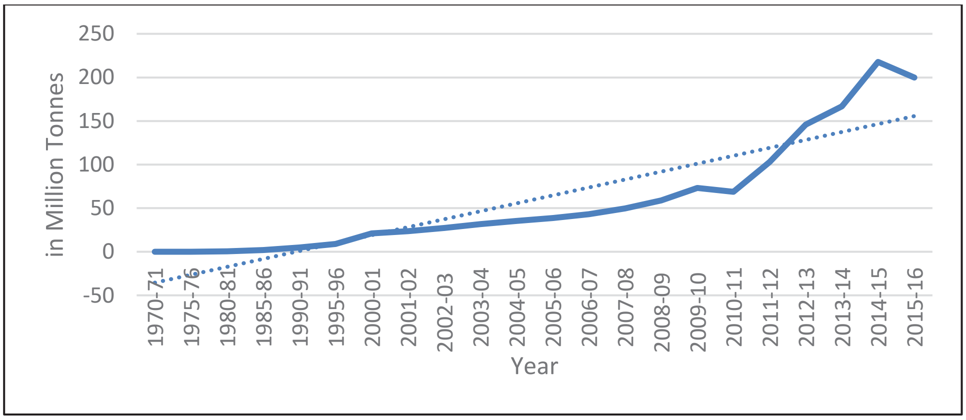


Figure 2-7: Imports of Coal, 1970 - 2015

Source: Central Statistics Office (2012-2017)

India is dependent on the import of crude oil and petroleum products to meet more than 70% of its requirements. As can be seen in Figure 2-8, there has been a linear growth in the overall trend of crude petroleum imports; in 2000-01, gross imports stood at 82.47 MT and increased to 231.15 MT in 2015-16 (Central Statistics Office, 2012-2017).

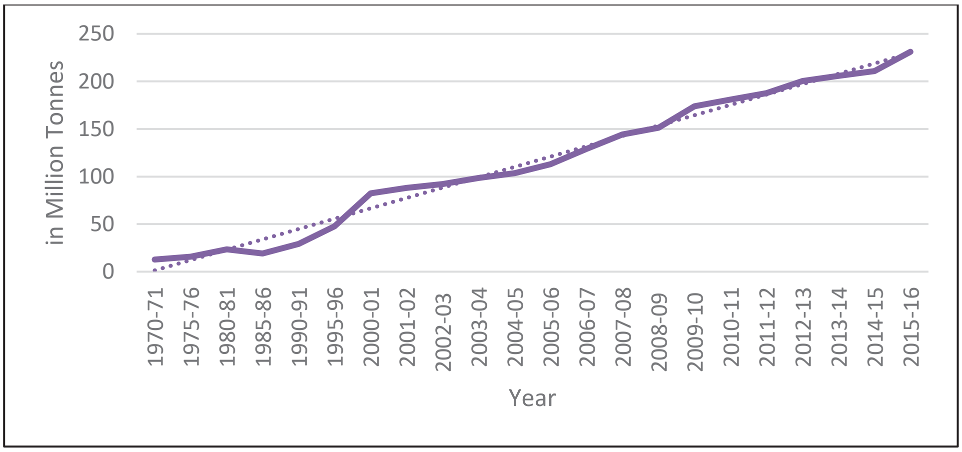


Figure 2-8: Imports of Crude Petroleum, 1970 - 2015

Source: Central Statistics Office (2012-2017)

When it comes to India's natural gas consumption, this has been met entirely in the past by domestic production. However, from the period 2005 to 2015, as can be seen in Figure 2-9, demand exceeded domestic production and to bridge this gap the import of liquid natural gas (LNG) rose from 2.5 BCM in 2004-05 to 16.58 BCM in 2015-16 (Central Statistics Office, 2012-2017) and (MPNG, 2005). The overall trend shows an increase in the import of natural gas from 1970 to 2015.

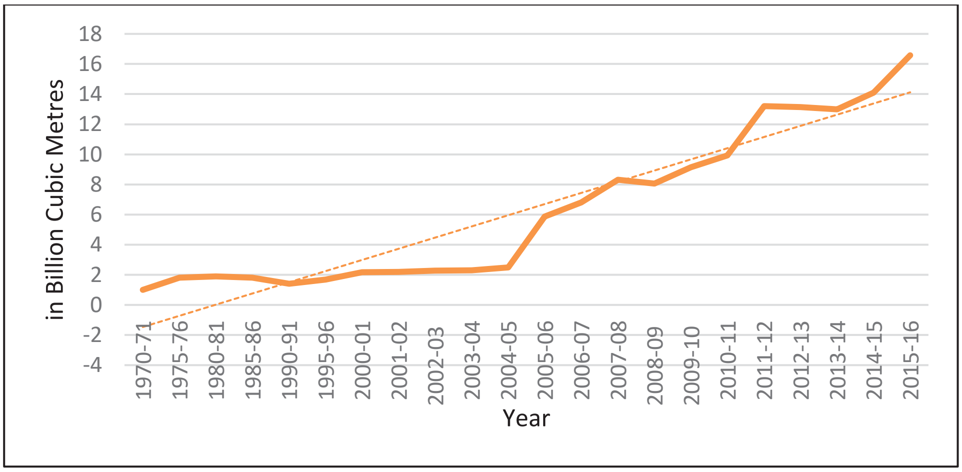


Figure 2-9: Imports of Natural Gas, 1970 - 2015

Source: Central Statistics Office (2012-2017), MPNG (2005)

India imports electricity from the neighbouring nations of Nepal and Bhutan through various cross-border power trading schemes. The graph in Figure 2-10 shows a step increase in its imports of electricity over the years; there were no imports from the 1970s until the early 1980s, in the mid-1990s the imports rose to 1675 GWh and then rose again to 5230 GWh in 2008, after which they remained steady at 5244 GWh in 2015-16 (Central Statistics Office, 2012-2017 and EIA, 2017a). The overall trend shows an increase in the dependence on electricity from imported sources for the period 1970 to 2015.

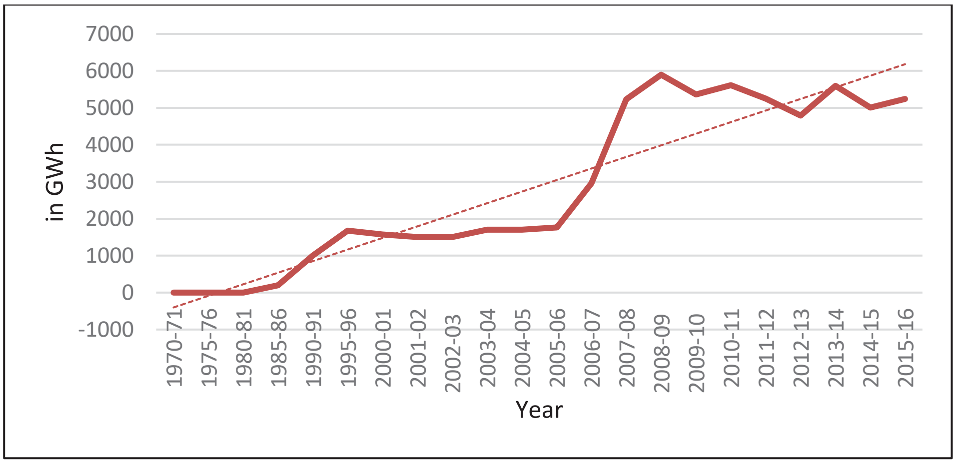


Figure 2-10: Import of Electricity, 1970 - 2015

Source: Central Statistics Office (2012-2017) and EIA (2017)

Over the years, there has been an increase in the import of all primary energy resources and electricity. This is an indication that the country is dependent on energy for its economic progress, and to support the demands of its growing population, the domestic shortage of these resources has increased the pressure on imports. As shown in Figure 2-11, which is the author’s compilation based on Figure 2-7 to Figure 2-10, India’s import dependency, comprising of primary energy sources and purchased electricity, has risen from a mere 1% in the 1970s to 35% in the early 2000s and to more than 50% in more recent years still.

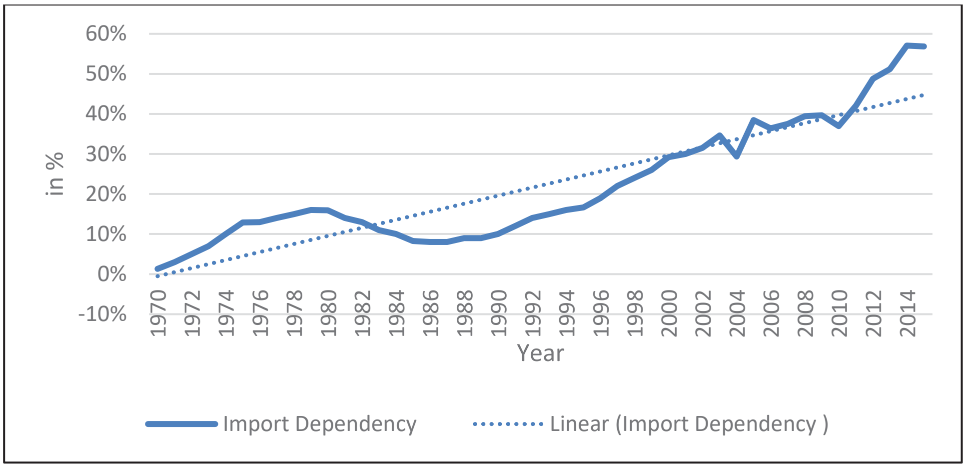


Figure 2-11: Import dependency, 1970 - 2014

Source: Author's compilation

India is not endowed with an abundance of domestic primary energy reserves. As the above discussion shows, this has resulted in an increased dependency on imports to bridge the demand-supply gap. This increased level of imports contributes further to the issue of energy security in India.

2.2.1.2 Energy Affordability

Energy affordability in this research is defined as the share of expenditure on energy by the key energy-consuming end-use sectors of the economy, including residential, industrial, transport and agriculture, from 1970 till 2014, as indicated in the discussion below.

Residential Affordability

The residential sector's energy affordability in this research is defined as the share of household disposable income spent on energy to meet the household needs of lighting, cooking and heating/cooling. The energy consumption in the residential sector is closely linked to the urbanisation rate. Urban households tend to have higher energy needs, and as the rural population migrates to urban regions the level of energy consumption rises. As seen in Figure 2-12, to meet these demands over the years there is an increase in the share of expenditure of the disposable household income on energy, from an average of 1% in the 1970s to about 2% in the 1990s and a sharp increase to 3% in 2005 before a gradual decrease to about 2% in more recent years, which indicates a decrease in the energy affordability.

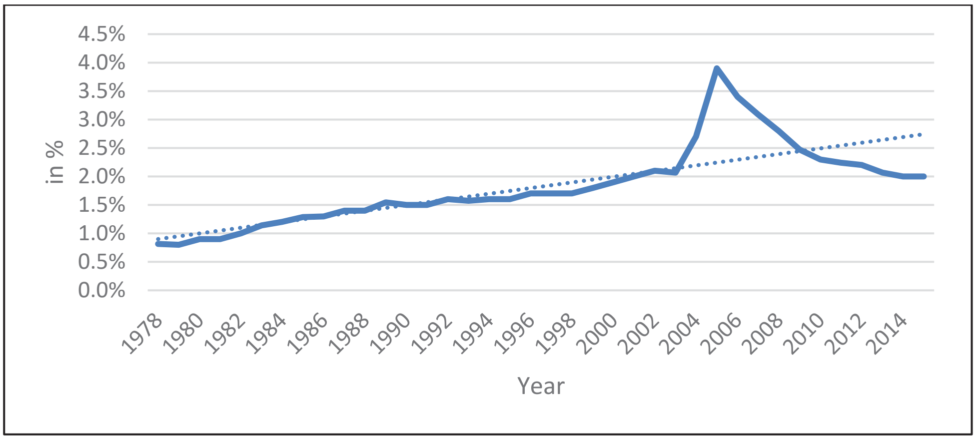


Figure 2-12: Residential Affordability, 1978 - 2014

Source: National Sample Survey Office (1983, 1997, 2001, 2007, 2012a, 2012b), Author's compilation

Industrial Affordability

Industrial affordability in this research is the percentage of the industry sector's gross value added (GVA) spent on energy. The industry sector has been growing steadily over the years due to the contribution of public-private investments. The GVA has increased significantly and the industrial sector has contributed significantly to India's overall GDP. The demand for huge infrastructure and improved manufacturing practices drive the demand for energy-intensive materials. As can be seen in Figure 2-13, the overall share of expenditure that industry sector spends on energy has remained relatively steady, ranging between 25% and 30% for the period from 1970 to 2015.

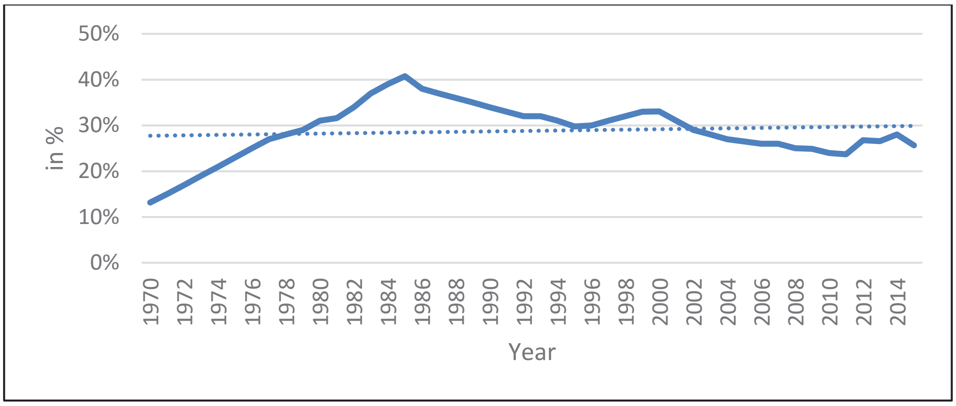


Figure 2-13: Industrial Affordability, 1970 - 2014

Source: Central Statistics Office (2009b, 2009a, 2011, 2012a, 2013, 2014, 2015), Author's compilation

Agricultural Affordability

Agricultural affordability in this research is the percentage of the agriculture sector's GVA spent on energy. As the already large population of India is expected to continue to grow there will be an increase in the demand for food. Over the years, to improve agricultural productivity, traditional manual and animal labour are being replaced by modern-day, energy-intensive practices and equipment. Thus, as can be seen in Figure 2-14, there is an exponential increase in the share of expenditure on energy from the agriculture sector's GVA for the period from 1970 to 2015.

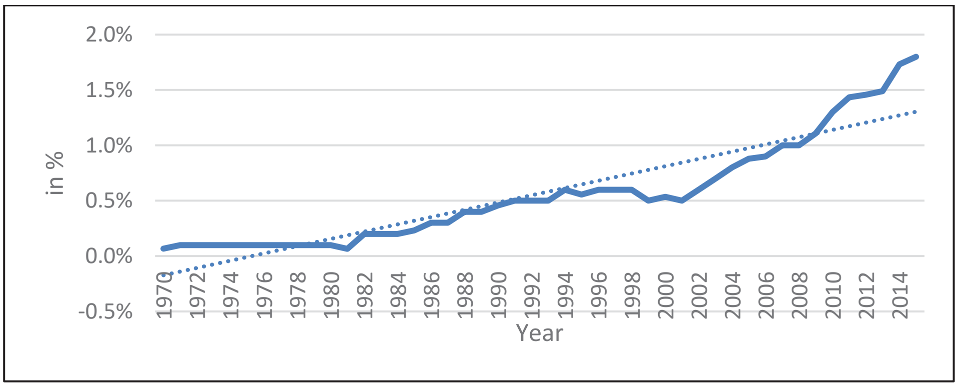


Figure 2-14: Agricultural Affordability, 1970 - 2014

Source: Directorate of Economics & Statistics (2014, 2014, 2015, 2016), Author's compilation

Transport Affordability

Transport affordability in this research is the percentage of the transport sector's GVA spent on buying energy. The transport sector, comprising commercial and private transport, is one of the fastest growing end-use sectors in India. The GVA of the transport sector increased from Rs. 4500 crores[1] in 1978 to Rs. 398,497 crores in 2011, while the expenditure on energy increased from Rs. 154 crores to Rs. 19,444 crores over the same period. As can be seen in Figure 2-15, the share of transport expenditure on energy as part of the GVA shows an exponentially increasing trend from the period 1970 to 2015.

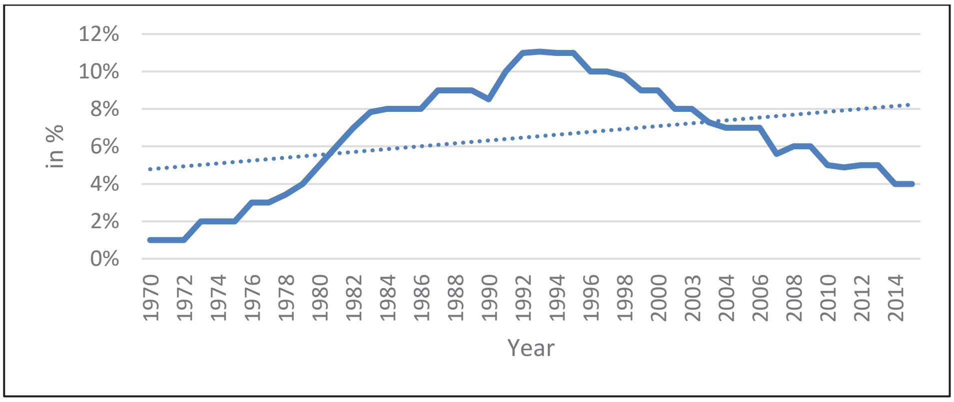


Figure 2-15: Transport Affordability, 1970 - 2014

Source: IEA (1995, 1996, 1997, 1998, 1999, 2011, 2012, 2013, 2014, 2015, 2016, 2017a), Author's compilation

The above discussion shows that as the country continues to develop economically, the percentage of expenditure on energy compared to the total earnings of each key economic sector rises, indicating that the overall energy affordability is falling over time.

[1] 1 crore = 10 million

2.2.1.3 Energy Accessibility

Energy accessibility is defined as the proportion of the population that has access to modern energy services such as electricity for lighting and heating/cooling and fuel for cooking. The discussion below considers the fraction of the Indian population that has access to modern energy services to meet its basic requirements over the period from 1970 to 2015. About 300 million people in India still do not have access to electricity grid connections. Electrification of the nation, in particular rural electrification, has been a key topic on the agenda of the Indian Government and there have been significant investments in providing uninterrupted power to all to achieve the desired economic success.

Access to Electricity

The rise in urbanisation has seen an increase in the financing of and investment in infrastructure power projects to provide reliable electricity supply to households. This can be seen in Figure 2-16, which shows that in 2014, more than 98% of India's urban population had access to electricity.

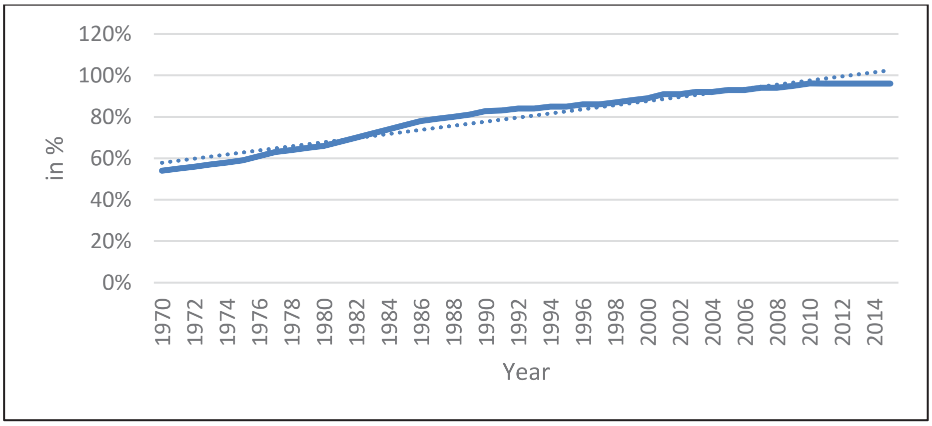


Figure 2-16: Access to Electricity – Urban, 1970 - 2014

Source: Author's compilation

There have also been significant financing schemes to bring electricity to villages in the rural regions. One of the key challenges has been to connect these remote and difficult-to-access villages with a grid supply. Alternative measures have been taken, such as to boost the use of renewable energy by distributing solar packs and battery banks to rural households. Through such measures, the government has been able to provide power supply to nearly 70% of the rural population, as can be seen in Figure 2-17.

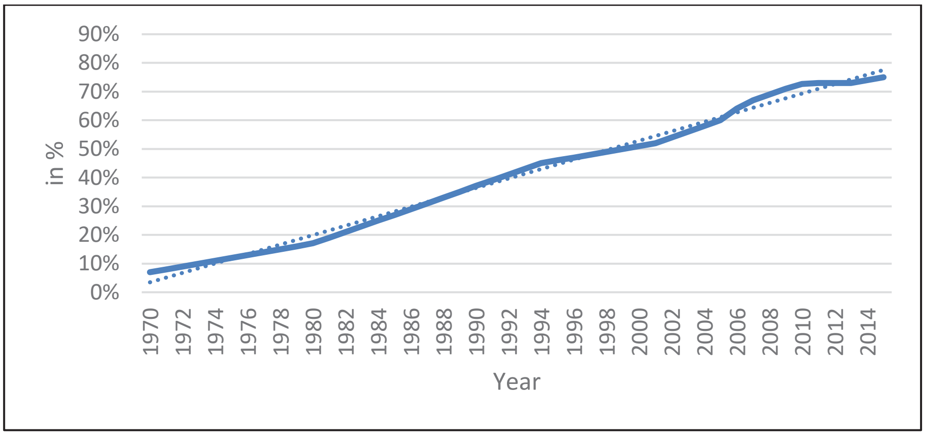


Figure 2-17: Access to Electricity – Rural, 1970 - 2014

Source: Author's compilation

Overall, as the population of the country has grown and more and more people demand better living conditions and lifestyles, the proportion of people gaining access to electricity has also grown, specifically from 1970 to 2014, as can be seen in Figure 2-18.

The Figure 2-18 shows the normalised values for access to electricity, which is the author's compilation based on Figure 2-16 and Figure 2-17. These values are determined by calculating the Herfindahl-Hirschman Index (HHI) for the proportion of total electricity consumed by the residential sector, including both urban and rural households in a particular year over the period from 1970 to 2014.

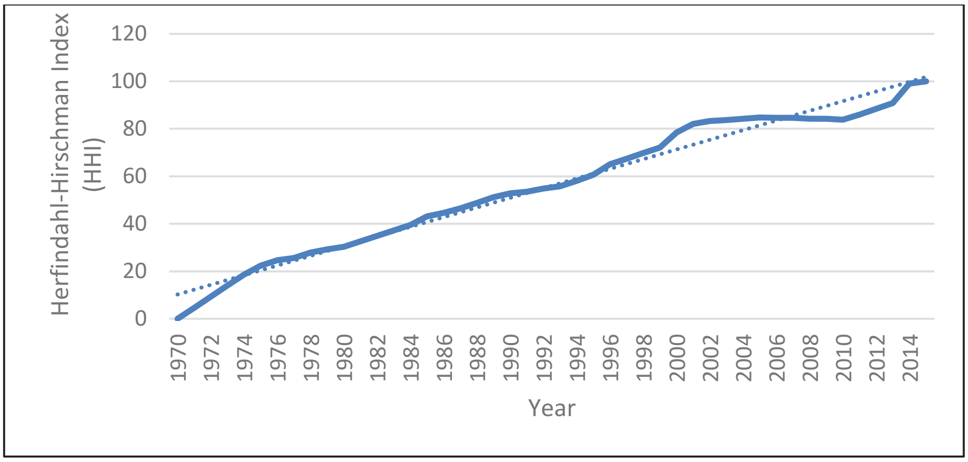


Figure 2-18: Access to Electricity, 1970 - 2014

Source: Author's compilation

Access to Modern Cooking Facilities

To study the accessibility to modern cooking facilities for both urban and rural regions, the data considered is the use of LPG as the primary source of energy for cooking in the home.

As urban households have adapted to better living conditions, they have transitioned from traditional fuels to LPG to meeting their cooking needs, as can be seen in Figure 2-19. In the early years from 1970s-1980s, the urban population was dependent on kerosene and firewood for cooking; however, over time, access to LPG improved and the population became increasingly aware of the adverse health impacts of cooking with traditional fuels, which encouraged them to adopt LPG.

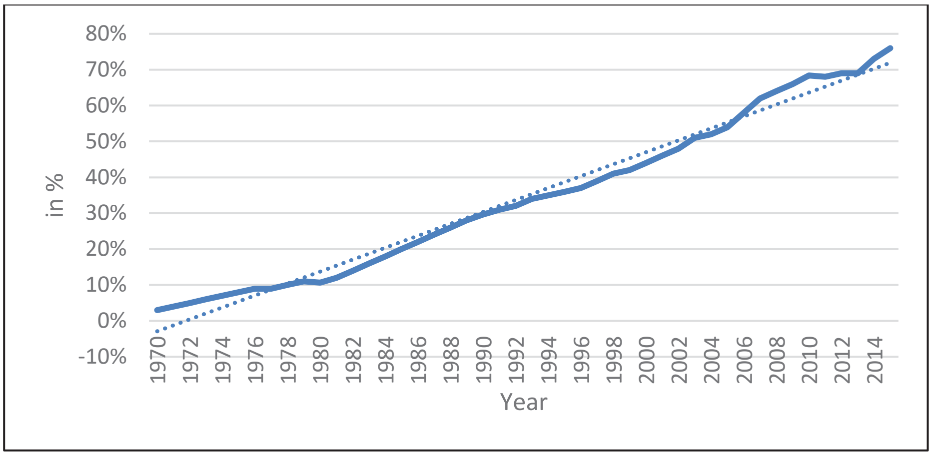


Figure 2-19: Access to Modern Cooking – Urban, 1970 - 2014

Source: Author's compilation

Unlike in the urban regions, rural households are still largely dependent on traditional fuels for cooking. This is mainly because of the cheap and easy access to firewood and agricultural by-products. Further, access to LPG is difficult and expensive compared with the traditional fuels. It is only since the early 2000s that rural households have had access to modern cooking facilities; however, the proportion of these in comparison to the population in these regions is still very small, as can be seen in Figure 2-20. Thus, access to modern cooking facilities continues to be a challenge, particularly continued dependence on traditional fuel sources can have adverse health impacts.

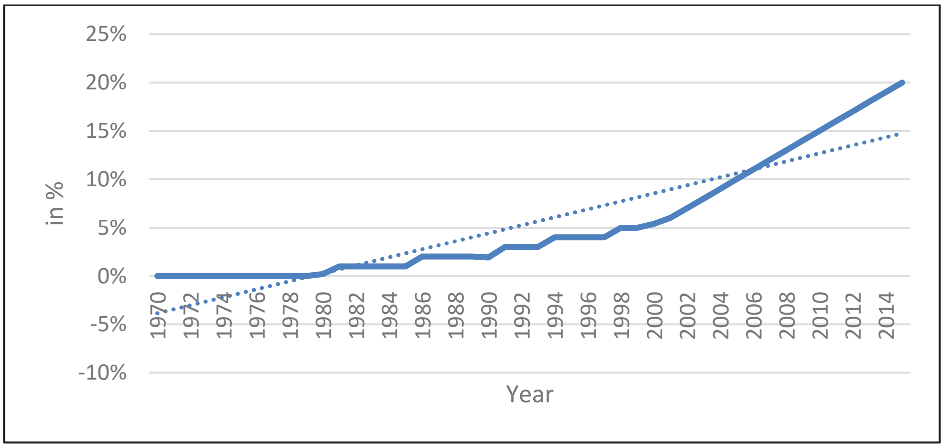


Figure 2-20: Access to Modern Cooking – Rural, 1970 - 2014

Source: Author's compilation

The overall trend in access to modern cooking fuels shows a slight decrease over the period from 1970 to 2014, as can be seen in Figure 2-21; this is a result of the varying rates at which the urban and rural populations of India have gained access to modern cooking facilities. As more and more of the population continue to have improved better living conditions, the rate of transition from traditional firewood to LPG has increased. This accounts for the cumulative increases in access to modern cooking fuel seen around the year 2012.

The Figure 2-21 shows the normalised values for access to modern cooking, which is the author's compilation based on Figure 2-19 and Figure 2-20. These values are determined by calculating the HHI for the proportion of total oil products (LPG) consumed by the residential sector, including both urban and rural households in a particular year over the period from 1970 to 2014.

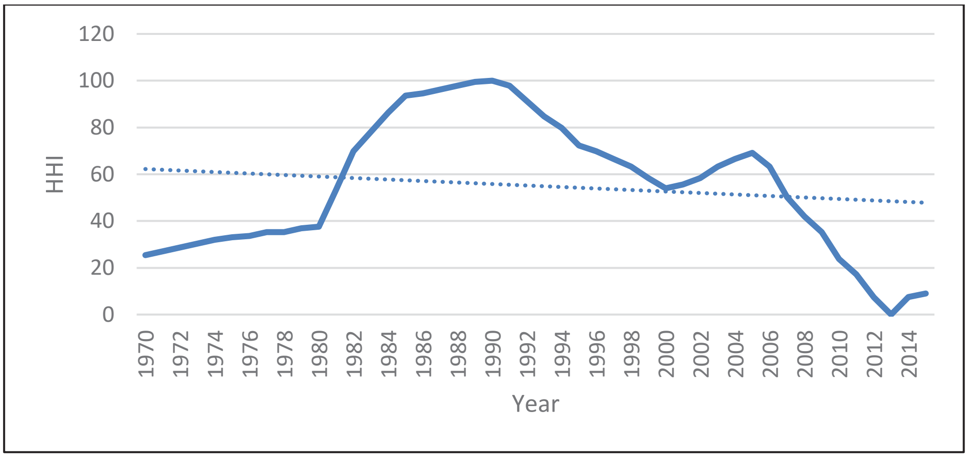


Figure 2-21: Access to Modern Cooking, 1970 - 2014

Source: Author's compilation

The Indian government has adopted various schemes and initiatives to provide electricity to all households, particularly to the village areas and it is through such measures that the government aims to boost the growth of the country. Thus, as stated by Pricewaterhouse Coopers (PwC) energy specialist, Mr. Kameswara Rao, '*access to energy is central to development and these initiatives to expedite that access is strongly positive for growth*.' (ET Bureau, 2017) The discussion above shows the trend of increasing accessibility to energy is a result of the growing rate of urbanisation and improved living conditions throughout the country.

2.2.1.4 Energy Reliability

Energy reliability refers to the ability of the energy generation (electricity) system to provide consistent energy at expected levels under stated conditions for a specified period of time (uninterrupted electricity). To better understand energy reliability, this section will discuss the change in the energy mix to generate adequate electricity, the percentage of electricity transmission and distribution (T &D) losses and the amount of each fuel consumed as part of the total fuel consumption for the period from 1970 to 2014.

Energy Mix for Electricity Generation

India continues to be dependent on coal for power generation. As at September 2017, the national grid had a total installed capacity of 326.83 GW. Coal contributed 58.80% and renewable energy sources 17.51% of the total energy generation, as can be seen in Figure 2-22. One of the key initiatives of the government is to install 175 GW of renewable energy generation as a significant diversification away from import-dependent coal-fired power plants (Central Statistics Office, 2012-2017). This is reflected by the increase in the share of renewable energy sources in recent years from 2007 to 2017.

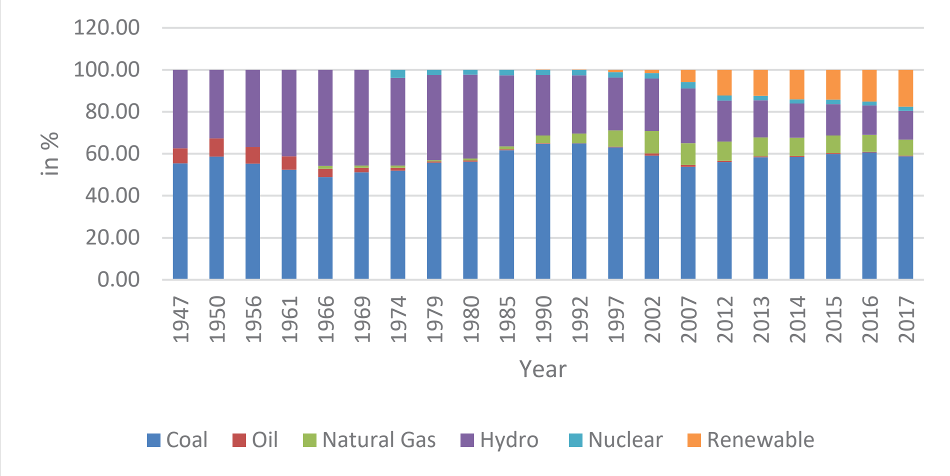


Figure 2-22: Energy Mix for Electricity Generation, 1947 - 2017

Source: Central Statistics Office(2012-2017)

Transmission and Distribution Losses

The energy losses that occur in the process of supplying electricity to end-users can be a result of technical losses due to energy dissipated in the conductors and transmission equipment. These losses can be classified into the following three subgroups:

1. transmission losses – 400kV/220kV/132kV/66kV
2. sub-transmission losses – 33kV/11kV
3. distribution losses – 11kV/0.4kV

Another type of loss is the aggregated technical and commercial (AT&C) loss caused by pilfering, defective meters, errors in meter readings and errors in the estimation of unmetered electricity supply. The transmission and distribution (T&D) losses have gradually escalated from 15% in 1966 to a peak of 34% in 2002, hovering around the 22% range in more recent years, as can be seen in Figure 2-23. The average AT&C losses in 2017 were about 23% (Shastri and Kulkarni, 2018). While the government has made some effort to curb these losses, there is not much evidence that these efforts have had an impact.

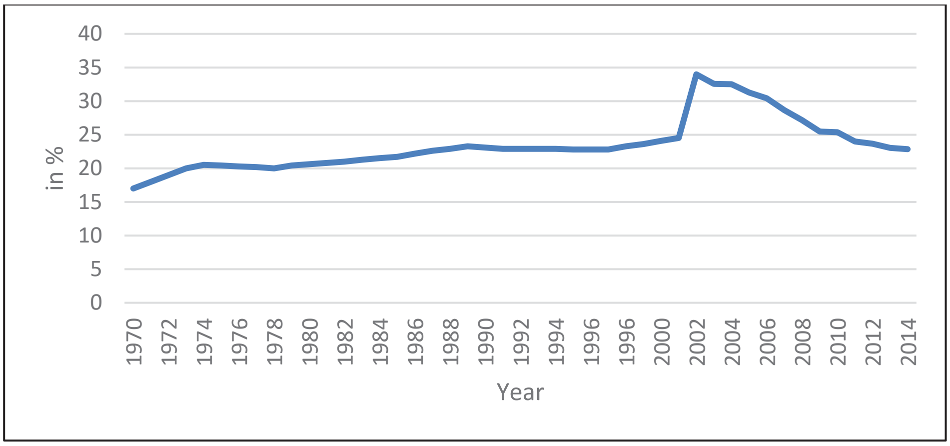


Figure 2-23: Transmission and Distribution Losses, 1970 - 2014

Source: Central Statistics Office(2012-2017)

Total Consumption by Fuel Type

The calculated Herfindahl-Hirschman Index (HHI) value ranging between 0.30 to 0.35 indicates there is a diversity in the consumption pattern by fuel type, with the total consumption dominated by coal and lignite. The contribution of each fuel type to total energy consumption on a yearly basis for the period 1970 to 2015 is as seen in Figure 2-24. The contribution of coal has remained steady at about the 40%-45% mark, whereas the contribution of crude oil and electricity are almost inversely proportional over the years; the contribution of natural gas has remained constant at about 8% since the early 2000s (Central Statistics Office, 2012-2017).

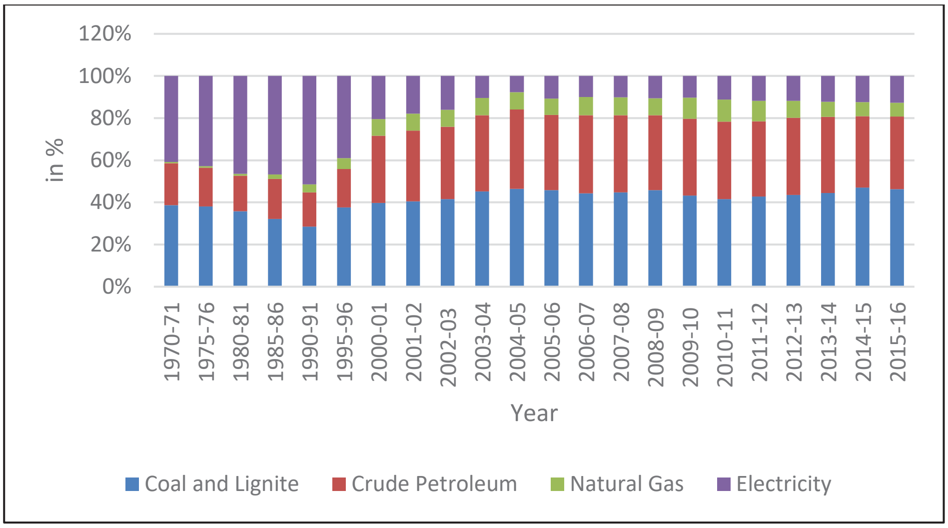


Figure 2-24: Total Consumption by Fuel Type, 1970 - 2015

Source: Central Statistics Office(2012-2017)

To achieve the target of the present government to connect all households to the national grid by 2018 means reliability of supply is key, but less dependability on the grid means households and businesses alike must invest substantially in alternative backup supplies through invertors, batteries and diesel generators.

2.2.1.5 Energy Sustainability

Energy sustainability is the ability to meet present-day energy needs without compromising future energy needs. To describe sustainability, the key GHG trends on a per-capita basis as a result of anthropogenic and non-anthropogenic activities related to the economy and the growing population are discussed.

Carbon Dioxide (CO_2) Emissions

In 2015, India ranked third in the highest CO_2 emitters globally after China and the US. Most of that CO_2 comes from the combustion of fossil fuels such as coal, oil and gas. The CO_2 emissions per capita rose from 0.3 tCO_2/capita in 1971 to 1.6 tCO_2/capita in 2015 and account for 46% of the total emissions in Asia, as can be seen in Figure 2-25

(Chatterjee, 2017). Despite efforts to increase the share of renewable energy sources, India still depends largely on coal for the electricity generation needed to support the nation's growing population and its economic development.

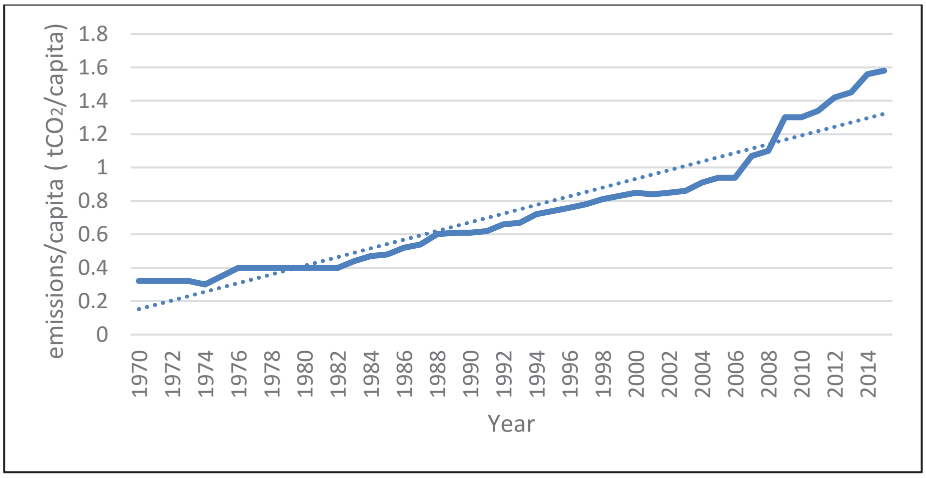


Figure 2-25: CO_2 emissions per capita, 1970 - 2014

Source: Olivier et al.(2016), (IEA, 2016), Author's compilation

Sulphur Dioxide (SO_2) Emissions

In 2010 India ranked as the second highest emitter of SO_2 after China. Coal-fired power plants contributed to more than half of these emissions, followed by industry (34%) and residential (6%) sector activities, which in turn reflection the dependence of rapid economic development on fossil fuels. SO_2 emissions from power plants increased by 105%, from 2.6 Tg in 1996 to 5.2 Tg in 2010 (Lu, Zhang, and Streets, 2011 and (Varshney and Garg, 1978). As seen in Figure 2-26, SO_2 emissions per capita show a rising trend with emissions increasing from 0.002 tCO_2/capita in 1970 to 0.008 tCO_2/capita in 2014.

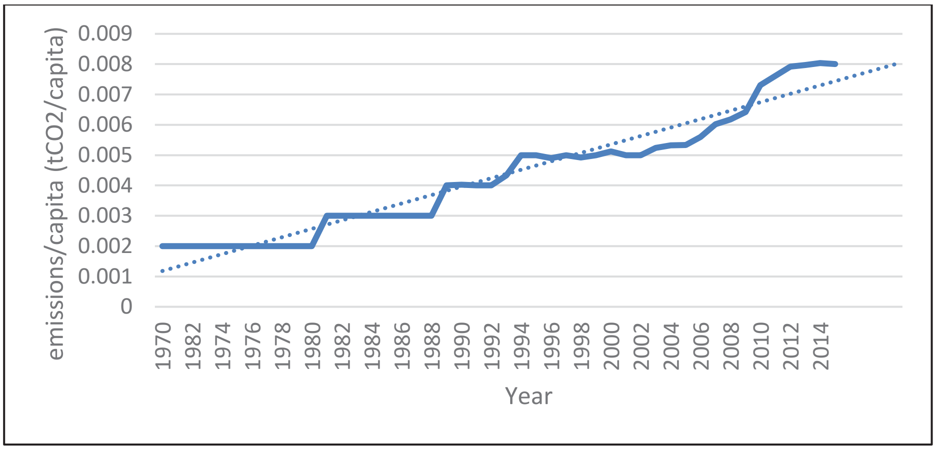


Figure 2-26: SO_2 emissions per capita, 1970 - 2014

Source: Klimont, Smith, and Cofala (2013), Author's compilation

Methane (CH_4) Emissions

Methane is the second most potent GHG and its concentration in the atmosphere is rising. India's total methane emissions are about 10 times larger than those of the UK, although they are less per capita, and over the last few years, there has been very little growth in these emissions (Srivastava, 2017). The largest contributors to methane emissions are animals such as cows and buffaloes, and waste and fossil fuels. India has the world's largest ruminant population, which digest their food through the process of fermentation and produce methane gas which is released in the atmosphere. Other sources of methane emissions include rice paddies, which require high levels of water and warm weather. Together with the burning of fuels, especially during the winter months, result in a rise in methane emissions. However, per capita CH_4 emissions have been decreasing over the years as the population increases, as can be seen in Figure 2-27.

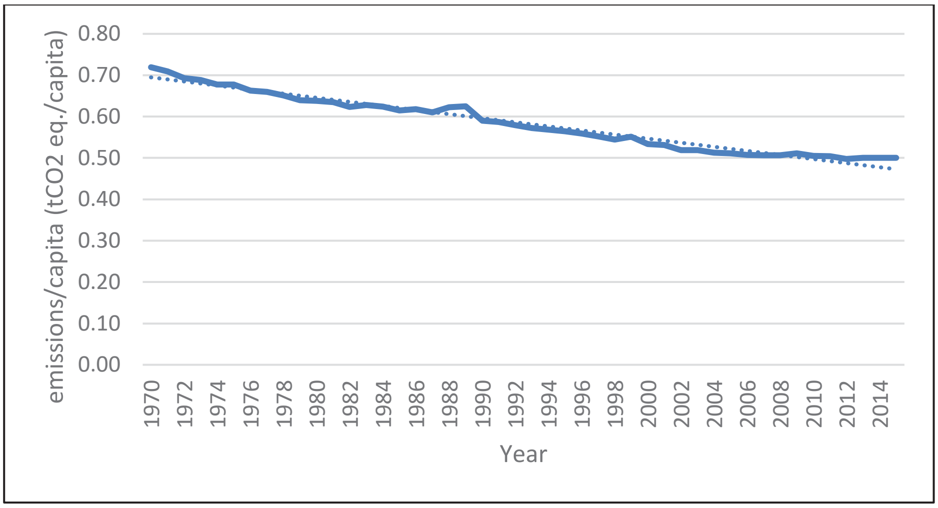


Figure 2-27: CH_4 emissions per capita, 1970 - 2014

Source: The World Bank (2017), EPA (2006), Author's compilation

Nitrous Oxide (NOx) Emissions

Agricultural contributions to nitrous oxide emissions are from the burning of agricultural waste matter while the industry sector contributions are mainly from the manufacturing industries and construction. The volume of agricultural nitrous oxide emissions in India increased from 222.8 Gg in 1970 to 351.43 Gg in 2008. Emissions from electricity generation contribute the most, with emissions increasing rapidly from the late 1980s. Oil and gas emissions, however, have been relatively low over the years (European Commission, 2012). The NO_x emissions per capita in India show an overall rising trend, from 150,000t CO_2 eq. in 1970 to 210,000t CO_2 eq. in the late 1990s; in more recent years, this dropped to around 180, 000t CO_2 eq., as can be seen in Figure 2-28.

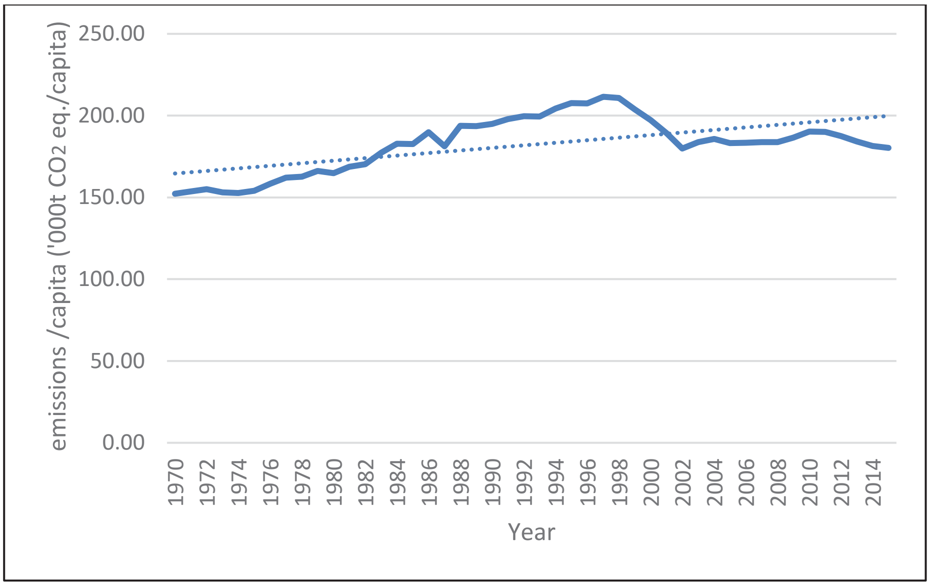


Figure 2-28: NO_x emissions per capita, 1970 - 2014

Source: The World Bank (2017), European Commission (2012), Author's compilation

From the discussion above, it is clear that as India continues to be largely dependent on conventional fossil fuels, in particular on coal, to meet its growing energy needs, it adds to the pressures of GHG emissions and related adverse climate and health concerns, which implies that current practice has resulted in a decline in overall sustainability over the years from 1970 to 2014.

2.2.2 Energy Security Definition in the context of this research

The review of the literature on energy security indicates there is no one definition that comprehensively and concisely defines energy security. Nor does the literature take into account all the key energy security dimensions and the relationships between these dimensions.

Therefore, energy security, in the context of this research, is defined as '*the environmentally sustainable availability and access to reliable, safe and clean sources of energy to meet the energy demands of India at prices that are affordable.*'

This definition addresses all the key dimensions and includes the context of the energy-economy-environment relationship. This, in turn, will help give policymakers insights that will be valuable in formulating policies that take all the key dimensions into account.

2.3 Energy Security Is a Challenge

2.3.1 Indicator trends

The historical trend in energy security over the years is studied by developing a graph. This is done by developing a composite index, Herfindahl-Hirschman index (HHI) using different weights of the attributes of accessibility, affordability, availability, reliability and sustainability. On the basis of this a composite index for energy security is determined. The index is obtained by the linear aggregation of the weighted and normalised values of the individual indicators from the years 1970 to 2014. As the graph rises across the scale, so is the country considered to be more energy secure. The trend analysis is carried out first by assigning equal weights to all the considered energy security attributes and, second, using unequal weights.

Composite Index for the Attributes

(a) Composite index - energy availability

As can be seen from Figure 2-29, overall energy availability remained constant from the 1970s to 2014. This was a result of the continuous increase in the early years which is counterbalanced by a decreasing trend from the early 1990s, which was a result in turn of the growing population and increasing energy needs during those later years. This resulted in a rising import dependency to bridge the energy supply gap.

The composite index for energy availability (in GJ) is determined by calculating the HHI for the normalised values of production per capita and import dependency in a particular year over the period 1970 to 2014.

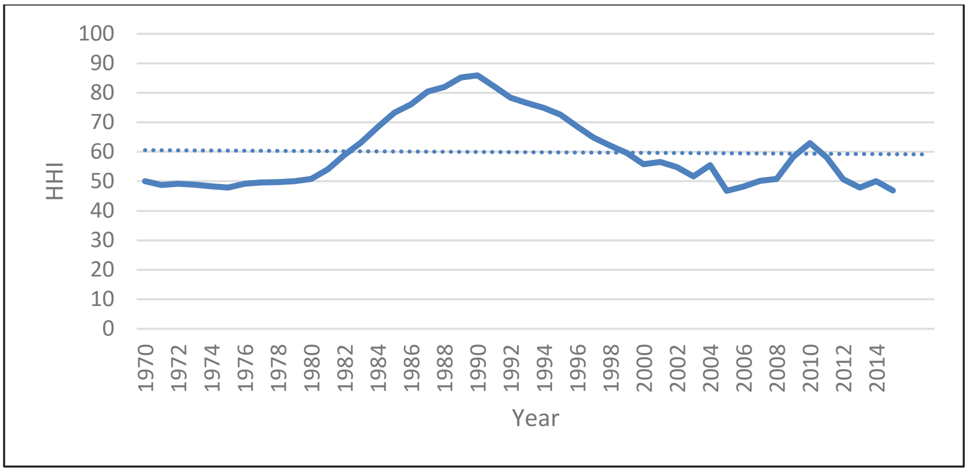


Figure 2-29: Composite Index-Energy Availability (in GJ), 1970 - 2014

Source: Author's compilation

(b) Composite index - energy Affordability

As India has continued to grow economically, there has been increased investment in the energy sector to support the growing needs of people and to boost domestic manufacturing. This has resulted in an overall decline in the energy affordability over the period under examination, as shown in Figure 2-30, indicating a reduction in the share of expenditure on energy from the total sectoral gross value added for the industry, agriculture and transport and a reduction in the share of expenditure of household income on energy for the residential sector.

The composite index for energy affordability (in %) is determined by calculating the HHI for the normalised values of the share of expenditure on energy from the total gross value added for the industry, agriculture and transport sector and the share of expenditure of household income on energy for the residential sector in a particular year over the period 1970 to 2014.

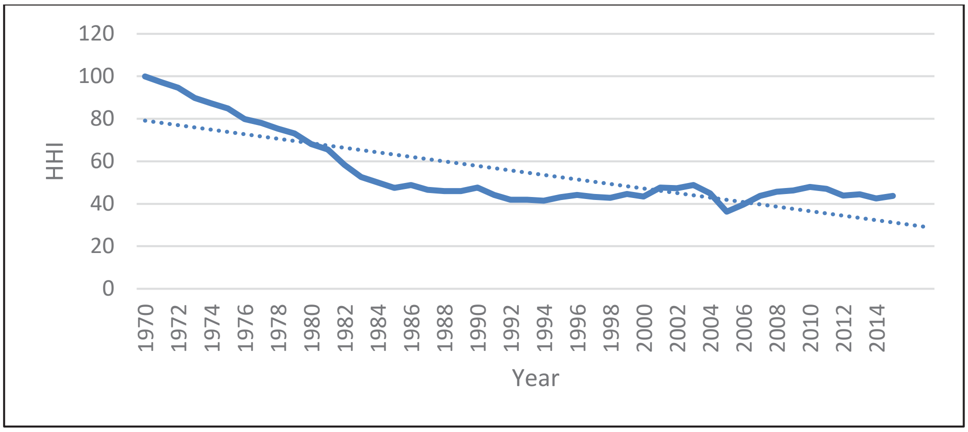


Figure 2-30: Composite Index-Energy Affordability (in %), 1970 - 2014

Source: Author's compilation

(c) Composite index - energy accessibility

The historical trend from 1970 to 2014 shows an increase in overall energy accessibility, as can be seen in Figure 2-31, a result of the increased rate of urbanisation and improved standard of living conditions whereby more and more people gained access to modern energy sources to meet their cooking, heating/cooling, lighting and other needs.

The composite index for energy accessibility (in %) is determined by calculating the HHI for the normalised values of the proportion of total electricity and oil products (LPG) consumed by the residential sector in a particular year over the period 1970 to 2014.

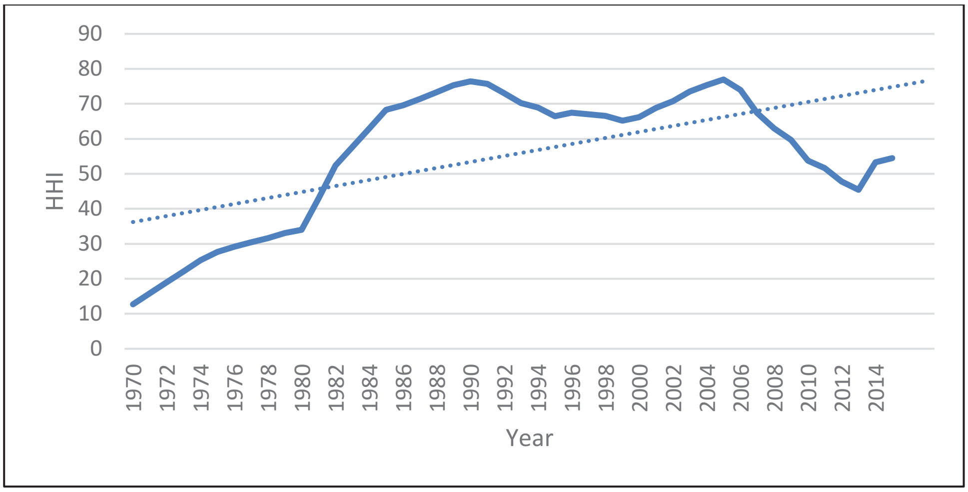


Figure 2-31: Composite Index-Energy Accessibility (in %), 1970 - 2014

Source: Author's compilation

(d) Composite index - energy reliability

The historic trend from 1970 to 2014 shows an almost constant energy reliability (see Figure 2-32), however, there is a decrease in reliability between the period 2000 to 2004 due to a peak rise in T&D losses as seen in Figure 2-23. This was a result of the increase in electricity generation to meet the growing energy needs of the population over the years counterbalanced by the poor infrastructure of the national grid, which resulted in substantial T&D losses.

The composite index for energy reliability (in %) is determined by calculating the HHI for the normalised values in a particular year over the period 1970 to 2014 for the following:

1. the proportion of various fuels such as coal, oil, natural gas, hydro, nuclear and renewable in the electricity generation mix,

2. the proportion of transmission and distribution (T&D) losses,

3. the proportion of consumption each fuel including coal, lignite, crude petroleum, natural gas, and electricity as part of the total energy consumption.

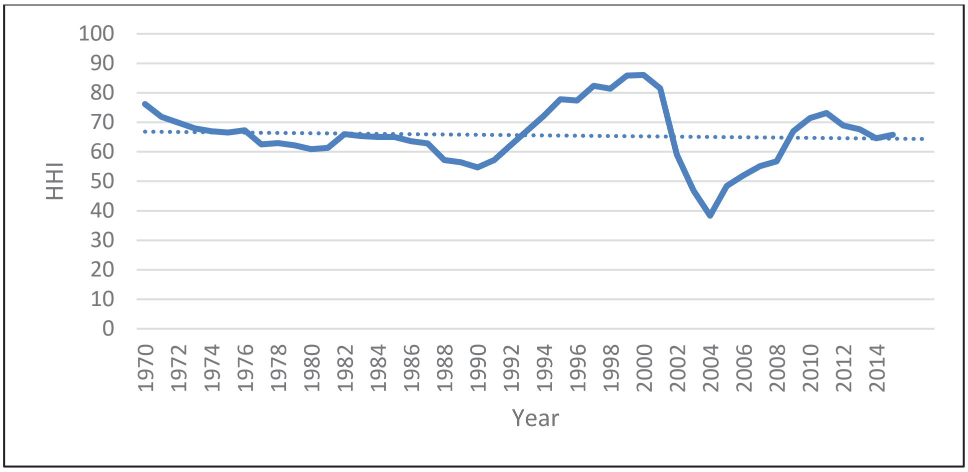


Figure 2-32: Composite Index-Energy Reliability (in %), 1970 - 2014

Source: Author's compilation

(e) Composite index - energy sustainability

Over the trend period used in this research, India was hugely dependent on fossil fuels, particularly coal, to meet the growing energy needs of the population. There are no incentives to reduce this consumption, hence the rise in GHG emissions as a result of the economic activities to meet those growing needs, wand consequent degraded environmental conditions and adverse health concerns, as reflected in Figure 2-33.

The composite index for energy sustainability (in CO_2 eq per capita) is determined by calculating the HHI for the normalised values of the emissions per capita for CO_2, SO_2, CH_4 and NO_x in a particular year over the period 1970 to 2014.

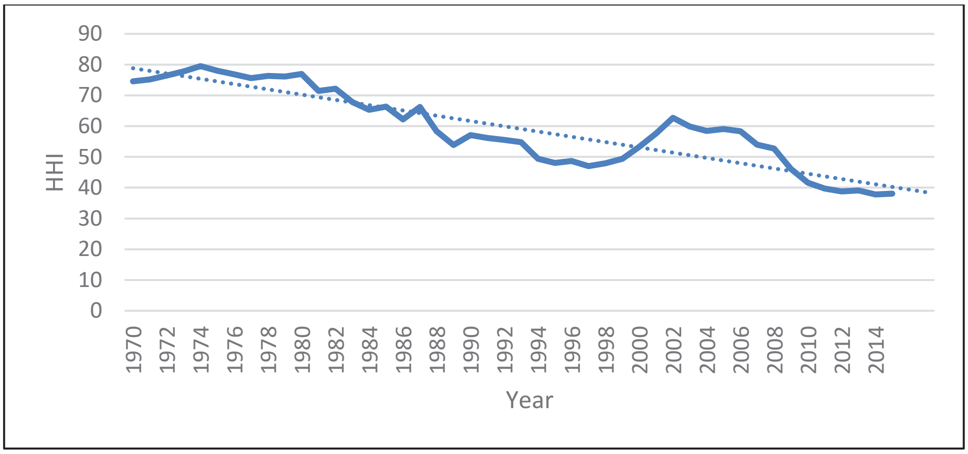


Figure 2-33: Composite Index-Energy Sustainability (in tCO_2 eq per capita), 1970 - 2014

Source: Author's compilation

Composite Index for Energy Security

(a) Equal Weights

A composite index of energy security based on the equal weights given to the normalised values of each of the attributes namely energy availability, accessibility, affordability, reliability and sustainability is shown in Figure 2-34. Equal weight implies the recognition of an equal status for all attributes. Equal weights, using an assumed value of 0.2 per attribute (there being five attributes), are assigned to each attribute.

The composite index for energy security is determined by calculating the HHI for the composite index of each of the attributes, this method of normalisation enables to adjust the values measured in different units to a notionally common scale allowing the comparison of the corresponding normalised values from the different attributes on a single time series.

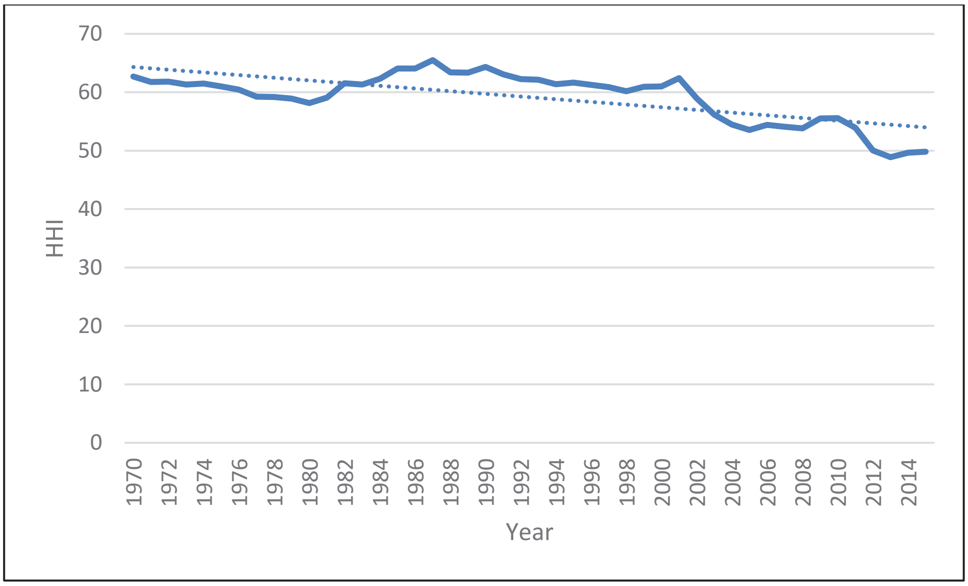


Figure 2-34: Composite Index - Energy Security (equal weights), 1970 - 2014

Source: Author's compilation

From 1970 to the mid-1980s, the index declined to 55. This could be attributed to the decrease in energy affordability across all key end-use sectors of the economy, the weak electricity infrastructure and increased T & D losses. From the second half of the 1980s to the early 2000, the index averaged at 62 and gradually declined to 50 by 2014.

The overall trend of the energy security index was to decline over the years. As India continues to progress economically, its demand for energy resources to support these developments will increase. In addition, the growing rate of urbanisation and improved standard of living means larger proportions of the population are transitioning from traditional fuels to conventional fossil fuels to meet their needs across both the urban and rural regions. This, in turn, implies that improving overall access to energy and improving the fuel mix enhances electricity generation diversity. These improvements are slowed by the limited availability of indigenous resources, higher energy prices due to India's dependence on imported fuel, and the increasing environmental issues of consuming fossil fuels. These contributed to the overall impact on energy security behaviour over the years from 1970 to 2014, indicating India was becoming less energy secure.

(b) Unequal weights

India's limited domestic energy reserves raises the pressure on energy affordability and availability over time, thus increasing the dependence and the need to paying higher prices for imported energy resources. As the current oil minister of India, Dharmendra Pradhan, said at the 16th International Energy Forum (IEF) conference in New Delhi, India, '… *to take care of the interest of the consumers especially in an aspiring country like India. We need a balance. We have to have affordable energy price*.' (ET Energy World, 2018) This is further supported by a study by The Federation of Indian Chambers of Commerce and Industry (FICCI), '*Environment issues, dependency on imports and high energy costs are some of the challenges currently facing India.*' (ENS Economic Bureau, 2018). This indicates that greater emphasis needs to be given to the attributes of affordability and availability. Accordingly, the revised composite index for energy security, developed in this research by giving a higher but equal weight to the attributes of affordability (0.35) and availability (0.35) and keeping the weights of the remaining three attributes at 0.10, is shown in Figure 2-35.

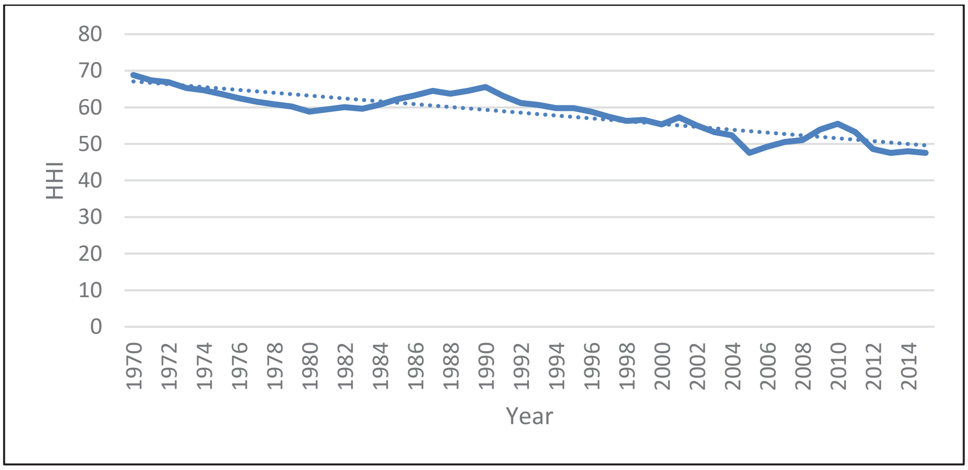


Figure 2-35: Composite Index - Energy Security (unequal weights), 1970 - 2014

Source: Author's compilation

The graph in Figure 2-35 is determined by calculating the HHI for the composite index of each of the attributes as stated above. It indicates that India is becoming more and more energy insecure as it continues to progress economically. The continuous expansion of the population, increased urbanisation and fast-growing industry, manufacturing and services sectors mean there is a growing need for a continuous and uninterrupted supply of electricity. The existing infrastructure has many barriers, one of them being the availability of fuel, since power generation continues to be largely dependent on fossil fuels, particularly coal. In addition, the poor and inefficient physical infrastructure means increased T & D losses and reduced reliability, making it difficult to keep pace with the extra demand. Increased dependence on fossil fuels to support economic activities also raises sustainability issues. For instance, the capital city of Delhi was called a '*gas chamber*' (Heanue, 2018), with reports stating that breathing the city's air was the equivalent of smoking 50 cigarettes a day; the environmental crisis risks becoming a humanitarian catastrophe (Heanue, 2018). Further estimates show that 75% of air pollution-related deaths in 2015 came from rural areas in India, where a major proportion of the population resides (Wu, 2018). Although efforts are made by the state to substitute conventional fuels with more efficient and cleaner renewable energy sources across all end-use sectors, the overall contribution of these is negligible and energy sustainability and environmental concerns continue to grow.

Against this background, it can be said that energy security is a key challenge for India. The country's economy has always been and continues to be largely energy dependent in order to achieve projected levels of economic growth. The average Indian becoming richer, resulting in rising energy needs, has in turn attracted further attention to the importance of energy security (Pachauri and Jiang, 2008). Inadequate domestic fuel supplies force India to increase its import bills. The changing geopolitical situation further hampers access to these resources, leading to rising prices and affordability concerns. The emphasis on economic growth and a long neglect of environmental issues have resulted in a polluted and degraded environment, compounded by the effects of climate change that further add to these concerns.

2.3.2 Energy Security in the years to come

Energy Demand Forecasts

India is home to 18% of the world's population and consumes 6% of the world's primary energy. Its energy consumption has doubled since 2000 and is projected to grow to 9% of the world's primary energy by 2035, ranking it second among the Brazil, Russia, India and China (BRIC) nations. India is expected to be one of the fastest growing economies, with an average annual growth in GDP of 5% per year from 2015 to 2040 (EIA, 2017b). It is also expected to contributing to around one-quarter of the projected global energy demand, much of it is a result of growing urbanisation and energy-intensive infrastructure developments across the country (IEA, 2015a).

Much (75%) of this growing energy demand continues to be met by fossil fuels. Coal is one of the dominant resources used in response to an average growth in the total primary energy demand by 2.6% per year from 2015 to 2040, as shown in Figure 2-36 (EIA, 2017b).

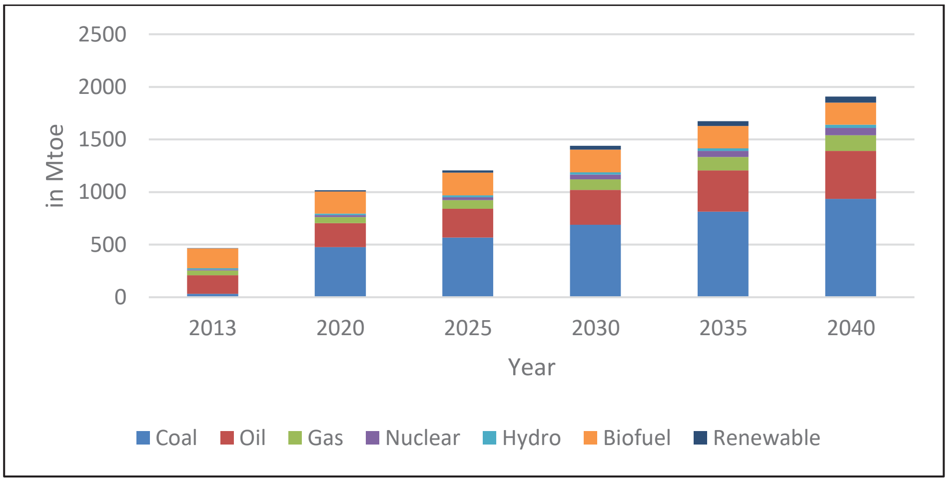


Figure 2-36: Predicted total Primary Energy Demand by source, 2013 – 2040

Source: IEA (2015)

Electricity demand is expected to more than triple by 2040 from an average of 900 TWh in 2013 to 3300 TWh in 2040, as shown in Figure 2-37 (IEA, 2015a). This raises a concern regarding the reliability of electricity supply. To meet this growing demand, new power plants need to be added, the reliability and quality of the power supply needs to be improved and this needs to be integrated into the new efficient technologies and generation mix to ensure it is environmentally sustainable.

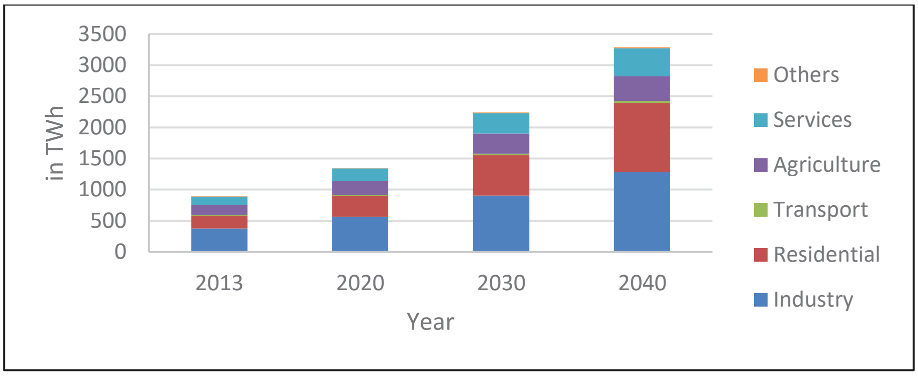


Figure 2-37: Predicted electricity demand by sector, 2013 – 2040

Source: IEA (2015)

The industry sector remains the largest consumer of electricity, and the steel and aluminium industries the key contributors. Coal consumption by the industry sector is expected to increase by nearly 3% per year from 2015 to 2040, as shown in Figure 2-38 (EIA, 2017b). This level of consumption is followed by that of the residential sector in line with the rising incomes.

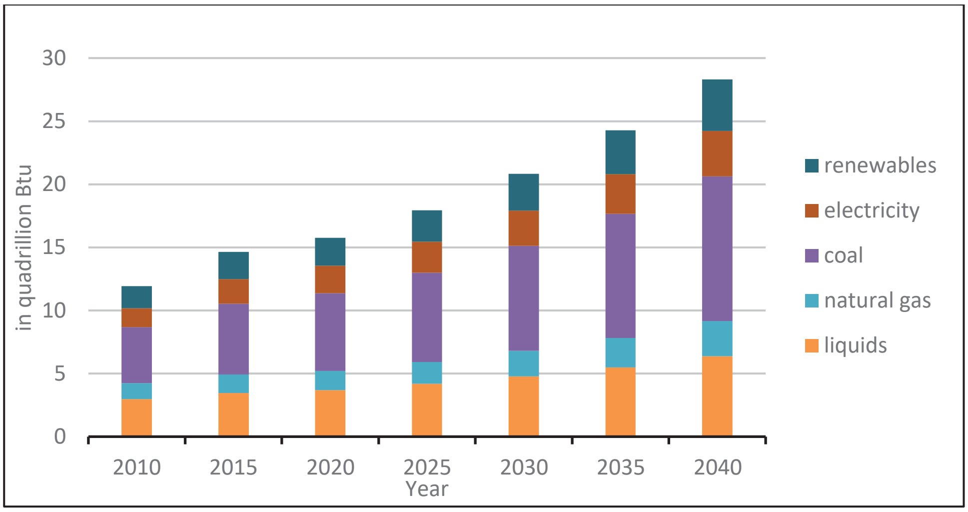


Figure 2-38: Predicted industry sector energy consumption by source, 2010 – 2040

Source: EIA (2017b)

Consumption of petroleum and liquid fuel is predicted to grow by 142% from 2015 to 2040 as there will be increased demand from the transportation services. Energy consumption in transport will grow by 5.8% per year, with oil constituting 93% of the total share in 2035 (BP, 2017).

Energy Investment Forecasts

With energy demand expected to grow by 95% by 2030, India will likely remain a net importer of energy in the future. To be able to meet these growing future energy demands, India will need large-scale investment in the production of such energy sources as coal, oil and gas to support the infrastructure development in the industrial, transport and electricity generation domains. In 2016, India ranked third globally in its energy investments, behind only China and USA, with investments jumping by 7%. Investment in the electricity sector reached nearly US$55 billion as a result of the push from the present government to modernise and expand the national grid (IEA, 2017b).

In 2016, India's total investment in renewable energy stood at US$9.7 billion (as can be seen in Table 2-3), which was almost double the investment in fossil fuel generation (McCrone et al., 2017). Significant investment in renewables of between US$120 billion and US$130 billion are projected in India to achieve the target of 175GW of electricity generation from renewables by 2022 (Puri, 2016), making it one of the fastest growing markets. However, since India has an infrastructure debt estimated at around US$190 billion (Puri, 2016), it will need to look at alternative viable options such as bonds, trusts and securitised loans to ensure these investments are successful.

Renewable Energy Investment, 2016	in US$ billion
Solar	5.5
Wind	3.8
Biomass	0.1
Small hydro	0.3
Total	**9.7**

Table 2-3: Renewable Energy Investment, 2016

Source: McCrone et al. (2017)

The production of indigenous coal is expected to increase at a CAGR of 3.8% from 340 Mtce[2] in 2013 to 926 Mtce in 2040, as shown in Figure 2-39. Most new investment is in coal mining, and this is projected to increase from US$2.1 billion in 2020 to US$7.2 billion in 2040, while the remaining new investment will be in the transport sector, averaging around US$2.9 billion a year over the same period (IEA, 2015a). Large quantities of coal are transported from mines across the country, mainly via the railways. One of the problems leading to the short supply of coal despite mining investment has been poor access to railways and other forms of transport services. The railways in some freight routes are already operating at full capacity, which cause delays in the coal shipments. Thus, the transport investment is directed towards building rail access links to accommodate the growth in coal demand.

[2] Mtce: Metric Tons Carbon Equivalent

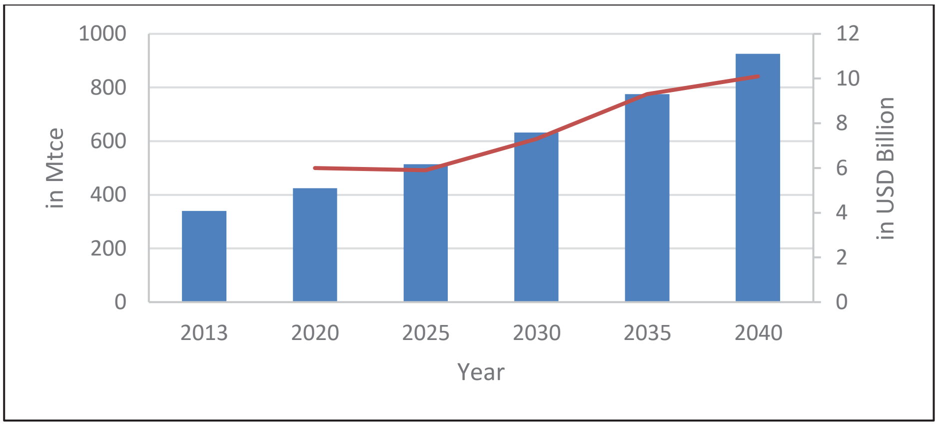


Figure 2-39: Predicted coal production and investment forecasts, 2013 - 2040

Source: IEA (2015)

Domestic oil production comes primarily from the states of Gujarat, Assam and Rajasthan. The future production is expected to reduce from 0.9 mb/d in 2013 to 0.7 mb/d in 2040, as shown in Figure 2-40. As a result of limited indigenous production in the face of increasing demand for oil, the oil companies are seeking opportunities for offshore investments, which come with their own uncertainties. Further, investments in domestic refining capacity will be needed to meet growing demands. Both gasoline and diesel consumption are increasing fast due to the demand from both passenger and road freight transport (IEA, 2015a). And India has become the second largest consumer in the world of LPG as a cooking fuel for the residential sector (Dutta, 2017).

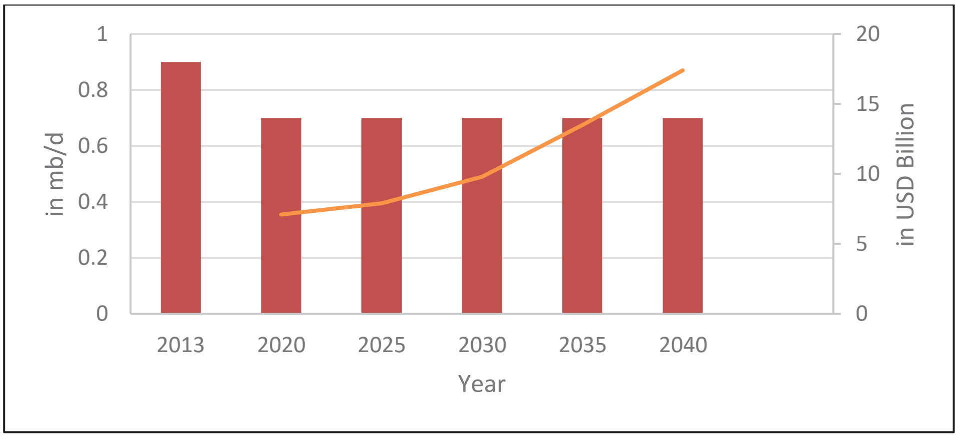


Figure 2-40: Predicted oil production and investment forecasts, 2013 - 2040

Source: IEA (2015)

While a sizable increase in the production of natural gas has been forecast, from 35 BCM in 2013 to 89 BCM in 2040, as shown in Figure 2-41, this still falls short of the expected demand by 80 BCM, which will need to be met by investment in imported gas. Many of the new discoveries of offshore gas are in water depths of between 700 and 1700 metres (IEA, 2015a), meaning investment is required in technology that can assist in drilling these wells while mitigating the potential adverse environmental impacts on water and soil. This, in turn, will keep the development costs high and hence lead to higher gas prices. India has large coalbed methane resources, but much of these lies in complex environments requiring large investments. Shale gas is another option, but no commercially viable activities are currently present. In addition, water use is key to the shale gas production and its use means increasing the stress on this already scarce resource. These challenges further impact the economic viability of these alternative sources.

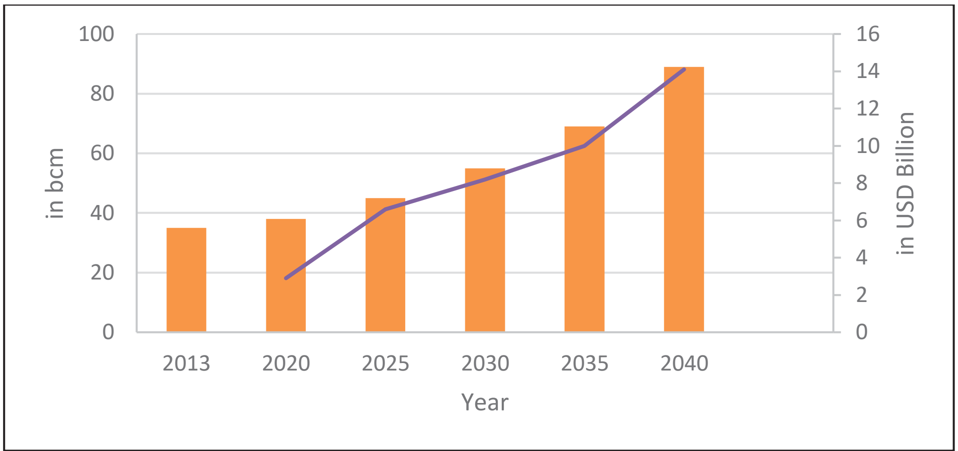


Figure 2-41: Predicted natural gas production and investment forecasts, 2013 – 2040

Source: IEA (2015)

The power sector has expanded its generation capacity rapidly, due to private sector participation and policy measures designed to exploit potential renewable sources; this has improved access to electricity by expanding the national transmission grid. One of the key challenges that can impact the future of this sector however lies in the distribution network. The distribution companies (DISCOMS) have incurred huge losses as the average revenue per kWh of power is negative. Due to these financial constraints, the discoms are unable to invest in upgrading the aging network and purchasing electricity; this results in load shedding and difficulties in purchasing the required power generated from renewable energy sources. The discoms are also unable to raise the electricity tariff to cover these losses as electricity affordability is a matter of social and economic concern.

Even though the demand for coal will increase by 90% from 2010 to 2040, its share of the total consumption of energy for electricity generation is expected to fall from 49% in 2015 to 43% in 2040; this will be due to the increase in the proportion of nuclear and renewable energy sources for electricity generation from 18% in 2015 to 46% in 2040, as shown in Figure 2-42, as a result of policy measures to reduce GHG emissions. India's nuclear energy capacity is estimated to increase from 5GW in 2015 to 17GW in 2025 and 41GW in 2040 (EIA, 2017b).

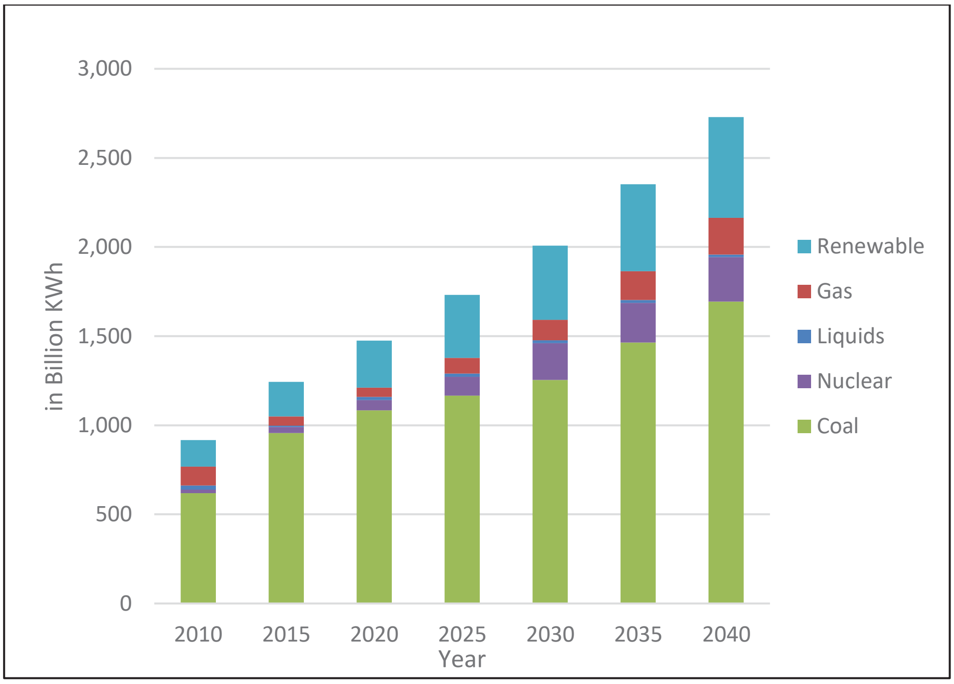


Figure 2-42: Predicted electricity generation by source, 2010 – 2040

Source: EIA (2017b)

Against the backdrop of India's power generation projected growth of 16,000 TWh by 2040, the country will be responsible for nearly 50% of the increase in global coal-fired power plants and the world's largest importer of coal before 2020. Installed power capacity will grow from 290 GW in 2013 to 1075 GW in 2040, as shown in Figure 2-43. The overall share of coal for electricity generation in India is expected to fall from 60% in 2014 to 41% in 2040, but it continues to dominate the generation of power, making India one of the key contributors of CO_2 emissions and India's power sector the second largest emitter of CO_2 from power generation in the world. The proportion of renewables, particularly solar and wind, along with nuclear and gas, help to increase capacity in a sustainable manner, but rapid growth in solar installations will require increased investment. The estimated investment of US$170 billion to financing PV panels is beyond the domestic financial capacity, and relying on foreign capital comes with its own risks of foreign currency fluctuations and geopolitical tensions (IEA, 2015a).

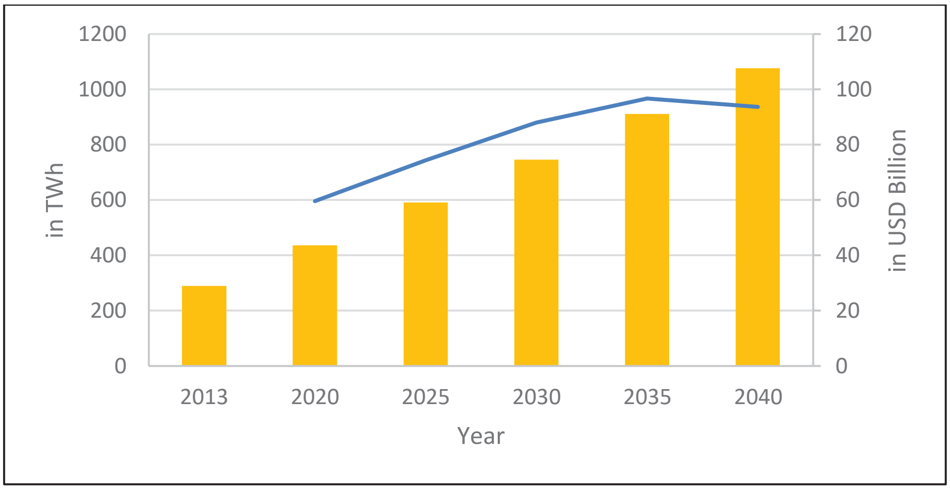


Figure 2-43: Predicted electricity generation and investment forecasts, 2013 – 2040

Source: IEA (2015)

Energy Imports Forecasts

India's need to meet the requirements of its power plants and its growing industrial demand has made India one of the leading importers of coal. Its imports are projected to increase by 105% from 144 Mtce in 2013 to 410 Mtce in 2040, as shown in Figure 2-44. Of this, steam coal will be accounting for nearly 70% and the remainder will be coking coal. Importing coal is facilitated by India's long coastline and several low-cost coal exporters. Indonesia is the major exporter to India, accounting for nearly 60% of imports in 2013, but this is expected to fall to 45% by 2040. The higher ash coals used in the power plant boilers are imported from South Africa and Australia is the primary supplier of coking coal (IEA, 2015a).

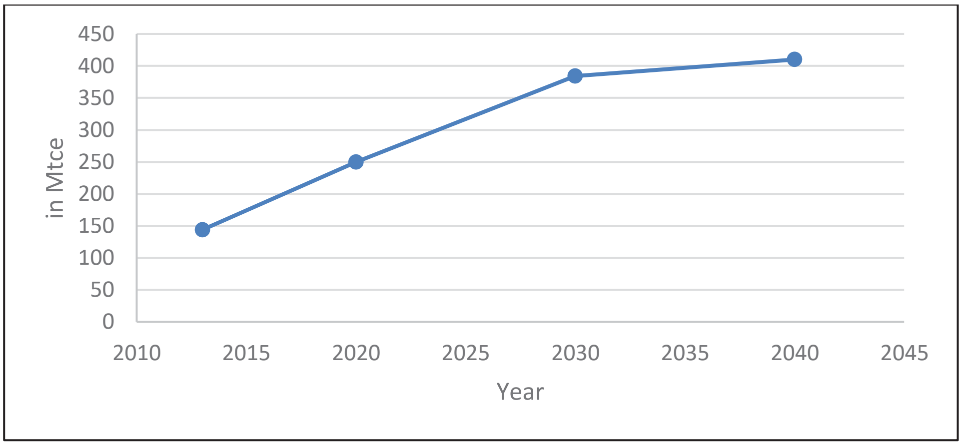


Figure 2-44: Predicted coal imports forecasts, 2010 - 2040

Source: IEA (2015)

India is expected to be dependent on imported oil for over 90% of its oil demands. These oil imports are forecast to increase from 3.7 mb/d in 2013 to 7.2 mb/d in 2040, as shown in Figure 2-45, a projected increase of 165%. The Middle East continues to be India's major source of oil, and it is projected to supply 63% of India's total oil imports by 2040. By 2040, India is projected to be importing 1.2 mb/d in diesel and gasoline and 1 mb/d in LPG (IEA, 2015a).

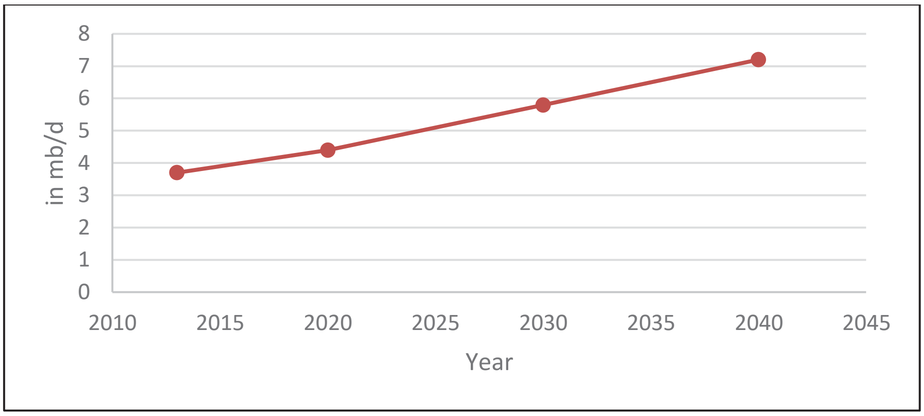


Figure 2-45: Predicted oil imports forecasts, 2010 - 2040

Source: IEA (2015)

Again, to meet rising needs in the face of domestic production shortages, India is expected to import considerable volumes of natural gas. The primary sources of LNG and pipeline gas are Turkmenistan and Iran. However, due to political constraints in these regions, India is at risk of supply disruptions and the need to rely on other relatively expensive sources. LNG and pipeline gas imports are expected to rise to over 80 BCM by 2040, as can be seen in Figure 2-46, an increase in total gas imports of 173%, and LNG being the major import fuel (IEA, 2015a).

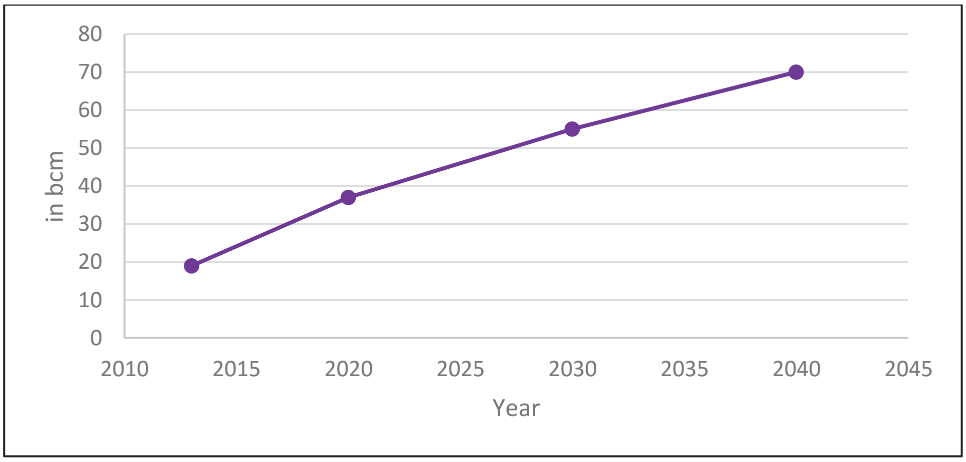


Figure 2-46: Predicted natural gas imports forecast, 2010 – 2040

Source: IEA (2015)

Effect on the End-user

The population of India is projected to reach 1.4 billion by 2020, 1.6 billion by 2040 and about 1.7 billion by 2050, as shown in Figure 2-47 (WB, 2017). The path of economic growth chosen by India will further dictate the growth in its energy demand and emission trajectories. India has scarce domestic energy resources. The rise in population and environmental deterioration represent a challenge to sustainable development, the rising population in particular putting pressure on fossil fuel consumption, which in turn will increase GHG emissions.

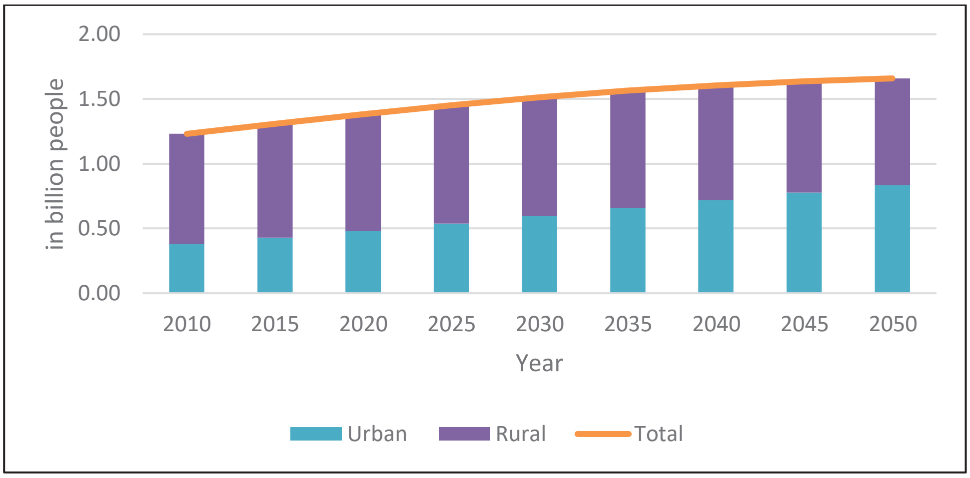


Figure 2-47: Projected population growth, 2010 – 2050

Source: WB (2017)

Large sections of India's rural and urban population live without access to electricity. Power lines fail to reach most rural areas while in many of the urban slum areas the people cannot afford the high cost of setting up connections to the grid, even if there is availability. Further, the lack of public awareness and knowledge dissemination about the impact of various energy sources has a direct impact on the daily lives of citizens. It is crucial that people be made aware of the environmental and health issues related to the consumption and use of different energy sources, and of the relevant policy decisions about those energy sources.

To cope with its energy problems, India will need to invest in sustainable and improved energy efficiency technologies. This requires investment in more sustainable and probably more expensive energy sources over the next several decades. Failure to commit to aggressive measures to adopt non-fossil fuel sources could lead to an estimated 1.6 million deaths due to air pollution by 2030 (Wu, 2018).

India is irrevocably integrated into the global energy market. Thus, to alleviate poverty and achieve economic development while providing a reliable and adequate supply of modern and clean energy is an energy security challenge for the years to come.

2.4 Summary of Key Findings

This chapter reviews the importance of energy as the backbone of India's economic development. It also defines what energy security means in the context of . Based on this review:

- Five key attributes, namely, energy availability, energy affordability, energy accessibility, energy reliability and energy sustainability have been identified as central to the definition of energy security in the Indian context.

- The composite index for energy security is determined by calculating the HHI for the selected attributes; this method of normalisation enables to adjust the values measured in different units to a notionally common scale allowing the comparison of the corresponding normalised values from the different attributes on a single time series.

- The composite index for energy security is developed for the period from 1970 to 2014. The trend shows that India is becoming increasingly energy insecure and as the population, industrialization and urbanisation continues to grow, there is a corresponding increase in the energy demand and hence a need for increased investments in the energy sector to expand and improve the energy infrastructure to support growing demand for energy. Further, India has limited indigenous energy resources; it is dependent to a significant extent on imported fuel sources to meet the growing demand. Further, to continue to achieve economic growth along the country has over the years increased the use of fossil fuels which in turn are contributing to increased GHG emissions. This therefore poses a challenge for sustainable development in the future.

- Based on the existing research the forecasts predict an increase in the pre-capita production of primary energy sources, for instance, the production of coal is forecasted to increase at a CAGR of 4% p.a. As the country has limited indigenous energy sources, to meet the growing demand the country will become increasingly dependent on the supply of imported fuels. For instance, the oil imports are estimated to increase to 90% of the oil demand by 2040 and the coal imports are estimated to increase from 144 Mtce in 2013 to 410 Mtce in 2040.

- The population of India is expected to reach 1.6 billion by 2040. As the population continues to grow, the energy demand is estimated to account for 9% of the world's total primary energy demand by 2035. Further, as the country strives to achieve economic growth and alleviate poverty, the economy becomes largely energy dependent. As the average Indian becomes richer their energy needs also increase, which increases the fossil fuel consumption and hence increased GHG emissions. India was ranked the third highest in global CO_2 emissions in 2015 with per capita levels of 1.6 tCO_2.

- As the standard of living conditions improve, access to electricity increases in both the urban and rural regions, with nearly 100% of the urban areas and roughly 70% of the rural regions having access to electricity supply in 2015. The electricity generation is expected to reach 3300TWh by 2040, which is estimated to be three times the 2015 generation levels. The energy-intensive electricity sector is largely dependent on coal (over 50%). In addition, the poor grid infrastructure leads to large T & D losses, which raises sustainability concerns of high levels of GHG emissions resulting in adverse health and environmental conditions.

- The growing demand for energy requires large-scale investments for the future. Investment in the electricity sector reached US$55 billion in 2016. Significant investments of between US$120 to US$ 130 billion are projected to be made in the renewable energy sources to achieve the target of 175GW of electricity generation from renewables by 2022. Investments in indigenous coal mining are expected to reach US$2.1 billion in 2020 and US$7.2 billion by 2040.

- The emphasis on economic growth largely neglects the long-term environmental issues, resulting in a polluted and degraded environment compounded by the effects of climate change. Thus, energy security is a key challenge for India and will get even more pertinent in the years to come. In the following chapters this challenge is addressed by considering energy efficiency as a mechanism to redress it.

Chapter 3 : Review of India's Existing Energy Policies

3.1 Introduction

This chapter reviews the existing energy policies with a view to assess their adequacy for redressing the energy security challenge in India. It also reviews existing research on energy with the view to assess the strengths and weaknesses of underlying methodologies to provide policy-useful insights. Overall, the reviews in this chapter will help develop an appropriate framework for this research, to assess the policy relevant macroeconomic impacts of alternative energy efficiency improvement measures for India in the future.

The review of existing energy policies focuses on their objectives, strategies, and plans to address the challenges facing India's energy system. The review of energy studies likewise focuses on their objectives, the level of disaggregation, the methodological approaches used to carry out the analysis and the scope - to address the energy issues.

The organisation of this chapter is as follows: Section 3.2 reviews India's existing energy policies. Section 3.3 reviews the key recent energy studies undertaken in the context of India, with specific emphasis on reviewing the modelling approaches adopted in these studies. Section 3.4 proposes an analytical research framework appropriate for this study and Section 3.5 summarises the key conclusions reached in this chapter.

3.2 Review of India's Existing Energy Policies

This section reviews the key existing energy policies intended to address the energy security challenges in India as (as discussed in Chapter 2). Figure 3-1 shows the timeline of these policies.

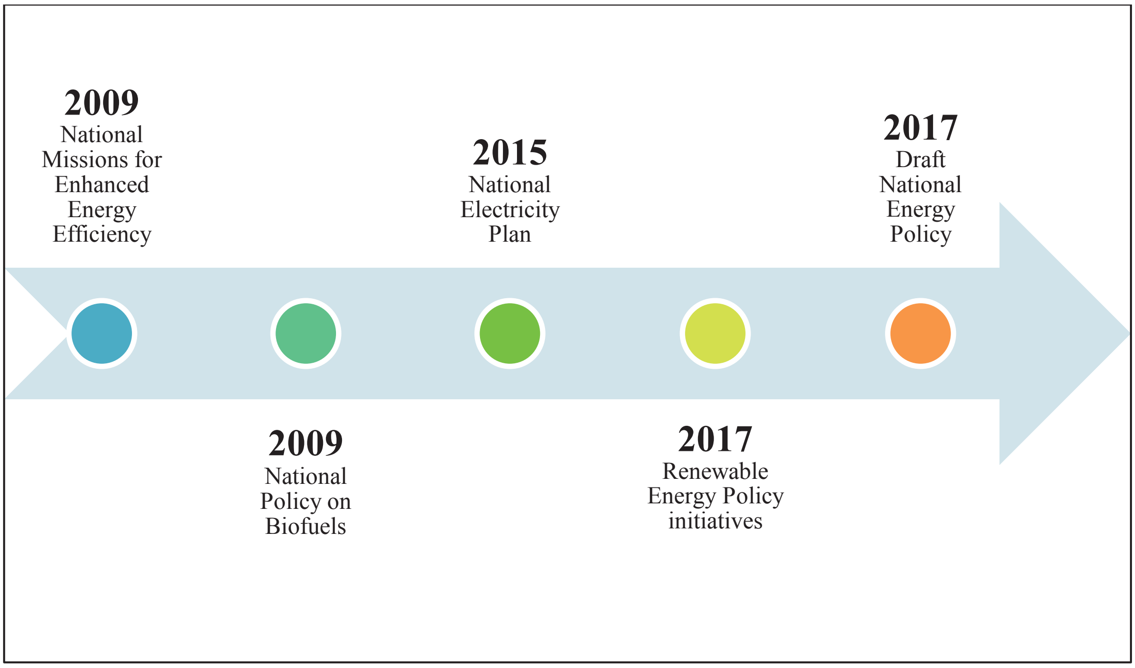


Figure 3-1: Timeline of existing energy policies for India

Source: Author's compilation

3.2.1 Draft National Energy Policy, 2017

To meet the growing energy demand required to improve Indians citizens' living conditions, The National Institution for Transforming India (NITI Aayog), the policy think tank of the Government of India formulated a *Draft National Energy Policy, 2017*. This covered short-term energy development to 2022 and medium-term energy development to 2040 to take into account the diversity of technology and fuel mix options (NITI Aayog, 2017). The main objectives and targets in this policy are:

- To strengthen the exploration and development of domestic fuel sources through robust policy interventions, by increasing the exploration of 22 sedimentary basins across 3.17 million square km of sea area. At present only 7 basins (which account for 19% of the total) are producing oil and gas and a potential further 15 basins remain to be explored. To explore the potential of alternative coal technologies such as coal bed methane (CBM) and underground coal gasification (UCG). To provide 24x7 electricity to all households by 2022 as well as clean cooking fuel. To improve indigenous supply of energy sources by expanding the energy infrastructure. The potential production targets according to the different fuel types are:

- Coal: 582 Mtce in 2012 to 904 Mtce by 2022 and 1190 Mtce by 2040.
- Oil: 38 Mtoe in 2012 to 44 Mtoe by 2022 and 54 Mtoe by 2040.
- Gas: 48 BCM in 2012 to 46 BCM by 2022 and 95 BCM by 2040.
- Renewable Energy: 175 GW by 2022 and 710 GW by 2040.
- Nuclear: 6780 MW in 2016 to 22,480 MW by 2030.

➢ To develop renewable and nuclear energy sources through the promotion of policies such as a renewable energy policy as a subset of the electricity sector policy in conjunction with other policies, such as rural electrification and poverty alleviation. The share of renewable energy in power generation is expected to account for 50%-56% of renewable energy capacity in total installed capacity and 29%-36% of energy capacity generated by renewables in total electricity generation from all sources of power generation by 2040, compared to 14% and 6.5% respectively in 2015.

➢ In terms of energy efficiency and energy conservation, to increase total energy savings by implementing robust regulatory and statutory mechanisms across all sectors. To introduce mandatory disclosure programs, such as reporting energy use by commercial and large residential buildings, and to require that all key appliances and vehicles be covered by mandatory standards and labelling programs by 2020. To award financial incentives and tax rebates to encourage energy conservation and boost energy efficiency. The specific target of this policy would be to reduce total energy consumption by 2040 to 17% below that of 2012.

The various key government programs and initiatives to achieve energy efficiency across all demand sectors include:

- 100 smart cities.

- Housing for all by 2022.

- Power for all by 2022.

- 175 GW of renewable energy by 2022.

➢ To achieve sustainable use of energy to improve local air quality. That future energy work across all the sectors are required to develop consistently with The National Environment Policy objectives through a slew of regulations. Through education and training to increase awareness among individuals and businesses of the potential benefits of energy saving.

➢ To encourage competition between different divisions in the energy market. To facilitate energy investment from local and foreign financial enterprises. To establish upstream coal and petroleum markets to ensure security of supply. To develop a legal framework for the national energy market in India.

➢ To meet the increasing energy demand for continued economic growth, a huge capital investment of nearly US$150 billion per annum is needed until 2040 to expand the energy sector. This demand could be met by deploying overseas equity in long-duration infrastructure projects and by implementing such tools as extended debt venture, tolling, and dollar dominated returns to attract private capital investment. The World Bank has taken initiatives to support the Government programs to promote energy efficiency in the residential and public sectors by proposing an investment program of US$380 Million to support energy saving activities for the FY 2018 to 2022 (The World Bank, 2018b).

➢ To establish a more effective energy pricing mechanism to help improve the financing of energy businesses through cross-subsidisation, attracting investment and reducing government's subsidies.

- To ensure the security of energy supply by diversifying the energy supply fuel mix and improve energy efficiency. To this end, India has already engaged with various overseas stakeholders. The directions for developing international cooperation as proposed by this policy are:

    - To reduce imports and give priority to the use of domestic fuel supply.

    - To diversify the import sources across all fuel types – oil, gas, coal, nuclear and electricity.

    - To ensure reasonable availability of energy resources supply for export purposes.

    - To encourage investment in offshore exploration and extraction of energy resources.

Key observations:

The review of the *Draft National Energy Policy, 2017* suggests that the scope and objectives for the energy sector development and its associated targets are comprehensive. The strategies to achieve these objectives do not however clearly discuss how they will be achieved in the state, national and global contexts. The policy discusses strategies to secure energy supply through diversification of the fuel mix, by promoting new and renewable energy sources and by expanding the energy system by exploring domestic energy resources. However, this policy does not address the economy-wide implications of such measures.

There are inconsistencies in the targets set in the policy framework. For example, it proposes that coal will constitute 67% of total electricity generation in 2022. It also claims that India will make a big push to introduce renewables yet will continue to rely on coal. This directly conflicts with the twin goals of sustainability, namely, the security of energy supply and environmental protection from the damage caused by energy activities.

The policy instrument is characterised by its orientation towards economic growth, by its exclusive focus on a single sector and by its significant neglects of the cross-sectoral and cross-thematic issues arising from the complex energy-economy-environment interrelationships. The existing policy settings are, therefore, unlikely to satisfactorily address India's energy security challenge.

3.2.2 Renewable Energy Policy Initiatives, 2017

The Government of India has undertaken several policy initiatives in the renewable energy sector. It is through these initiatives that India has become the third largest solar power market globally and remains one of the largest wind energy markets in the world (Ministry of New & Renewable Energy, 2017b). Some of the key renewable energy policy initiatives are discussed below:

- *Renewable Energy Targets (RET):* Following the launch of the National Solar Mission in 2010, the RET were revised from an initial target of 20 GW of utility-scaled projects and 2 GW of rooftop solar power projects in 2014 to 100 GW of installed capacity by the year 2022. The overall RET were set to 175 GW by 2022, with solar power parks and rooftop solar power projects each revised in 2014 to 40GW and wind power at 60 GW. At 'RE-Invest 2015', the renewable energy investors summit held in New Delhi, public sector organisations pledged to add more than 19 GW of solar and wind power.

- *Renewable Purchase Obligation (RPO):* According to the *National Tariff Policy, 2016,* the development of thermal projects would require setting up renewable energy projects equivalent to at least 10% of planned thermal power plant. The RPO for solar power will increase to 8% by the year 2022 from the current solar RPO of below 1% for most states. RPO is an obligation imposed on entities by law to either purchase electricity generated by specified green energy sources, or buy, in lieu of that, renewable energy certificates (REC) from the energy market.

- *Green Energy Corridors*: To propose a dedicated transmission network to be developed for renewable energy projects to reduce stress on the existing transmission grid and allow interstate transmission of solar and wind power with no additional transmission cost as part of the Green Energy Corridor scheme for evacuation and integration of renewable energy capacity.

- *Hydropower policy, 2008*: The aim of this policy was the need to meet all of India's peak demand and energy requirement from 2012 to 2017. This would require a total capacity addition of 82 GW, of which 30 GW would be added through hydropower projects (International Environmental Law Research Centre, 2008). One hundred and one (101) potential hydro projects with an installed capacity of about 40 GW have been shortlisted to date by the Central Electricity Agency (CEA), comprising the federal (33), state (37) and private (31) sectors. It is estimated that the full potential of hydropower with a total hydro generation capacity of 149 GW could be operational by 2027.

- *National Offshore Wind Energy Policy, 2015*: To set up wind power installations, two main maritime areas are available, namely, Indian territorial waters, which extend up to 12 nautical miles from the baseline and the Exclusive Economic Zone (EEZ) beyond the 12 nautical miles to a distance of 200 nautical miles from the baseline. In India, the states of Gujarat and Tamil Nadu are listed as potential sites for establishing offshore wind power, each with a capacity of 1 GW (Ministry of New & Renewable Energy, 2015).

- *National Wind-Solar Hybrid Policy, 2017*: Wind and solar are complementary and hybridising these two technologies will help create large grid-connected wind-solar PV systems that will use the transmission infrastructure, including land, more efficiently and reduce the instability in renewable power generation. The aim of this policy is to reach a wind-solar hybrid capacity of 10 GW by the year 2022 (Ministry of New & Renewable Energy, 2017a).

Key observations:

The intent of the various renewable energy policy initiatives is to achieve set targets, but the effectiveness of the strategies proposed to achieve them is less than convincing. One of the key challenges is that establishment of most of these new renewable projects are proposed in rural areas (Tongia, 2014). A large proportion of the population resides in these remote areas where they lack basic facilities and infrastructure. Thus, the push to achieve 100% rural electrification, is a challenge when the rural population are unlikely to consider electrification as a pressing need, despite the benefits of electrification. This disincentivises the commercial considerations for rural electrification.

The high costs involved in establishing renewable energy infrastructure for power generation compared to existing, conventional power plants further challenges investment in renewable energy development (Tongia, 2014). The high initial costs of installation compared to coal-based power plants provided little incentive for investments in renewable energy project. In addition, the lack of data on renewable energy sources, lack of affordable renewable technology, the absence of an appropriate regulatory framework, and limited access to finance for project development are some of the barriers to renewable energy project development. In addition, the decentralised nature of renewable energy development means there is a need for an integrated planning system. Social acceptance of renewable energy is another challenge, despite the subsidies provided by government; this is a result of the lack of awareness among citizens of the potential benefits of renewable energy. Shortages of skilled manpower required for the development and deployment of renewable energy projects also adds to the low penetration rate.

3.2.3 Draft National Electricity Plan, 2015

For the period 2017-2022 and with perspectives up to 2027, the Draft National Electricity Plan 2015, is based on the National Electricity Policy, 2005, in compliance with section 3 of *The Electricity Act 2003*, Government of India (Central Electricity Authority, 2016). The main objectives and targets of this policy are as follows:

- Electricity demand forecast for the period 2016-2027 is based on the forecast electrical energy requirements and peak demand of all states. They are calculated as 7.28% and 7.44% per annum respectively for the period 2016-2022 and 6% and 6.15% per annum respectively for the period 2022-2027.

- The power supply plan includes generation from coal, gas, hydro, nuclear and renewable energy sources; imports from Bangladesh, Bhutan, Nepal, and

Pakistan; and T&D from high, low and medium voltage lines in order to meet the electricity demand forecast of 1611 BU (CAGR: 6.34%), 1704 BU (CAGR: 7.34%) and 1802 BU (CAGR: 8.34%) for the period 2016-2022 for Scenario 1, Scenario 2 and Scenario 3 respectively.

- The fuel supply plan for power generation includes domestic sources and imports of coal, oil, gas, hydro and renewable energy sources. The supply plan for the domestic availability of coal for electricity generation would be 677 to 747 MT by 2022 and 851 MT by 2027. The share of capacity from non-fossil fuels is forecast to increase from 30% in 2016 to 46.8% by 2022 and to increase again to 56.5% by 2024. Renewable energy is forecast to contribute 20.3% of the total energy requirement by 2022 and 24.2% by 2027.

- Funding requirements for power generation projects based on additional capacity of 116800 MW is estimated to be Rs. 10,33,375 crores for the period 2017-2022 and Rs. 6,05,965 crores for the period 2022-2027. This includes investment in additional renewable energy sources and other projects during that period.

- CO_2 emissions are estimated to reach 983 MT and 1165 MT for the years 2022 and 2027 respectively. However, the emissions intensity is likely to reduce by 43% in 2022 and by 53.96% in 2027 from the 2005 level.

- Energy savings are planned to increase through various programs on both the supply and the demand side (DSM). These programs include Agriculture DSM (AgDSM), Municipality DSM (MuDSM), standards and labelling, Perform Achieve andTrade (PAT) schemes for industry, LED domestic and street lighting and so on.

Key observations:

One of the key observations of this plan is the projection of the electrical energy requirements and the peak electricity demand on an all-India basis. The optimisation model, the Electric Generation Expansion Analysis System (EGEAS) computer model, neglects to accommodate the structure of the electricity industry, neglects the linkages of the electricity industry with other energy sectors and neglects the assessment of economy-wide impacts of the electricity market development in the short-to-medium term.

The policy does not address changes in the price of coal, the dominant input fuel source, and the impact of changes in the price of coal on the fuel supply for electricity generation. Coal prices for the power sector are regulated, and generally at lower than market prices. This encourages the Coal India Limited (CIL) and other coal producers to continue to encourage the use of coal for electricity generation. Further, the coal producers, such as CIL, have very little incentive to sell coal to electricity producers at prices lower than the international market prices. Instead, they seek export markets to earn revenue and to offset the losses arising from selling coal at below market prices in the domestic market. This incentive increases coal mining of coal and hence accelerates the depletion of indigenous coal reserves which the increases the pressure to import coal at high international market prices in the future, as shown in Figure 3-2.

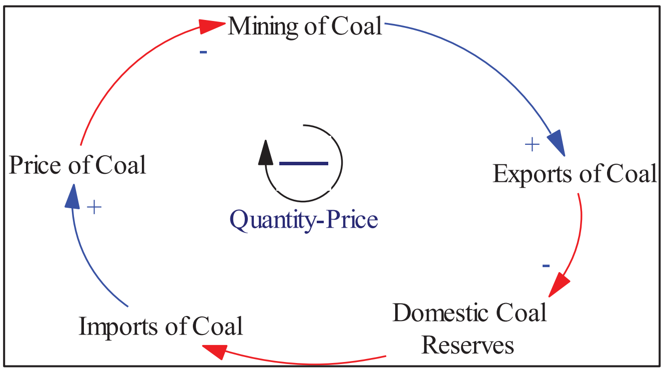


Figure 3-2: Causal relationship between price and quantity of coal

Source: Author's compilation

This dual pricing of coal makes it a challenge to determine the true cost and hence price of electricity. While the price of electricity is regulated by the government, the price of coal is in accordance with the global coal markets, which increases the uncertainties for investors seeking to invest in thermal electricity generation plants. This shows that the objectives of the coal and electricity sector are incoherent.

3.2.4 National Policy on Biofuels, 2009

The *National Policy on Biofuels, 2009* was drafted by the Ministry of New and Renewable Energy (Ministry of New & Renewable Energy, 2008). The main objectives and targets in this policy are as follows:

- Biofuels are a renewable energy source and environmentally sustainable fuel sources. These fuels are derived from renewable biomass resources and have the potential to curb air pollution resulting from vehicular emissions in the transport sector.

- Biofuels in India are based on non-edible feed stocks raised on non-agricultural land, unlike current global practices that can have an impact on food security.

- The aim of the policy is to use biofuels as a replacement for mainstream fuels such as petrol and diesel in the transport sector. This policy proposed a target blend of 20% biofuels for both bio-diesel and bio-ethanol by 2017. However, this could not be achieved because the policy was poorly implemented; the supply-chain infrastructure to deliver biofuels to consumers was inadequate and there were barriers to private investment which discouraged improvements in technology and limited the potential to build the infrastructure required for biofuel production.

- The promotion of biofuels will encourage farmers to cultivate feed stocks for biofuels, thus generating employment opportunities. There will be a boost to the sugar industry to manufacture ethanol from molasses and sugar cane juice.

- Investment will be required to build the infrastructure for manufacturing, storage, and distribution of biofuels in a sustainable manner. Multi-lateral and bilateral funding opportunities are sourced from domestic sources such as the Indian Renewable Energy Development Agency (IREDA), Small Industries Development Bank of India (SIDBI) and through foreign direct investment (FDI) participation.

Key observations:

This review of the policy suggests that to make India's energy supply secure, diversity in the fuel mix to substitute for shortages is crucial. The policy's focus is on restricting emissions from the transport sector. It does not consider the economy-wide impacts of other energy-consuming sectors and the potential to expand the use of biofuels as an input to those sectors.

A large proportion of India's population lives in rural areas which are materially poor. These people do not have access to the basic needs of health, food, education, etc. Though the development of biofuels will help meet the energy needs of the rural population through electrification, the people themselves are less likely to consider that their most pressing need.

Biofuels are extracted from crops that have high levels of sugar in them, such as sugarcane, and most of them are food crops. Even though waste material from these crops can be used as raw material, the cultivation requirements of these food crops will take up agricultural land and could potentially lead to an acute shortage of food and hence rise in food prices. Further, these crops require large quantities of water for irrigation, which could put a strain on regional water resources, thereby potentially threatening water security. It is to be noted that the policy does not state any measures to restrict the use of agricultural land for cultivation of crops or the monitoring of water usage for biofuel manufacture.

Huge investments will be required to manufacture biofuels. While the current investment and capital to produce biofuels are fairly low and can meet the demand, as demand increases, increasing the supply long term will be expensive.

Though biofuels are a cleaner source of fuel than conventional fossil fuels, the manufacturing process makes up for the emissions. Production of biofuels requires significant quantities of water and oil, thus causing large amounts of emission and water pollution. Nor is the existing technology for the production of biofuels efficient. Thus, unless more efficient means of production are put in place, there is a risk of increasing overall carbon emissions. Additionally, farmers could displace existing products from land currently used for food crops to biomass production for biofuels. This would not only increase the price of food but also induce deforestation that would exacerbate climate change.

3.2.5 National Mission for Enhanced Energy Efficiency, 2009

The National Mission for Enhanced Energy Efficiency (NMEEE) is one of eight national missions under the National Action Plan on Climate Change (NAPCC) (Bureau of Energy Efficiency, 2010). The main objective of this mission is to reduce energy intensity and carbon intensity by strengthening the market for energy efficiency to achieve sustainable growth. Through this mission, the Government of India aims to foster favourable regulatory and innovative policies to reduce the use of fossil fuels without compromising on growth.

The main initiatives to enhance energy efficiency are as follows:

- ***Perform Achieve and Trade (PAT)***: This is a market-based compliance scheme to enhance energy efficiency in large energy-intensive industries. It aims to accelerate the implementation of cost-effective energy efficiency improvements by assigning energy reduction targets and distribute Energy Saving Certificates (ESC) to those that meet these targets.

- ***Market Transformation for Energy Efficiency (MTEE)***: This scheme encourages the adoption of energy efficiency equipment and appliances through innovative business models. Several DSM initiatives have been put in place to accelerate the shift to energy-efficient appliances to make the products more affordable. Some of these include:

    - Bachat Lamp Yojana (BLY): The aim of this initiative is to replace 400 million incandescent light bulbs (ICL) with affordable compact fluorescent lamps (CFL) which will result in likely savings of 6,000 MW of power, approximating Rs. 25,000 crores.

    - Standards and Labelling (S&L): This is a requirement for mandatory labelling of high energy end-use equipment and appliances and stipulation of minimum energy performance standards. This allows consumers to make informed choices about energy savings and potential cost savings.

- Energy Conservation Building Code (ECBC): This required mandatory compliance of energy performance in all new and existing commercial buildings.

- ***Energy Efficiency Financing Platform (EEFP)***: This initiative provides a platform to encourage financial institutions and investors to support and invest in energy-efficient initiatives and projects.

- ***Framework for Energy Efficiency Economic Development (FEEED)***: This program encourages energy efficiency initiatives by developing fiscal instruments to leverage financing.

- ***Power Sector Technology Strategy***: To enhance energy efficiency in the power sector through initiatives such as:

  - adoption of energy-efficient technologies in new and existing power plants.

  - transition to cleaner fuels compared to conventional fossil fuel-based energy sources.

Key observations:

The NMEEE initiatives suggest that the government's steps to encourage energy efficiency focus on macro-level energy intensity (energy consumed per unit of GDP), compared this value with other countries. The NMEEE does not comprehensively consider the efficiency of the Indian economy at the sub-sector levels, nor does it show an understanding of the factors that could have influenced the changes it is recommending. It considers the reduction of energy intensity at the macro level as the principal criterion for the success of its energy efficiency initiatives and hence successful energy and cost savings.

Also, this measure of macro-level energy intensity does not consider the structure of India's economy. An improvement in the overall energy efficiency of the economy does not necessarily imply that energy efficiency will improve at the sectoral level; this is because the share of various sector outputs in the total output of the economy changes over time. For instance, it is possible that the economy's overall energy intensity may improve over time but the energy intensity at the sectoral level may worsen over the same period. The existing framework thus fails to provide for potential energy efficiency improvements at the sectoral level.

Another barrier is the associated financial risks and uncertainties. These include the development of projects to encourage energy efficiency using technologies that require high upfront costs yet attract only limited financing opportunities. Individual energy efficiency projects are diverse in commercial financing terms, thus making it difficult to attract investors. The lack of adequate funding opportunities due to a lack of widely agreed measurement and verification standards against which financial institutions can evaluate projects systematically also hinders the uptake of energy efficiency improvement measures. The fragmented nature of energy efficiency is one of the reasons for the exacerbation of financial and market barriers.

Energy efficiency improvement opportunities are complex and difficult to understand. The lack of information and/or the difficulty in understanding the technical information leaves market players, including consumers, displaying a loss-aversion and status-quo bias (Angell, 2009).

3.2.6 Key points in India's existing energy policies

The key points of India's existing energy policies are:

- Much of the policy objectives in terms of the targets, strategies, plans and programs are economic growth-oriented. The premise of economic growth is embedded in the philosophical premise of an 'affluent society' (Glabraith, 1958). The belief in the principle of growth (Guha, 2006) among the people implies continuous consumption and hence production of consumer goods and security of supply. Thus, much of the emphasis in the policy instruments is on identifying and implementing supply options to meet growing demand.

- The policy initiatives focus on a single sector. Developmental psychologist Robert Kegan (Kegan, 1982) suggests that there are two choices in dealing with an increasingly complex world. The first is to see the world as simple and the second is to increase the complexity of our own perspective to the extent necessary to meet emerging challenges. In terms of this research, this means that policymakers can focus only on the energy sector to address the energy security challenge or we can consider multiple stakeholder perspectives by considering cross-sectoral and cross-thematic interdependencies between energy, the economy and the environment to craft solutions that are complex enough and possess a wide enough perspective to address the energy security challenge in a sustainable manner.

For this, there is a need for frameworks (models) that will enable incorporation of various perspectives, representation of interdependencies and judicious reconciliation of diverse trade-offs in a cohesive manner.

3.3 Review of Current Energy Research Studies in India

Against the backdrop of above discussion this section reviews the existing energy research studies in India, with specific emphasis on understanding the methodological underpinnings of these studies of various energy alternatives through a quantitative modelling analysis of the energy sector. A broad view of the various energy studies conducted, and the methodologies applied for examining India's energy sector is shown in Figure 3-3. This review will assist in the selection of an appropriate analytical framework for this research. A detailed discussion of the various approaches to energy modelling is explained in Chapter 5 of this thesis.

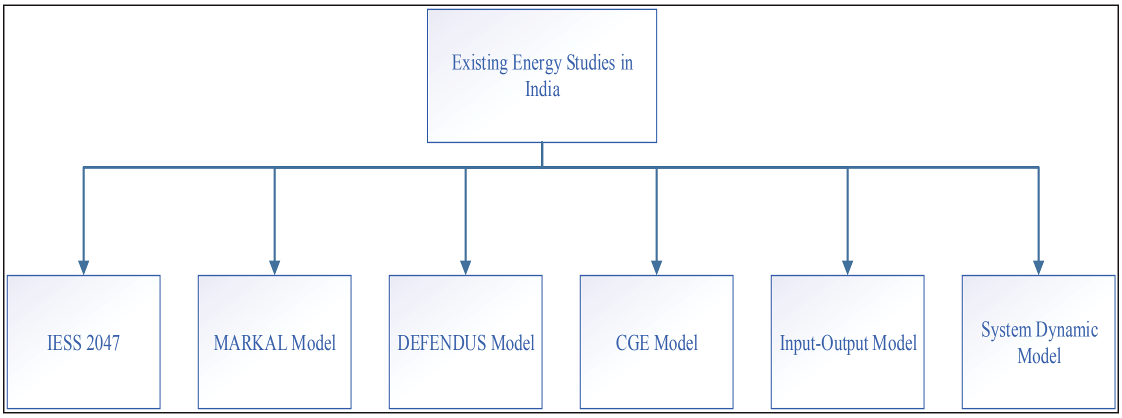


Figure 3-3: Existing Energy Studies in India

Source: Author's compilation

3.3.1 IESS 2047

Scenario development is a useful methodology to explore the alternative pathways for energy futures. The NITI Aayog developed the Indian Energy Security Scenarios (IESS) 2047 tool to study both the demand side and supply side of the energy sector of India and provide policy recommendations (NITI Aayog, 2017). The scenarios in the IESS 2047 tool were developed using the MESSAGE modelling framework (Riahi and Krey, 2013). The range of scenarios developed were:

- Business as usual.
- Housing for all by 2022.
- 24*7 Electricity for all by 2022.
- Low carbon growth scenarios.

The MESSAGE model allows analysis of future uncertainties and develop strategies in terms of the technology mix and investment portfolios required to meet a set of specified policy objectives. It provides the following information for each of the scenarios:

- Energy mix in the economy

- Water utilisation

- Land utilisation

- Carbon emissions

- India's dependence on imports for energy security.

It is through this integrated energy modelling scenario approach that a cross-sectoral analysis can be carried out to advise the different energy ministries and departments on various policy options and the impact these options could have on India's future energy security.

3.3.2 Studies using the MARKAL model

MARKAL models are bottom-up optimisation models used to analyse energy systems, particularly to understand the linkages between energy, the economy and the environment. The Indian MARKAL model was developed by The Energy and Resources Institute (TERI), and is known as the TERI Energy Economy Environment Simulation Evaluation model (TEEESE). It is used for evaluating energy-economy-environment complex interrelationships. The TEEESE model is used to project energy demand and supply dynamics under different scenarios (Chikkatur and Chakravarty, 2008). The TEESE model consists of three components, a reference energy system, an input-output model and a linear programming model. Other versions of the MARKAL model include the ANSWER-MARKAL model, a mathematical model used to evaluate the technology, fuel mix, and investment portfolios at detailed end-use level while maintaining consistency in terms of energy supply, demand, investment and emissions (Shukla, Dhar, and Mahapatra, 2008) and (Nair et al., 2003). This model, which covers the 105-year period spanning 1995 to 2100 in 15-year steps, computes a partial equilibrium of the energy system by optimising a set of quantities and prices of all energy sources (such as supply equals demand) at each 15-year period to assess alternative development pathways for transitioning to a low-carbon future for India.

3.3.3 Studies using the DEFENDUS Model

The Development-Focused End-Use-oriented Service-directed (DEFENDUS) model was developed to estimate the demand and supply of energy within the energy system itself. The main objective of this model is to advance the energy sub-system within the larger socio-economic system of India and it was used for a quantitative study of the electricity sector scenario in the state of Karnataka. The DEFENDUS model constructs scenarios of future energy demand with particular attention to equity and energy efficiency considerations. It considers the various costs of energy in terms of savings, investment, expenditure and cost of T&D, including any losses involved. The different scenarios enabled researchers to analyse the impact of energy on the economy and the environment and reach conclusions critical to the state's electricity sector. These conclusions included integrated energy conservation options; consideration of a decentralised energy option with 26,000 rural energy centres, and a focus on development while ensuring electricity connection (Reddy et al., 1995).

3.3.4 Studies using the CGE Model

India's Institute of Economic Growth (IEG) developed a computable general equilibrium (CGE) model to analyse the impact of two post-Kyoto climate policy instruments on key economic and environmental factors in India, including GDP growth, carbon emissions and welfare. It uses a recursive dynamic CGE model that is multi-sectoral, neoclassical and price-driven to study the linkages within the energy system. The model comprises 18 sectors and two production factors. The model's assumptions are analysed across three scenarios, namely the business-as-usual (BAU) scenario and two baseline scenarios of two different GDP growth projections for India to 2050. According to the analysis carried out, this model projected a significant reduction in CO_2 emissions and a decline in the GDP growth for the period from 2045-2050.

Another study that used a CGE model for energy analysis is that by Rana (Rana, 2003), which used a CGE model to analyse the effects of rapid reduction in the cost of solar power generation in India. This study considered alternative scenarios to analyse the impact of cost reduction of solar power, and the introduction of a carbon tax. It considered eight economic sectors and three production factors of land, labour and capital. The electricity sector was divided into six sub-sectors by generation fuel type.

Technological changes were exogenously introduced in the model as a change in the total factor productivity.

Another very widely used CGE model is the GTAP model. The GTAP model is a multi-sector CGE model that is used extensively for carrying out quantitative analysis of economic policy issues, including India's trade policy (Department of Agricultural Economics, 2018). The model uses the GTAP database which covers many sectors of the economy and provides details of the production, consumption and intermediate use of resources, including energy resources. It also provides data on GHG emissions, land use and the import and export of goods and services between India and other global economies.

3.3.5 Studies using Input-Output Model

The input-output model has been applied in numerous studies in India to examine such energy policy issues as GHG emissions and energy intensities, and their impact on the end-use sectors of the economy. The study by Shukla (Shukla, 2007) constructed energy input-output tables to examine India's CO_2 emission estimates and concluded that if existing practices continued without any corrective measures, carbon emissions would continue to increase and have severe adverse consequences. Another study carried out by Jain (Jain, 2012) used the input-output model to analyse the impact of economic growth on energy consumption. This study examined how energy intensity in the various end-use sectors of the economy changed from 1967 to 2012 and provided energy efficiency options to reduce energy intensity and consumption and hence their overall impact on India's economy. A study conducted by Tandan and Ahmed (Tandon and Ahmed, 2015) used the Input-Output model to analyse changing energy use resulting from changes in technology and price. They did this by measuring the linkages between energy and various end-use sectors of the economy. This study was followed up with an analysis of export structure by assessing the energy intensity of India's exports using a constant price hybrid of the Input-Output model (Tandon and Ahmed, 2016).

3.3.6 Studies using the System Dynamics Model

System Dynamic models help understanding of the complex interrelationships between energy, the economy and the environment. Several studies in India have been conducted with a focus on understanding the role and behaviour of energy within a sector of the economy at national level and state (micro) level. A study by Lakshman and Ramesh (Lakshman and Ramesh, 2014) uses a system dynamic model to analyse steel demand, production, consumption and mitigation of CO_2 emissions. The model examined energy consumption in the steel industry through alternative scenarios of steel production and energy conservation techniques from 2011 to 2031. The work by Gayathri and Gayathri (Gayathri and Gayathri, 2011) studied an existing energy scenario for the city of Chennai and with the help of a system dynamic model examined the energy requirement levels for a sustainable transport sector by 2026. Another study for the transport sector, by Hayashi et al (Hayashi et al., 2008) evaluated the impact of Delhi's mass rapid transit system (MRTS) on energy demand and carbon emissions for passenger transport. Three alternative scenarios – No MRTS, BAU and Policy Control scenarios – were used to estimate current trends and future energy demand and CO_2 emissions. A study by Anand (Anand, Vrat and Dahiya, 2006) developed a system dynamics model to examine the projections of cement production influenced by population growth, GDP growth and technological changes in the cement industry to 2020. A recent study conducted by Sisodia (Sisodia, Sahay and Singh, 2016) used a system dynamics approach to explored solar energy as an alternative way to meet India's growing energy demand.

3.4 Energy Framework for This Research

The energy research framework, used by the reviewed energy studies in India, can broadly be termed as 'energy scenario analysis' framework. The pre-requisites for a framework for analysing the economy-wide impacts of alternative scenarios are: firstly, scenarios are developed around a set of assumptions, taking into account the key drivers that are likely to shape the future evolution of the energy system. Secondly, energy models are used for examining the energy impacts for the different energy alternatives. The models that have been used for quantitatively modelling the energy scenaris are either engineering-based or economic-based models. A detailed discussion of the existing energy models is provided in Chapter 4.

Based on the above review of existing energy policies and energy research studies in India, the appropriate energy framework in which to analyse the economy-wide impacts of energy efficiency improvement measures and hence to put forth policy recommendations should include the following:

i. A scenario-based approach, involving the development of long-term energy scenarios for India. The details of the scenario development approach and the alternative long-term energy scenarios to assess the impacts of energy efficiency improvement measures in the context of India are discussed in detail in Chapter 4. The scenario approach explores the possibilities of alternative futures for India's energy system.

ii. A quantitative modelling approach to analyse the economy-wide impacts of the alternative long-term energy scenarios. The energy-oriented input-output model will be developed to assess the macroeconomic impacts of energy efficiency improvement measures on the national energy sector, the economy and the environment. A detailed discussion of the development of a quantitative energy-oriented input-output model and the steps necessary for this modelling approach are explained in Chapter 5. The input-output model allows researchers to analyse and examine impacts not only on an aggregate macro level but also at disaggregated, sectoral, micro levels. It captures the complex interrelationships between energy and various end-use sectors (energy and non-energy) of the economy.

3.5 Summary of the Key Findings

This chapter reviewed existing policy regimes and energy research studies using various models in India. Following are the main conclusions drawn from this review:

- The review provides key insights into existing energy policy instruments and institutional frameworks for India's energy sector. These policies aim to address the issues facing the energy system, namely, security of supply to meet the growing energy demands and the adverse impact on the environment arising from growing energy activities. These existing policies typically follow the objective of continuous economic growth, with much emphasis on identifying alternative supply options to meet future demand. Further, these policies neglect the intra- and inter-sectoral linkages and cross-thematic issues, which fail to consider the impact of energy targets on India's wider economic structure.

- Existing energy studies implemented a quantitative modelling analysis method to explore alternative scenarios for the energy sector over a certain time period. These models help us to examine in great detail the economy-wide impact of energy activities on the end-use sectors (energy and non-energy) of the economy and the environment in the future.

- The existing policies and studies give little prominence to energy efficiency and its potential impact on the wider economy. The analytical research framework proposed for this research employs a scenario analysis approach to comprehensively explore alternative energy efficiency pathways for India in the long-term future and a quantitative economics-based energy-oriented input-output model to analyse the scenarios and examine the impact of energy efficiency on the energy sector, the economy and the environment.

Chapter 4 : Development of an Analytical Research Framework

4.1. Introduction

The energy studies discussed in Chapters 2 and 3 appear to be narrow in focus and limited in their understanding of the strong relationship that exists between energy and the economy. Since the impact of energy management (policy) is likely to be felt not only by the energy sector itself but also by the non-energy sectors of the economy, from a policy perspective, it is important to establish a deeper understanding of these impacts. This would help policymakers determine which sectors would benefit and which sectors would be disadvantaged by specific policies.

The objective of this chapter is to establish the inter-relationship between energy and the economy by developing an analytical framework from which to explore the economy-wide impact of energy efficiency. To this end, an energy-oriented input-output model is developed following a five-step process.

This chapter is divided into three key sections. Section 4.2 reviews two approaches to energy system modelling, namely top-down and bottom-up. Some existing methodologies using these approaches will also be discussed. Section 4.3 describes the fundamental structure of the input-output model and explains in detail the five-step modelling process that extrapolates the standard model to the energy-oriented input-output model used in this research. A summary of the key findings is discussed in Section 4.4.

4.2. Review of Existing Models and Methodologies

This section discusses the existing methodologies associated with energy modelling. It focuses on computer-based models applied to energy, economic and environmental policy issues. The discussion spans a wide variety of models that apply different system boundaries to the energy system, for example, an entire energy system or part of an energy system, and they may be applied in different contexts, such as global, regional, national or state level. The energy models are simplified representations of real energy systems and economies and provide a good approximation of present-day reality. These models differ in terms of their mathematical computations; some are descriptive (top-down) while others are normative (bottom-up) (Grubb et al., 1993). Such modelling provides insights into complex realities and allows scenarios to be transformed into a format suitable for analysis and forecasting and hence, better policy decision-making. This section discusses two types of model, namely, bottom-up and top-down. Hybrid models try to bridge the gap between bottom-up and top-down models by including elements from both approaches, but these are not discussed here.

A bottom-up modelling approach is an engineering approach generally constructed and used by engineers and scientists to focus on the technological aspects of energy systems (Springfeldt and et al., 2010). Such models are developed in optimisation, simulation and multi-agent format and they provide an analysis of how energy demand can be met in a cost-optimal manner. Under the modelling constraints, existing technologies are replaced by new technologies if there is an indication of greater overall cost savings (Helgesen, 2013).

A top-down modelling approach, by contrast, focuses on an economy as a whole, be it on a national or regional level. This type of modelling emphasises the relationship between labour, capital and energy to optimise socio-economic scenarios. The representation of energy in an integrated manner to create economic growth is captured in production functions and changes in fuel mixes are described by elasticities of substitution (Helgesen, 2013). This type of approach provides an aggregated macroeconomic view showing the feedback relationship between the energy sector and other sectors of the economy.

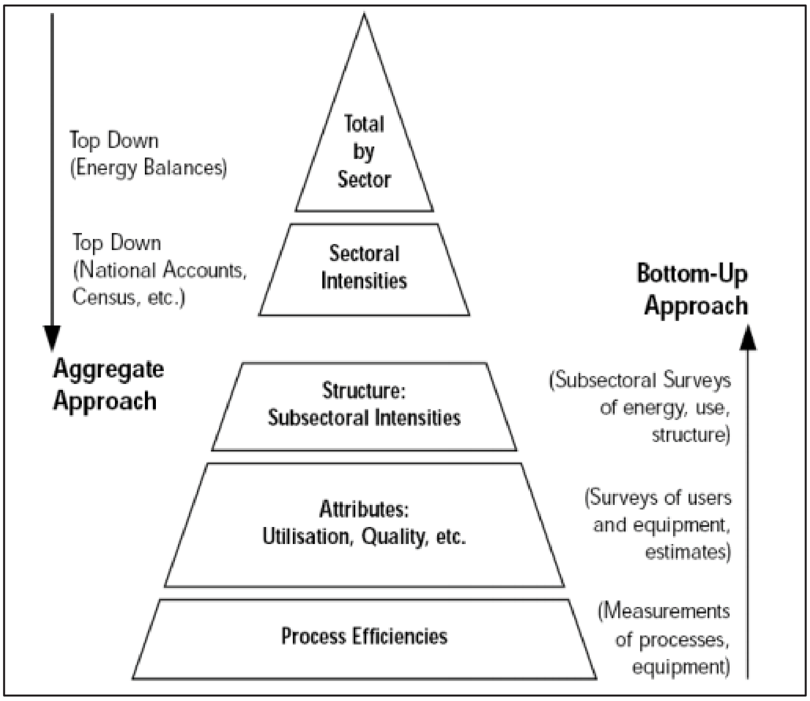


Figure 4-1: Modelling Approaches

Source: Rue du Can et al. (2010)

Figure 4-1 shows a hierarchy with the most detailed energy indicators at the bottom of the pyramid and an aggregate result at the top. The pyramid shows how the top-down approach looks at energy consumption across the economy and across sectors while the bottom-up approach provides more detailed data. The top-down and bottom-up approaches conceptually converge when bottom-up totals are matched to higher level data. The further down the pyramid the modelling goes, the more accurate the measure of energy (efficiency) for specific sectors, end uses, processes and/or technologies.

The aggregate indicators are generally defined as a ratio of energy consumption to a macroeconomic variable such as GDP or population. The indicators of energy intensities are used to measure energy (efficiency) at a high level. These indicators provide a general idea of the reasons behind energy consumption in a sector, but more detailed information is required to understand the underpinning drivers of energy consumption and to provide policy-relevant analysis on how to influence these trends.

The intermediate levels define the energy intensity of each major sector measured by energy consumption per unit activity in each of the end-use sectors of the economy.

The lower rows of micro-level analysis represent sub-sectors, techno-economic ratios or end-use devices that make up each sector and progressively provide more details. Unit consumptions are calculated at a disaggregated level by relating energy consumption to an indicator of activity measured in physical terms.

Through this hierarchy, we can demonstrate how the detailed changes at the lowest level can be linked to a higher order. This means more aggregated changes in energy consumption in terms of components can be better explained, which in turn can produce a better in-depth analysis.

These two approaches complement each other and therefore produce different outcomes and results for long-term policy decision-making. Some of the common bottom-up and top-down models are discussed below.

4.2.1. Optimisation models

Optimisation models are primarily technology-oriented and optimise the choice of technology alternatives to meet demand in the most cost-effective manner under a set of constraints, keeping price and demand quantity in equilibrium. These types of models are regarded as partial equilibrium models as the energy sector is a part of the entire economy. They consider the technical energy conversion system on both the supply side (electricity) and demand side (end-use efficiency measures). The models are optimised to minimise the overall system costs and improve technological performances. The MARKet Allocation (MARKAL) model is a typical optimisation model.

The MARKAL model was developed by the IEA's Energy Technology Systems Analysis Programme (ETSAP) in the late 1970s. It is a mathematical linear programming model that computes energy balances at all levels of the energy system, including primary energy resources, secondary energy resources, final energy resources and energy services over a time period of 40 to 50 years. The basic components of the model are specific types of energy and emission control technologies (IEA-ETSAP, 2018). The model assumes partial equilibrium, i.e., the prices and quantities over the time period are such that at those prices, suppliers produce the exact quantity demanded by the consumers. A set of existing and future technologies feed as inputs to the model, and at the optimum level, the model can select a combination of technologies that can minimise the total cost of the energy system. The main use of this model is to perform long-term analysis under different scenarios and to identify the least-cost energy system and the marginal cost of emission reduction over a specific time period (Loulou, Goldstein and Noble, 2004). There are several versions of the original MARKAL model; the TIMES model (The Integrated MARKAL-EFOM System), for example, uses the same modelling approach as the conventional model but provides special features such as flexible time periods, flexible processes, commodity-related equations, climate equations and so on. (IEA-ETSAP, 2005).

Optimisation models require information on investment and operating costs, hence their application is limited to certain technological areas and final end-use energy sectors, such as transport. A further limitation is that these models do not consider market imperfections, making it a challenge to simulate energy demand in such end-use sectors as industry and services, which use a wide variety of technologies, leading to unrealistic projections of energy demand (Herbst et al., 2012).

4.2.2. Input-Output models

Input-Output modelling is based on the works of Francois Quesnay's *Tableau-economique* (Quesnay, 1766) and Leon Walras and Wassily Leontief's *Input-Output Economics* (Leontief, 1966). Input-Output models provide a macroeconomic analysis by showing the interdependencies between the economic sectors as a flow of total goods and services. The foundation of input-output analysis involves a systematic description of the interrelationships in the form of input-output tables. These tables are a set of rows and columns that quantify the monetary flows between different sectors of the economy. The various sectors of the economy are listed in the header of each row and column. The data in each column correspond to the level of inputs used in that sector's production function. Production functions are the amount of input used by a sector to the maximum amount of output that could be produced by that sector with those inputs (Miller and Blair, 2009). These tables provide an evaluation of the energy policies of the underlying economic structure based on historical data. They can provide an estimate in terms of the direct, indirect and intermediate impacts that ripple through the economy when a change is made to a given input. This is useful for conducting analysis to estimate the change in economy-wide impacts resulting from a change in inputs in one or more sectors of the economy and assist in the formulation of policies and economic forecasting.

Input-output models essentially illustrate the key technological relationships, involving quantities of inputs and outputs in production processes. These models do not show a complete picture of the supply and demand sides of the economy; thus they cannot predict the behaviour that will optimise the economy. The Leontief input-output model considers a linear production function, which excludes the possibilities of substitution between inputs because the inputs and outputs in the model are proportionately fixed as represented by the technical coefficients. The optimising on the supply side is considered by assuming the quantities of inputs used are directly proportional to the quantity of output. Optimising on the demand side is characterised by assuming the technical coefficients are dropped in one or more sectors and the input provided to these sectors by the other sectors of the economy become a component of the final demand. Alternatively, if the technical coefficients are known and the final demand is specified, the total output required of each sector can be determined (Herbst et al., 2012).

4.2.3. Computable General Equilibrium (CGE) models

Computable general equilibrium (CGE) models are based on the microeconomic theory that consumers demand goods to maximise utility and producers supply goods to maximise profits (Helgesen, 2013). Unlike partial equilibrium models, that consider only one sector, these models consider the entire economy of which the energy system is a part. They capture the interdependencies between the different sectors of the economy and analyse the wider economic impacts of policy changes. The model calculates how prices and activities in all sectors change to reach a general equilibrium in the economy. CGE models use economic data to capture the structure of the economy and then compute the impact of changes in policy and technology on key economic variables such as market prices, household income and government expenditure. These models are large numerical models that fit economic data into a set of equations describing the model variables. The CGE model comprises a social accounting matrix (SAM), which captures the flows of all economic transactions that take place in an economy in a single year (data is obtained from input-output tables and national accounts), combined with the elasticities derived mainly from empirical studies (Chief Economist Directorate Scottish Government, 2016).

CGE modelling such as the General Algebraic Modelling System (GAMS) is a high-level modelling system for mathematical programming and optimisation. Another well-known model is the GTAP model of world trade. The GTAP model helps to quantitatively analyse the global economic issues within an economy-wide framework (Narayanan, G., Aguiar, and McDougall, 2012).

4.2.4. System Dynamics models

Simulation models are a logical and simplified representation of the energy system. These are used when it is impossible, too hard or too expensive to experiment with a real system (Neshat, Amin-Naseri and Danesh, 2014). Simulation models provide a quantitative representation of energy demand and conversion by modelling the behaviour of alternative technologies based on pre-determined drivers such as income, population, energy prices and so on. The decision-making does not follow a cost-minimising pattern (Herbst et al., 2012). Simulation models are flexible and can help to mimic market imperfections and failures. System dynamics is one type of simulation model.

System dynamics was developed by J.W. Forrester in the 1950s at MIT to analyse the long-term behaviour of corporate and industrial organisations (Forrester, 1961). This work has since expanded to management and research in various disciplines, including economics, public policy, environmental studies, social science and others.

System dynamics allows for modelling the big picture and understanding change over time in particularly complex systems. It is particularly powerful and suited to capturing the interactions of various variables and dependencies within a system, thereby providing critical insights into the impact of changing one or more variables on other variables. Thus, for example, the impact of changes in the efficiency of various energy-consuming elements within an economy may be usefully studied. These elements and their interdependencies are captured initially in an artefact called the causal loop diagram (CLD). From the CLD, the modelling is extended to create stock-flow diagrams (SFD), which enable the dynamics of the system behaviour to be examined over time. The dynamic behaviour on the system may be studied at whatever level of resolution suits the research objective. This clear visualisation of system behaviour over extended time series helps one to understand the patterns and sources of dysfunctions in a system, thus enabling better policy decision-making. This framework can incorporate the different perspectives of various stakeholders, along with different cultural and political mindsets needed to build consensus.

As this framework is used to model complex situations, it can carry out non-linear analysis at the micro level and examine system behaviour at the macro level (Helgesen, 2013). Developing policy recommendations for energy systems is complex, with intra- and inter-sectoral elements in close interactions. Simulation of the model through various scenarios, and the ease with which visual representations of the results are generated, help in the development of future energy policy recommendations.

Based on the above-mentioned energy models, one can generalise that top-down models provide an endogenous assessment of economic and social impacts that allows for comprehensive understanding of energy policy impacts on the economy at national or regional level. These models lack the level of technological details that are incorporated in the bottom-up models, which present a very detailed picture of energy demand and supply technologies as well as plausible technologies for the future. Consequently, top-down models focus on the monetary impact on policy decision-making, which is neglected in the bottom-up modelling processes.

This research will consider a top-down input-output model as its analytical modelling framework. The major advantages of the input-output model as compared to other economic models are as stated below:

- Enables to examine the interdependencies and inter-relationships between various sectors of the economy including the energy sectors and the effects of international trade on these relationships.

- Provide information about the structure of the economy that is not available from other frameworks.

- A higher level of disaggregation of economic sectors than any other economic model - the energy intensive sectors can be separated from the non-energy intensive sectors of the economy.

- Analysis can be provided at a very disaggregated level; it enables the analysis at the macro and the sectoral, disaggregated, macro levels of the economy.

- The input-output model enables to characterise the evolution of a large number of energy technologies which are represented poorly by other economic frameworks.

- Framework can be altered with ease to meet the desired objectives, they form the foundations for constructing a range of economic models, with underpinning assumptions, can be used to assess the impacts of policy changes and hence influence policy decision-making.

The input-output model will make use of the input-output tables published by the Central Statistical Office of India. These tables provide information at the disaggregated sector level and include the flow of energy within the economy. Traditional input-output models have fixed proportionality of the technical coefficients, which does not assist in evaluating the impact of changes in technology. Practically, these coefficients are likely to change due to innovation in technology, changes in the consumer and producer preferences or even policy regulations. To incorporate these changes as part of the analysis, the Leontief production function will be replaced with more flexible production functions that allow for substitutions in response to energy efficiency improvement policies. A detailed description of the development of the input-output modelling framework with flexible production functions and the introduction of energy within the economic framework of the analysis is discussed in Section 4.3 below.

4.3. Input-Output Modelling Framework

The framework for this research is adopted from the paper published by the Asian Development Bank (ADB), 'Energy Efficiency Improvements in Asia: Macroeconomic Impacts', 2014. This paper examines the macroeconomic impacts of energy efficiency improvements, particularly policy trade-offs, employment, trade balance, energy intensity, energy security and GHG emissions in seven major Asian countries from 2010 to 2050. These countries are the People's Republic of China, India, Indonesia, Japan, the Republic of Korea, Malaysia and Thailand (Sharma, Sandhu and Misra, 2014).

Although this paper provides a foundation, it is only a broad study and for a limited time period. It does not look at how a specific policy implementation will affect the macro economy. Nor does it take into consideration such technological factors such as the smart grid, carbon capture, utilisation and storage (CCUS), future mobility/electric vehicles, sustainable cities and others that impact energy efficiency results.

This research will focus on India alone and further extend this framework by including the various technological factors and specific policy implementations that impact energy efficiency decision-making from 2015 to 2050.

The framework developed is an energy-oriented input-output model for India based on the GTAP database. This database is the core of the GTAP, a document with information on global bilateral trade, transport and protection linkages and a representation of the global economy (Narayanan, G., Aguiar, and McDougall, 2012). This database incorporates data published by the Central Statistical Organisation, Government of India, and additional data from the IEA, the World Bank and the UN to carry out analysis at the disaggregated level of energy production and consumption by various energy and non-energy sectors of the economy, as well as electricity generation, using different technologies in India. This will help to assess the economy-wide impacts of energy efficiency improvement on policy decision-making.

This section discusses the basic input-output model followed by a detailed explanation of the input-output framework developed for this research.

4.3.1. Basic input-output model

The basic Leontief input-output tables show the flow of goods and services in the economy for a given year. The essential information required to develop input-output tables is contained in the inter-industry transactions table shown in Figure 4-2.

		PRODUCERS AS CONSUMERS								FINAL DEMAND			
		Agric.	Mining	Const.	Manuf.	Trade	Transp.	Services	Other	Personal Consumption Expenditures	Gross Private Domestic Investment	Govt. Purchases of Goods & Services	Net Exports of Goods & Services
PRODUCERS	Agriculture												
	Mining												
	Construction												
	Manufacturing												
	Trade												
	Transportation												
	Services												
	Other Industry												
VALUE ADDED	Employees	Employee compensation								GROSS DOMESTIC PRODUCT			
	Business Owners and Capital	Profit-type income and capital consumption allowances											
	Government	Indirect business taxes											

Figure 4-2: Basic Input-Output Table

Source: Miller and Blair (2009)

The rows in this table show the distribution of an industry sector's output throughout the economy. The columns list the inputs required by a particular sector to produce the required output. The additional columns, such as Final demand, include household consumption, government expenditure, capital stocks, government investments and net exports. Additional rows, labelled Value Added, are other non-industrial inputs to production such as labour, capital, indirect taxes and imports. The exchange of goods between and among all sectors of production are recorded in either physical units or monetary terms.

Outputs to sector j Inputs to sector i	Production sectors (j)	Final sectors	Total output
Production sectors	.... Inter-industry table (x_{ij}) (Intermediate demand)	(Y_i) (Final demand)	(X_i)
Primary inputs (k)	(v_{kj})	GNP	
Total input	(X_j)		

Figure 4-3: Flow of inputs and outputs

Source: Sandu (2007)

In Figure 4-3, x_{ij} represents the flow of outputs from sector i to sector j, where x_{ij} is used as inputs in the inter-industry transaction table; Y_i represents the final demand for sector i outputs; X_i is the total output of sector i; X_j is the total input to sector j and v_{kj} represents the flow of production factor inputs to sector j. The following relationships are derived from these elements:

$$X_i = \sum_{j=1}^{n} x_{ij} + Y_i$$ Equation 4-1

$$a_{ij} = \frac{x_{ij}}{X_j} \quad , \quad x_{ij} = a_{ij} X_i$$ Equation 4-2

$$f_{kj} = \frac{v_{kj}}{X_i}$$ Equation 4-3

where a_{ij} in Equation 4-1 is the amount of inputs required from sector i to produce one unit of output of sector j. The a_{ij} elements are referred to as technical coefficients, as can be seen in Equation 4-2. In Equation 4-3, f_{kj} represents the amount of primary inputs v_{kj} are required to produce one unit of output in sector j.

$$X = (I - A)^{-1} \, Y \qquad \text{Equation 4-4}$$

In Equation 4-4, $(I - A)^{-1}$ is known as the Leontief inverse, or the total requirements matrix; it represents the total (direct and indirect) requirement for sector i outputs to satisfy one unit of final demand in sector j (Miller and Blair, 2009). The above equation shows that the value of total output X depends upon the value of the final demand Y and the technical coefficients A.

Input-output modelling is well suited for analysing the interrelationships between energy, the economy and the environment. This research examines the economy-wide impacts of energy efficiency options on each of the key end-use sectors of the economy namely, residential, industry, transport, agriculture and commercial services in the context of India.

4.3.2. An input-output modelling approach for this research

The research follows a five-step modelling approach, as shown in Figure 4-4. The basic input-output model is extended to consider both physical quantity and monetary units. The Leontief's fixed-proportion production functions are replaced with a flexible production function in which the technical coefficients change in response to a change in price. This section discusses the analytical process in detail, including the mathematical computations that underpin the model.

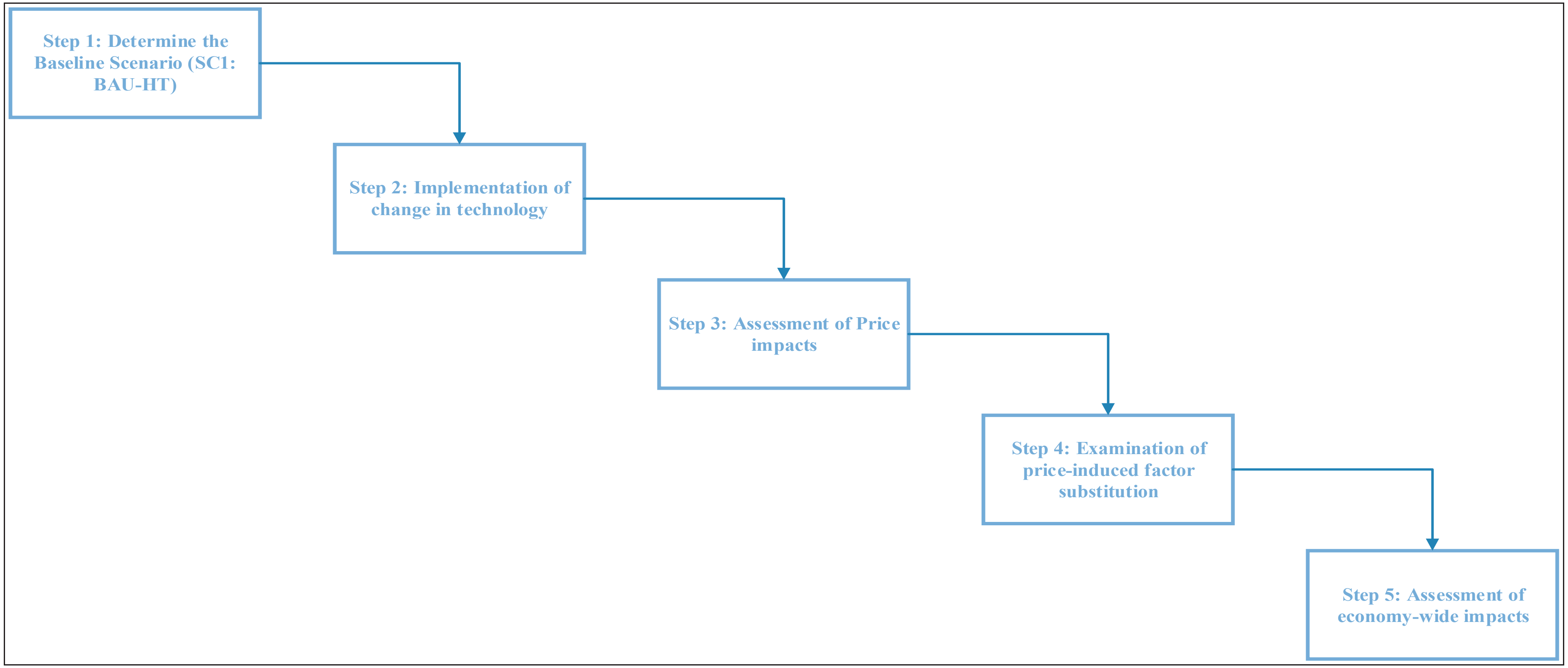


Figure 4-4: Steps for the modelling approach

Source: Sandu (2007)

Step 1: Determine the Baseline Scenario

The baseline scenario (SC1: BAU-HT), a more detailed description of which is provided in Chapter 5, considers no future technological changes. Rather, only assumptions about future macroeconomic conditions, such as GDP and population growth, drive it. This scenario thus forms the basis for step two of the analysis to demonstrate the implementation of technological change in the model.

The SC1: BAU-HT scenario is developed by using the standard input-output model. The input-output tables are adapted from the GTAP databases. This base input-output table is used to develop the technical coefficient matrices that underpin the modelling framework. The economic data extracted from the GTAP databases is in monetary units and satellite data, such as energy, employment and GHG emissions, is available in physical units. A satellite account is a term developed by the UN to measure the size of economic sectors that are not defined as industries in the national accounts (OECD, 2003).

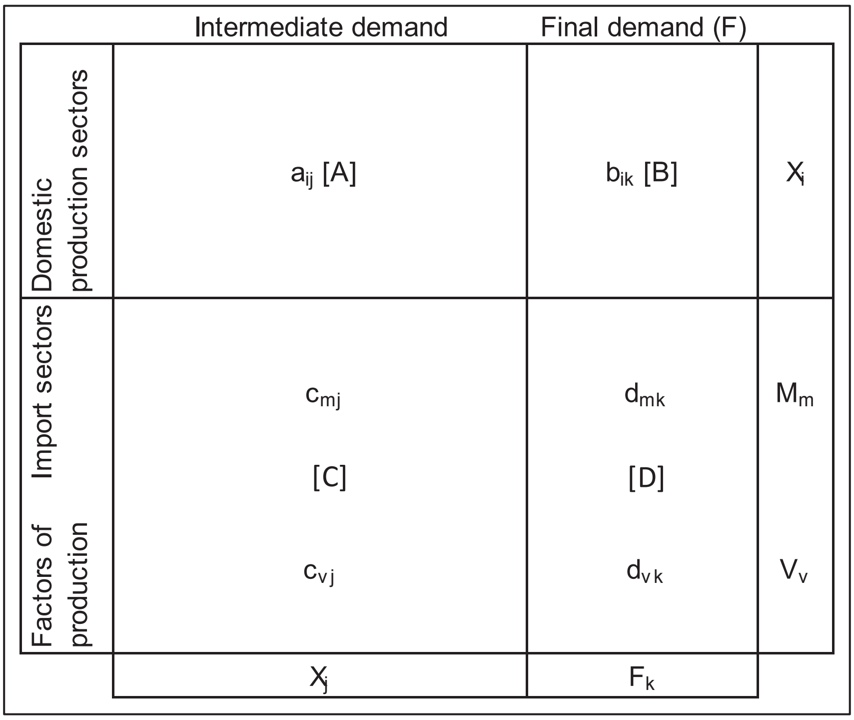


Figure 4-5: Input-Output technical coefficients table

Source: Sandu (2007)

As can be seen in Figure 4-5, the column labelled Intermediate demand represents the technology structure of a given sector. The intermediate demand comprises the technical coefficient a_{ij}, the import coefficient c_{mj}, and the primary factors of production coefficient c_{vj}. The technical coefficient a_{ij} represents the quantity of input i required from other sectors to produce one unit of output j for a particular sector. The import coefficient c_{mj} represents the proportion of input m required from sectors located in a foreign country to produce one unit of output j for a particular sector. The primary factors of production coefficient c_{vj} represent the unit production costs of a particular sector in terms of the primary factors of production or value added and indirect taxes. The column labelled Final demand F typically represents household consumption, government expenditure, government investments and net exports. The final demand comprises the final use coefficient b_{ik} and import coefficient d_{mk}.

Considering Leontief's fixed-proportion production function, the input to a particular intermediate sector can be expressed as:

$$z_{ij} = a_{ij} X_j \quad \text{Equation 4-5}$$

$$m_{mj} = c_{mj} X_j \quad \text{Equation 4-6}$$

$$v_{vj} = c_{vj} X_j \quad \text{Equation 4-7}$$

As can be seen in Equation 4-5, z_{ij} is the output of sector i used by sector j; m_{mj} is the import from foreign sector m used by domestic sector j as seen in Equation 4-6; and v_{vj} is the factor v use by sector j as seen in Equation 4-7.

The input to Final demand can be expressed as

$$f_{ik} = b_{ik} F_k \qquad \text{Equation 4-8}$$

$$m_{mk} = d_{mk} F_k \qquad \text{Equation 4-9}$$

$$v_{vk} = d_{vk} F_k \qquad \text{Equation 4-10}$$

As seen in Equation 4-8, Equation 4-9, and Equation 4-10, f_{ik} is the output of sector *i* used by final demand k; m_{mk} is the import from foreign sector *m* used by final demand *k*; v_{vk} is factor *v* paid by final demand *k*; and F_k is the total final demand *k*.

The above equations help to determine the national accounts at the aggregated and disaggregated levels. For instance, GDP can be determined from the income approach $\sum V_v$ or from the expenditure approach $\sum F_k$ - $\sum M_m$. Based on the above equations, the data from the input-output tables for the base year 2015 are used to develop the forecast of the input-output table for the future year *t*. This analysis is carried out based on the assumption of future macroeconomic drivers, such as economic growth and various final demand categories F_k^t.

This analysis is begun by first determining the total final demand for year *t*, for each row (sector) of the input-output table. This includes the total final demand from domestic production sectors F_{it} , as shown in Equation 4-11, total final demand from import sectors F_{mt}, and total tax paid by the final demand sectors F_{vt} , as shown in Equation 4-12.

$$F_i^t = B^s \cdot F'^t_k \qquad \text{Equation 4-11}$$

$$F_{m+v}^{t} = D^{s} \cdot {F'}_{k}^{t}$$ Equation 4-12

where B and D are the technical coefficients for the year *t.*

These final demand outputs from the above equations are used to determine the total sectoral output X_i , as can be seen in Equation 4-13, total import M_m, and total factors of production V_v for the future year *t* , as shown in Equation 4-14.

$$X_i^t = (I - A^s)^{-1} \cdot F_i^t$$ Equation 4-13

$$M_m^t + V_v^t = [C^s \cdot (I - A^s)^{-1} \cdot B^s + D^s] \cdot {F'}_k^t$$ Equation 4-14

Finally, the individual components of the input-output table can be determined for the future year *t* in a manner similar to Equation 4-15.

$$z_{ij}^t = a_{ij}^s \cdot X_j^t$$ Equation 4-15

where $Xj = X'j$

In addition, the model is developed to determine satellite accounts such as energy, employment and GHG emissions. These satellite accounts allow for an estimation of energy, employment and GHG emissions in the economy to be made. Below is the mathematical computation of energy demand. A similar principle can be applied to develop estimates for other satellite accounts.

$$e_{fi} = \frac{E_{fi}}{X_i}$$ Equation 4-16

E_{fi} is the energy of type *f* consumed by production sector *i*. From above, the total output *Xi*, of production sector *i* satisfies the intermediate and final demands. Therefore, the energy intensity of sector *i*, $e_{fi,}$ is as shown in Equation 4-16. In the matrix notation, the above equation can be expressed as

$$e = E\, X^{-1}$$ Equation 4-17

where *e* is the matrix of energy intensities in toe per $ and *R* is the matrix of total energy use in toe.

Based on the above Equation 4-17, the energy demand for the production sectors can be represented as shown in Equation 4-18:

$$E = e\, X$$ Equation 4-18

By replacing the total output *X* from Equation 4-13 into Equation 4-18, the sectoral energy demand for the future year *t* can be expressed as shown in Equation 4-19:

$$E_{ft}^{t} = e_{ft}^{t}\, (I - A^{t})^{-1}\, F_i^{t}$$ Equation 4-19

Labour productivity, the amount of labour required for the production of one unit of economic output, can be determined similarly. It is expressed as shown in Equation 4-20.

$$l = \frac{L}{X} \tag{Equation 4-20}$$

where l is the matrix representing people employed per unit of output for each end-use sector, L is the vector representing the level of employment, and X is the vector representing sectoral output.

Step 2: Implementation of Change in Technology

In this step, we determine how the change in technology in one sector can have an impact on the rest of the economy. To study these impacts, the technical coefficients are changed exogenously. The technical coefficients in each of the columns in Figure 4-5 illustrate the inputs, including intermediate and primary factor inputs, used in a production process. This information helps to design future technology scenarios. This method of adjusting the technical coefficients to examine the impact of a change in energy technologies has been a common approach used by energy modellers (Miller and Blair, 2009).

This research focuses on the impact of energy efficiency improvements on the economy, that is, a decrease in the use of energy as an input to produce the same level of output in the economy. In the context of the framework, a reduction in the value of the energy input coefficient a_{ij} signifies energy efficiency improvements. Thus, the technical coefficients representing energy inputs in the framework are assumed to be exogenously reducing over time. The rate of reduction is determined by the historical estimates of energy efficiency improvements considered in India. A detailed description of these assumptions for each of the long-term energy efficiency improvement scenarios of SC2: CP and SC3: SF are discussed in Chapter 5.

To study the energy efficiency improvements of transitioning to more advanced and efficient technology for the generation of electricity requires adjustments to the technical coefficients in the model. The column representing electricity supply in the technical coefficients table shows the share of electricity produced by various technologies. A switch from conventional fossil fuel technology to new and advanced renewable technology means the technical coefficients are reduced for the conventional technology while for the advanced technologies the technical coefficients are increased in the same proportion.

Step 3: Assessment of Price Impacts

A change in technology means a change in the inputs of various production sectors. As a result, there is an impact on the price of sectoral outputs. By introducing energy-efficient technology, the unit of energy produced requires less energy input and hence a decrease in the production cost, which results in a decrease in the output prices.

This impact on the change in price as a result of technological change is determined by using Leontief's standard input-output price model, as can be seen in Equation 4-21.

$$P_i = (I - A')^{-1} C_j' \qquad \text{Equation 4-21}$$

where C_j is the sum of factors of production and imports for each sector j.

Similar to the Step 1 process, to assess the impact of price, the price for the base year 2015 needs to be estimated first. For the base year, using Equation 4-21 along with the technical coefficients, a vector of the base year prices for all sectors will be equal to one, a method similar to CGE models. This is because of a normalisation of prices. In this approach, the base year input-output table comprises only price x quantity flows. It translates value data into price and quantity data by normalising the initial base prices in the model into one. Thus, the technical coefficients for each column are interpreted as the quantity of input per \$1 of produced output (Sandu, 2007).

To determine the price of the sectors in the future year t, the new technical coefficients are exogenously changed, as in the previous step, as can be seen in Equation 4-22.

$$P^t = (I - A'^t)^{-1} C'^t \quad \text{Equation 4-22}$$

where P^t is the vector of new sectoral price levels, A^t is the matric of technical coefficients adjusted for new energy-efficient technology and C^t is the matrix of primary factors of production and import coefficients for the future year t.

Thus, the changes in sectoral prices as compared to the base year are expressed in Equation 4-23.

$$\frac{P'}{P} = \frac{P_t - P_s}{P_s} \quad \text{Equation 4-23}$$

Step 4: Examination of price-induced factor substitution

The basic input-output tables have limited scope to allow for substitution through the use of Leontief's fixed-proportion production function. However, the change in sectoral prices as discussed in Step 3 will need to allow for substitution among factor inputs. This model considers these substitution possibilities by introducing flexible neoclassical production functions to the standard input-output model.

This process is introduced by assuming a nested structure for the technical coefficients, by assuming a particular functional form, by assuming the values for elasticities of substitution based on the review of the literature, and by calculating each tier in the nested structure to determine the values for an updated input-output table.

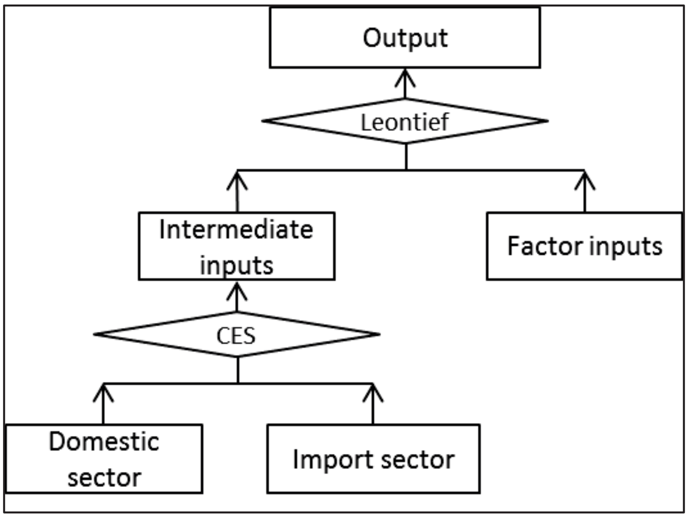


Figure 4-6: Nested structure of technical coefficients

Source: Sandu (2007)

As can be seen in Figure 4-6, the nested structure of the technical coefficients consists of two nests or tiers. The first tier shows the final output of a particular sector is determined according to a nested Leontief function, using intermediate inputs and factor inputs. The second tier employs the intermediate inputs from the domestic production sectors and import sectors, according to a nester's constant elasticity of substitution (CES) function. A production function has the CES between every pair of inputs if and only if the production is either of the functional form or of the Cobb-Douglas form.

In the first tier, the production function represents a Leontief production function with zero elasticity of substitution. The final demand X_i is expressed in Equation 4-24.

$$X_i = \min(\frac{h_{ij}}{a_{ij}}, \frac{v_{vj}}{c_{vj}}) \qquad \text{Equation 4-24}$$

where, h is the intermediate inputs, which includes inputs from domestic production sectors z_{ij} and import sector m_{mj} and a is the technical coefficients for intermediate inputs a_{ij} and c_{mj}.

Since the elasticity of substitution function is *zero*, changes in price will not have any impact on the choice of inputs used. Thus, the quantity of intermediate inputs can be determined on similar lines to Equation 4-15.

$$h_{ij} = a_{ij} X_j \qquad \text{Equation 4-25}$$

$$v_{vj} = c_{vj} X_j \qquad \text{Equation 4-26}$$

In the second tier of the nested structure, intermediate inputs are determined by flexible, domestically produced inputs and import sector inputs through a CES production function, as shown in Equation 4-27.

$$h_j = (a_{ij} z_{ij}^{\frac{\sigma-1}{\sigma}} + c_{mj} m_{mj}^{\frac{\sigma-1}{\sigma}})^{\frac{\sigma}{\sigma-1}} \qquad \text{Equation 4-27}$$

where σ is the elasticity of substitution between z_{ij} and m_{mj}.

The about equation can also be expressed as an input demand function, as shown in Equation 4-28 and Equation 4-29.

$$z_{ij} = 1^{\sigma-1} a_{ij} (\frac{P_j}{P_{ij}})^{\sigma} h_j \qquad \text{Equation 4-28}$$

$$m_{mj} = 1^{\sigma-1} c_{mj} (\frac{P_j}{P_{mj}})^{\sigma} h_j \qquad \text{Equation 4-29}$$

where h_j is the total intermediate inputs used by sector *j*, p_j is the unit costs of total intermediate inputs used in sector *j*, p_{ij} is the unit costs of domestically produced intermediate inputs *i* used in sector *j* and p_{mj} is the unit costs of intermediate import sector inputs *m* used in sector *j*.

The nesting structure of technical coefficients assumed in the model is more complex than the one discussed above. A nested structure of the electricity generation analysis is as shown in Figure 4-7.

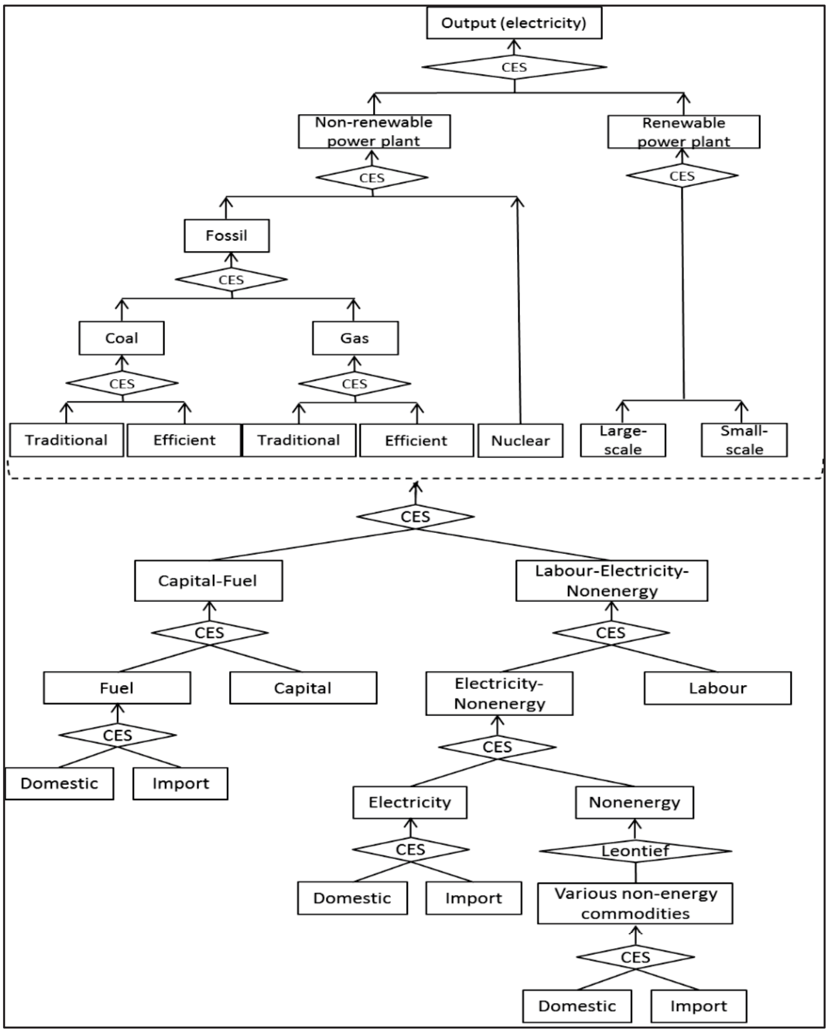


Figure 4-7: Nested structure for electricity generation analysis

Source: Sandu (2007)

Equation 4-28 and Equation 4-29 enable the capture of substitution possibilities within the input-output modelling framework. To update the input-output table for the future year *t* as a result of technological change, we use Equation 4-25, Equation 4-26, Equation 4-28, and Equation 4-29, depending on the type of production functions within the nested structure.

Step 5: Assessment of Economy-wide Impacts

The assessment of economy-wide impacts resulting from introducing energy-efficient technologies is the final stage of the modelling approach. The new input-output structure forms the basis for calculating the updated economic accounts. Once the technical coefficients, electricity generation mix and final demand have been modified, these changes are incorporated into the base year model to generate revised results for the different macroeconomic impacts. The results will then be fed into the first model again and impacts for the next year will be determined. A similar process is followed to determine the impacts for all years to the end of 2050. The changes in the values of the various economic, energy and environmental impacts, such as GDP, energy demand, employment and GHG emissions, are compared to the baseline input-output structure by using Equation 4-15. The difference in the results shows the economy-wide impacts of energy efficiency improvements. The key impacts that are considered as the focus of this research include energy, socio-economic and environmental impacts, as can be seen in Figure 4-8.

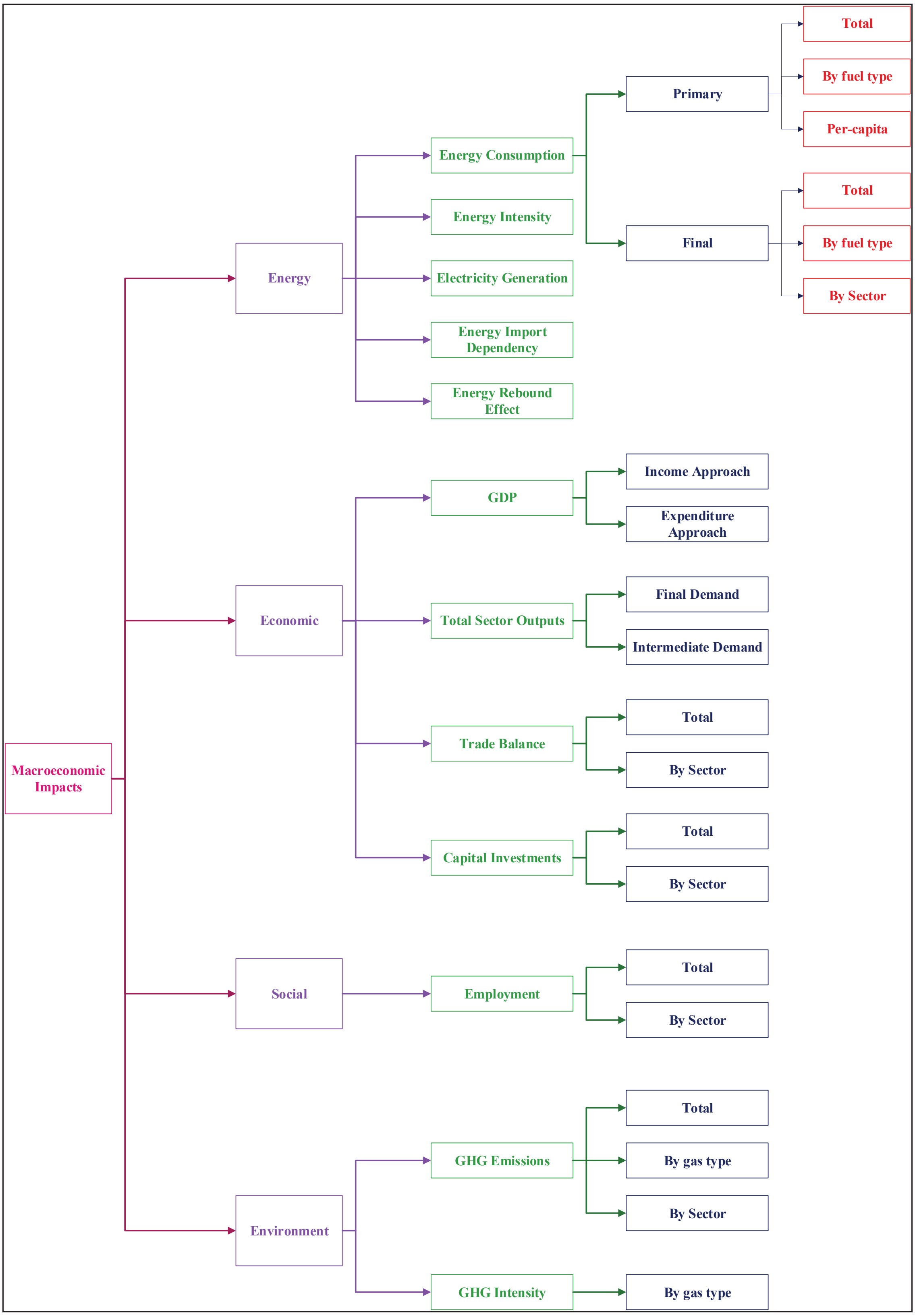


Figure 4-8: Attributes for Assessing the Impacts of Energy Efficiency Improvements

Source: Author's compilation

4.3.3. Data sources

To quantitatively examine the links between energy, the economy and the environment, this research has developed a set of energy-oriented input-output tables for India from 1978 to 2015. The original national input-output tables were obtained from the published sources by the Central Statistics Office of India (CSO), Ministry of Statistics and Programme Implementation (MOSPI). The three main elements of the model include the inter-industry matrix, primary input and final sectors.

The inter-industry matrix in these tables ranged from 60 sectors in 1978 to 130 sectors in 2015. The tables needed to be aggregated to ensure consistency of the sectors and coherence with other data sources. This was done by considering the changes in the manner in which the sectors were classified in the tables across the different years. In view of the focus of this research, the various sectors were grouped in accordance with their energy intensiveness; the high energy-intensive sectors were kept separate while the less energy-intensive sectors were grouped as one sector. These sectors were made consistent with the National Industrial Classification (NIC) classification defined by the CSO using the GTAP database. A summary of the sector grouping for this research is shown in Table 4-1. Details of each sector and sub-sector are shown in Table A-1 and Table A-2 from Appendix A. Thus, this research considers a 20-sector input-output table.

Energy Sector	Energy Extraction	1. Coal 2. Crude Oil 3. Natural Gas 4. Uranium 5.1. Combustible Renewable 5.2. Non-combustible Renewable
	Energy Conversion	6. Coal Products 7. Oil Products
		8.1. Coal-fired PP - traditional 8.2. Coal-fired PP - efficient 8.3. Oil-fired power plant 8.4. Gas-fired PP - traditional 8.5. Gas-fired PP - efficient 8.6. Nuclear power plant 8.7. Renewable PP - large scale 8.8. Renewable PP - small scale
		8. Electricity
Non-Energy Sector	Industry	9. Paper manufacturing 10. Chemical manufacturing 11. Iron & steel manufacturing 12. Non-ferrous metals manufacturing 13. Non-metallic minerals manufacturing 14. Non-intensive manufacturing 15. Non-Energy Mining
		16. Agriculture
		17.Commercial Services
	Transport	18. Water transport 19. Air transport 20. Land Transport

Table 4-1: Sectoral Classification

Source: Sharma, Sandhu and Misra (2014)

The electricity sector is a single sector in the current input-output tables. Given the importance of the electricity sector as a major contributor to GHG emissions, the electricity generation sector is further disaggregated into eight sub-sectors based on their generation technology, namely, coal-fired power plant (traditional and efficient), oil-fired power plant, gas-fired power plant (traditional and efficient), nuclear and renewable power plants (large and small scale). The data for the electricity generation classification is not directly available from the CSO Annual Energy Statistics (Central Statistics Office, various) reports. This can be estimated by apportioning the energy consumed in the electricity sector from the CSO reports, using the energy consumed by each fuel type obtained from the CEA Annual Generation Programme reports (PlanningCommission-GOI, various), and the Energy Balance data from the IEA World Energy Statistics and Balances (IEA, 2017a).

The final demand X_{ij} sector is classified as the final demand and indirect taxes in the national input-output tables. This consists of six categories, as follows:

1. Private Final Consumption Expenditure (PFCE), which represents the household expenditure details obtained for the National Account Statistics (NAS) and National Sample Survey (NSS) surveys.

2. Government Final Consumption Expenditure (GFCE), which represents current expenditures of compensation of employees, depreciation and intermediate consumption of goods and services covered in the Annual Survey of Industries (ASI) and NSS survey.

3. Gross Fixed Capital Formation (GFCF), which includes data on exports, imports and import duty obtained through the ASI.

4. Change in Stocks (CIS), which is estimated for the manufacturing and non-manufacturing sectors received from ASI and the Reserve Bank of India (RBI).

5. Exports, which is represented by data that comprises exports of goods and services obtained from the DGCI&S publications and the RBI.

6. Imports, which includes data of the imports of goods and services by different sectors available from DGCI&S publication and the RBI.

Indirect taxes are distinguished as commodity taxes and other indirect taxes. Commodity taxes include excise duties, sales tax and customs duties excess. Other indirect taxes include electricity duty, motor vehicle tax, entertainment tax, stamp duty and others. The data was obtained from the budgets of the Central and State Government and the Ministry of Finance (Central Statistics Office, various).

The final demand sectors are categorised as Household Consumption, Government Consumption, Investment and Export, the last of which is further divided into Asia-7 Economies and Other Regions, as shown in Table 4-2.

FINAL DEMAND														
			Export											
			Asia-7 Economies							Other Regions				
Household Consumption	Government Consumption	Investment	PRC	Japan	Republic of Korea	India	Indonesia	Malaysia	Thailand	Other East Asia	Other South East Asia	Other South Asia	Central & West Asia	Rest of World

Table 4-2: Final Demand Sectors classification

Source: Sharma, Sandhu and Misra (2014)

The primary inputs considered in the model are capital, including land (K), labour (skilled and unskilled) and natural resources (NR), as available from the GTAP database. This is shown in Table 4-3.

Primary Factors	Capital (incl. land)
	Labour - Unskilled
	Labour - Skilled
	Natural Resources

Table 4-3: Primary input factors classification

Source: Sharma, Sandhu, and Misra (2014)

The energy account F_{ij} for the model is determined from the data available from the IEA World Energy Statistics and Balance (IEA, 2017a). The historical data on the energy sources in physical units in ktoe are determined for the years 1978 to 2015. This data was used to calculate the final demand for the future years till 2050. The energy account was classified into three categories of primary energy, secondary energy and non-energy use, as shown in Table 4-4.

Primary Energy	Coal
	Crude Oil
	Natural Gas
	Uranium
	Combustible renewables
	Non-combustible renewables
Secondary Energy	Coal Products
	Oil Products
	Electricity
Non-energy Use	Coal Products
	Crude Oil
	Oil Products
	Natural gas

Table 4-4: Energy Account

Source: Sharma, Sandhu, and Misra (2014)

This energy-oriented input-output model with flexible production functions is used to study the macroeconomic impacts of energy efficiency on the key end-use sectors. This is determined by carrying out scenario analysis for the years 2015 to 2050 based on different underlying assumptions. The development of the various long-term energy scenarios and the step-by-step process of the scenario analysis is discussed in Chapter 5.

4.4. Summary of the Key Findings

The objective of this chapter was to develop an analytical modelling framework based on an input-output model with a modified production function to analyse the economy-wide impacts of energy efficiency for India. The key findings of this chapter are summarised as follows:

- A review of the two approaches used for energy modelling was discussed, namely top-down and bottom-up models. A bottom-up modelling approach is an engineering approach generally constructed and used by engineers and scientists that focuses on the technological aspects of the energy system. These models provide an analysis of how energy demand can be met in a cost-optimal manner. On the other hand, a top-down modelling approach is an economic approach generally constructed and used by economists that focuses on an entire economy at national or regional level. This type of modelling approach emphasises the inter-relationship between labour, capital and energy to optimise socio-economic wellbeing.

- Based on this review, the input-output method with flexible production function was selected as the appropriate framework for this research. The various scenarios in this research are characterised by a large number of energy technologies that evolve over the study period, 2015 to 2050, the input-output model will enable to study the economy-wide impacts of these changes in energy technologies. The input-output model provides a macroeconomic analysis by showing the interdependencies between the economic sectors as a flow of total goods and services. The model developed in this research comprised 20 sectors categorised according to their energy intensiveness. The data required for modelling these disaggregated sectors is available from publicly available national input-output tables. The production functions in the standard model were replaced with other flexible production functions to carry out the analysis for future years.

- The modelling followed a five-step approach to assess the impacts of energy efficiency on indicators of energy, socio-economic factors and the environment that are important for good policy decision-making. This analysis for the future is carried out through scenario analysis, as discussed in the next chapter.

Chapter 5 : Development of Long-term Energy Scenarios for India

5.1. Introduction

This chapter will comprehensively examine the economy-wide impacts of energy through a scenario-based approach. Three long-term energy scenarios are developed taking into account the key drivers that have the potential to influence the development of future energy systems and policies in India. They are then analysed using an energy-oriented input-output model to represent the most likely future energy directions for India.

The chapter is divided into three key sections. Section 5.2 provides an overview of the importance of scenarios and the scenario development processes and discusses the key methodologies and techniques adopted for the scenario analysis. Section 5.3 discusses the key variables and driving forces for each of the three energy scenarios and the main features of these scenarios are summarised in Section 5.4.

5.2. Literature Review on Scenario Development

The future of energy provision for India is highly complex and depends upon effective energy policies being proposed and implemented. Various methodologies and approaches are generally used to identify the key drivers and make decisions about possible futures for energy security. Scenario analysis is one such method that may be applied to research the energy domain and to provide policy advice.

5.2.1. What is a Scenario?

A scenario may be defined as 'a description of a possible future situation, including the path of development leading to that situation.' (Hannah and Gabner, 2008). Schoemaker elaborates further, stating that a scenario is *'a script-like characterization of a possible future presented in considerable detail, with special emphasis on causal connections, internal consistency, and correctness.'* (Schoemaker, 1991) Thus, scenarios are instruments that contain various conceptions about the future in which the impacts of decisions made today may be perceived. Often multiple scenarios are developed to cover a broad range of possibilities in which the future is likely to evolve.

5.2.2. The importance of scenario development

Scenario development is an important tool for policy analysis, as it helps to systematically examine the interaction of trends and uncertainties within a given domain and time frame. Scenario development complements traditional linear forecasting approaches that assume the future world will be much like the present-day world. Scenario development, on the other hand, allows one to examine the impact of changing one variable and recognising how the other variables might change, leading to improved decision-making for the future (Huss and Honton, 1987); (Blyth, 2005).

Scenarios cannot, nor are they intended to, represent a full description of the future; rather, they are stories about the future based on an understanding of the present. They highlight the key factors and sequence of events of future developments, allowing decision makers to become aware of possible unlikely events that may occur by thinking broadly and creatively about possible alternative futures (Bishop, Hines and Collins, 2007); (Schoemaker, 1991).

5.2.3. Scenario development processes

The literature suggests several different processes for developing scenarios. Some of these are outlined below.

5.2.3.1. An heuristic approach to scenario planning

(Schoemaker, 1991)

Step 1: Define the issues in terms of time frame, scope and decision variables.

Step 2: Identify the major stakeholders.

Step 3: List current trends that will affect the variables.

Step 4: Identify key uncertainties which will affect the variables.

Step 5: Create two scenarios by placing all positive outcomes of key uncertainties in one scenario and all negative outcomes in the other scenario.

Step 6: Assess the internal consistency and plausibility of the above two scenarios.

Step 7: Eliminate combinations that are not credible and create two or more new scenarios that cover a range of uncertainty.

Step 8: Assess the revised scenarios in terms of how the key stakeholders behave in them.

Step 9: Re-examine the internal inconsistencies from these new scenarios with the help of quantitative analysis.

Step 10: Re-assess the range of uncertainty of the variables, repeat steps 1 – 9 to arrive at decision scenarios that help to enhance decision-making about the uncertainty.

5.2.3.2. Developing scenarios - adopted from the Art of the Long View

(Schwartz, 1991)

Step 1: Identify the focal issue or decision

Step 2: Identify the key factors that influence decision-making

Step 3: List driving forces that influence the key factors

Step 4: Rank the factors by importance and uncertainty

Step 5: Select scenario logics that influence decision-making

Step 6: Flesh out the scenarios in line with the factors and forces in the form of a narrative

Step 7: List the implications of the decision-making

Step 8: Select leading indicators

5.2.3.3. Steps for Emissions Scenarios developed by the IPCC

(IPCC, 2000)

Step 1: Review the set of scenarios from the literature to represent the range of driving forces and emissions

Step 2: Undertake an extensive assessment of the driving forces and emissions along with alternative modelling approaches

Step 3: Formulate four different narrative storylines to describe the relationships between emission-driving forces and their evolution

Step 4: Quantify the scenarios covering a wide range of demographic, economic and technological driving forces of GHG and sulphur emissions

Step 5: Undertake an open review process using multi-model models of emission scenarios and their assumptions

5.2.3.4. Five-phase process of scenario development adopted by the German Development Institute

(Hannah and Gabner, 2008)

Phase 1: Identification of the scenario

In this phase, the purpose of the scenario is developed, and the research objective is defined.

Phase 2: Identification of key factors

The key factors, which include those variables, parameters, trends, developments and events that are central to the scenario process, are identified.

Phase 3: Analysis of key factors

Individual key factors are analysed to find their possible salient characteristics.

Phase 4: Scenario generation

The consistent factors are grouped together and drawn into the scenarios using different methods, from narrative literary procedures to more formalised mathematical techniques.

Phase 5: Scenario transfer

The further application and processing of the scenarios is described.

5.2.4. Methods for scenario analysis

Scenario analysis approaches are broadly classified into two categories: *Explorative vs. Normative* and *Qualitative vs. Quantitative*. This section discusses these approaches as well as some of the key techniques used for scenario analysis.

5.2.4.1. Explorative v Normative Approaches

Explorative approaches pose 'What-would-happen-if?' questions (Hannah and Gabner, 2008). With the explorative technique, a set of scenarios is developed taking into account a variety of perspectives. They are typically useful when the analyst has a good knowledge of the current system, giving the analyst an opportunity to explore the consequences of alternative developments for the long term. For example, the World Energy Outlook 2002 used the explorative scenario approach by changing energy parameters in the model to take into account structural changes and to analyse the possible evolution of global energy markets in the future (Börjeson et al., 2006).

Normative approaches on the other hand pose questions such as ‘How can we reach a specific target in the future?’ (Hannah and Gabner, 2008). With this technique, the objective is to attain certain future states, and to demonstrate how these may be achieved in a cost-effective manner. For example, in the IPCC study on emissions scenarios, the aim was to attain stabilisation of CO_2 concentrations in the atmosphere at targeted levels. Scenarios were developed using the MARKAL energy optimising model to model the various possibilities to achieve the desired outcomes (Börjeson et al., 2006).

5.2.4.2. Qualitative v Quantitative Approaches

Quantitative approaches typically use mathematical models to arrive at firm conclusions about key factors while qualitative approaches use narrative and literary techniques essentially to make a meaningful observation of details and nuances. Quantitative approaches are used mainly in the domain of economics and demography while qualitative approaches help in the long-term analyses to politics, institutional and cultural domains (Hannah and Gabner, 2008).

Some key scenario techniques that are a combination of the above approaches are discussed below.

Trend Impact Analysis (TIA)

Trend impact analysis, which has been practiced since the early 1970s, combines traditional forecasting techniques such as time series and econometrics with qualitative factors to identify the key impact factors and the probability of a set of future events occurring. Consisting of trend analysis and trend extrapolation, the method projects trends into the future, either by statistical analysis of quantitative data or by descriptions derived from available qualitative data (Amer, Daim, and Jetter, 2013).

Cross Impact Analysis (CIA)

Cross impact analysis, developed in 1966 by Gordon and Helmer, illustrates the causal relationships among different possible future probabilities, and provides rich material with which to analyse and consider mutual consequences. The future values of the possible events are determined along with an estimation of each of their initial independent probabilities. Thereafter, conditional probabilities are calculated, typically with the help of mathematical and linear optimisation tools, to determine the interlinked probabilities of future events.

Systematic Formation

Systems models are used to illustrate possible estimations of the future. Scenarios are developed by grouping together similar future events and the causal relationships between them are mapped using such causal models as CLDs. The output of these models shows the change in the values of the key variables between the present and the considered future (Hannah and Gabner, 2008); (Bishop, Hines and Collins, 2007).

Creative-Narrative

The creative-narrative scenario approach uses creative techniques, intuition and implicit knowledge to develop desirable scenarios. These scenarios are formalised by quasi-literary texts which describe a set of possible alternative futures. Different methods, such as *intuitive logic*, where the focus is on decision-making processes, take into account all the available information about the future and develop new ideas based on an evaluation of estimates and uncertainty, in addition to data analysis. The intuition (*gut feelings*) of the experts are taken as a reference point in the analysis (Hannah and Gabner, 2008). Another creative-narrative method is *morphological analysis*, which explores possible futures in a systematic way by studying all combinations resulting from the disaggregation of a system. It is used to study ‘wicked’ problems by analysing the highly complex network of interrelationships between the key variables (Hannah and Gabner, 2008). The third creative-narrative method is *normative-narrative*, which describes the future in the form of science fiction stories. This method helps to combine feasible technology with social contexts in a workshop-based environment (Gaßner and Steinmüller, 2004).

This discussion on the review of the various scenario development processes and methodologies from the literature will form the basis for the development of energy scenarios in the context of this research. These are discussed in the following section.

5.3. Scenario Development in the Context of This Research

In this research, an explorative approach using quantitative data is taken to develop three long-term energy scenarios to determine the macroeconomic impacts of energy efficiency, and hence to address the energy security challenge for India in the future. This method will help to explore the alternative energy security trends into the future at the national level (such as on GDP, employment) and micro-levels (such as outputs and employment in different sectors) by providing a vision on a set of perspectives with numerical data for the key energy, economy and environment indicators in a succinct and concrete manner that will enable to reflect the changes on the socio-economic and environmental aspects that are crucial from the point of view of policy decision-making.

This research adopted a four-step scenario development process;

Step 1: **Identification of the key scenario variables** that are important for policy making and have the potential to influence the development of India's future energy systems.

Step 2: Construction of alternative energy scenarios by **developing a set of assumptions** for the identified variables as a set of policy constraints.

Step 3: **Descriptions of the alternative energy scenarios** for modelling purposes.

Step 4: **Quantitative modelling of the scenarios,** using an energy-oriented input-output model to assess their impacts on energy, the economy and the environment.

5.3.1. Identification of key scenario variables

In order to develop policies that can help address the energy security challenge facing India while maintaining socio-economic development and protecting the environment, five key variables were identified as the driving forces for this purpose. These key variables are discussed in detail in the following section.

5.3.1.1. The diversity of the energy supply mix

The diversity of the energy supply mix is likely to be one of the critical issues for India, especially if it is to meet the rapidly increasing energy demand needed to support its socio-economic development. Currently, India's primary energy mix is dominated by two fossil fuels, namely, coal and petroleum products. They collectively accounted for nearly 90% of the total primary energy supply in the year 2015-16, with coal accounting for 66% and petroleum products for 26% (Central Statistics Office, 2017).

The research scenarios assume that diversifying the energy fuel supply mix will help to reduce the risks associated with the overwhelming dependence on these two sources of energy. Currently, India is significantly dependent on the highly vulnerable and geopolitically disturbed (or unstable) regions of the Middle East for its supply of oil. Further, India plays a key part in the global stand on reducing CO_2 emissions worldwide, and if India is to meet the set sustainable development targets, its over-reliance on coal, although an indigenous energy source, could pose a big problem. The nation's push to 100% electrification means diversification of fuels for electricity generation is equally important. In 2015-16, coal contributed 80% of the total power generation mix and was also a major source of CO_2 emissions (Central Statistics Office, 2017).

For this research, energy diversification is focused not only on fossil fuels such as coal, oil and gas, but also considers nuclear and renewable energy sources such as solar, wind, biomass and geothermal. Diverse energy fuel mixes are incorporated into the scenarios in this research, through fuel use in electricity generation and in key end-use sectors of the economy, to achieve some technological improvements.

5.3.1.2. Energy import dependency

India remains dependent on imports for its traditional energy sources. Reducing this import dependency in the future is both urgent and critical in shaping the country's future energy pathways. This urgency is all the greater because India's dependence on foreign sources for primary energy fuels continues to grow in line with population increase and hence energy demand, while domestic production remains relatively static. Imports accounted for nearly 46% of the total primary energy consumption in 2015-16 (Central Statistics Office, 2017). The challenge is how to spur economic growth without de-stabilising India's energy security. One of the ways to address this issue is by increasing domestic production of primary energy sources such as coal and oil. An alternative is promoting energy efficiency. While reducing its dependence on energy imports is important, India's current indigenous oil reserves are not enough for the long term. Domestic oil production can meet only 25% of the nation's oil need. In 2014, oil imports were 3.3 times higher than domestic production while coal imports stood at 25%. Moreover, nearly 75% of the oil imports come from politically unstable and economically volatile nations of the Middle East, Africa and Venezuela (Babajide, 2018).

The Government of India has considered several policy measures to reduce energy import dependency. These include strategic investment in offshore and onshore energy reserves, enhancing energy efficiency through technological advancement and conservation programs to increase overall energy savings.

5.3.1.3. Technological advancement

The advent of new and affordable energy technologies plays a key role in improving energy efficiency, enhancing energy security and reducing adverse environmental impacts. These technology changes have made energy one of India's most dynamic sectors. The present-day technology in the conversion and end-use sectors is relatively obsolete, resulting in high energy intensity; the country's primary energy intensity is 0.56 kgoe/USD, making India a relatively inefficient user of energy, while at the same time indicating significant potential for improvement. These energy improvements could be achieved through advanced technologies that are not only energy efficient but also cost-effective for the major end-use sectors of the economy. The push in the transport sector towards hybrid and electric vehicles is one example of new technology adoption. The promotion in the power sector of renewable energy sources such as solar, wind and hydro for electricity generation is another example, while improved technology for metal processing in the industrial sector will contribute to enhancing India's energy security and reducing the rate of GHG emissions.

5.3.1.4. Socio-economic factors

The choices made by society in terms of values, environment and lifestyle are reflected directly in energy consumption patterns. Increasing population and the growth in GDP results in improved lifestyles and increased rates of urbanisation, which in turn influence energy accessibility and affordability. Through education, society is becoming more environmentally conscious, and the choice of more energy efficient and environmentally friendly technology and appliances is becoming more acceptable. These social beliefs play a critical role in formulating energy policies for the future.

5.3.1.5. GHG emissions

Energy activities have become one of the major contributors to global GHG emissions. Reducing GHG emissions is emerging as a major issue in the energy policy debate worldwide. Under the Paris Agreement, India has set a target to reduce its GDP emissions intensity by 33-35% by 2030 from 2005 levels (Babajide, 2018). However, the Carbon Free Energy Portfolio (CFEP), an indicator used to evaluate the extent of India's efforts to transition from a carbon concentrated energy mix to a carbon free energy mix, is declining due to the country's increased dependence on fossil fuels to meet growing energy demands. This signals that India is at risk of environmental degradation and climate change threat. Thus, there is a need to mitigation of the impact of energy activities on the environment caused by GHG emissions ever more expeditiously.

5.3.2. Construction of energy scenarios

Three energy scenarios have been developed in this research around the five key variables discussed above, their aim being to present three different energy alternative pathways for India to 2050. These key variables are the drivers that define the boundaries of these scenarios. The scenarios themselves emphasise both the supply side and the key end-use energy-consuming sectors, such as the industrial, transport, residential, agriculture, and commercial services sectors of the economy.

The business-as-Usual (**SC1: BAU-HT**) scenario presents a continuation of the current trends in India's energy sector in terms of policies and technologies. The Country Policy (**SC2: CP**) scenario is formulated on the objectives of India's draft National Energy Policy in order to realise the India Vision 2040, a transition to an ambitious pathway that is cleaner and more sustainable than the BAU-HT scenario. The third scenario, Sustainable Future (**SC3: SF**), is based on the Sustainable Development Scenario designed by the IEA in the World Energy Outlook 2017 to integrate with the key objectives of the Sustainable Development Goals of the United Nations (IEA, 2017c), which align with the definition of energy security in the context of this research (Chapter 2).

Socio-Economic Assumptions (% p.a.) from 2015 to 2050	**All Scenarios**
Population growth rate	0.75%
GDP growth rate	6.28%
Labour productivity growth rate	1.76%

Table 5-1: Socio-Economic Scenario Assumptions

All three scenarios assume the same population growth rates from 2015 to 2050, as shown in Table 5-1, taken from the World Bank data catalogue (The World Bank, 2018a). The economic growth rates for 2015-2050 are based on the projections as stated in the *Global Economic Prospects* report by the World Bank (The World Bank, 2008).

5.3.2.1. Business-as-Usual–Historical Trend (SC1: BAU-HT)

Scenario Overview

The business-as-usual (**SC1: BAU-HT**) scenario represents the continuation of the historical commitments to energy production, economic development and technological advancements. This scenario is characterised by having no restriction on the fossil fuels used in power generation or on the end-use energy-consuming sectors of industrial, transport, agriculture, residential and commercial services. Nor is there any specific commitment to encourage renewable energy sources and limit GHG emissions. The energy productivity growth projections to 2050 in this scenario are made on the basis of the final energy consumption for the whole economy and for the key end-use sectors in the economy. The long-term historical energy efficiency improvements are as provided by the IEA dataset on World Energy Balances from 1978 to 2015. The historical value-added figures for each of the end-use sectors are as published in the National Accounts Statistics by the MOSPI, Government of India. For the electricity sector, it is assumed that the future share of different electricity generation fuel sources (coal, oil, gas, nuclear and renewables) from 2015 to 2050 will grow at long-term historical rates, as estimated from the IEA dataset from 1978 to 2015.

Energy Resources

In this scenario, India would face no constraints on the availability of fossil fuels to meet its energy needs. In 2015-16, fossil fuels accounted for nearly 95% of its total primary energy supply (Central Statistics Office, 2017). This scenario assumes that fossil fuels will maintain this share in the years to come. The fossil fuel supply mix is supported by the availability of indigenous resources, mainly in the eastern and southern central parts of the country, made up of nearly 308 BT of coal, 620 MT of petroleum products and 1227 BCM of natural gas, plus imported sources (Central Statistics Office, 2017). There is no immediate urgency to reduce the consumption of oil and oil products, and it will continue to be an important fuel in the transport sector. This will increase India's dependence on imported oil due to the limited availability of domestic oil reserves. There is potential for the generation of renewable energy from various sources; in 2015-16, these contributed 3% of the total primary energy supply (Central Statistics Office, 2017).

Electricity Generation

In this scenario, there is no specific policy to restrict the share of electricity generated from fossil fuels and energy efficiency is low. As there is no restriction on fossil fuel use, coal continues to dominate the electricity generation mix and this would increase beyond its current share of around 60% (Central Statistics Office, 2017). The lack of policies in place to encourage clean technologies means current coal-fired power plants are performing poorly in terms of their conversion efficiency and new clean coal technologies are less competitive and will enter later in the projection period (IEA, 2015b).

Gas and hydro-electricity, though attractive sources for generation in terms of low CO_2 emissions per unit of electricity produced, have limited indigenous reserves, contributing 25% to the total generation mix during the planning period. The share of renewable energy, such as solar and wind, in the generation mix is also expected to be small, 10% of the total (Central Statistics Office, 2017). The share is so low because the unit cost of investment in renewable-based power plants is a lot higher than that of the fossil fuel based power plants. This is further exacerbated by the constraints related to land acquisition and network expansion (IEA, 2015b).

End-use Sectors

This scenario assumes that the end-use sectors of the economy will continue to be dependent on the existing structure and technologies employed. Thus, the energy consumption by these sectors is expected to remain high in parallel with economic growth. Due to the lack of appropriate policies, coal, oil and electricity will continue to be major energy sources.

The industrial sector will consume the largest share of total final energy. Energy-intensive industries such as iron and steel, and cement, paper and chemical manufacturing, will see no significant changes from the present old and energy-inefficient technologies, while in the transport sector, energy consumption will continue to increase. This will be driven by increased economic activity and improved living conditions. The transport sector, mainly road transport, will continue to rely on petroleum-based technologies such as petrol and diesel, making it one of the leading sectors contributing to CO_2 emissions. In the residential and commercial services sector, energy consumption will be driven by the increased rate of urbanisation and rural electrification, leading to improved living standards with greater access to modern energy sources and electricity for the projected study period.

GHG Emissions

This scenario assumes that India will face no pressure to reduce GHG emissions. This assumption is supported by the current low emissions per capita of 1.8 tonnes of CO_2 per capita, which is lower than the average global emissions of 4.2 tonnes of CO_2 per capita in 2017 (Andrew, 2018). The early stages of economic growth and the aim to alleviate poverty have resulted in emissions growing at an average overall rate of 6% over the past decade (Andrew, 2018).

The major characteristics of SC1: BAU-HT are summarised in Table 5-2 below.

1. Energy resources

- The current trend in the consumption of coal will continue, with no specific policy to discourage coal use.
- Natural gas and oil supply will be met by indigenous resources available in the eastern and central states.
- There are no immediate concerns to reduce dependency on oil.
- Renewable energy share will remain low due to high financial constraints.

2. Electricity Generation
• There will be no restriction on conventional coal-based power plants for electricity generation. • There will be no specific policies to promote renewable energy for power generation.
3. End-use Sectors
• Technologies for energy-intensive industries such as iron and steel and cement production will remain as they are. • There will be no policies to promote alternative fuels and technologies in the transport sector. • For the residential and commercial services sectors, there will be no specific policies to promote energy-efficient appliances and technologies.
4. GHG Emissions
• There will be no policy measures to reduce GHG emissions.

Table 5-2: Major Characteristics of SC1: BAU-HT

5.3.2.2. Country Policy (SC2: CP)

Scenario Overview

The Country Policy (**SC2: CP**) scenario is based on the objectives of India's draft National Energy Policy (NEP) 2017. The four key objectives are access to affordable prices, improved security and independence, greater sustainability and economic growth. The scenario is characterised by the Government of India's aim to achieve universal electrification with 24 x 7 electricity to all by 2022. India aims further to increase the share of all manufacturing to 25% through its 'Make in India' campaign and to reduce its dependency on oil imports by 10% of the 2014-15 levels by 2022. The NEP has an additional target to reduce emissions intensity by 33-35% of the 2005 levels and to generate 40% of its energy from non-fossil fuel sources by 2030. The long-term assumptions for this scenario are in line with the NITI Ambition Scenario (NAS), which comprises lower energy demand, higher domestic production and a transition to cleaner sources of energy (NITI Aayog, 2017). To achieve these targets, India must focus on demand-side interventions by exploiting and incorporating new emerging energy-efficient technologies into its energy and economic infrastructure.

To adopt these new and efficient technologies, and to be able to achieve sustainable growth in the future, India will require high financial investment. The World Bank has offered US$300 million to scale up the existing government programs that align with the findings of the Systematic Country Diagnostic (SCD) for India. The SCD emphasises that '*climate change related risks would be partially mitigated and neutralized through a more resource-efficient growth path*.' Through the SCD, the Indian government will invest in energy efficiency savings by contributing to government programs. One such energy-saving strategy would transform the residential sector by focusing on LED bulbs, tube lights and ceiling fans under the Unnat Jyoti by Affordable LEDs for ALL (UJALA) program. Similar energy savings will be derived by replacing existing public street lights with more energy-efficient LED street lighting under the Street Light National Programme (SLNP) (The World Bank, 2018b).

While the NEP focuses on the short term (to 2022) and medium-term (to 2040) horizon, these assumptions are extended in this scenario to a long-term time horizon (to 2050) through trend extrapolation.

Energy Resources

India is heavily dependent on imports for its coal, oil and gas demands. The overall import dependency is estimated to rise from 31% in 2012 to 36%-55% in 2040. The primary energy supply will grow at a CAGR of 3.6% to 2040, while the per-capita energy demand is expected to increase from 503 kgoe per capita in 2012 to 1055-1184 kgoe per capita in 2040. Through the NAS, a greater penetration of renewable and cleaner sources of energy is assumed and the supply of coal and oil would be restricted. This scenario assumes that through the NEP there will be interventions to exploit domestic coal reserves to reduce dependence on imports. Apart from conventional fuel supplies, sources such as CBM, UCG and shale oil/gas will contribute towards increasing overall domestic production of energy resources (NITI Aayog, 2017).

Electricity Generation

The NEP expects the share of electricity in India's energy consumption to rise in the future. This is due to the increased affordability of electricity generation from renewable sources and the advent of more efficient appliances and technology. India's electricity supply is expected to rise to 4800 TWh by 2040, contributing to 26% of the total final energy demand under the NAS, and growing at a CAGR of 5.5% to 2040. The per-capita electricity consumption is estimated to increase from 887 kWh in 2012 to 2911-2924 kWh in 2040. Adoption of newer and cleaner technologies, such as ultra-supercritical and IGCC technologies in coal-based power plants is also assumed. Enhanced gas-based power generation capacity, along with renewable energy capacities, would further encourage cleaner sources of power generation. The potential to consider carbon capture and sequestration (CCS) in coal- and gas-based plants will also contribute to generation capacity. Concentrated Solar Power (CSP) and offshore wind capacities, in addition to solar PV, distributed solar photovoltaic and onshore wind, will contribute to the renewable energy generation capacity. Nuclear energy is the only baseload power source offering green energy and with the development of fast breeder technology, India intends to increase its nuclear power capacity to 63 GW by 2030. Thus, the overall share of non-fossil fuel based electricity generation capacity by 2040 is estimated at around 57-66% and the AT&C losses will be reduced by 15%; this can be achieved by strengthening the national electricity grid through the introduction of smart grids and by upgrading the existing T&D network (NITI Aayog, 2017).

End-use Sectors

In this scenario, the aim is to show how efficiency and technological measures on the demand side can help reduce overall energy demand. In the industry sector, energy efficiency can be increased through the PAT scheme to transition towards the best available technologies. An example of this is the move in the iron and steel industry towards disruptive technologies such as electric furnaces for the steel production processes. The adoption of new technology includes a shift from solid and liquid hydrocarbons to electricity. The agriculture sector, for example, is adopting more efficient pump sets, shifting from diesel pump sets to electric and solar-powered sets, and reducing energy demand by introducing fuel-efficient tractors. In the residential and commercial services sectors, there is a transition from conventional fuels such as firewood and kerosene to modern fuels such as LPG, PNG and electricity. Improved living standards and better access to modern fuels for cooking and lighting mean an increase in the demand for gaseous and liquid hydrocarbon and electricity in the future (NITI Aayog, 2017). Further, energy efficiency standards and labelling will be made mandatory for air-conditioning systems, lights, televisions and refrigerators under the Standards and Labelling Program of the Bureau of Energy Efficiency (BEE). The main objective of this program is to make the consumer aware of the energy-saving and thereby cost-saving potential of household equipment and appliances. Another BEE scheme launched in 2007 is the ECBC, developed primarily for new commercial buildings in India. The main objective of this code is to set as a minimum energy standard for buildings with a connected load of 100kW or a contract demand of 120KVA (The World Bank, 2018b).

Technological advancement in the transport sector, mainly road transport, includes hybrid vehicles, electric vehicles and fuel cell vehicles and improved vehicle fuel economy will help reduce demand for liquid fuels, a strategy that is part of the National Electric Mobility Mission Plan 2020. The Bharat Stage VI (BS VI) emissions standard focuses on the automobile industry, particularly the changes needed in terms of pollutant emissions. Through this emission norm, India aims to reduce GHG emissions from vehicles and be at par with other advanced global automotive markets (Embitel, 2018). Under the BS VI there will be increased support for natural gas, particularly in the urban public transport system, and there will be a push to construct dedicated rail corridors to shift freight transport from road to rail (IEA, 2017c). Better planning and well-connected public transport facilities are necessary for overall sustainable development.

GHG Emissions

The goal of sustainability is emphasised by the NEP through its aim of achieving de-carbonisation by promoting energy efficiency as well as renewable energy. The target is to reduce emissions intensity by 33-35% below the 2005 levels by 2030, which will require a significant focus on energy efficiency (NITI Aayog, 2017).

The major characteristics of SC2: CP are summarised in Table 5-3 below.

1. Energy resources

- Energy demand rises 2.7-3.5 times from 2012 to 2040.
- Electricity demand rises to 4.5 times from 2012 by 2040.
- Electricity to contribute to 26% of the final energy demand by 2040.
- There are measures to reduce the consumption of coal by adopting new technologies such as CBM, UCG and shale oil/gas to contribute to overall domestic energy production.
- Per-capita energy consumption rises from 503 kgoe/capita in 2012 to 1055-1184 kgoe/ capita by 2040.
- Per-capita electricity consumption rises from 887 kWh in 2012 to 2911-2924 kWh by 2040.
- Overall import dependency is rises from 31% in 2012 to 36%-55% by 2040.

2. Electricity Generation

- Universal electricity access achieved by 2025.
- Electricity supply to reach 4800 TWh by 2040.
- Renewable energy generation capacity to reach 175 GW by 2022 (100 GW solar, 75 GW non-solar).
- The share of non-fossil fuel based electricity will be 57%-66% in 2040 compared to 23% in 2012.
- The share of solar will be 14%-18% in 2040 as compared to 0.2% in 2012.
- The share of wind will be 9%-11% in 2040 compared to 3% in 2012.

- There is a focus on clean coal technologies, such as ultra-supercritical and IGCC for coal-based power plants for electricity generation.
- Reduce AT&C losses by 15%.

3. End-use Sectors

- Adoption of energy-efficient technologies for energy-intensive industries such as iron and steel, and cement production.
- Encourage alternative fuels and technologies, such as EV in the transport sector.
- Passenger light-duty vehicles (PLDV) fuel economy standards to reach 113g CO_2 /km by 2022.
- For the residential and commercial services sectors, this scenario encourages the use of energy-efficient appliances and technologies for cooking and lighting purposes. These include LPG, PNG, LED bulbs, energy-efficient ceiling fans and air-conditioning systems and smart LED street lighting.
- Transition to fuel-efficient pump sets and tractors to carry out agricultural farm activities.

4. GHG Emissions

- The target is to reduce emissions intensity of GDP by 33%-35% below 2005 levels by 2030.

Table 5-3: Major Characteristics of SC2: CP

5.3.2.3. Sustainable Future (SC3: SF)

Scenario Overview

The Sustainable Future scenario (**SC3: SF**) is based on the objectives and assumptions of the Sustainable Development Scenario (SDS) introduced in the World Energy Outlook 2017 (IEA, 2017c). These objectives align with the energy security definition developed in Chapter 2 in this research. The objectives of the SDS are developed in line with three of the United Nations Sustainable Development Goals (SDGs):

1. SDG 7.1: Ensure universal access to affordable, reliable and modern energy services by 2030

2. SDG 3.9: Substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution and contamination by 2030, and

3. SDG 13: Take urgent action to combat climate change and its impacts (United Nations, 2015).

This scenario provides an integrated strategic pathway for the energy sector to ensure energy security for the future. The targets set by the SDG focus on a time horizon up to 2030 and this scenario will extend the timeline up to 2050 by trend extrapolation.

Energy Resources

The Indian economy is transitioning from heavy industry towards higher value-added domestic manufacturing and services. Investments are being made in the energy sector to encourage low-carbon technologies and energy efficiency. There is an increased penetration of renewable and cleaner energy sources, including hydro and bioenergy with an aggregated share of 27%, while nuclear energy is estimated to contribute 8% of the total primary energy demand by 2040. The share of fossil fuel energy sources of coal and oil is expected to decrease to 28% and 24% respectively by 2040, resulting in a substantial decline in fossil fuel import bills. Total primary energy demand is estimated to reach 1479 Mtoe by 2040. To meet the SDG of providing modern energy services to all, electricity demand will grow and is estimated to account for 24% of the TFC by 2040. This will be a result of further efforts to alleviate poverty, improve living standards and boost rural electrification (IEA, 2017c).

Electricity Generation

There is a considerable shift in the electricity generation mix. Total electricity generation is estimated to reach 4069 TWh by 2040, with an increased penetration of renewable and nuclear energy sources in the power generation sector contributing 60% and 11% respectively to total electricity generation. The advanced types of clean coal technologies, such as IGCC and CCS, will be available and will compete with conventional power plants; this will result in substantial decreases in the electricity generated from conventional fossil fuel sources such as coal, oil, and gas, specifically to 10%, 1%, and 17% respectively by 2040 (IEA, 2017c) resulting in a decrease in the demand of these sources for electricity generation. Other improvements to the national electricity grid will further reduce the AT&C losses below the SC2: CP levels.

End-use Sectors

In this scenario, people would become more aware of the importance of environmental protection and would prefer to invest in energy-efficient appliances and technologies such as energy-efficient fans and air-conditioning systems, refrigerators, LED lighting, solar water heaters and rooftop PVs. This would lead to considerable energy savings and reductions in GHG emissions. In the industry sector, there would be a technological break-through in high energy-efficient technologies, such as DRI in steel making and the dry method in cement production, to reduce overall emissions. The wider applications of green building standards and deployment of clean-carbon technologies such as CCS would result in further energy savings. In the transport sector, there would be a rapid rise in the number of electric vehicles and increased support for natural gas, thus reducing dependence on liquid fuels. The fuel economy would as a result be further improved through advanced engine technologies and the share of alternative fuels such as CNG, methanol and hydrogen would rise. There would be an increased improvement in the energy efficiency of agricultural machinery and equipment, which would lead to further energy savings from the agriculture sector (IEA, 2017c).

GHG Emissions

In this scenario, the increasing pressures from the global community and government measures to protect the environment, particularly from climate change caused by CO_2 emissions, would be the focus. The focus would be supported by the deployment of more affordable advanced technologies that are both clean and energy efficient.

The major characteristics of SC3: SF are summarised in Table 5-4 below.

1. Energy resources
• Greater use of renewable energy compared to the SC2: CP scenario. • Government initiatives to further reduce fossil fuel consumption compared to the SC2: CP scenario. • The share of coal has fallen 28% of the total primary energy demand and 24% of the TFC by 2040. • The share of renewables accounts for 27% of the total primary energy demand and 11% of the total final energy consumption by 2040.
2. Electricity Generation
• The share of renewable energy accounts for 60% of the total electricity generation mix by 2040. • The share of solar PV is 26% of the total renewables by 2040. • The share of coal is only 10% of the total electricity generation mix by 2040.

3. End-use Sectors
• There is greater use of alternative fuels, such as CNG and biofuels, in the transport sector. Transport sector energy demand grows at a CAGR of 3.8% p.a. by 2040. • Industry sector energy demand grows at a CAGR of 3.6% p.a., with coal constituting 50% of the total industry sector energy demand by 2040. • The residential and commercial services sectors depend largely on electricity to meet their energy demands, accounting for 55% of the total sector energy demand by 2040. • Increased reliance on modern energy sources for cooking and lighting purposes.
4. GHG Emissions
• Total CO_2 emissions are estimated to be 2621 MT by 2040 compared to 2065 MT in 2015. • CO_2 emissions from the electricity sector will reduce to about 991 MT by 2040 from 1065 MT in 2015.

Table 5-4: Major Characteristics of SC3: SF

5.4. Summary of Key Findings

This chapter began with a literature review on the definition of scenarios and the various techniques, key methodologies and processes used for developing scenarios. On the basis of the review, steps to develop scenarios for this research were formulated.

Based on the scenario development process adopted in this chapter, three key long-term energy scenarios, namely SC1: BAU-HT, SC2: CP and SC3: SF, were developed to reflect possible future energy pathways for India. The scenarios were developed by considering five key variables that have the potential to influence the future development of the energy sector. The key scenario assumptions for all three scenarios are provided in Table 5-5.

The SC1: BAU-HT scenario reflects the continuation of historical trends in energy policy with no major changes. This scenario is characterised by the continued reliance of conventional fossil fuels as the major source of energy in the generation of electricity and key end-use sectors of the economy. No specific commitments to promote renewable energy and no restrictions on GHG emissions are imposed.

The SC2: CP scenario is characterised by the objectives of the Draft National Energy Policy 2017. This policy is notable for the urgent need to encourage energy efficiency and energy diversity. Further, the policy objectives emphasise the need to reduce India's dependence on energy imports and to reduce GHG emissions. This scenario requires moderate initiatives to encourage clean and energy-efficient technologies and shift from carbon-intensive fuel mix to new and renewable energy.

The SC3: The SF scenario accords with the objectives of the Sustainable Development Scenario introduced in the IEA World Energy Outlook 2017. It is characterised by greater urgency to increase the diversity of supply, further reduce dependence on energy imports, encourage the deployment of more advanced and energy-efficient technologies across all end-use sectors of the economy and reduce the GHG emissions intensity levels beyond those projected in the SC2: CP scenario. Society at large, encouraged by government initiatives, would pay increased attention to the environmental aspects of economic development.

A summary of the key scenario assumptions is as seen in Table 5-5 below:

Socio-Economic Assumptions (% p.a.)	**All scenarios**
Population	0.75%
GDP	6.28%
Labour Productivity Growth	1.76%

Energy Productivity Growth (% p.a.)	**BAU-HT**	**CP**	**SF**
Residential	0.5	1.1	1.7
Industry			
Paper	0.8	1.5	2.0
Chemical	1.3	1.5	2.0
Iron and Steel	2.0	3.0	4.0
Non-ferrous metals	0.7	1.5	2.0
Non-metallic minerals	2.0	2.5	3.0
Non-energy intensive	0.9	1.5	1.8
Non-energy mining	0.3	1.0	1.5
Transport			
Water Transport	1.5	1.8	2.0
Air Transport	1.0	1.5	1.8
Land Transport	1.8	1.8	2.0
Agriculture	0.4	1.5	1.8
Services	0.7	1.0	1.5

Electricity Generation Mix (%)	2015	2050		
	Base Year	BAU-HT	CP	SF
Coal - traditional	75.3	77.0	62.4	4.0
Coal - efficient	0.0	0.0	0.0	8.1
Oil	1.7	0.5	1.9	1.0
Gas - traditional	4.9	8.6	3.6	1.5
Gas - efficient	0.0	0.0	0.0	15.4
Nuclear	2.7	6.7	3.6	11.0
Renewable - large scale	15.4	8.2	28.8	53.0
Renewable - small scale	0.0	0.0	0.0	6.0

Table 5-5: Key Scenario Assumptions

Source: Author's compilation

A discussion of the impacts of energy efficiency initiatives to address India's energy security challenge is based on the results generated by a quantitative analysis of the alternative energy pathways with the help of these long-term energy scenarios. This is explained in the following chapters.

Chapter 6 : Assessment of the Long-term Energy Scenario Results

6.1 Introduction

In the previous chapter (Chapter 5), three long-term energy supply scenarios (BAU-HT, CP and SF) were created, taking into account five key scenario drivers that are likely to shape the future development of India's energy system. The energy input-output modelling framework (Chapter 4) helps to capture the links between energy and a large number of economic factors in a coherent manner and examines the likely impact of these economic factors on India's economy in the long-term. The objectives of this chapter are to examine the long-term impacts of the key scenario variables on the country's energy sector, in terms of primary energy supply mix, final energy requirements, energy intensity, electricity supply, the generation technology mix, energy import dependency and GHG emissions and intensities. This chapter also examines the impact on the economic sectors in terms of economic growth (GDP), total sectoral outputs ($Bn), employment levels (Mn persons) and trade balance.

The structure of this chapter is as follows: Section 6.2 assesses the energy impact of the modelling undertaken across the three scenarios. Section 6.3 assesses the economic impact resulting from the modelling undertaken across the three scenarios and the final Section 6.4 summarises the key findings of this chapter.

6.2 Energy Impact of the Scenarios

This section presents the results of the modelling undertaken in this research and assesses the energy impact of each of the three scenarios. These energy impacts are quantified in this research in terms of primary and final energy consumption, energy intensities, energy import dependency, electricity generation fuel mix and GHG emissions and intensities, during the period from 2015 to 2050.

6.2.1 Primary energy consumption

The modelling results suggest that energy consumption in India will continue to rise throughout the period modelled in the BAU-HT and CP scenarios, while in the SF scenario, energy consumption will rise in the short-to-medium term (2015-2035) and decrease in the long term (2036-2050), as can be seen in Figure 6-1. For instance, in the BAU-HT scenario, the total primary energy consumption more than doubles from 1047 Mtoe in 2015 to 5632 Mtoe in 2050 at a CAGR of 5% p.a. In the CP scenario, which involves a modest increase in energy efficiency and constraints on GHG emissions, primary energy consumption increases at an annual growth rate of 3% in the period examined. The SF scenario, however, which envisages higher reductions in GHG emissions, the primary energy consumption increases at an annual growth rate of 2% from 2015 to 2050.

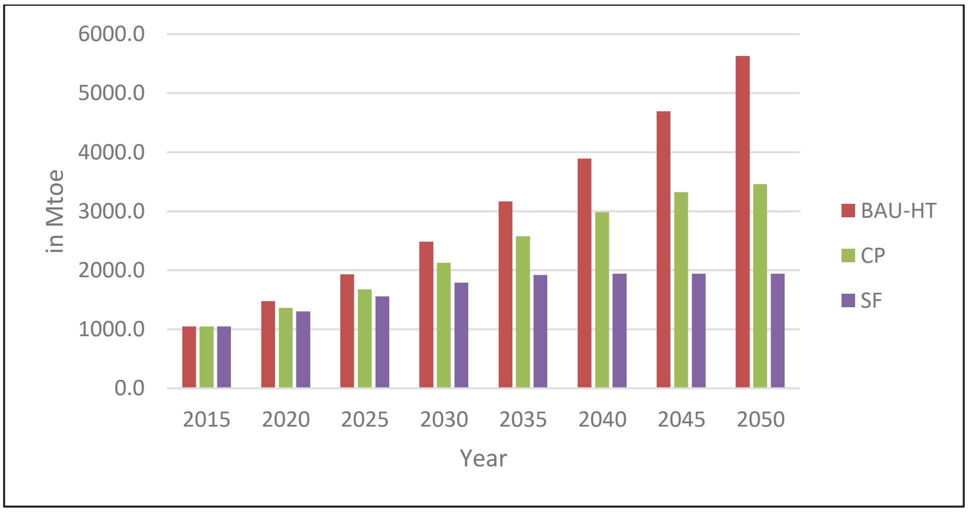


Figure 6-1: Model of primary energy consumption, 2015 – 2050

Source: Author's compilation

The increase in India's primary energy requirements is a result of increased economic activity, population growth, government initiatives to encourage industrialisation and changes in people's lifestyles due to improvements in their income and access to modern energy, for example, rural electrification. The CP and SF scenarios show relatively fewer demand for primary energy, mainly due to increased energy efficiency by introducing more efficient power plants and improvements in end-use technology in the transport, industrial and residential sectors. This is very important for India in the context of emerging concern about the rapid increase in energy demand required for continued economic growth and the adverse effect of that energy demand on the environment.

6.2.1.1 Coal

The results show that the dominant role of coal in the country's energy mix will diminish in the coming decades. In the BAU-HT scenario, coal remains the dominant fuel, contributing about 36% to the total energy resource mix over the study period, and the demand for coal increasing from 388 Mtoe in 2015 to 2021 Mtoe in 2050. However, with growing concerns about climate change, coal's contribution is expected to decline in the future, as shown in Figure 6-2. In the SF scenario, coal share of the total resource energy decreases significantly from 37% in 2015 to only 7% in 2050. According to the model, as existing coal plants retire, they will increasingly be replaced by new and renewable energy sources, and electricity generation will switch to a less carbon-intensive fuel mix.

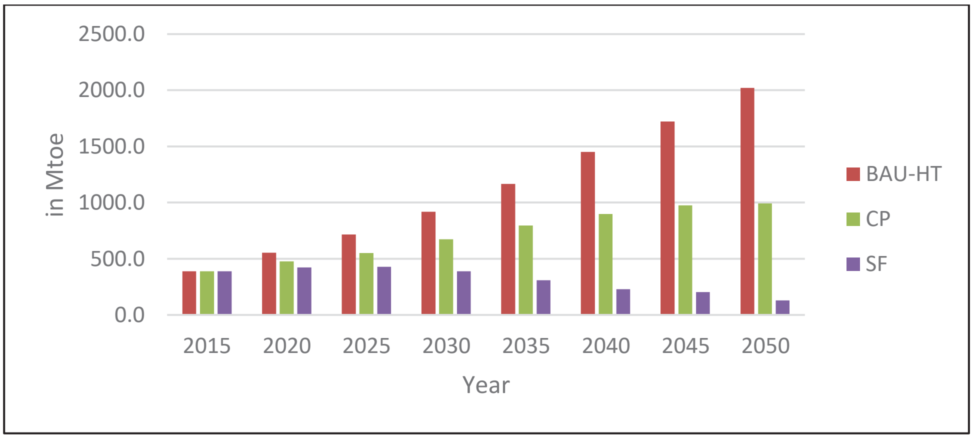


Figure 6-2: Model of primary coal consumption, 2015 – 2050

Source: Author's compilation

6.2.1.2 Oil

Oil will continue to occupy an important role in India's energy mix and increases in oil consumption will be driven mainly by the transport sector. Oil consumption over from 2015 to 2050 will grow by 5% p.a. in the BAU-HT scenario, by 4% p.a. in the CP scenario and by 1% p.a. in the SF scenario, as shown in Figure 6-3. If the present trend continues, and as the BAU-HT scenario shows, oil demand will more than double by 2050, from 362 Mtoe in 2015 to 1700 Mtoe in 2050. These rates of growth are faster in the first 15 years of the study period (2015-2030), being about 5% for all three scenarios. This will be mainly due to high industrial demand for oil and low energy-efficient technologies employed. In the latter half of the study period (2030-2050), the annual growth rate for oil demand will drop to 4%, 2% and -1.3% respectively for the BAU-HT, CP and SF scenarios as a result of energy-saving measures and the promotion of renewable energy uses, such as in hybrid cars and biofuels. An interesting point to note over the total period 2015-2050 is that despite measures to encourage oil saving, the share of oil in the total primary energy mix will increase in the both the CP and SF scenarios and oil will become the most significant energy source by 2050. For example, the share of oil by 2050 in the CP and SF scenarios is projected to be 35% and 28% respectively. This is a result of increasing use of cars per person, a growing population and growth in other forms of transportation, such as sea travel and air travel. With limited indigenous oil reserves, India is likely to become a net oil importer in the future. It is therefore critical for India to have a long-term sustainable oil supply to avoid being impacted by the vulnerability and volatility of global oil markets in terms of supply and price.

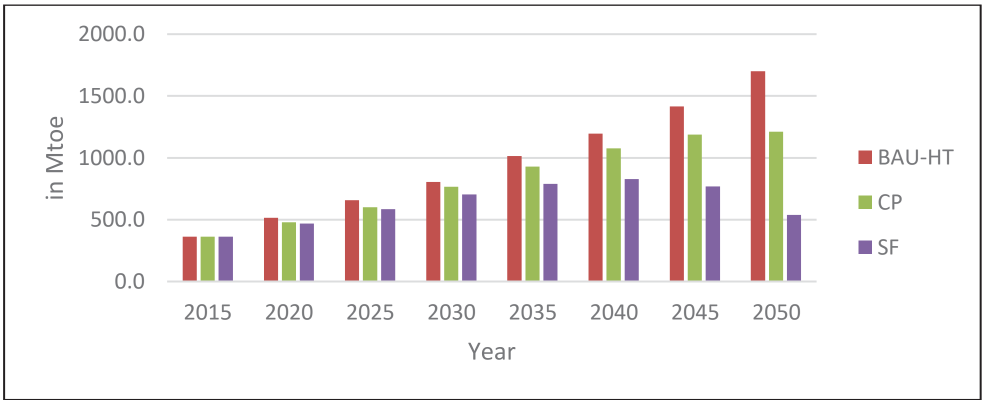


Figure 6-3: Model of primary oil consumption, 2015 – 2050

Source: Author's compilation

6.2.1.3 Natural Gas

India has modest indigenous natural gas reserves. In the BAU-HT scenario, natural gas consumption will increase at an annual rate of 5%. In the CP and SF scenarios, gas consumption will increase annually by 5% and 6% for the CP and SF scenarios respectively from 2015 to 2030, as seen in Figure 6-4. After that, as the reserves of indigenous gas deplete, gas consumption will decline at an annual rate of 1% and 4% for the CP and SF scenarios respectively. In the BAU-HT scenario, natural gas constitutes roughly 4% of the total over the study period, a proportion that falls reduces across the more advanced scenarios of CP and SF to 3% and 2% respectively over the same period.

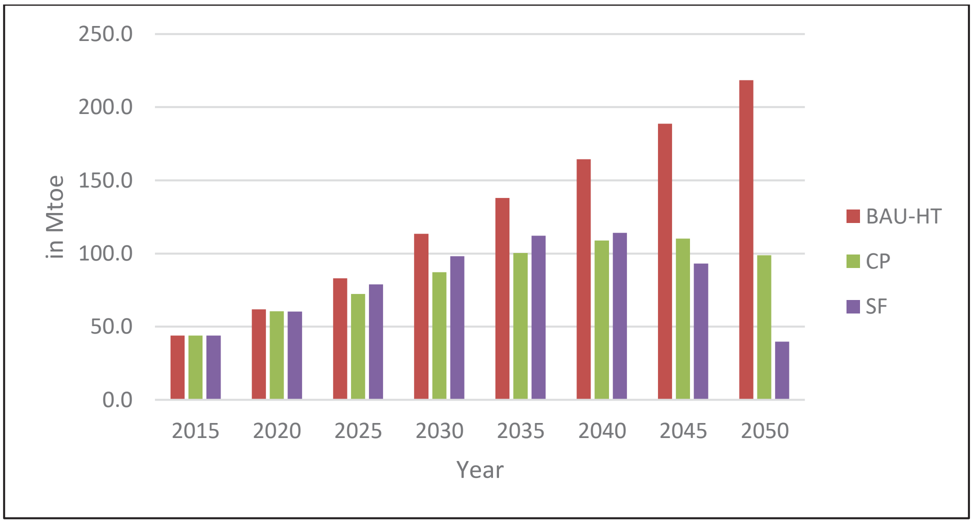


Figure 6-4: Model of primary natural gas consumption, 2015 – 2050

Source: Author's compilation

6.2.1.4 Nuclear energy

Nuclear energy will continue to account for roughly 2% of total consumption over the period 2015-2050. In absolute terms, India's nuclear energy requirements in the BAU-HT scenario will increase annually by 8% from 9 Mtoe in 2015 to 122 Mtoe in 2050, as can be seen in Figure 6-5. In both the CP and SF scenarios, consumption rises by 7% and 12% p.a. respectively until 2030 and then from 2030 to 2050 the consumption of nuclear energy will slow by 2% and -0.5% annually respectively. The main drivers for nuclear energy are the need to improve energy supply security and reduce GHG emissions. Nuclear energy is mainly required as a source for electricity generation, constituting 7%

of the total generation mix by 2050 in the BAU-HT scenario, 4% in the CP scenario and 11% in the SF scenario.

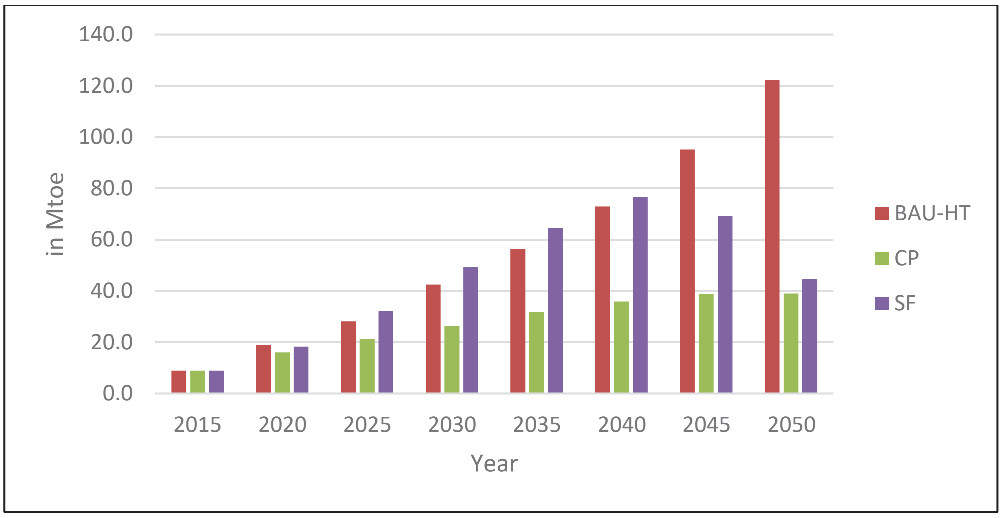


Figure 6-5: Model of primary nuclear consumption, 2015 – 2050

Source: Authors' compilation

6.2.1.5 Renewables

Renewable energy sources in the context of this research consist of hydro, wind, solar and biofuels. The share of renewables in the total energy mix increases from 23% in 2015 to 28%, 32% and 34% for the BAU-HT, CP and SF scenarios respectively by 2050, as shown in Figure 6-6. This increase in the share of renewables is explained by the fact that due to improved living standards and rural electrification, a large proportion of the population will have access to modern energy (gas and electricity), resulting in a reduction in biomass demand for cooking. In absolute terms, renewable energy supply will increase across all three scenarios. Compared to the BAU-HT scenario, the consumption of renewable energy in the CP and SF scenarios is much higher as a result of new measures and incentives to encourage the use of renewable energy, such as solar and wind energy in power generation and biofuels in the transport sector, to increase the diversity of energy supply and at the same time reduce overall GHG emissions.

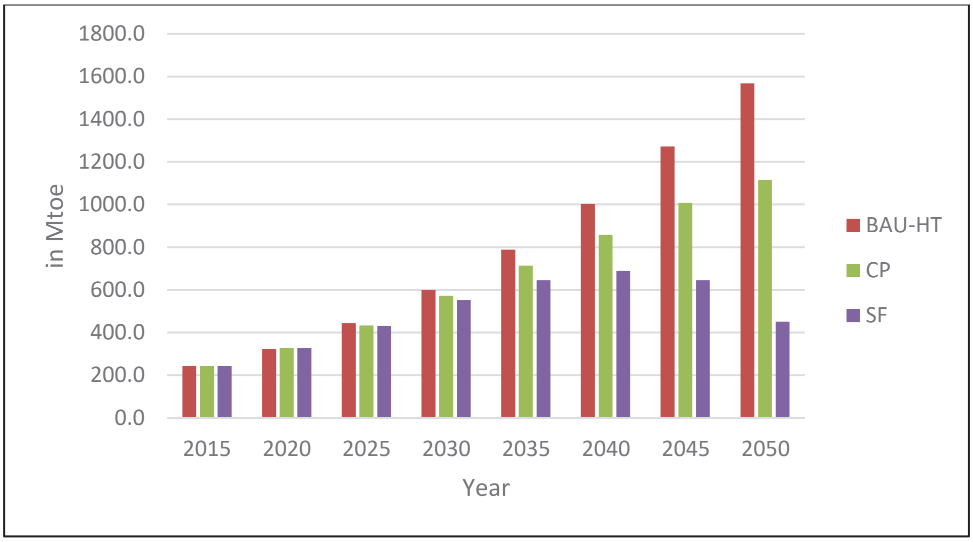


Figure 6-6: Model of primary renewables consumption, 2015 – 2050

Source: Author's compilation

6.2.1.6 Energy Intensity

Energy intensity is the amount of energy required to produce one unit of economic output, represented as toe/$. The modelling results for the period 2015-2050 show that energy intensity is expected to gradually decrease across all three scenarios, from 268 toe/$ in 2015 to 178 toe/$ for the BAU-HT scenario, 108 toe/$ for the CP scenario and 36 toe/$ for the SF scenario in 2050, as shown in Figure 6-7. The decrease in energy intensity is a result of energy efficiency measures and changes in economic structure. For instance, existing low-fuel-economy cars will be replaced by hybrid and electric cars and the share of energy consumed in high energy-intensive industries such as steel and cement will decline in the future as advanced technology, such as direct reduced iron (DRI) in the iron and steel making processes, offer an alternative route to the blast furnace-basic oxygen furnace (BF-BOF) process and to the electric arc furnace (EAF) process for steel production.

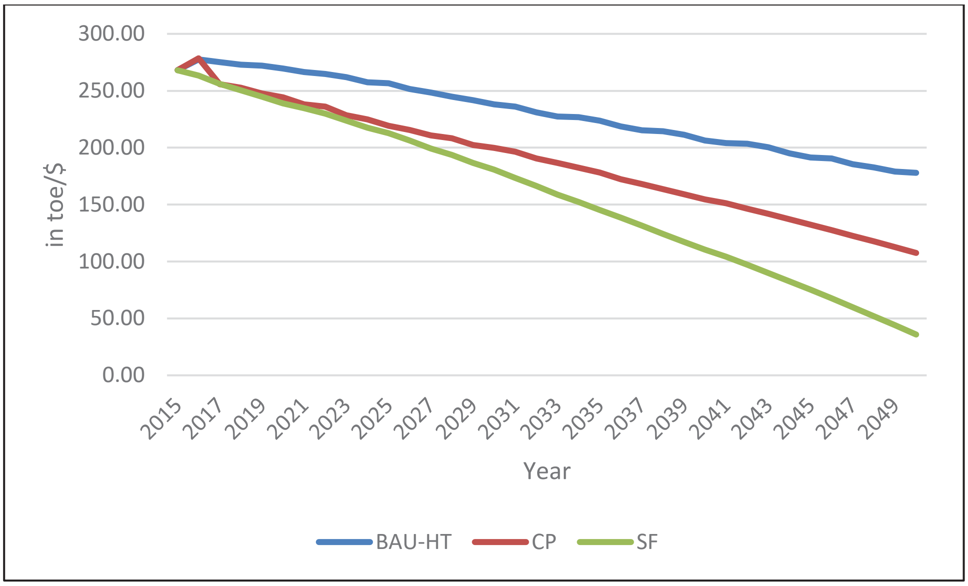


Figure 6-7: Model of energy intensity, 2015 – 2050

Source: Author's compilation

6.2.1.7 Per-capita Primary Energy Consumption

Per-capita primary energy consumption (toe/person) will increase in the BAU-HT scenario at a rate of 4% annually over the period 2015-2050, while in the CP and SF scenarios it will decline. In the CP scenario, this consumption will increase at an annual rate of 3% until 2040, after which it will decline at 1% p.a. till 2050. In the SF scenario, the per-capita consumption will increase gradually at an annual rate of 3% until 2030, after which it will decline at an annual rate of 2% to 2050, as can be seen in Figure 6-8. These changes in per-capita energy consumption will be driven by an increase in economic activity, improved standard of living and population growth over time.

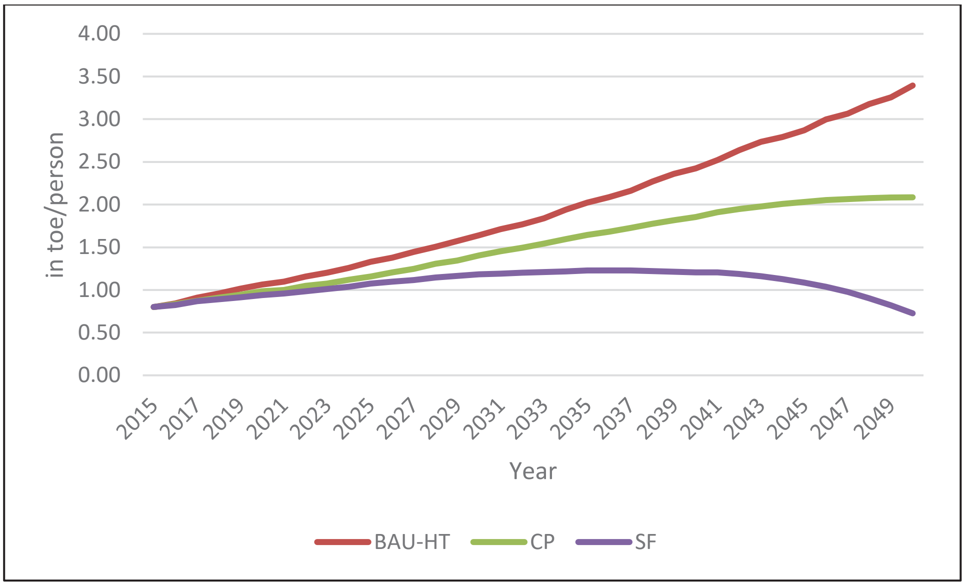


Figure 6-8: Model of per-capita primary energy consumption, 2015 – 2050

Source: Author's compilation

6.2.2 Final energy consumption

In the BAU-HT scenario, final energy consumption will continue to grow over the study period. In the CP scenario, consumption will increase until the mid-2030s, after which it will remain is relatively constant in absolute terms. In the SF scenario, consumption will increase in the short-to-medium term (2015-2030), after which it will decline, as shown in Figure 6-9. According to the modelling, the rates of growth for each scenario will be 5% p.a. in the BAU-HT scenario and 2% in the CP scenario, and there will be a rate of decline of 1% in the SF scenario. The consumption declines in the CP and SF scenarios are a result of the increased energy efficiency measures across all sectors of the economy and the use of new and renewable resources to generate electricity in power plants.

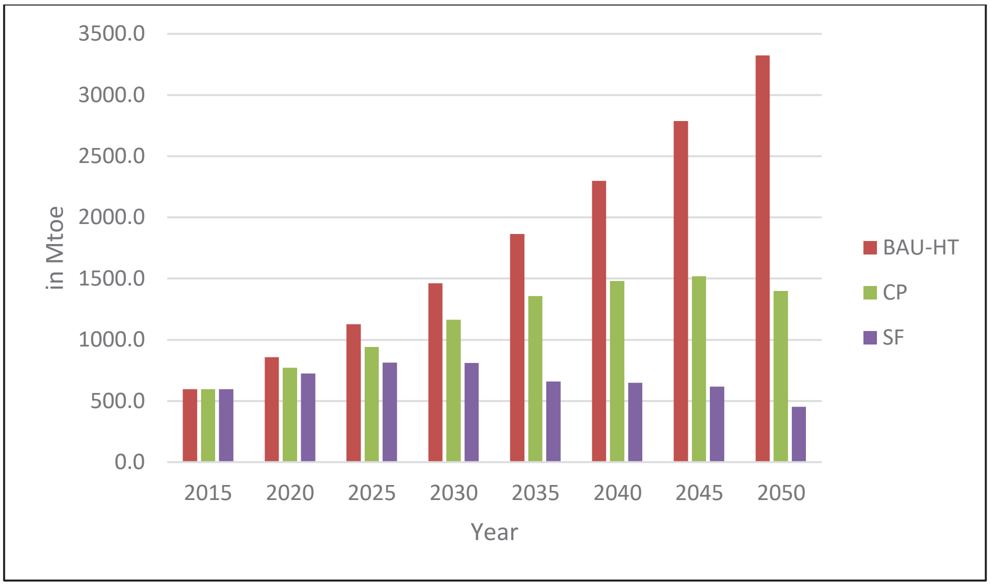


Figure 6-9: Model of final energy consumption, 2015 – 2050

Source: Author's compilation

The total final energy requirements for the BAU-HT, CP and SF scenarios are summarised in Table 6-1 below. The table suggests that the annual total final energy consumption by the agriculture, industry, transport, residential and services sectors is expected to decrease over the period 2015-2050. The residential sector constitutes the dominant sector for all three scenarios. Even though overall consumption is decreasing, the proportion of overall energy that the residential sector will consume will grow. This will result from population growth and a greater share of the population gaining access to modern energy resources, itself a result of changing lifestyle patterns, increased urbanisation and rural electrification programs. In the residential and commercial sectors, energy efficiency will be improved by such energy-efficient appliances as refrigerators, lighting, fans and air-conditioning systems. Consumption in the industry and transport sectors, however, will decrease over time, thanks to the adoption of energy-efficient technology. For instance, the initiatives taken to replace the coal-based technologies in the iron and steel industries, such as blast furnace-basic oxygen furnace (BF-BOF) and EAF technologies, are being phased out and natural gas-based DRI technologies are being introduced. Similarly, in the transport sector, energy consumption is falling as a result of improved vehicle efficiency. Particularly in the SF scenario, energy requirements will reduce significantly, due to the increased use of hybrid and electric vehicles. In the agriculture sector, energy consumption will fall as energy-efficient pump sets and tractors are adopted more widely.

BAU-HT	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	5	5	5	6	6	6	7	7
Industry	38	37	35	34	31	29	26	22
Transport	12	16	15	14	13	12	12	12
Residential	41	38	41	43	46	48	52	55
Commercial	3	3	3	4	4	4	4	4
CP	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Agriculture	5	5	5	5	5	5	1	1
Industry	38	37	32	30	29	27	13	22
Transport	12	12	13	12	12	11	10	9
Residential	41	42	46	48	50	53	56	87
Commercial	3	4	4	4	4	4	4	5
SF	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Agriculture	5	5	5	6	6	4	4	4
Industry	38	38	35	32	18	15	12	10
Transport	12	13	12	12	5	4	3	2
Residential	41	41	43	46	70	74	78	81
Commercial	3	4	4	4	4	3	3	3

Table 6-1: Predicted final energy consumption for the three scenarios (in %)

Source: Author’s compilation

The share of coal, oil and natural gas in the final energy mix is expected to decrease gradually across all three scenarios over the study period between 2015 and 2050, as shown in Figure 6-10. This will result from the increasing adoption of energy-efficient technologies across all key end-use energy-consuming sectors of the economy. For instance, the existing efforts for improvement in vehicle efficiency and the use of CNG and biofuels in road transport will result in decreases in oil consumption. Similarly, the alternative routes for introducing advanced technologies such as DRI in steel production will reduce the dependency on coal. The demand for electricity will be driven by increased economic activity and rural electrification. The share of renewable energy will increase significantly as a result of improving energy efficiency, leading to energy savings and reduced GHG emissions.

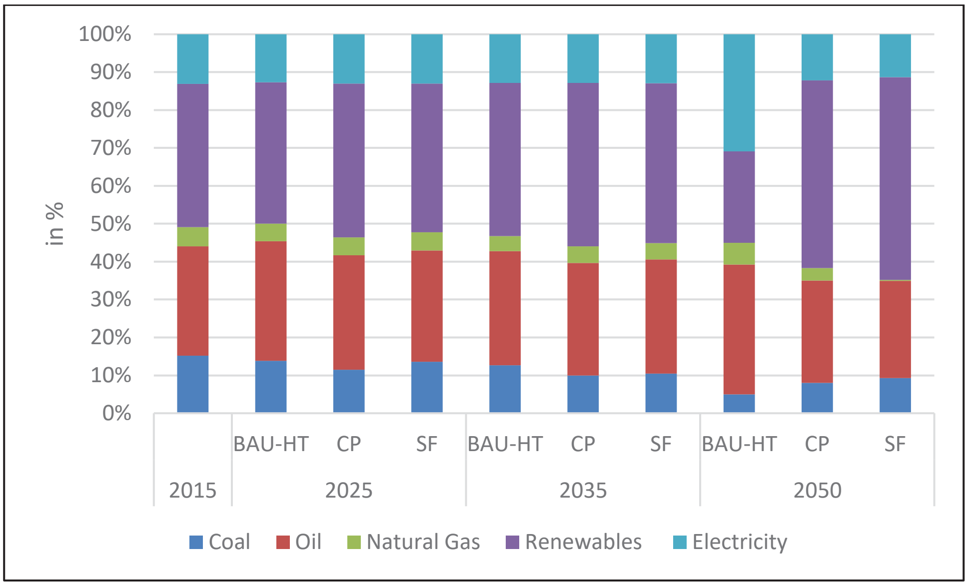


Figure 6-10: Model of share of final energy consumption by fuel type, 2015 – 2050

Source: Author's compilation

6.2.3 Electricity generation

The demand for electricity is expected to increase in the future, from 13% of the total final energy consumption in all three scenarios in 2015 to approximately 25% by 2050. This increase is attributed to the increase in economic activity and to population growth. The main electricity consuming end-use sectors include industry, residential and commercial services. The residential and commercial sectors together consume more than half of the total electricity consumed. Electricity generation will grow by 6% in the BAU-HT scenario and by 4% in the CP scenario. and decrease by 2% in the SF scenario during the period 2015-2030, as can be seen in Table 6-2. The electricity generation growth rate is lower in the CP and SF scenarios due to the decline in demand for electricity as a result of energy efficiency improvements in the end-use sectors of the economy.

BAU-HT	2015	2020	2025	2030	2035	2040	2045	2050
Coal	75	78	77	75	76	76	76	76
Oil	2	2	2	1	1	1	1	1
Gas	5	5	6	7	7	8	8	8
Nuclear	3	4	5	5	5	6	6	7
Renewable	16	11	11	11	10	10	9	9
CP	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Coal	75	70	67	65	64	63	62	61
Oil	2	1	1	1	2	2	2	2
Gas	5	6	6	5	5	5	4	4
Nuclear	3	4	4	4	4	4	4	4
Renewable	16	19	22	24	25	27	28	30
SF	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Coal	75	61	49	35	22	13	12	12
Oil	2	1	1	1	1	1	1	1
Gas	5	7	10	12	15	16	16	17
Nuclear	3	4	6	8	9	11	11	11
Renewable	16	26	34	44	53	59	59	60

Table 6-2: Predicted electricity generation fuel mix for all three scenarios (in %)

Source: Author's compilation

The electricity generation fuel mix is expected to change significantly over the study period of 2015-2050. The share of coal will decline from 75% in the base year 2015 to 65% (2030) and 61% (2050) in the CP scenario and to 35% (2030) and 12% (2050) in the SF scenario. In the SF scenario, the introduction of clean coal technologies such as IGCC and efforts to limit GHG emissions will result in a decrease in the share of coal in the total generation mix from 35% in 2030 to 12% by 2050. The increase in nuclear and renewable energy in power generation means these fuels will play an important role in ensuring the security of energy supply, through diversification of the fuel mix and in environmentally-friendly energy activities. Renewable energy will constitute 9%, 30% and 60% of the total generation mix by 2050 in the BAU-HT, CP and SF scenarios respectively, as shown in Figure 6-11.

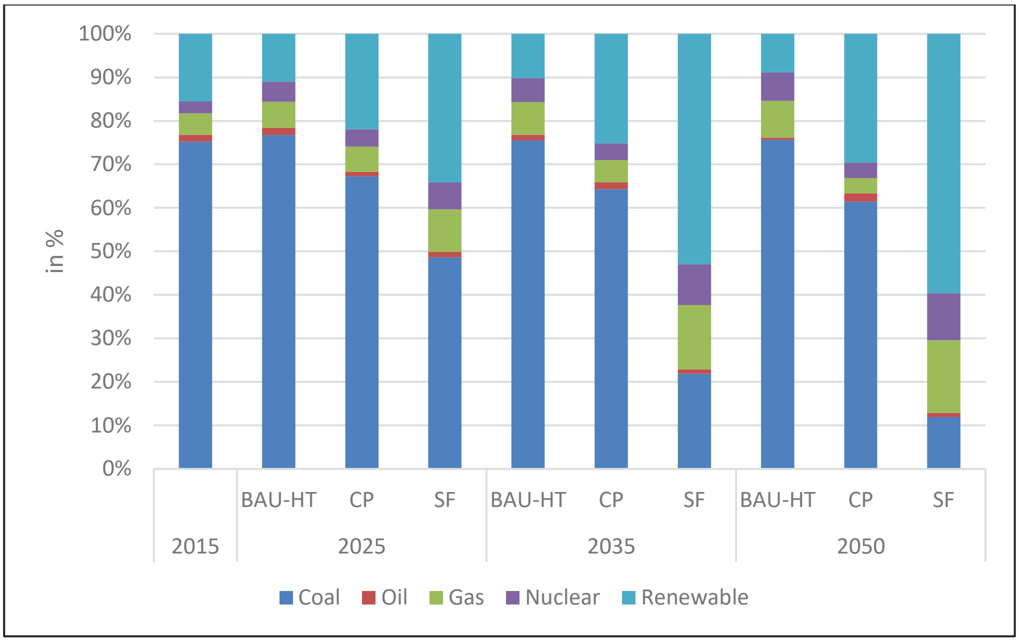


Figure 6-11: Model of electricity generation mix by fuel types, 2015 – 2050

Source: Author's compilation

6.2.4 Energy import dependency

Energy import dependency is expressed in terms of the ratio of net energy imports to total primary energy consumption. Figure 6-12 shows the change in trend across the CP and SF scenarios compared to the BAU-HT scenario over the study period 2015-2050. As efforts to encourage energy efficiency measures increase along with the introduction of new and renewable energy sources, energy import dependency will decrease in the CP and SF scenarios compared to the BAU-HT scenario. The fact that import dependency remains relatively constant in the BAU-HT scenario at around 20% of the total primary energy consumption across the study period, indicates little or no effort to encourage energy efficiency or alternative renewable sources. While import dependency remains relatively constant in the short term across all three scenarios, this trend changes in the medium to long term, when energy-efficient improvements begin to show effect. In 2035, in the case of the CP and SF scenarios, import dependency declines at a rate of 1% for both scenarios. As people become aware of the benefits of energy efficiency improvement measures, for example by using more energy-efficient lighting, fans, refrigerators, air-conditioning systems, televisions and so on, and by investing in better fuel-economy vehicles, total primary energy consumption will fall, resulting in a decline in energy import dependency. As more aggressive measures to encourage energy efficiency continue, energy import dependency will decrease at a faster rate, as shown in the SF scenario long term in Figure 6-12.

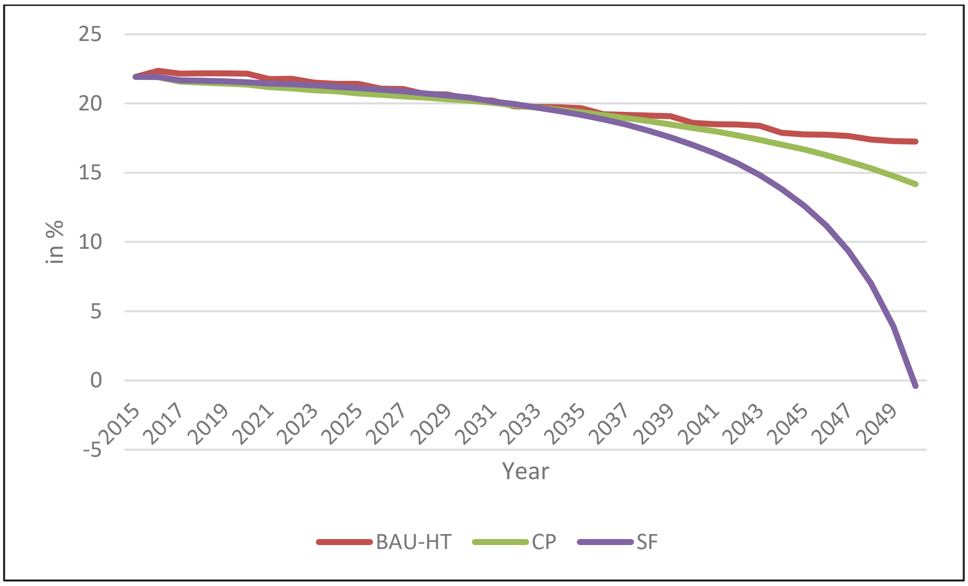


Figure 6-12: Model of total energy import dependency, 2015 – 2050

Source: Author's compilation

Import dependency by fuel type is as seen in Figure 6-13. In the BAU-HT scenario, India continues to be highly reliant on imported oil across the study period. In the two alternative scenarios, this level of oil dependency decreases as a result of increased reliance on domestic coal, nuclear and renewables. Conversely, the proportion of imported gas dependency increases across the years. This is attributable to the limited gas reserves in the country and the increase in demand to replace coal with natural gas; for example, gas-based DRI technologies will replace coal-based DF/BOF technologies in the iron and steel industry. By 2050, as energy efficiency promotion continues and demand shifts to cleaner alternative fuels such as nuclear and renewable energy sources, the dependency on oil will have decreased by 5% in the SF scenario. Example of this are that improved vehicle efficiency in the transport sector will see a shift from oil to biofuels and the electricity sector will see an increase in nuclear and renewable energy for power generation.

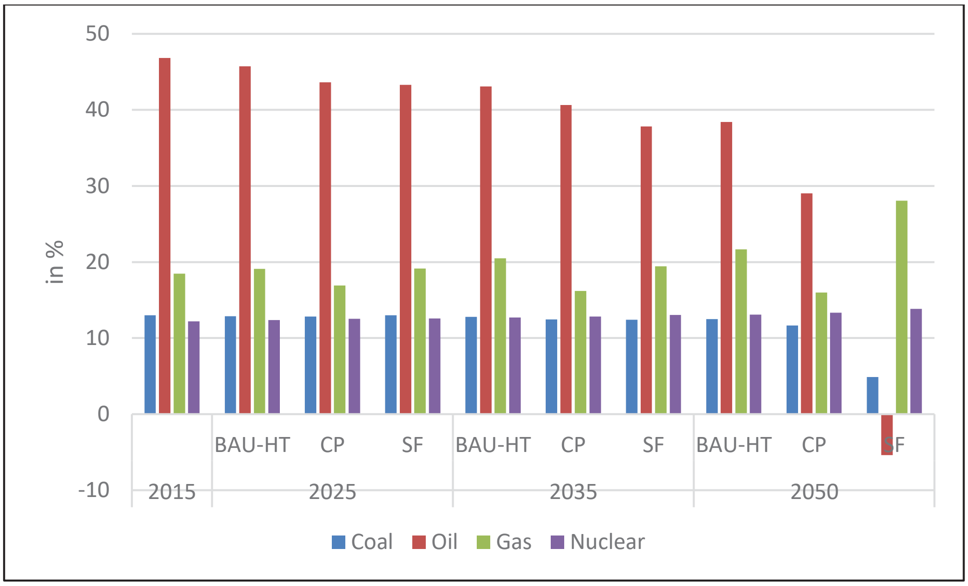


Figure 6-13: Model of energy import dependency by fuel types, 2015 – 2050

Source: Author's compilation

6.2.5 Energy rebound effect

The rebound effect is a result of changes in the economy in which energy savings due to efficiency improvements are partly or wholly offset by an increase in energy consumption. Estimates of the rebound effect are as shown in Figure 6-14. India will experience a population growth rate of 0.75% per year and a GDP growth rate of 6.28% per year from 2015 to 2050, which can be expected to result in larger rebounds. Further, as stated by Sorrell (2009), countries that rely on domestic energy resources to meet their demand are likely to have higher rebound effects. For India, the energy import dependency decreases as energy efficiency increases, indicating India is becoming more and more self-sufficient in meeting its energy needs; this is reflected in Figure 6-14 across the CP and SF scenarios, especially when compared to the BAU-HT scenario.

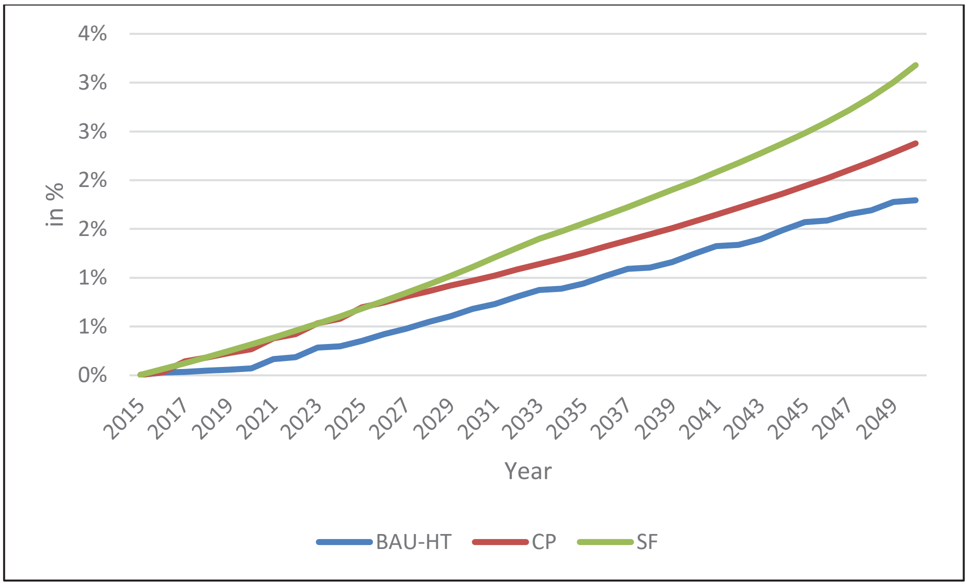


Figure 6-14: Model of energy rebound effect, 2015 – 2050

Source: Author's compilation

The annual energy productivity growth rates for the CP and SF scenarios are both higher than the BAU-HT scenario, as seen earlier in Table 5-5. This means that in the CP and SF scenarios more energy would be saved through energy productivity improvements but leave little room for further improvement measures to increase demand-side efficiency.

The rebound effect associated with energy-intensive sectors is generally higher than in non-energy-intensive sectors, as shown in Figure 6-15. For instance, the annual productivity growth rate for the agriculture sector in the CP scenario is 1.5%, which is significantly higher than the rate of 0.4% in the BAU-HT scenario. In this case, the rebound effect of 0.5% in the CP scenario by 2025 will be greater compared to the 0.1% in the BAU-HT scenario. Similarly, in the residential sector, the annual productivity growth rates in the CP and SF scenarios are 1.1% and 1.7% respectively, compared to only 0.5% in the BAU-HT scenario. The rebound effects in 2035 and 2050 are higher for CP and SF scenarios – 2.6% and 3.2% in 2035 and 5% and 6% in 2050 – compared to 2% by 2035 and 4% by 2050 in the BAU-HT scenario.

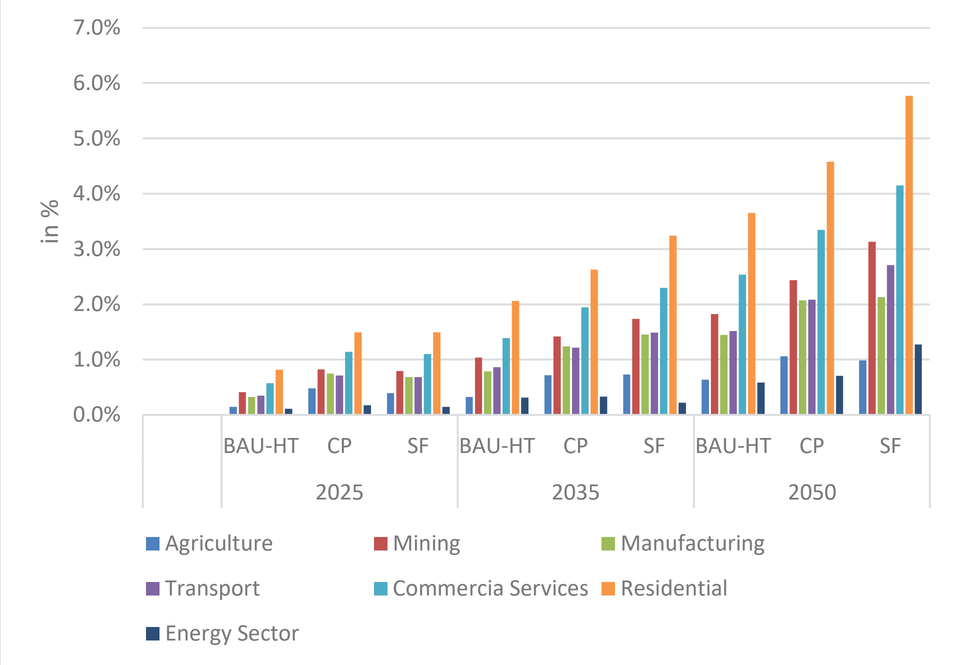


Figure 6-15: Model of energy rebound effect by sectors, 2015 – 2050

Source: Author's compilation

6.2.6 GHG emissions

GHG emissions in the BAU-HT scenario continue to increase in step with the increases in economic growth and the population. Total GHG emissions in 2015 were 2779 $MtCO_2$ –e; in the BAU-HT scenario, this would increase to 6739 $MtCO_2$ -e by 2030 and 15084 $MtCO_2$ -e by 2050. These increases would result from a combination of an increase in high energy-intensive technologies and lack of energy efficiency. In the CP scenario, GHG emissions increase to 5249 $MtCO_2$ -e by 2030 and 8280 $MtCO_2$ -e in 2050. In the SF scenario, emissions will increase to 3834 $MtCO_2$ -e by 2030 and decline to 2370 $MtCO_2$ -e by 2050, as shown in Figure 6-16. The overall decrease in the GHG emissions in the CP and SF scenarios over the study period will be a result of increased energy efficiency measures such as clean technologies and energy savings through the use of renewable energy sources.

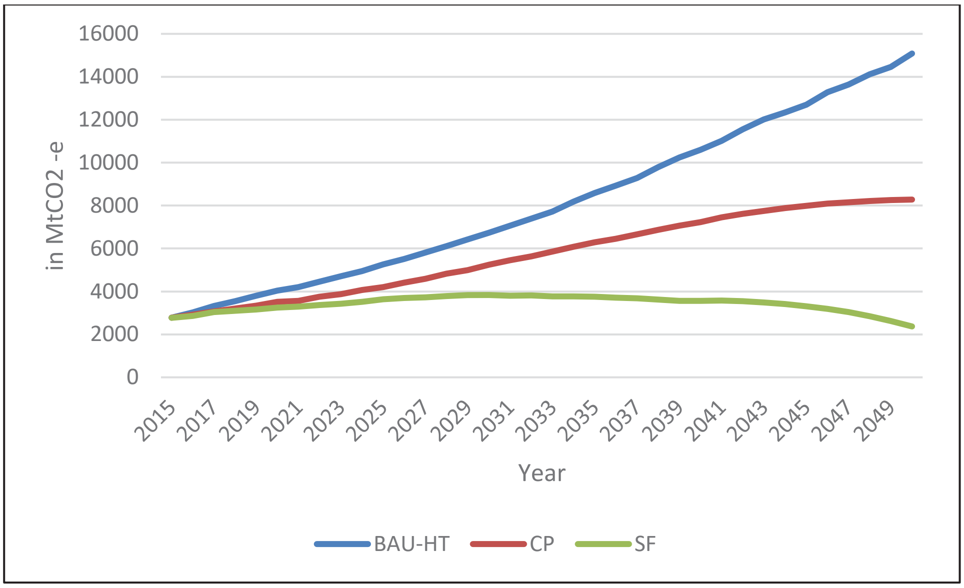


Figure 6-16: Model of GHG emissions, 2015 – 2050

Source: Author's compilation

The major contributor to GHG emissions is CO_2 emissions. Across the three scenarios, these CO_2 emissions will have decreased by 2050 to 97% (BAU-HT), 97% (CP) and 96% (SF) from the 2015 base year level of 98%, as shown in Figure 6-17.

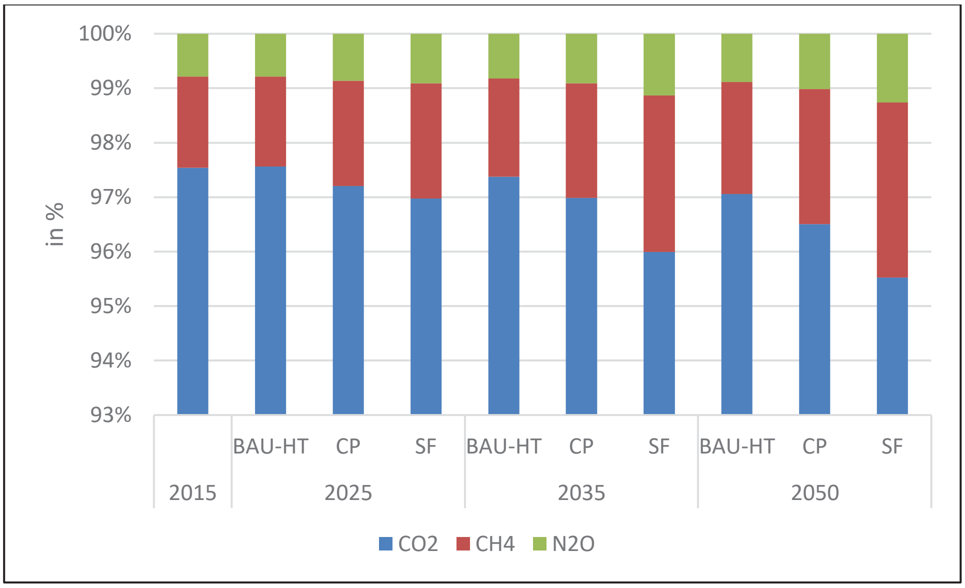


Figure 6-17: Model of GHG emissions by fuel type, 2015 – 2050

Source: Author's compilation

The major contributors to GHG, particularly CO_2 emissions, are electricity generation, followed by residential and industry sectors, as shown in Figure 6-18. Collectively, these sectors constituted approximately 88% of total GHG emissions in 2015 and according to the BAU-HT scenario, this will drop to only 86% by 2050. The projected falls in GHG emissions to 45% in the CP scenario and to 84% in the SF scenario by 2050 as compared to the BAU-HT scenario are attributable to the renewable energy and energy efficiency improvements that they advocate.

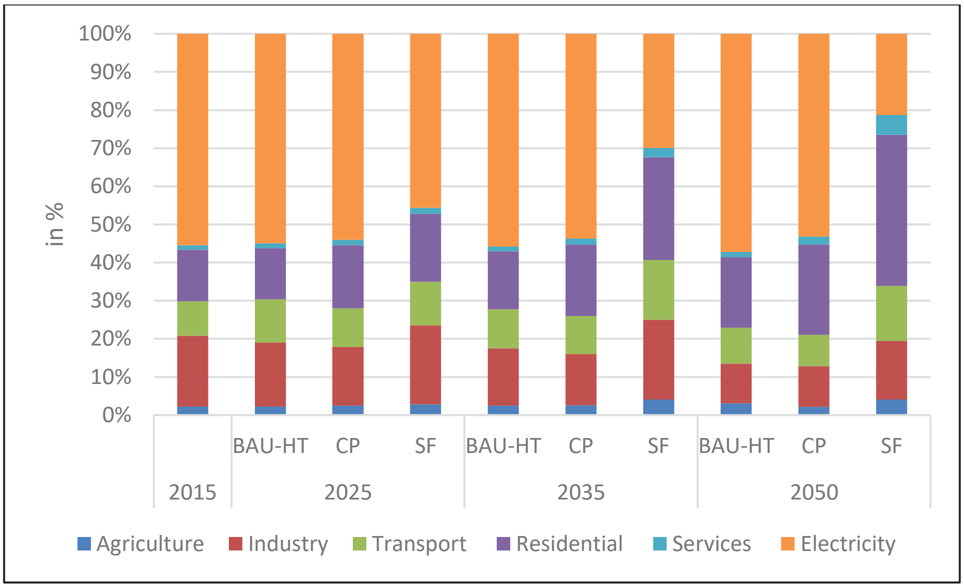


Figure 6-18: Model of GHG emissions by sector, 2015 – 2050

Source: Author's compilation

GHG intensity is predicted to decrease significantly across all three scenarios over the study period of 2015-2050, specifically by 1% in the BAU-HT scenario, by 3% in the CP and by 6% in the SF scenarios, as shown in Figure 6-19. This decrease is attributable to the adoption of improved energy-efficient technologies, increasing use of renewable energy for power generation, switching to more efficient fuels such as biofuels in the transport sector and DRI in the steel industry. These efforts collectively will help reduce GHG emission intensity while achieving economic growth and better living standards for India's growing population.

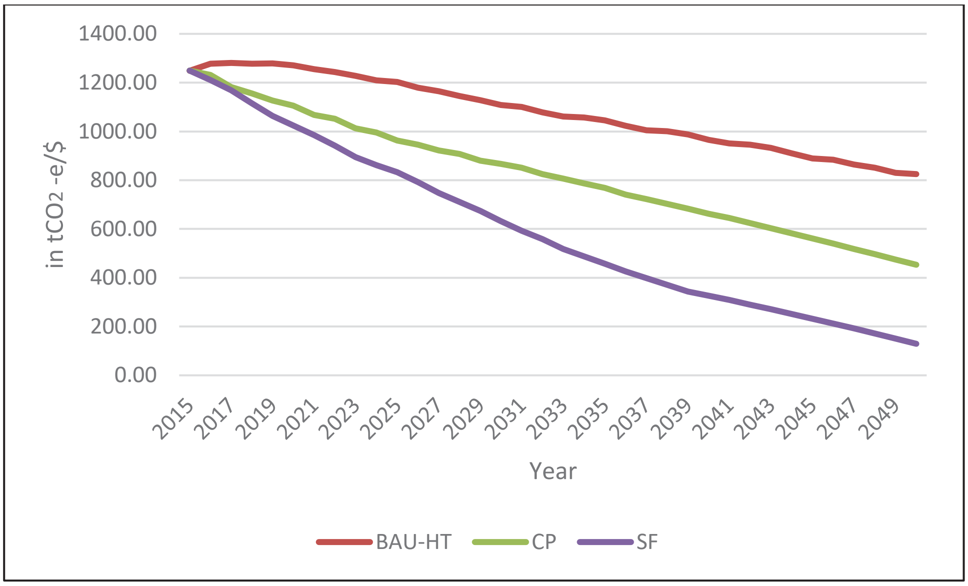
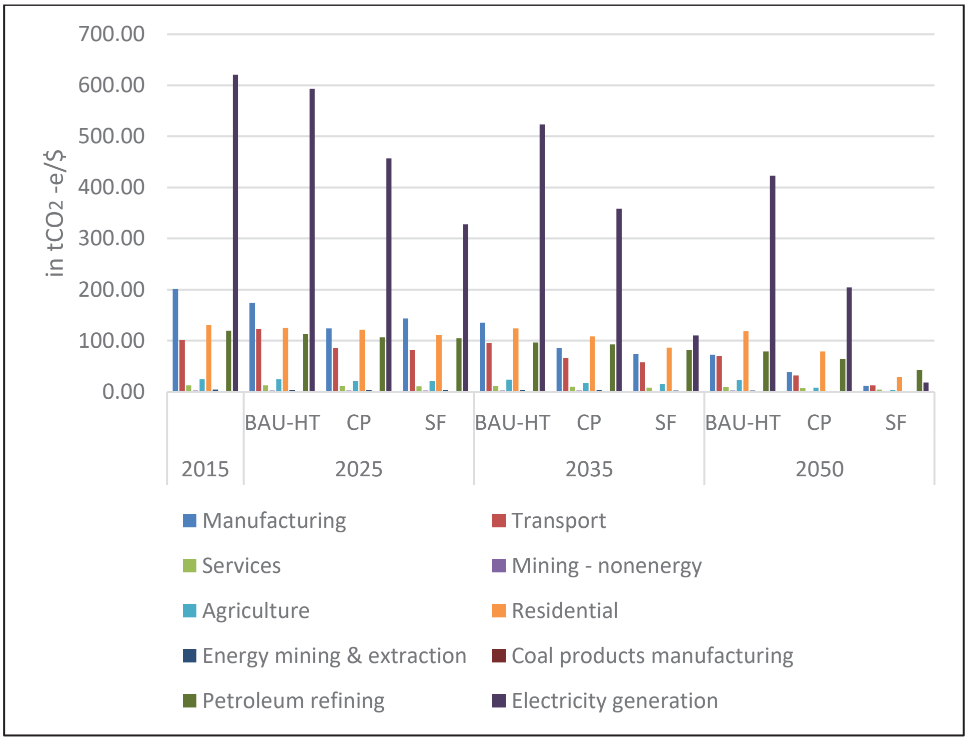


Figure 6-19: Model of total GHG intensity, 2015 – 2050

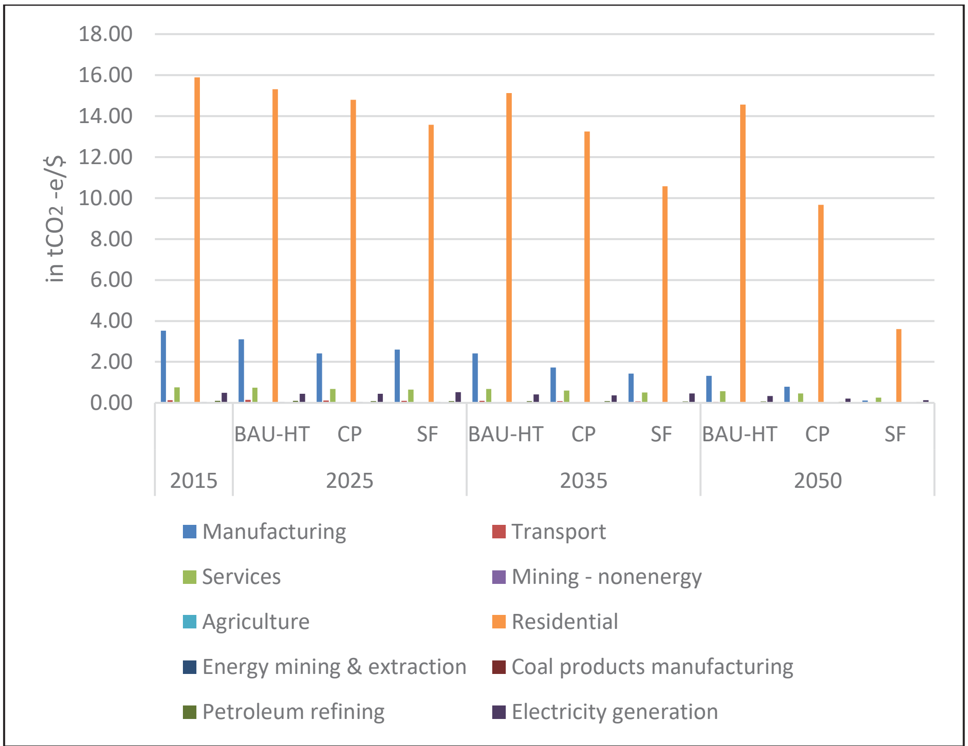
Source: Author's compilation

Estimates for GHG intensity are developed at sectoral level for the non-energy sectors of agriculture, industry, residential, transport and services and for the energy sectors of coal, petroleum, mining and electricity generation. The GHG intensity for each sector is determined for three main gases – CO_2, CH_4, and NO_x – for the CP and SF scenarios and are compared with the BAU-HT scenario for the study period 2015-2050, as shown in Figure 6-20. Some key findings from the analysis of this research are discussed below.

(a) CO_2 emissions intensity



(b) CH_4 emissions intensity



(c) NO_x emissions intensity

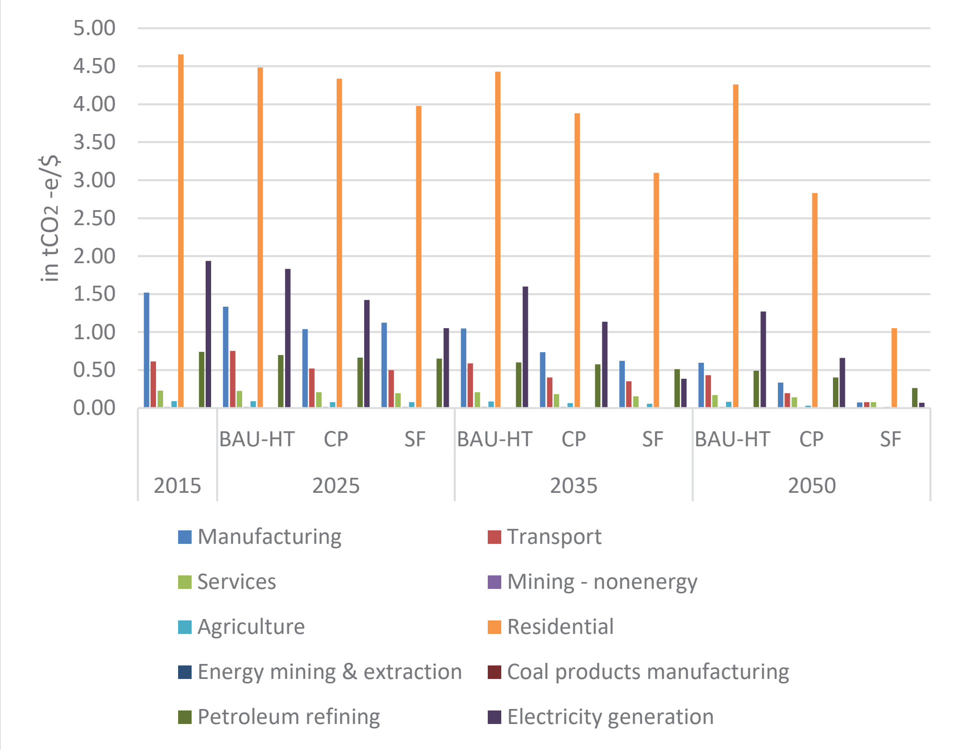


Figure 6-20: Model of GHG emissions intensity by sectors, 2015 – 2050

Source: Author's compilation

- According to the three scenarios, by 2025, total CO_2 intensities will vary widely across the economic sectors. For instance, in the BAU-HT scenario CO_2 intensities will range from 12.41 tCO_2 -e/$ in commercial services to 175 tCO_2 -e/$ in manufacturing. This is because the manufacturing sector includes industries such as iron and steel, aluminium and other non-ferrous metals that use large amounts of electricity in the smelting process. The electricity generation process contributes to large amounts of emissions from power plants, hence it will have a higher value of total CO_2 intensity across all three scenarios of 593 tCO_2 -e/$ (BAU-HT), 457 tCO_2 -e/$ (CP) and 328 tCO_2 -e/$ (SF). CO_2 intensity will decrease in all the sectors, due to the introduction of energy savings through the use of new and renewable energy and advanced technology for electricity generation. By 2025, the transport sector will have high CO_2 intensity in all three scenarios: 122 tCO_2 -e/$, 86 tCO_2 -e/$ and 82 tCO_2 -e/$ for the BAU-HT, CP and SF scenarios respectively, reflecting large direct consumption of fossil fuel energy sources such as petroleum products, mainly in road and rail transport. The residential sector will also have high CO_2 intensity: 126 tCO_2 -e/$, 121 tCO_2 -e/$, and 111 tCO_2 -e/$ for the BAU-HT, CP, and SF scenarios respectively, reflecting high electricity consumption. This intensity decreases after 2025 across the three scenarios, reflecting more adaption of energy-efficient appliances in the residential sector, leading to reduced emissions and greater energy savings. The commercial services sector has low CO_2 intensity, 11 tCO_2 -e/$, 10 tCO_2 -e/$, and 8 tCO_2 -e/$ in 2025 for the BAU-HT, CP and SF scenarios respectively compared to 13 tCO_2 -e/$ in the base year 2015; this reflects a smaller share of fossil fuel energy sources (and a larger share of electricity) in its energy consumption fuel mix.

- By 2035 and 2050, total CO_2 emissions intensity for the economic sectors will be generally lower in the CP and SF scenarios, compared to the BAU-HT scenario. This is due to reduced energy consumption, in particular, coal consumption, across these scenarios. For instance, in the CP scenario, the CO_2 intensity for the manufacturing sector will decline to 86 tCO_2 -e/$ in 2035 and 38 tCO_2 -e/$ in 2050 and in the SF scenario from 74 tCO_2 -e/$ in 2035 and 12 tCO_2 -e/$ in 2050, compared 135 tCO_2 -e/$ in 2035 and 73 tCO_2 -e/$, in 2050 in the BAU-HT scenario. One reason for this is the decline in CO_2 emission intensity from the iron and steel industry, due to the reduction in coal consumption as this sector shifts from coal-based blast furnaces to natural gas-based DRI technology. In the commercial services sector, total CO_2 emission intensity declines in both the CP and SF scenarios. For instance, in the CP scenario, the CO_2 emission intensity declines from 10 tCO_2 -e/$ in 2035 to 7.5 tCO_2 -e/$ in 2050, compared to the 11 tCO_2 -e/$ in 2035 and 9 tCO_2 -e/$ in 2050 in the BAU-HT scenario. Electricity is the main source of energy for this sector, so as CO_2 emissions decline (as discussed above), the total CO_2 intensity in the services sector also declines.

- The CH_4 and NO_x emissions intensities are relatively low across all sectors for all three scenarios compared to the CO_2 intensities. For instance, the intensity of the NO_x emissions from the agriculture and livestock sectors declines from 0.09 tCO_2 -e/$ in 2015 to 0.06 tCO_2 -e/$ by 2035 and 0.01 tCO_2 -e/$ by 2050 in the SF scenario, which reflects better use of nitrogen-based and organic fertilisers. The

CH_4 emissions intensity in the SF scenario in the agriculture sector declines from 0.01 tCO_2 -e/$ in 2015 to 0.008 tCO_2 -e/$ by 2035 and 0.002 tCO_2 -e/$ by 2050, which reflects improved cattle feed and digesters and better rice paddy cultivation practices. The overall emissions intensity is reduced as a result of the energy-efficient technology initiatives at different stages in the agriculture sector.

6.3 Economy-wide Impacts of Scenarios

6.3.1 Economic growth

The impact of energy efficiency improvement measures, such as energy efficiency technologies and alternative technologies such as new and renewable sources of energy for electricity generation on economic growth (GDP) are as shown in Figure 6-21. The BAU-HT scenario values are used as a benchmark for analysing the CP and SF scenario outcomes. Overall, energy efficiency improvement measures will play a key role in ensuring long-term sustainable economic growth for India. The energy efficiency measures for the two alternative scenarios – CP and SF – will result in mostly modest reductions in GDP. In the CP scenario, for instance, GDP will decline by 0.28% in 2025, by 0.30% by 2035 and by 0.09% by 2050, while in the SF scenario, the GDP will decline by 0.14% by 2025, by 0.13% by 2035 and an increase in GDP by 0.27% by 2050 compared to the GDP in the BAU-HT scenario for the same years.

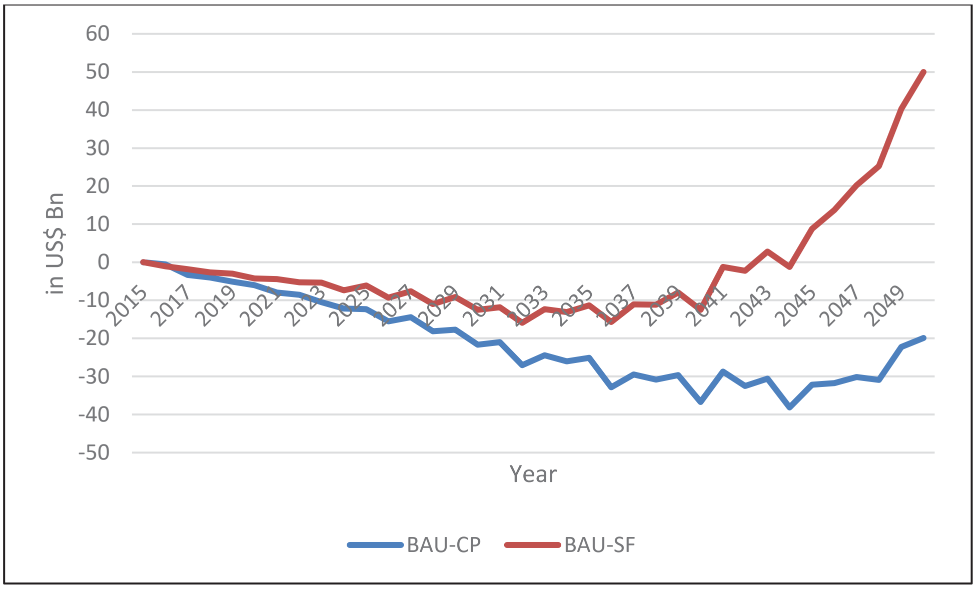


Figure 6-21: Model of changes in GDP compared to BAU-HT Scenario, 2015 – 2050

Source: Author's compilation

Introducing energy efficiency improvement measures will have a positive impact on GDP, based on expenditure, namely private consumption, government expenditure and investment over the study period. These impacts will be particularly pronounced in the SF scenario, as shown in Figure 6-22. For instance, by 2050, private consumption will be 0.21% greater, government expenditure 1.62% greater and investment 2.72% greater for the SF scenarios compared to the BAU-HT scenario; whereas there will be a decline in net exports according to the CP and SF scenarios over the same period. For instance, net exports will decline by 1.5% and 1.9% in 2025, by 1.4% and 3.2% in 2035 and by 2.4% and 5.7% in 2050 for the CP and SF scenario respectively. This implies that net exports of goods and services would be more negatively affected, thus offsetting the gains obtained from other contributors to the total GDP.

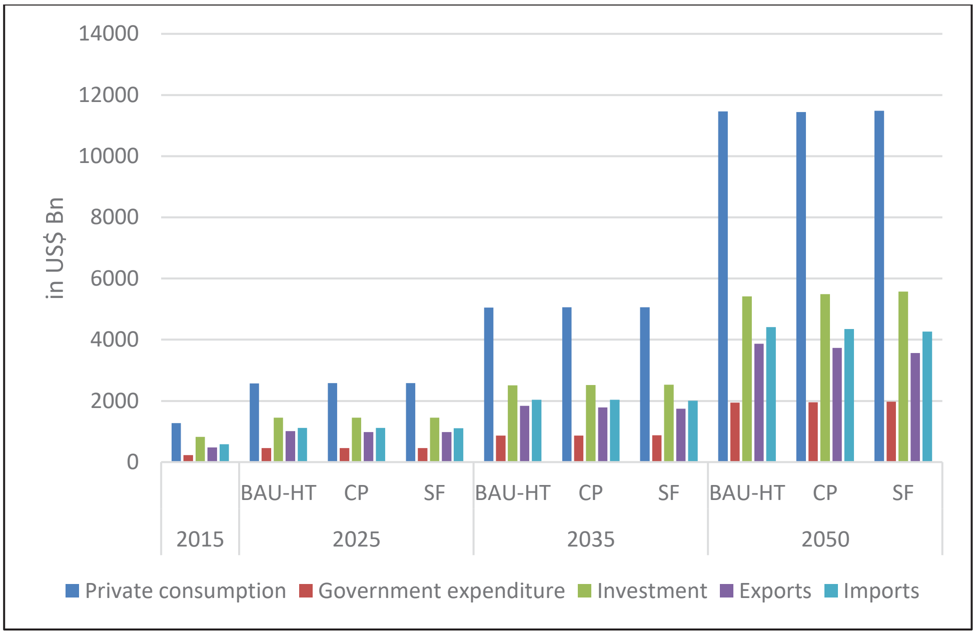


Figure 6-22: Model of GDP-by-expenditure approach, 2015 – 2050

Source: Author's compilation

However, the GDP-based-on-income approach shows mixed results compared to the GDP-by-expenditure approach, as can be seen in Figure 6-23. Income from capital services will be positively affected by introducing energy efficiency improvement measures. For instance, the income from capital services by 2025 will increase by 1.14% and 1.31%, by 2035 by 0.93% and 2.07% and by 2050 by 1.54% and 3.43% for the CP and SF scenarios respectively compared to the BAU-HT scenario. The impact on 'other income' would be mixed. For instance, by 2025, income from labour will be negatively affected by 0.05% in the CP scenario but will be positively affected by 0.29% in the SF scenario.

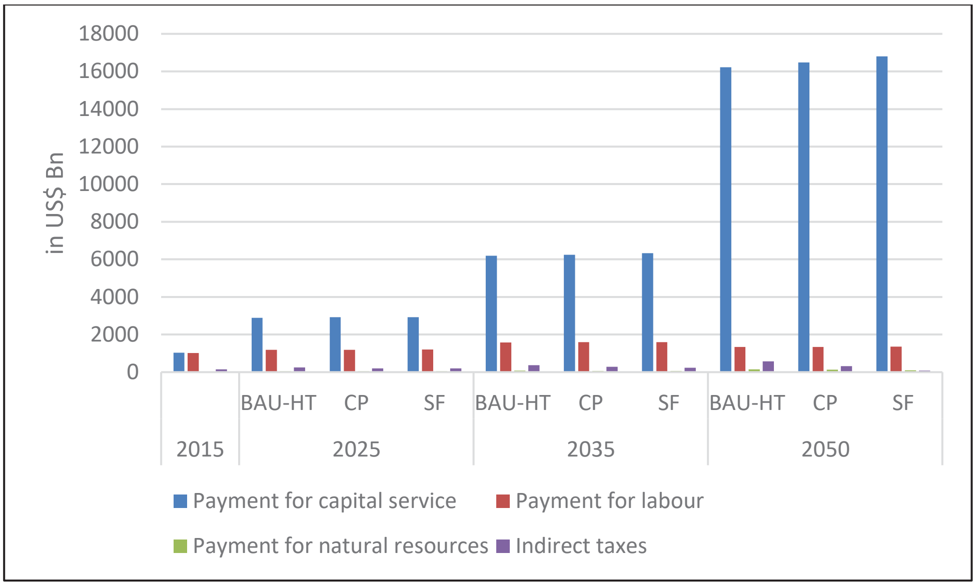


Figure 6-23: Model of GDP by the income approach, 2015 – 2050

Source: Author's compilation

6.3.2 Total sectoral outputs

Table 6-3, Table 6-4 and Table 6-5 show the impact on sectoral outputs (in US$ Bn) associated with varying levels of energy outcomes such as energy consumption, technology and fuel mix specific to the CP and SF scenarios for the years 2025, 2035 and 2050. These impacts are expressed as a percentage of the differences between the output values in the CP and SF scenarios compared to the output values in the BAU-HT scenario. The overall trend across the three scenarios over the study period shows that total industry output decreases as efforts to boost energy efficiency increase and there is greater penetration of advanced efficient technology and practices, as shown in Figure 6-24. The CP and SF scenarios follow a similar trend in the short-to-medium-term (2015 to 2030) with an average rate of decline in total output of 0.9% and 1.1% respectively. This decline continues in the long-term (2030 to 2050) at an average rate of 1.6% for the CP scenario and 3.1% for the SF scenario compared to the outputs in the BAU-HT scenario. Due to the increase in energy efficiency measures, long-term output decreases at a faster rate. Some key results of the outputs are discussed below.

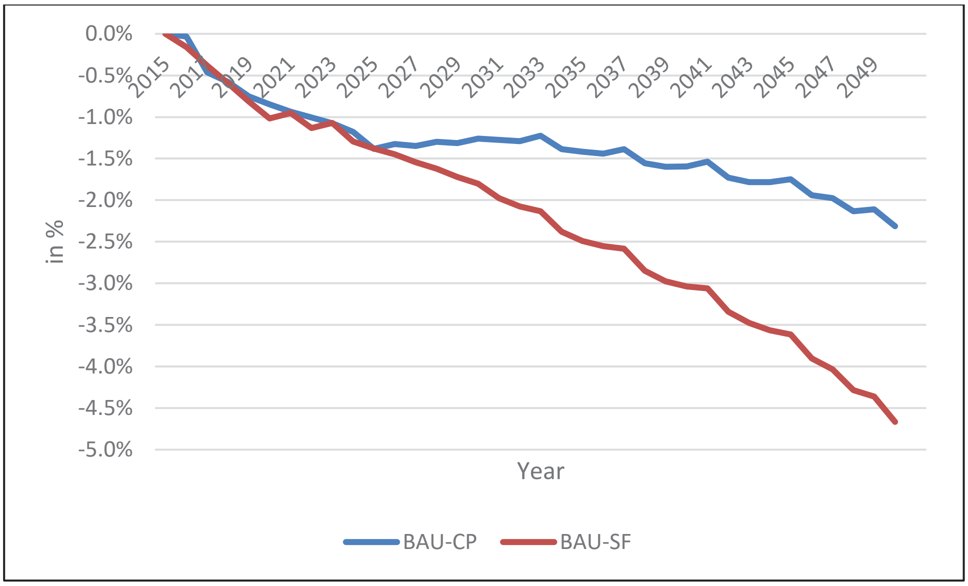


Figure 6-24: Model of change in total industry output, 2015 – 2050

Source: Author's compilation

- The commercial services sector, which includes financial services, community services, real estate and hotels and restaurants, shows comparatively higher values of total output in the CP and SF scenarios compared to the BAU-HT scenario. By 2025, the output of these sectors will be respectively US$15Bn and US$30Bn higher than the BAU-HT scenario and the increases in sectoral outputs will be respectively 0.5% and 0.9% of total output in the BAU-HT scenario. This increase will result from increases in the construction of housing and other community facilities, such as hospitals, hotels, education infrastructure, communication and media to meet the growing rate of urbanisation and better living standards as the population continues to gain increased access to modern energy. These industry outputs will continue to increase to 2035 and 2050 for both the alternative scenarios. In the CP scenario, the output will be higher by US$46Bn in 2035 and by US$257Bn in 2050 compared to the BAU-HT scenario, which represent an increase in the output by 0.75% and 1.84% respectively. In the SF scenario, the output will be higher by US$17Bn by 2035 and by US$545Bn by 2050 compared to the BAU-HT scenario, which represent an increase in the output by 1.87% and 3.8% respectively. These increased rates in the long term will be a result of aggressive efforts to introduce energy-efficient technology advancements and the need to support the changing lifestyles of the growing population and their economic activities in the future.

- The total output in the land transport sector will increase according to the CP scenario to US$6Bn by 2025, which is 1% of output in the BAU-HT scenario; while for the SF scenario the increase is US$3.9Bn by 2025, which is 0.65% of output in the BAU-HT scenario; this will be a result of the increasing affordability for the population of two-wheeled and four-wheeled vehicles and the expansion of the rail and road infrastructure network across the country to provide better connectivity between the rural and urban regions.

- In contrast, most of the non-energy sectors will have lower outputs in the CP and SF scenarios compared to the BAU-HT scenario. For instance, the output of the agriculture sector will have declined by 0.13% and 0.54% respectively for the CP and SF scenarios by 2025. The output will further decline by US$34Bn in 2035 and by US$199Bn in 2050 in the CP scenario, the rate of decline in output being 1.2% and 3.2% respectively as compared to the output of the BAU-HT scenario for the years 2035 and 2050. In the SF scenario, the output will decline by US$39Bn in 2035 and by US$221Bn in 2050, the rate of decline being 1.3% and 4.3% in 2035 and 2050 respectively as compared to the output of the BAU-HT scenario for the years 2035 and 2050. By 2025, the total output of the chemical industry in the CP scenario will be lower by US$6Bn and in the SF scenario it will be lower by US$14.5Bn. The rate of decline in total output in this sector will be 1.5% in the CP scenario and 3.5% in the SF scenario as compared to the BAU-HT scenario by 2025. Similarly, the total output of the iron and steel industry in the CP and SF scenarios will be US$25.5Bn and US$10Bn lower than the BAU-HT scenario in 2025. The drops are respectively equal to 13.5% and 5% of the total output in the BAU-HT scenario. The main driver for the decrease in total output in these sectors will be the decline in energy demand, itself a result of energy efficiency improvement measures. In addition, a switch to more clean and renewable energy sources from traditional fossil fuel sources in the generation of power will also contribute to reductions in the total outputs of these sectors.

2025	BAU-HT		CP		SF	
			Difference in		Difference in	
Sectors	Total Output ($Bn)	Employment (Mn person)	Total Output ($Bn)	Employment (Mn person)	Total Output ($Bn)	Employment (Mn person)
Agriculture	1461.06	373.33	-1.94	1.29	-7.86	3.14
			(-0.13)	*(0.34)*	*(-0.54)*	*(0.83)*
Non-energy mining	68.05	2.44	0.06	0.0	-0.22	0.01
			(0.09)	*(0.01)*	*(-0.32)*	*(0.58)*
Paper manufacturing	60.79	2.58	-0.50	0.02	-1.21	0.06
			(-0.82)	*(0.64)*	*(-2.03)*	*(2.26)*
Chemical manufacturing	433.13	18.24	-6.18	0.20	-14.56	0.57
			(-1.45)	*(1.09)*	*(-3.48)*	*(3.04)*
Iron and steel manufacturing	214.32	9.10	-25.51	1.24	-9.96	0.49
			(-13.51)	*(11.99)*	*(-4.88)*	*(5.07)*
Non-ferrous metals manufacturing	85.39	3.32	-2.32	0.09	-3.61	0.15
			(-2.79)	*(2.78)*	*(-4.41)*	*(4.44)*
Non-metallic minerals manufacturing	199.40	7.96	-4.71	0.19	-2.95	0.14
			(-2.42)	*(2.33)*	*(-1.50)*	*(1.70)*
Non-intensive manufacturing	1325.46	54.22	-28.76	1.19	-21.98	1.04
			(-2.22)	*(2.14)*	*(-1.69)*	*(1.88)*
Water transport	69.19	2.52	-0.72	0.03	-0.90	0.04
			(-1.05)	*(1.08)*	*(-1.31)*	*(1.49)*
Air transport	21.97	0.84	-0.74	0.03	-0.88	0.04
			(-3.51)	*(3.43)*	*(-4.16)*	*(4.23)*
Land transport	592.20	26.69	6.10	-0.40	3.89	-0.21
			(1.02)	*(-1.51)*	*(0.65)*	*(-0.78)*
Commercial services	3263.85	180.55	15.21	-0.44	30.39	0.48
			(0.46)	*(-0.24)*	*(0.92)*	*(0.26)*

Table 6-3: Predicted economic impact of alternative scenarios for 2025

Source: Author’s compilation

2035	BAU-HT		CP		SF	
			Difference in		Difference in	
Sectors	Total Output ($Bn)	Employment (Mn person)	Total Output ($Bn)	Employment (Mn person)	Total Output ($Bn)	Employment (Mn person)
Agriculture	2846.47	511.42	-34.45	7.43	-38.75	9.80
			(-1.23)	*(1.43)*	*(-1.38)*	*(1.88)*
Non-energy mining	128.60	3.23	-0.81	0.03	-2.01	0.07
			(-0.64)	*(0.79)*	*(-1.59)*	*(2.03)*
Paper manufacturing	112.77	3.53	-2.75	0.08	-5.43	0.18
			(-2.50)	*(2.19)*	*(-5.06)*	*(4.96)*
Chemical manufacturing	768.31	25.90	-6.91	0.13	-37.87	1.17
			(-0.91)	*(0.50)*	*(-5.18)*	*(4.34)*
Iron and steel manufacturing	376.33	12.50	-30.93	1.15	-30.48	1.21
			(-8.96)	*(8.42)*	*(-8.81)*	*(8.86)*
Non-ferrous metals manufacturing	152.97	4.52	-7.68	0.24	-13.49	0.45
			(-5.28)	*(5.04)*	*(-9.67)*	*(9.13)*
Non-metallic minerals manufacturing	353.60	10.67	-10.35	0.31	-11.61	0.38
			(-3.02)	*(2.81)*	*(-3.40)*	*(3.43)*
Non-intensive manufacturing	2398.98	72.40	-50.56	1.52	-72.69	2.45
			(-2.15)	*(2.05)*	*(-3.12)*	*(3.28)*
Water transport	127.50	3.48	-0.98	0.02	-2.71	0.08
			(-0.77)	*(0.67)*	*(-2.17)*	*(2.20)*
Air transport	39.75	1.15	-0.99	0.03	-1.46	0.05
			(-2.57)	*(2.53)*	*(-3.82)*	*(3.99)*
Land transport	1071.27	37.27	32.77	-1.37	26.21	-1.16
			(2.97)	*(-3.81)*	*(2.39)*	*(-3.21)*
Commercial services	6139.56	236.79	46.21	0.27	116.72	1.70
			(0.75)	*(0.11)*	*(1.87)*	*(0.71)*

Table 6-4: Predicted economic impact of alternative scenarios for 2035

Source: Author's compilation

2050	BAU-HT		CP		SF	
			Difference in		Difference in	
Sectors	Total Output ($Bn)	Employment (Mn person)	Total Output ($Bn)	Employment (Mn person)	Total Output ($Bn)	Employment (Mn person)
Agriculture	6447.75	436.72	-199.28	15.74	-221.20	19.71
			(-3.19)	*(3.48)*	*(-3.55)*	*(4.32)*
Non-energy mining	287.80	2.71	-5.68	0.06	-11.40	0.13
			(-2.02)	*(2.30)*	*(-4.12)*	*(-4.74)*
Paper manufacturing	244.37	3.06	-14.89	0.19	-27.08	0.36
			(-6.49)	*(5.70)*	*(-12.47)*	*(10.49)*
Chemical manufacturing	1577.80	23.65	-38.90	0.44	-159.29	2.36
			(-2.53)	*(1.83)*	*(-11.23)*	*(9.06)*
Iron and steel manufacturing	762.16	11.44	-1.34	0.08	-1.07	0.18
			(-0.18)	*(0.73)*	*(-0.14)*	*(1.53)*
Non-ferrous metals manufacturing	323.76	3.97	-32.35	0.44	-55.14	0.83
			(-11.10)	*(10.05)*	*(-20.53)*	*(17.33)*
Non-metallic minerals manufacturing	736.27	9.41	-4.14	0.03	-13.08	0.13
			(-0.56)	*(0.31)*	*(-1.81)*	*(1.36)*
Non-intensive manufacturing	5139.44	62.63	-131.83	1.61	-242.66	3.12
			(-2.63)	*(2.50)*	*(-4.96)*	*(4.74)*
Water transport	273.61	3.05	-5.06	0.05	-13.81	0.14
			(-1.89)	*(1.56)*	*(-5.31)*	*(4.49)*
Air transport	85.35	1.00	-2.60	0.03	-4.86	0.06
			(-3.14)	*(3.10)*	*(-6.03)*	*(5.91)*
Land transport	2303.30	32.46	40.41	-0.98	1.57	-0.83
			(1.72)	*(-3.11)*	*(0.07)*	*(-2.64)*
Commercial services	13708.43	198.47	257.31	0.77	544.99	2.48
			(1.84)	*(0.39)*	*(3.82)*	*(1.23)*

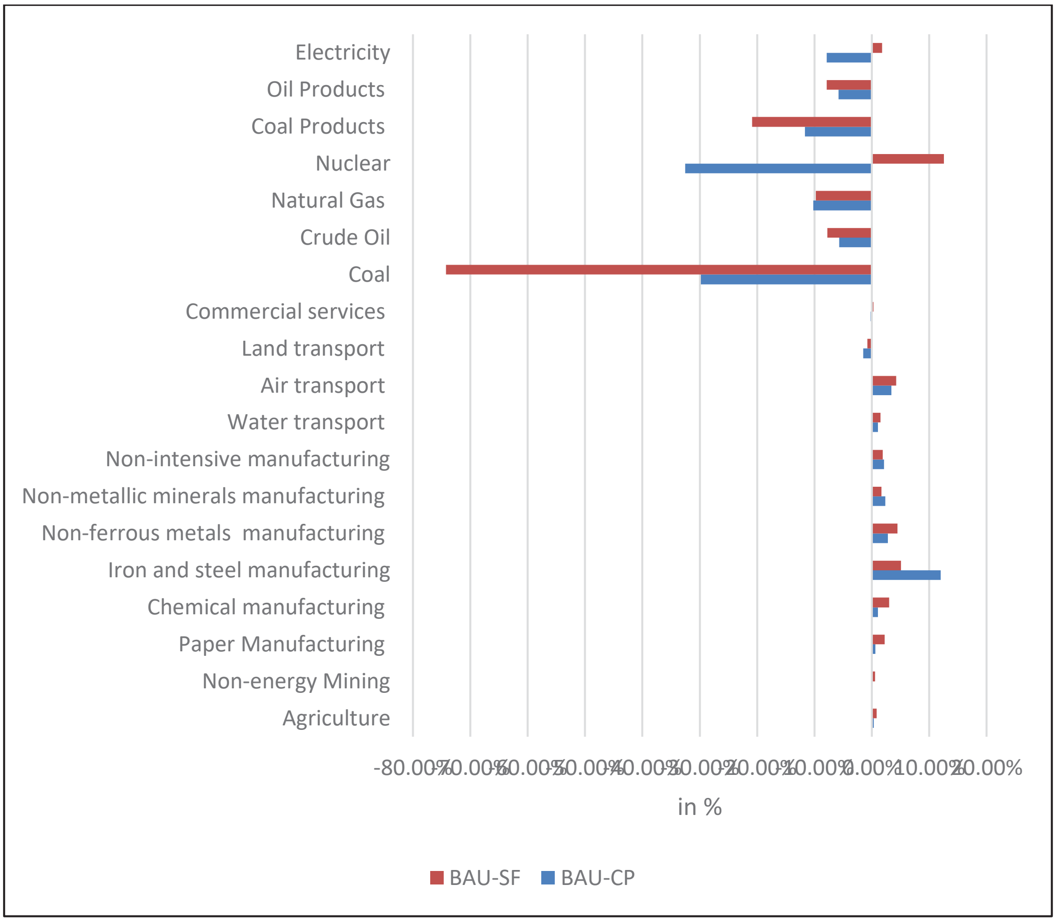
Table 6-5: Predicted economic impact of alternative scenarios for 2050

Source: Author's compilation

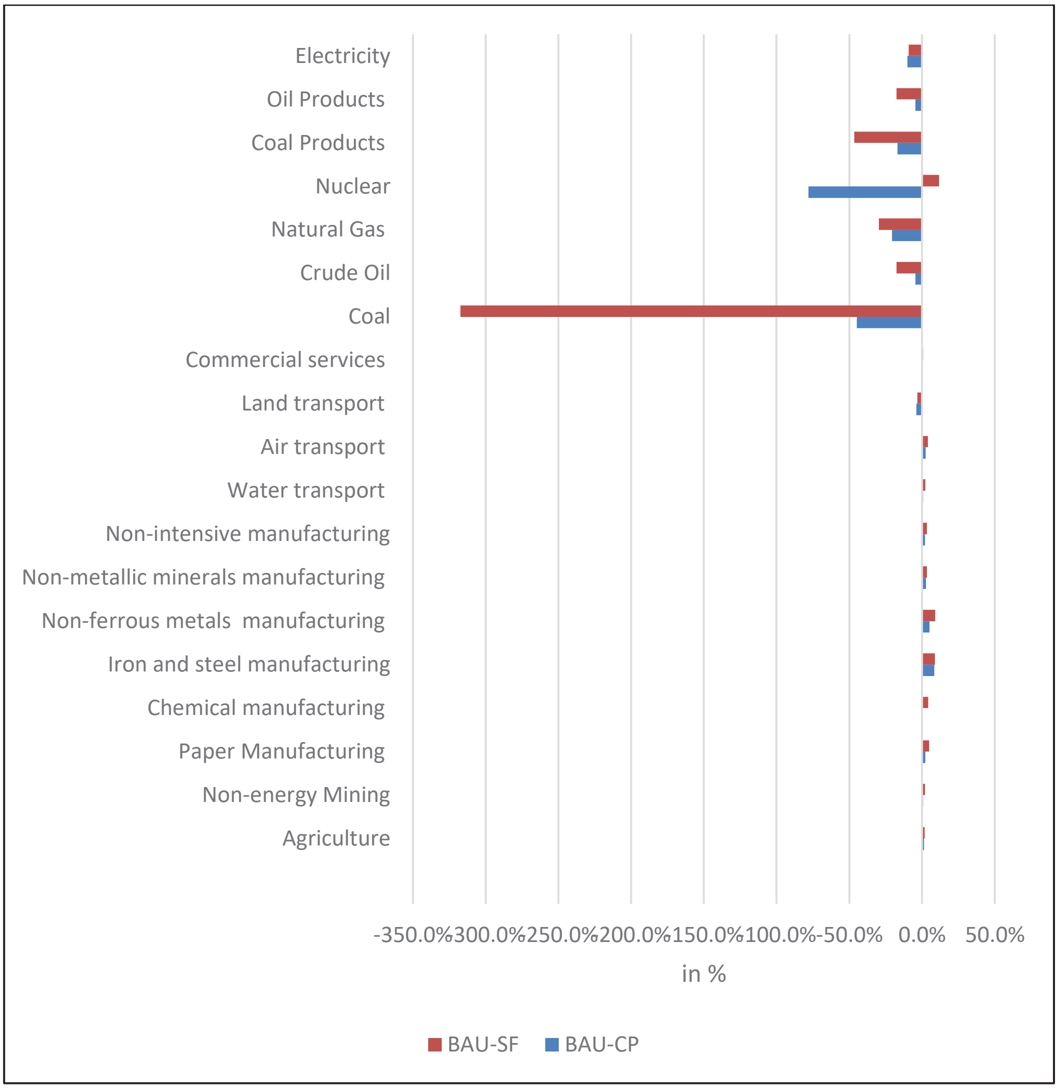
6.3.3 Employment

The impact of energy efficiency on employment (Mn people) across the various end-use sectors of the economy depends mainly on the differences in the economic activities of the various sectors. The predicted changes in total output for all three scenarios are as shown in Table 6-3, Table 6-4 and Table 6-5 above and result from changes in the energy settings in the CP and SF scenarios. The impact on employment in each sector is computed based on the ratio of employees per unit of the total output of that sector, taking into account future changes in annual labour productivity. The labour productivity is assumed to improve at the rate of 1.76% p.a. over the period 2015-2050, which is based on the World Bank labour force dataset. Figure 6-25 shows the employment impact across various economic sectors for 2025, 2035 and 2050. Some key findings are discussed below.

(a) Impact on employment for 2025



(b) Impact on employment for 2035



(c) Impact on employment for 2050

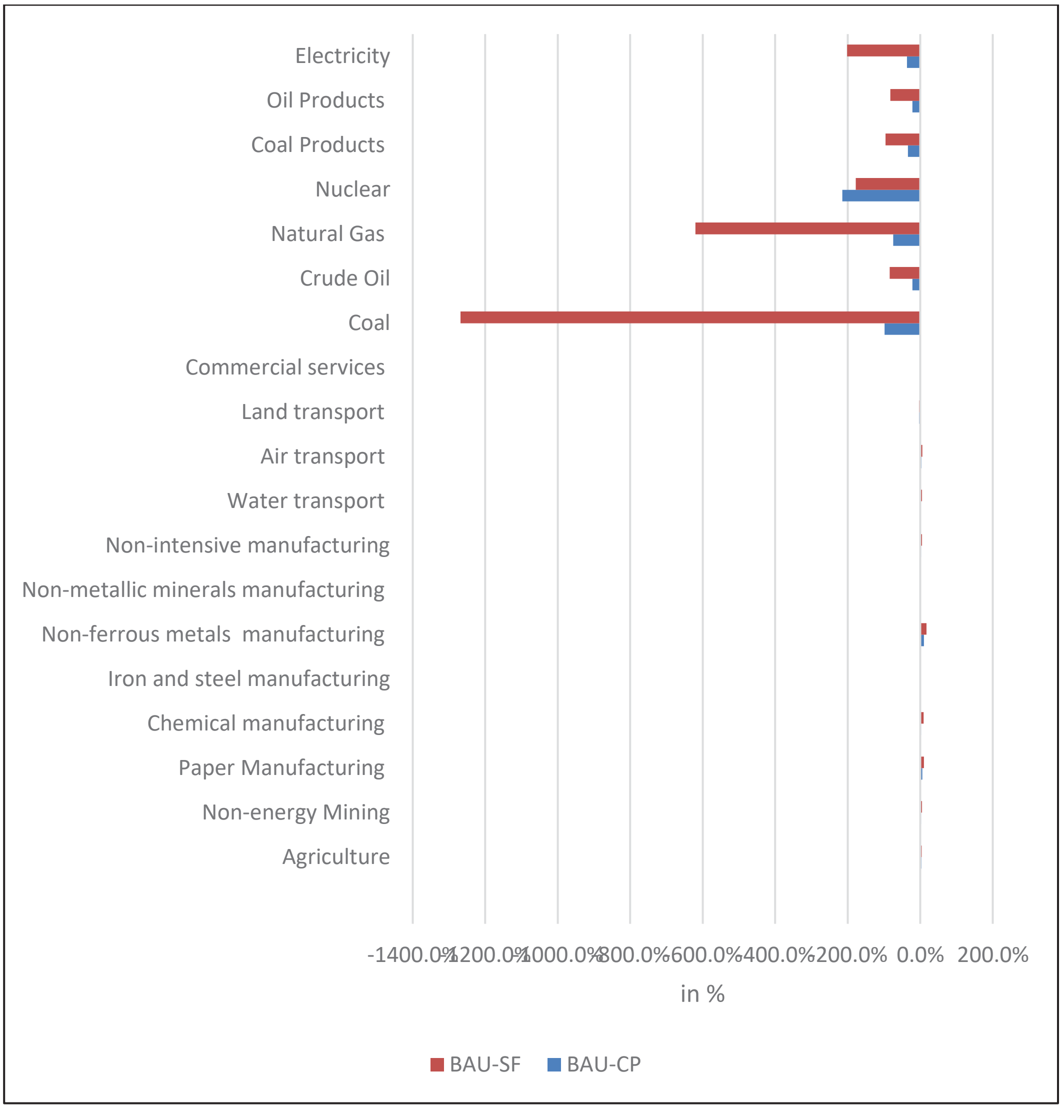


Figure 6-25: Model of changes in total employment, 2015 – 2050

Source: Author's compilation

- It can be observed that the agriculture, iron and steel, chemical, non-ferrous metals and non-intensive manufacturing (includes construction) sectors show higher levels of employment in both the CP and SF scenarios compared to the BAU-HT scenario. For example, by 2025, the agriculture sector will employ an additional 1.3 Mn people according to the CP scenario and an additional 3.1 Mn people in the SF scenario, compared to the BAU-HT scenario. Increases in employment in the agriculture sector in the CP and SF scenarios will be equal to 0.3% and 0.8% respectively of total employment in the BAU-HT. By 2035, employment in this sector will have risen by 7.4 Mn people in the CP and 9.8 Mn people in the SF scenarios, equal to an increase of 1.43% and 1.88% of employment for the CP and SF scenarios respectively compared to the BAU-HT scenario. By 2050, employment in this sector will be higher by 15.7 Mn people in the CP and 19.7 Mn people in the SF scenarios, equal to an increase by 3.5% and 4.3% of employment for the CP and SF scenarios respectively compared to the BAU-HT scenario. Similarly, the iron and steel industry, which experiences lower total industry output, generates a higher level of additional employment in both scenarios, because it is comparatively very labour intensive.

- The commercial services sector, which includes financial services, real estate and others, will experience an increase in employment. For instance, by 2035 according to the CP scenario, employment will be higher by 0.27 Mn people (0.11%) while in the SF scenario in 2035, employment will be higher by 1.7 Mn people (0.71%) than the BAU-HT scenario.

- The land transport sector, which include road and rail transport, will experience a decrease in employment as a result of increased penetration of energy efficient technology and automation. For instance, by 2035 according to the CP scenario, employment will be lower by 1.37 Mn people (3.81%) while in the SF scenario in 2035, employment will be lower by 1.16 Mn people (3.21%) than the BAU-HT scenario.

- In the energy sector, coal, petroleum, gas and electricity will experience a decline in employment in both the alternative scenarios. For instance, by 2025, employment in the coal, petroleum, natural gas and electricity industries according to the CP scenario will be respectively 0.28 Mn people, 0.11 Mn people, 0.08 Mn people, and 0.75 Mn people lower than the BAU-HT scenario. These declines will be equal to 30%, 5.7%, 10.2% and 7.8% of their employment in the BAU-HT scenario respectively.

- It can be observed from Figure 6-25 that employment in the energy sectors generally declines in both the CP and SF scenarios, whereas in the non-energy sectors, they tend to increase. By 2025, the net decrease in employment in the energy sectors will be 2.18 Mn people in the CP scenario and 1.84 Mn people in the SF scenario, compared with the BAU-HT scenario. These employment trends are likely to be due to the switch in power generation from fossil fuel based plants to renewable and nuclear energy-based plants, which are generally highly capital and labour intensive. The increase in renewable and nuclear energy-based technology will also generate employment in the various other sectors from which it draws its labour, energy and raw material inputs. For example, the expansion in wind farm installations will requires more inputs from the manufacturing, metal and construction sectors. Similarly, an increase in the demand for biofuels is likely to require more inputs from the agriculture sector, hence generating more employment in these non-energy sectors.

6.3.4 Capital investment

The capital investment is estimated based on the amount of interest paid on the borrowed money, i.e. the amount paid for servicing the capital (K) in a particular year. As can be seen in Figure 6-26, the total capital investments increases across all three scenarios from 2015 to 2050, this is an indication of costs associated with the introduction of new and advanced energy efficient technologies and/ or improvement of the existing technologies. The capital investment increases from US$1031 Bn in the base year 2015 to US$16223 Bn in the BAU-HT scenario, US$16477 Bn in the CP scenario and US$16800 Bn in the SF scenario for the year 2050, that is an increase in the capital investments at the rate of 8.19% p.a. (BAU-HT scenario), 8.24% p.a. (CP scenario) and 8.30% p.a. (SF scenario) from 2015 to 2050.

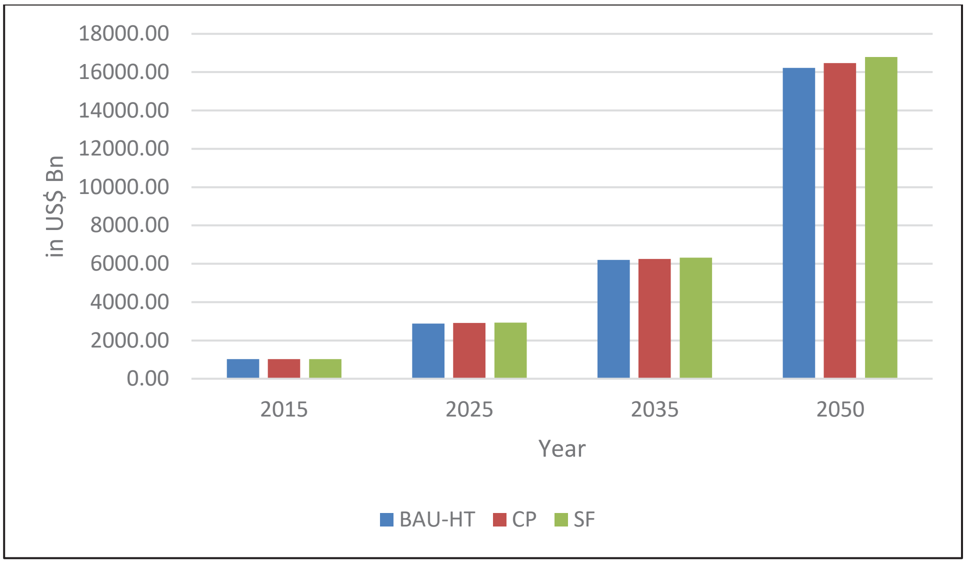


Figure 6-26: Model of total capital investments, 2015 – 2050

Source: Author's compilation

Over the years from 2015 to 2050 the capital investments shift from the energy sectors towards the non-energy sectors of the economy as can be seen in Figure 6-27 and Figure 6-28 across all three scenarios. The capital investments in the energy sector increase at a slower rate of 4.5% p.a. in the CP scenario and 2.2% p.a. in the SF scenario as compared to 5.8% p.a. in the BAU-HT scenario, conversely the capital investments in the non-energy sectors increases at a faster rate of 8.5% p.a. in the CP scenario and 8.4% p.a. in the SF scenario as compared to 8.3%p.a. in the BAU-HT scenario over the study period from 2015 to 2050.These increased rates of capital investments in the non-energy sectors in the long term will be a result of aggressive efforts to introduce energy-efficient technology advancements. For instance, gas-based DRI technologies will replace coal-based DF/BOF technologies in the iron and steel industry, the corresponding capital investments required increase from US$22 Bn in 2015 to US$368 Bn for the CP scenario and US$ 370 Bn for the SF scenario in the year 2050 as can be seen in Figure 6-27. In addition, a switch to more clean and renewable energy sources from traditional fossil fuel sources in the generation of power will also contribute to reductions in the total outputs of these sectors and hence the decreased capital investments in the energy sectors. For instance, the capital investments in the electricity sector will be at a slow rate in the CP and SF scenario at 4.4% p.a. and 1.7% p.a. as compared to the BAU-HT scenario at 5.9% p.a. as can been seen in Figure 6-28.

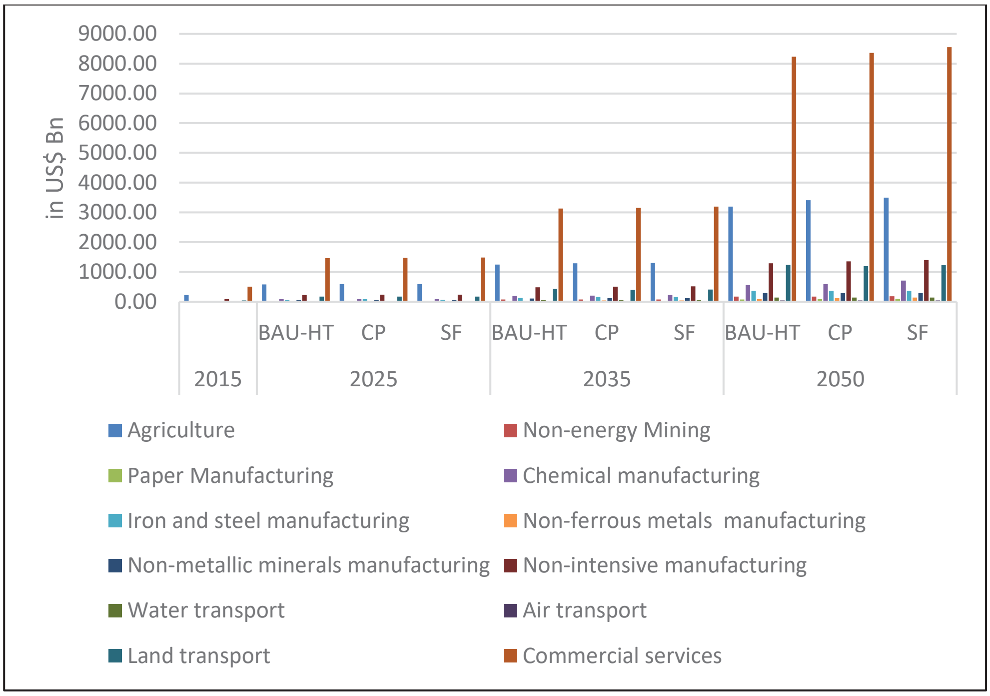


Figure 6-27: Model of capital investments in non-energy sectors, 2015 – 2050

Source: Author's compilation

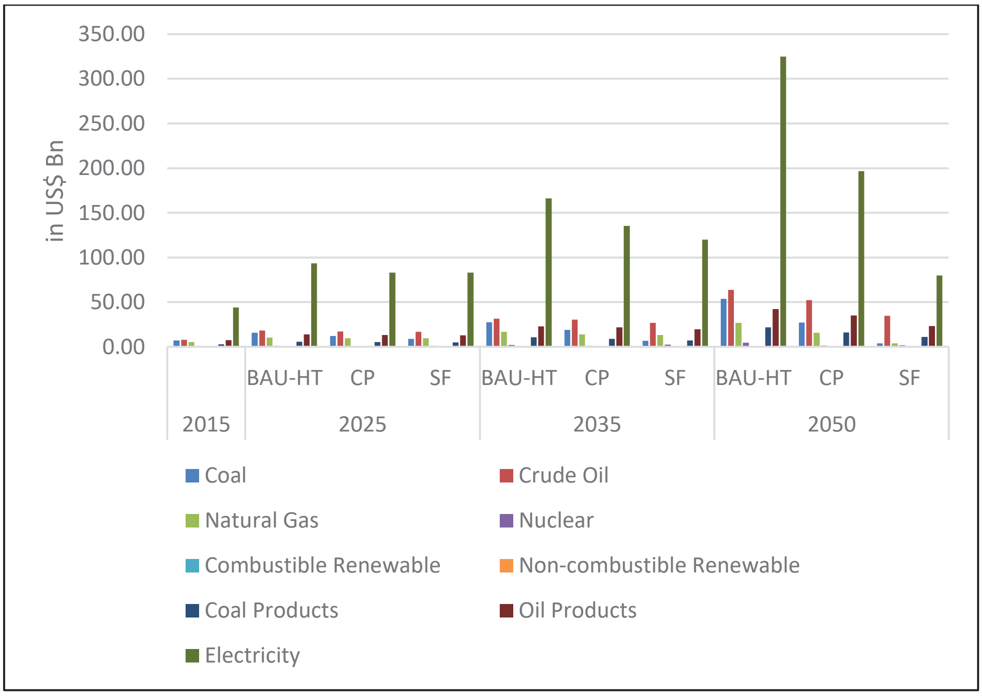


Figure 6-28: Model of capital investments in energy sectors, 2015 – 2050

Source: Author's compilation

6.3.5 Trade balance

Energy efficiency measures will generally see a significant decline in the trade deficit across the three alternative scenarios, as can be seen in Figure 6-29. The effects would, however, differ across the individual economic sectors. The overall trade deficit will increase by about US$28Bn in the CP scenario and by US$18Bn in the SF scenario by 2025, compared to the BAU-HT scenario, making India a net importer of goods and services. In the medium to long term, that is, by 2050, the trade balance will have further deteriorated by US$84Bn and US$158Bn in the CP and SF scenarios. This increase in the trade deficit will be a result of increased demand for manufactured goods as a result of economic growth and people's improved living conditions. As more and more of the population gain access to modern energy, the demand will increase; this means that domestic production will falls short of demand, resulting in an increase in the import of energy resources such as coal, oil, natural gas and electricity, which further contributes negatively to the overall trade balance.

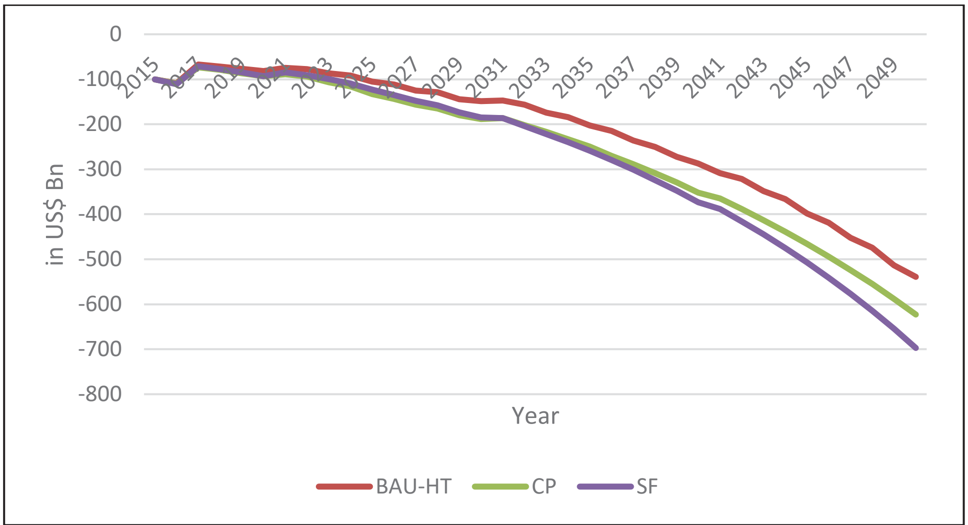


Figure 6-29: Model of total trade balance, 2015 – 2050

Source: Author's compilation

In terms of the net trade in goods and services, the relative proportions among the different sectors will vary considerably, as shown in Figure 6-30. Improvements in energy efficiency could have a positive impact on the energy industry (including electricity) by reducing the import and increasing the export of energy products. For instance, the energy industry is a net importer in the short-to-medium-term across all scenarios, but by 2050 according to the SF scenario, in which the energy efficiency improvement measures are more aggressive compared to the CP scenario, the energy industry would have become a net exporter of energy products to the value of US$37Bn. Total trade in manufactured products would be adversely affected by adopting energy efficiency improvement measures across all scenarios; this would be because of improved lifestyles and continuous economic growth, leading to an increase in demand for finished goods as well as the raw materials that feed as inputs into the manufacturing sector. The transport and services sectors, however, will become net exporters over the study period. For instance, in the transport sector, net trade will increase from US$26.5Bn in the base year 2015 to US$151Bn in the CP scenario and to US$174Bn by 2050 in the SF scenario. Similarly, in the services sector, net trade will improve from US$47.6Bn in the base year 2015 to US$362Bn in the CP scenario and to US$403Bn by 2050 in the SF scenario. These increases in net trade will be a result of increased energy efficiency measures, such as clean fuel technology (biofuels for vehicles) and generation of electricity from new and renewable energy sources, which are the main source of energy consumed by the services sector.

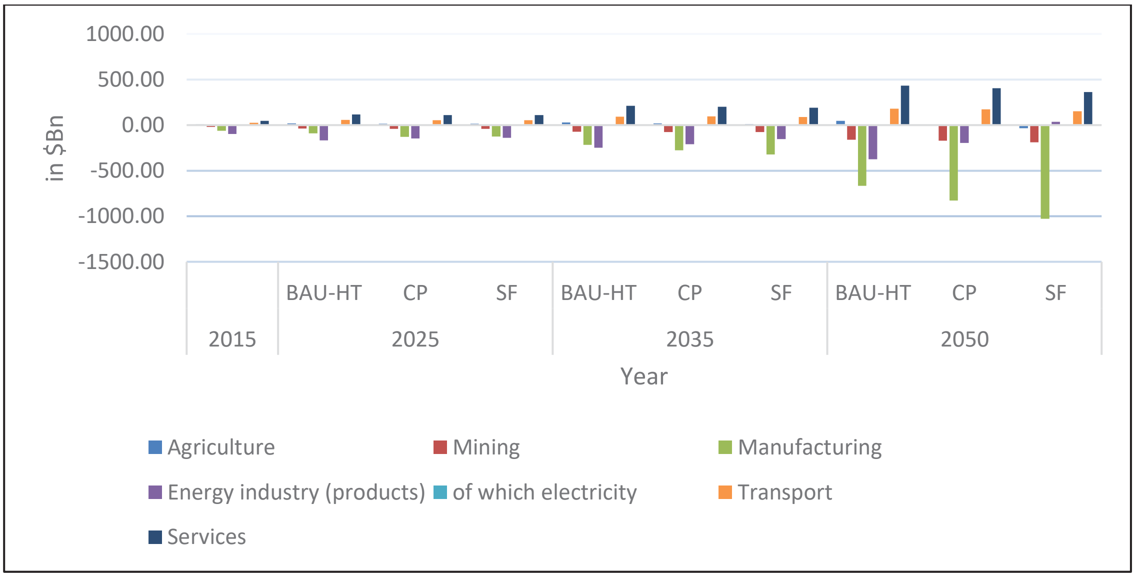


Figure 6-30: Model of trade balance by sectors, 2015 – 2050

Source: Author's compilation

6.4 Summary of Key Findings

This chapter examines the energy implications and economy-wide impacts of energy activities across three possible energy pathways (scenarios) for India, using an energy-oriented input-output model. Some of the key findings are discussed here.

- If the current trends in energy policy continue for the next 35 years, there will be an increase in India's primary energy requirements. Compared to the base year (2015), these energy requirements will increase by 5 times by 2050, dependency on imported energy sources will increase significantly and GHG emissions will rise by 80%, potentially leading to energy insecurity in the long term. The CP and SF scenarios demonstrate alternative pathways to help reduce overall energy consumption and GHG emissions by promoting energy efficiency improvement measures. For instance, by 2050 primary energy consumption could be reduced by nearly 1.6 and 2.8 times respectively in the CP and SF scenarios compared to the BAU-HT scenario and GHG emissions could be reduced by 1.8 and 6.3 times by 2050 respectively in the CP and SF scenarios compared to the BAU-HT scenario.

- The energy mix is expected to undergo a significant change over the study period. Historically India's energy mix has been dominated by coal and oil. Despite measures to encourage savings, the share of oil in the total primary energy mix in both the CP and SF scenarios increases and by 2050 oil will become the most significant energy source, claiming 36% and 40% respectively in the CP and SF scenarios. This will be a result of increasing per-capita vehicle driving activity, growing population and other forms of transportation such as sea travel and air travel. In the long term, as the reserves of indigenous gas deplete, gas consumption will decline at an annual rate of 2% and 10% respectively in the CP and SF scenarios. To compensate for the reduced consumption of fossil fuel sources and to limit GHG emissions, nuclear and renewable energy sources will be encouraged, resulting in an increase in the share of these fuels, especially in electricity generation, in the energy mix. For instance, the share of renewables in the generation mix will increase by 9% in the BAU-HT scenario to 30% and 61% in the CP and SF scenario respectively by 2050.

- India will become increasingly dependent on imported energy if current trends in energy consumption continue. For example, energy import dependency will increase and this will expose the country to increasing energy supply risks due to the volatility in international energy markets, limited domestic production and ongoing geopolitical uncertainty associated with the energy-rich nations. The results of scenario analysis, however, show that by applying energy efficiency measures and promoting new and renewable energy sources, India's energy import dependency requirements will have reduced at the rate of 1% per annum by 2035 in the CP and SF scenario.

- The electricity generation fuel mix is expected to significantly change over the study period. The share of coal will decline from 75% in the base year 2015 to 61% and 12% respectively by 2050 in the CP and SF scenarios. The introduction of clean coal technologies such as IGCC and efforts to limit GHG emissions will reduce the share of coal in the total generation mix from 35% in 2030 to 12% in 2050 in the SF scenario. The increase in nuclear and renewable energy in power generation means these fuels will play an important role in ensuring security of energy supply, through diversification of the fuel mix and in environmentally-friendly energy activities. Renewable energy will constitute 9%, 30% and 61% of the total generation mix respectively by 2050 in the BAU-HT, CP and SF scenarios.

- Among the end-use sectors, the residential and industry sectors are the two biggest energy consumers and contributors to GHG emissions. Over the study period, these two sectors account for nearly 90% of the total consumption and 76% of the GHG emissions by 2050 according to the SF scenario. Therefore, these two sectors offer significant opportunity to reduce energy consumption and GHG emissions. Such opportunities include the introduction of more advanced and efficient technologies such as DRI and EAF in steel production, thus reducing the dependency on coal. The electricity consumed by the residential sector is expected to increase as a result of improvements in individual incomes and in lifestyle conditions. There is therefore high potential for energy and electricity consumption reductions by increasing energy efficiency and conserving energy in building and electrical appliances through improved designs and by educating people about the benefits of energy saving and its environmental effects, thus helping them to make better consumer choices.

- The proportion of the capital investments increasing in the non-energy sectors as compared to the energy sectors of the economy as the introduction of new and advanced energy efficient technologies increases across the two alternative CP and SF scenarios. Capital investments in the energy sector increase at a slower rate in the (4.5% p.a.) CP scenario and (2.2% p.a.) SF scenario as compared to the (5.8%p.a.) BAU-HT scenario, conversely the capital investments in the non-energy sectors increases at a faster rate in the (8.5% p.a.) CP scenario and (8.4% p.a.) SF scenario as compared to the (8.3%p.a.) BAU-HT scenario over the study period from 2015 to 2050.

- The magnitude of the rebound effect associated with energy-intensive sectors is generally higher than in non-energy-intensive sectors. India's dependence on energy imports will decrease as energy efficiency improvements increase. For instance, in the residential sector, the annual productivity growth rate in the CP and SF scenarios is 1.1% and 1.7% respectively, compared to 0.5% in the BAU-HT scenario. The rebound effect in 2035 and 2050 will be higher for both the CP and SF scenarios at 1% and 2% respectively by 2035 and 2.4% and 3% by 2050 respectively for the CP and SF scenarios, compared to 1% in 2035 and 1.8% in 2050 in the BAU-HT scenario.

- The energy efficiency measures for the CP and SF scenarios will result in modest reductions in the GDP. For instance, in the CP scenario, the GDP will decline by 0.28% by 2025, by 0.30% by 2035 and by 0.09% by 2050, while in the SF scenario, the GDP will decline by 0.14% by 2025, by 0.13% by 2035 and improves by 0.27% by 2050, compared with the GDP in the BAU-HT scenario. Introducing energy efficiency improvement measures will have a positive impact on the GDP based on the expenditure approach but will produce mix results for the GDP based on the income approach.

- Overall, the trend across the three scenarios over the study period shows that total industry output decreases as energy efficiency measures increase and there is greater penetration of advanced efficient technology and practices. The CP and SF scenarios follows a similar trend in the short-to-medium term, with the average rate of decline in the total output at 0.9% and 1.1% respectively. This decline continues in the CP scenario in the long term at the rate of 1.6% for the CP scenario and 3.1% for the SF scenario compared to the outputs in the BAU-HT scenario. The commercial services sector, which includes financial services, community services, real estate, hotels and restaurants, shows comparatively higher total outputs in the CP and SF scenarios compared to the BAU-HT scenario. This increase is a result of increased construction of housing and other community facilities, such as hospitals, hotels, education infrastructure, communication and media, to meet the growing rate of urbanisation and better living standards as the population gains increased access to modern energy sources. Most of the non-energy sectors have lower outputs in the CP and SF scenarios compared to the BAU-HT scenario. For instance, the output of the agriculture sector will have declined by 0.13% and 0.54% respectively for the CP and SF scenarios by 2025. The output will further decline by US$34Bn in 2035 and by US$199Bn in 2050 in the CP scenario, the rate of decline in output being 1.2% and 3.2% respectively as compared to the output of the BAU-HT scenario for the years 2035 and 2050. In the SF scenario, the output will decline by US$39Bn in 2035 and by US$221Bn in 2050, the rate of decline being 1.3% and 4.3% in 2035 and 2050 respectively as compared to the output of the BAU-HT scenario for the years 2035 and 2050.

- The impact on employment in each sector is computed based on the ratio of employees per unit of total output in that sector, taking into account future changes in annual labour productivity. Labour productivity is assumed to improve at the rate of 1.76% p.a. over the study period. The agriculture, iron and steel, chemical, non-ferrous metals and non-intensive manufacturing (including construction) show higher levels of employment in both the CP and SF scenarios compared to the BAU-HT scenario. For instance, employment in the iron and steel industry, which produces comparatively lower output, generates a higher level of additional employment in both scenarios, it is comparatively labour intensive. The land transport sector, which include road and rail transport, will experience a decrease in employment as a result of increased penetration of energy efficient technology and automation. Employment in the energy sectors will generally decline in both the CP and SF scenarios but rise in the non-energy sectors. This will be due to the switch in power generation from fossil fuel based plants to renewable energy-based plants, which are generally highly capital and labour intensive. By 2025, the net decrease in employment in the energy sectors will be 2.18 Mn people in the CP scenario and 1.84 Mn people in the SF scenario, compared with the BAU-HT scenario.

- Energy efficiency measures will generally cause a significant decline in the trade balance across the three alternative scenarios. The overall trade deficit will increase by about US$28Bn according to the CP scenario and by US$18Bn according to the SF scenario by 2025, compared to the BAU-HT scenario, making India a net importer of goods and services. This increase in the trade deficit will be a result of increased demand for manufactured goods, itself a result of economic growth and improved living conditions. Improvements in energy efficiency have the potential to make a positive impact on the energy industry by reducing energy imports and increasing energy exports. Trade in manufactured products will be adversely affected by the adoption of energy efficiency measures across all scenarios, since improved lifestyles and continuous economic growth will contribute to an increase in demand for finished goods and the raw materials that feed into the manufacturing sector.

Chapter 7 : Energy Security Assessment in the context of this Research

7.1 Introduction

The results obtained through the scenario analyses help to determine the different trends, indicating the improvements derived from various energy efficiency measures, from the base BAU-HT scenario to the CP and SF scenarios. The results from the scenario analyses form the basis to assess India's future energy security in the context of this research. The assessment is carried out by developing composite indices using equal and unequal weights for the five energy security attributes of availability, affordability, accessibility, reliability and sustainability. In this chapter, the composite indices for energy security are obtained by the linear aggregation of the weighted and normalised values of the individual attributes from the years 1970 to 2050 in a similar manner as described in Chapter 2. Three indices for energy security are computed under three different situations, in each instance different weights are assigned to each of the five energy security attributes. The weights for determining energy security in the three different situations are assigned to align with the objectives of each of the three scenarios considered in this research.

This chapter is organised as follows. Section 7.2 discusses the impact of the key attributes of availability, affordability, accessibility, reliability and sustainability on future trends based on the results obtained from analysis of each long-term energy scenario considered in this research. Section 7.3 assesses energy security in the future based on the revised index determined for the indicators that comprise each of the key attributes. This section also examines the role of energy efficiency in addressing India's energy security challenge. Section 7.4 concludes the chapter with a summary of key findings.

7.2 Discussion of Revised Energy Security Attributes

This section explains in detail the revised indicators that comprise each of the attributes of energy accessibility, energy affordability, energy availability, energy reliability and energy sustainability in each of long-term energy scenarios − BAU-HT, CP and SF − considered in this research for the study period 2015-2050 compared to the historical trends from 1970 to 2015 (see Chapter 2).

7.2.1 Revised energy availability

Energy Availability is measured in terms of the domestic production of primary energy and electricity plus the level of imports of these resources to meet India's energy needs for its growing population and increased economic activities in the future.

As seen in Figure 7-1, the HHI for production per capita (in toe) is calculated based on the normalised valued of various fuel sources including coal and lignite, crude petroleum, natural gas and nuclear in a particular year over the period 1975 to 2050. If historical trends (HT) continue with little to no energy efficiency improvement measures in place, i.e. according to the BAU-HT scenario, domestic energy production is expected to increase exponentially with the increase in population in the future; this trend is similar to per-capita energy consumption (Chapter 6-Section 6.2.1). However, in the CP and SF scenarios, overall production declines despite the population increase over the study period compared to the historical trends; this is a result of increasing energy efficiency improvement measures such as new and advanced efficient technologies across all sectors of the economy and improving the diversity in the fuel mix for electricity generation by introducing nuclear and renewable energy sources. Further, increasing awareness among the population about the potential benefits of energy efficiency, such as energy savings and reduced GHG emissions, collectively contribute to reducing the overall consumption and hence the production of energy as the population grows in the future.

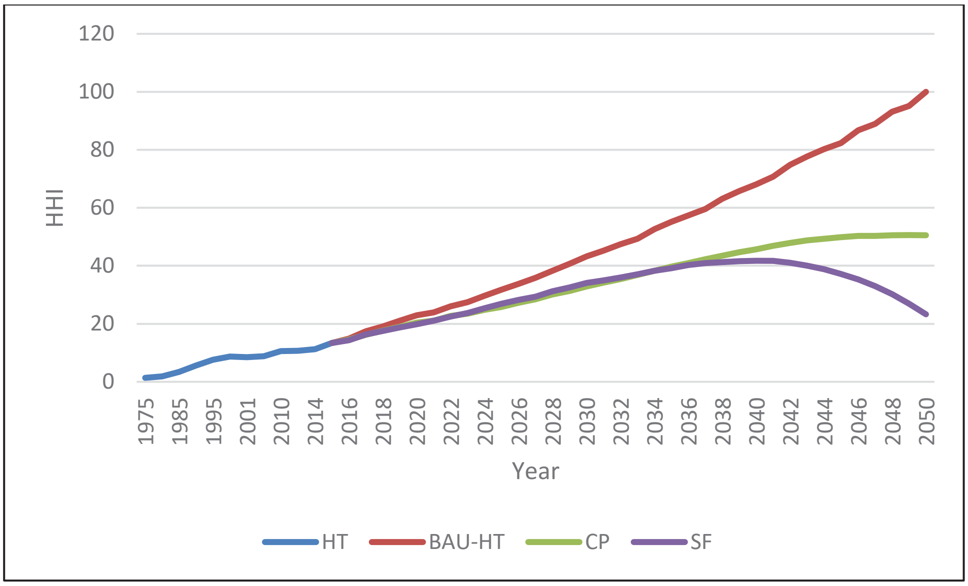


Figure 7-1: Revised normalised index-production per capita (in toe), 1975 – 2050

Source: Author's compilation

India has limited indigenous supplies of coal, oil and gas. If energy demand continues to grow, the production will increasingly fall short of the demand, increasing the pressure to import these fuel sources, as shown in Figure 7-2. The HHI for import dependency (in toe) is calculated based on the normalised values of various energy sources including coal, crude petroleum, natural gas and nuclear in a particular year over the period 1975 to 2050. As energy efficiency improvement measures continue to increase according to the CP and SF scenarios (Chapter 6, Section 6.2.4), overall consumption and demand for fuel sources will fall, indicating a corresponding decline in future imports. In the CP scenario, the effects of energy efficiency do not become apparent until the late 2040s, indicating the country will be dependent on imported fuel sources for longer to meet growing demand and India will need to introduce more aggressive measures if it is to achieve energy self-sufficiency and be more energy secure in the future. In the SF scenario, where energy efficiency measures are more aggressive compared to the CP scenario, the country becomes increasingly self-sufficient earlier in the medium to long term (2030 to 2050).

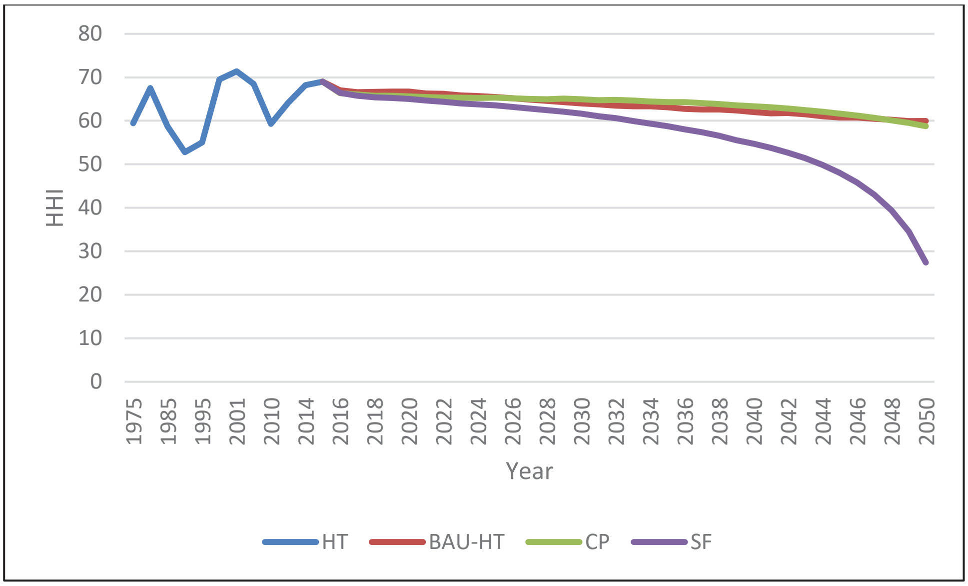


Figure 7-2: Revised normalised index-energy import dependency (in toe), 1975 – 2050

Source: Author's compilation

The overall impact of energy efficiency improvement measures on energy availability across the three long-term scenarios of BAU-HT, CP and SF decreases over the period 2015-2050, as can be seen in Figure 7-3. The composite index for energy availability (in toe) is determined by calculating the HHI for the normalised valued of production per capita and import dependency in a particular year over the period 1975 to 2050. Comparing the behaviour of each attribute between the scenarios, it is interesting to note that energy availability increases in the BAU-HT scenario from 49 in 2025 to 59 in 2035 and to 80 in 2050, in the CP scenario the energy availability increases but slower than BAU-HT from 46 in 2025 to 52 in 2035 and to 55 in 2050 but in the SF scenario the energy availability increases from 45 in 2025 to 49 in 2035 and decreases in the long-term to 25 in 2050. As little to no efforts are made in the BAU-HT scenario to encourage energy efficiency, energy availability continues to grow, indicating more energy is required to meet the growing consumption needs, either through increased domestic production or imports. As initiatives are taken to implement energy efficiency measures across all sectors of the economy in the CP and SF scenarios, diversity in the generative fuel mix rises, energy availability declines and demand shifts from the limited supplies of domestic fossil fuels (coal, oil and gas) to new and renewable energy sources (solar, wind, hydro and nuclear), which in turn reduces pressure to import energy resources.

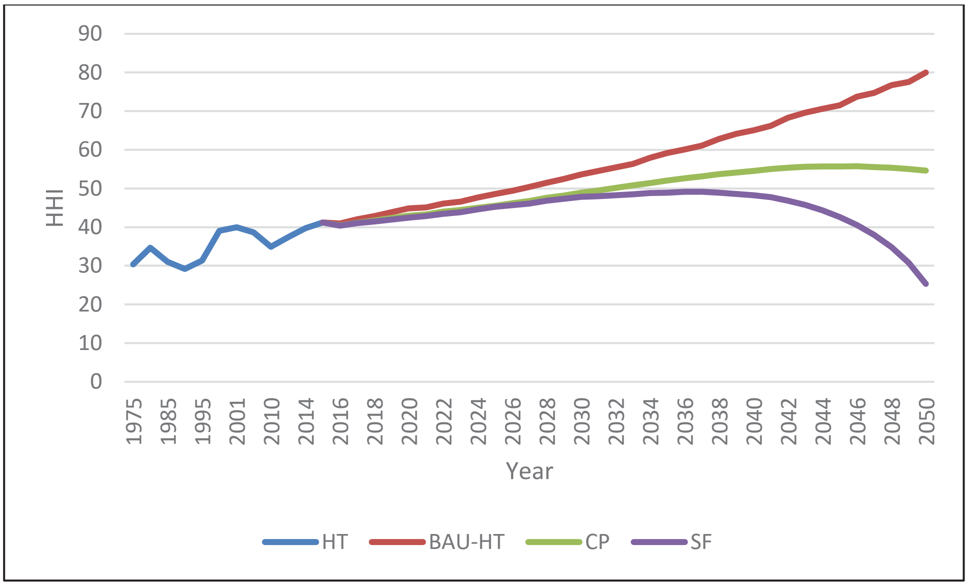


Figure 7-3: Revised composite index-energy availability (in toe), 1975 – 2050

Source: Author's composition

7.2.2 Revised energy affordability

Energy affordability is the share of expenditure on energy by the key energy-consuming end-use sectors of the economy, namely residential, industrial, transport, agriculture and commercial services. This section discusses the impact of energy efficiency improvement measures on the overall energy affordability for the future based on the analysis of the results for each of the long-term energy scenarios over the study period 2015-2050.

As India's economy continues to grow, household disposable income will rise and people's lifestyles will improve. If historic trends continue into the future, with no effort to improve energy efficiency, people will need to spend more on household lighting, cooking, heating/cooling, thus reducing their overall energy affordability, as shown in Figure 7-4. The HHI for residential affordability is calculated based on the normalised values of the share of expenditure of household income on energy for the residential sector in a particular year over the period 1975 to 2050.In the alternative scenarios of CP and SF, increasing energy efficiency improvements will make people increasingly aware of the benefits and overall cost savings to be derived from purchasing energy-efficient end-use appliances such as lighting, refrigerators, fans, air-conditioning systems, televisions and so on. As households' disposable incomes continue to rise in the long term, leading to less expenditure on energy both proportionately and in absolute terms, leading in turn to increased energy affordability in the residential sector in the long term.

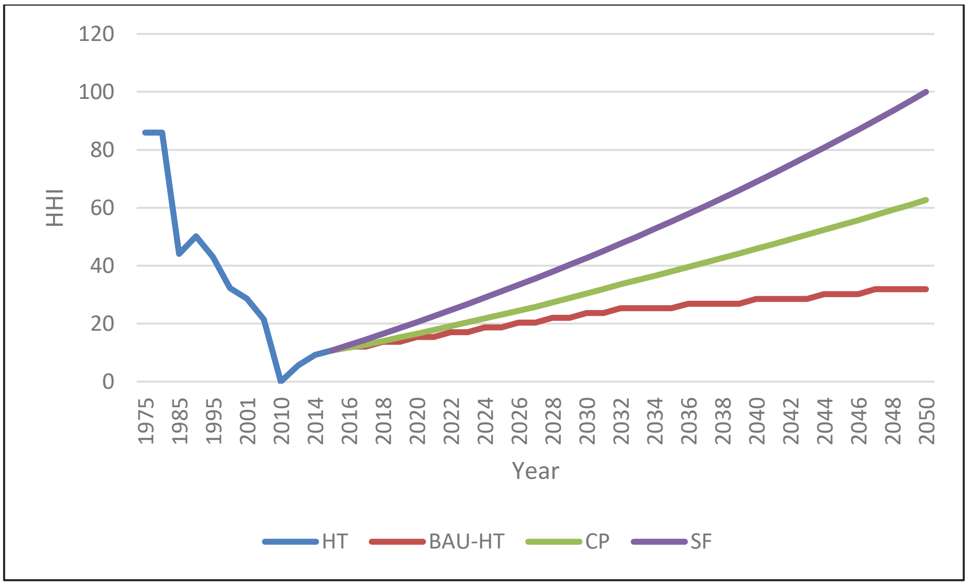


Figure 7-4: Revised normalised index-residential affordability (in %), 1975 – 2050

Source: Author's compilation

As energy efficiency improvement measures are incorporated into the industry sector through new and advanced efficient technologies and practices such as phasing out of BF/BOF coal-based technologies and introducing DRI and EAF technology in the iron and steel production, these advanced technologies will contribute to reducing the CO_2 emissions intensity (see Chapter 6, Section 6.2.6). This high potential to reduce overall energy and electricity consumption in the manufacturing sector by increasing energy efficiency and conservation will result in increased energy affordability in the industrial sector. In the CP and SF scenarios, as energy efficiency improvements become more aggressive, they will lead to reduced energy consumption (see Chapter 6, Section 6.3.2). In addition, industrial energy affordability improves in the CP and SF scenarios compared to the BAU-HT scenario, as can be seen in Figure 7-5, as more ambitious initiatives continue to generate greater energy efficiency. The HHI for industrial affordability is calculated based on the normalised values of the share of expenditure on energy from the total gross value added for the industry sector in a particular year over the period 1975 to 2050.

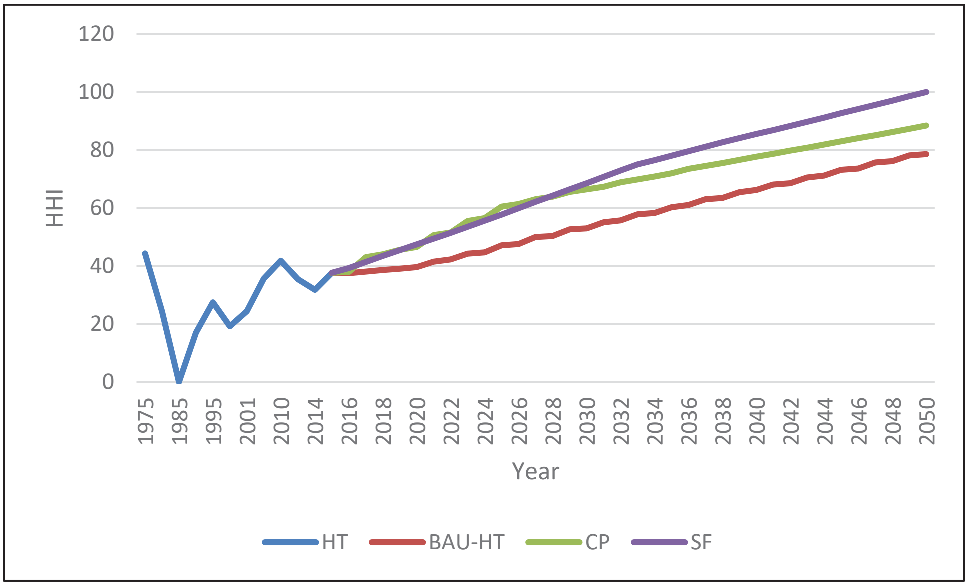


Figure 7-5: Revised normalised index-industry affordability (in %), 1975 – 2050

Source: Author's compilation

The transport sector is seeking similar benefits from energy efficiency improvement measures, particular because of its great dependence on oil. Any steps to introduce energy efficiency and decrease the demand for oil with the introduction of hybrid and electric vehicles, for example, with better fuel economy, will reduce the energy consumption in the transport sector (see Chapter 6, Section 6.2.2), leading to overall cost savings. As can be seen in Figure 7-6, in the SF scenario, aggressive energy efficiency measures in the transport sector lead to greater cost savings compared to the BAU-HT scenario and increase transport sector energy affordability in the short-to-medium term, while the cost savings remain relatively constant in the long-term future. The HHI for transport affordability is calculated based on the normalised values of the share of expenditure on energy from the total gross value added for the transport sector in a particular year over the period 1975 to 2050.

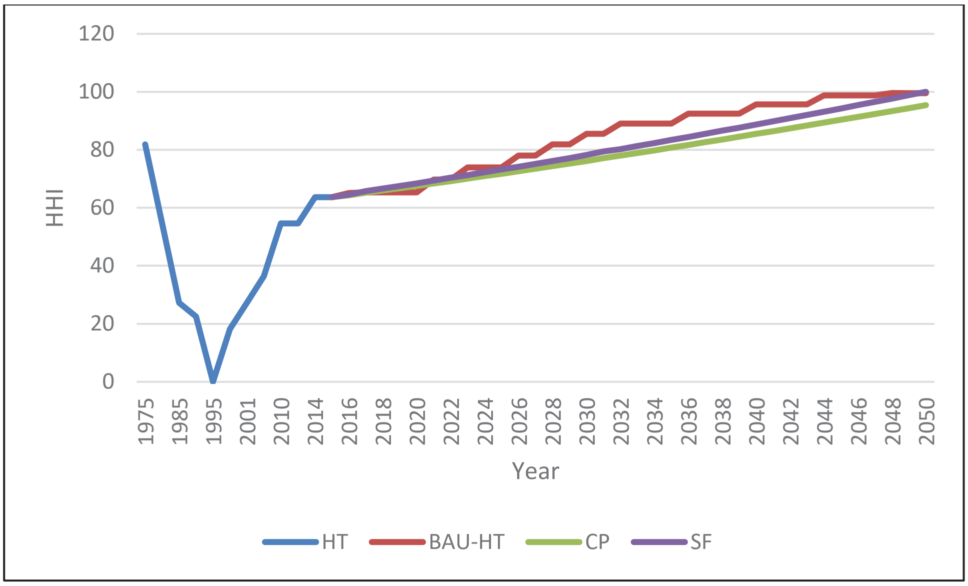


Figure 7-6: Revised normalised index-transport affordability (in %), 1975 – 2050

Source: Author's compilation

Overall, the agriculture sector contributes to a small percentage of the total energy consumption, both historically and in the future. Nonetheless, the introduction of such equipment as efficient pump sets and tractors in the sector will contribute to lowering India's overall energy requirements and increase energy affordability in the agriculture sector in the future long term, in the CP and SF scenarios, as can be seen in Figure 7-7. The HHI for transport affordability is calculated based on the normalised values of the share of expenditure on energy from the total gross value added for the agriculture sector in a particular year over the period 1975 to 2050.

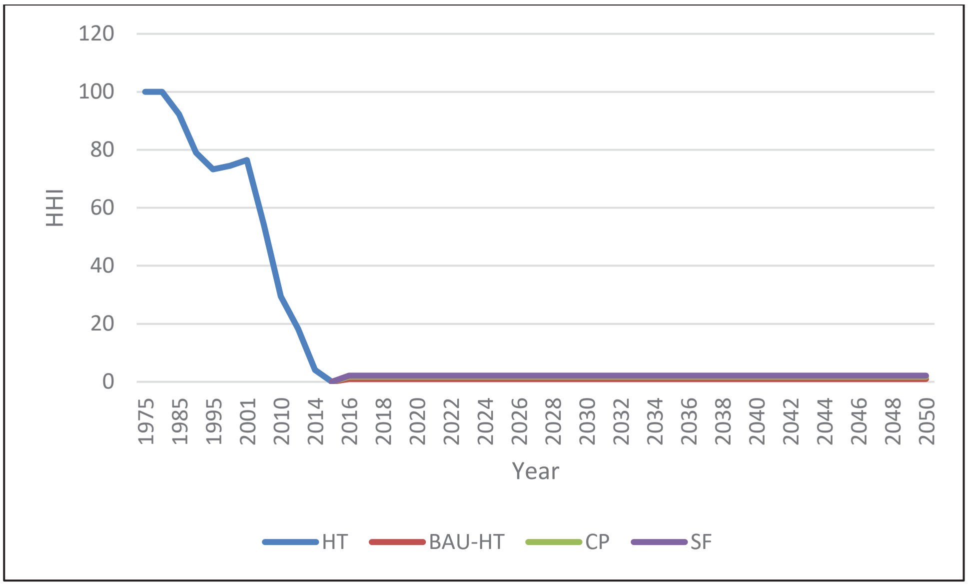


Figure 7-7: Revised normalised index-agriculture affordability (in %), 1975 – 2050

Source: Author's compilation

The commercial services sector, like the residential sector, has the potential to achieve substantial savings with the introduction of energy efficiency improvement measures, as can be seen in Figure 7-8. The HHI for transport affordability is calculated based on the normalised values of the share of expenditure on energy from the total gross value added for the commercia services sector in a particular year over the period 1975 to 2050. In this sector, energy efficiency is improved by better building design and the use of energy-efficient appliances. If historic trends were to continue into the future, with no proper energy efficiency improvement practices in place (such as poor insulation and inefficient lighting, fans and air conditioning), consumption of energy would rise, resulting in an increased share of expenditure on energy and hence reduced energy affordability. With the introduction of energy efficiency improvement measures in the CP and SF scenarios, the commercial sector's energy consumption would decline (see Chapter 6-Section 6.2.2) in the future, resulting in greater cost savings and hence improved energy affordability.

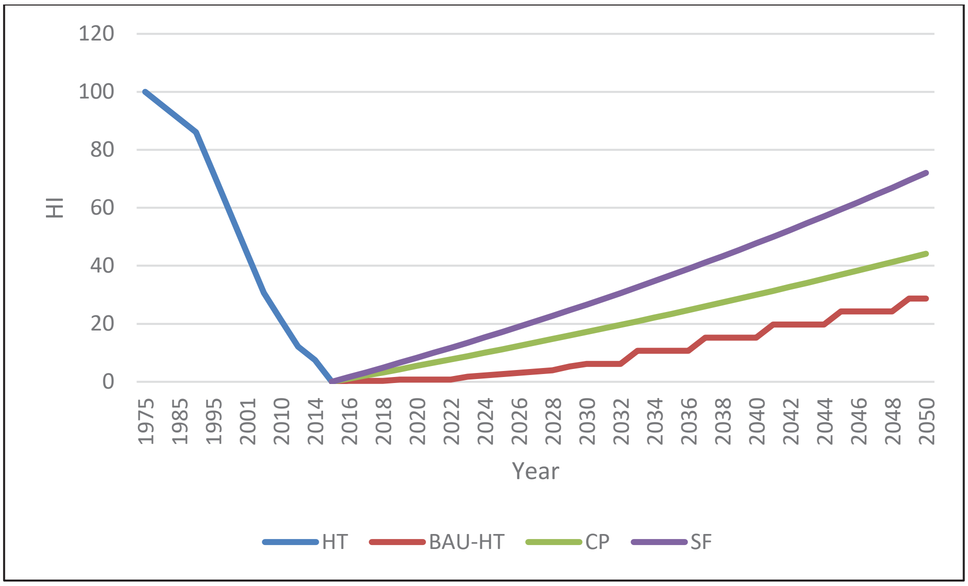


Figure 7-8: Revised normalised index-commercial services affordability (in %), 1975 – 2050

Source: Author's compilation

Based on the above discussion, it can be observed that the more ambitious the energy efficiency improvement measures in the future across all end-use sectors of the economy, the greater the reduction in energy consumption and the greater the potential energy cost savings in the long term. This is shown in Figure 7-9. The composite index for energy affordability (in %) is determined by calculating the HHI for the normalised values of the share of expenditure on energy from the total gross value added for the industry, transport, agriculture and commercial services sectors and the share of expenditure of household income on energy for the residential sector in a particular year over the period 1975 to 2050. Energy affordability increases across all three scenarios from 29, 34 and 36 in 2025 to 37, 43 and 51 in 2035 and to 48, 58 and 75 in 2050 for the BAU-HT, CP, and SF scenarios respectively. In the CP and SF scenarios, the cost savings are a lot higher compared to the BAU-HT scenario where little to no effort is expended on energy efficiency initiatives (see Chapter 2, Section 2.3.1.2), thus resulting in increased energy affordability in the long term.

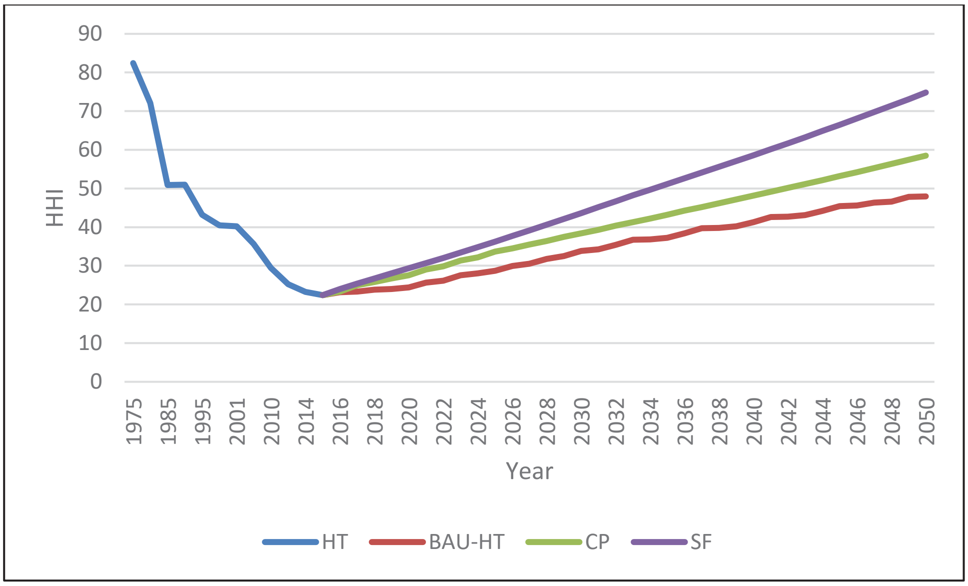


Figure 7-9: Revised composite index-energy affordability (in %), 1975 – 2050

Source: Author's compilation

7.2.3 Revised energy accessibility

Energy accessibility is the proportion of the population that has access to modern energy sources for cooking (LPG), lighting heating/cooling and so on. (electricity). This section discusses the impact of energy efficiency improvement measures on access to electricity and modern cooking for the period 1975-2050, derived from analysis of the BAU-HT, CP and SF scenarios.

As India's population grows and it advances economically, its rate of urbanisation will also increase. Further, government initiatives, such as those to achieve 100% rural electrification, will also improve living conditions overall. These lifestyle improvements will increase demand for modern energy to meet the lighting, cooling/heating, etc. needs of households. However, as energy efficiency initiatives are put in action, there will be increased awareness of the benefits and overall energy cost savings, which will contribute to a decline in energy consumption (see Chapter 6, Section 6.2.2). As can be seen in Figure 7-10, the proportion of the population with access to electricity in the CP and SF scenarios will increase from 2015 to 2050 as energy efficiency increases over that period. The HHI for access to electricity is calculated based on the normalised values of the proportion of total electricity consumed by the residential sector in a particular year over the period 1975 to 2050.

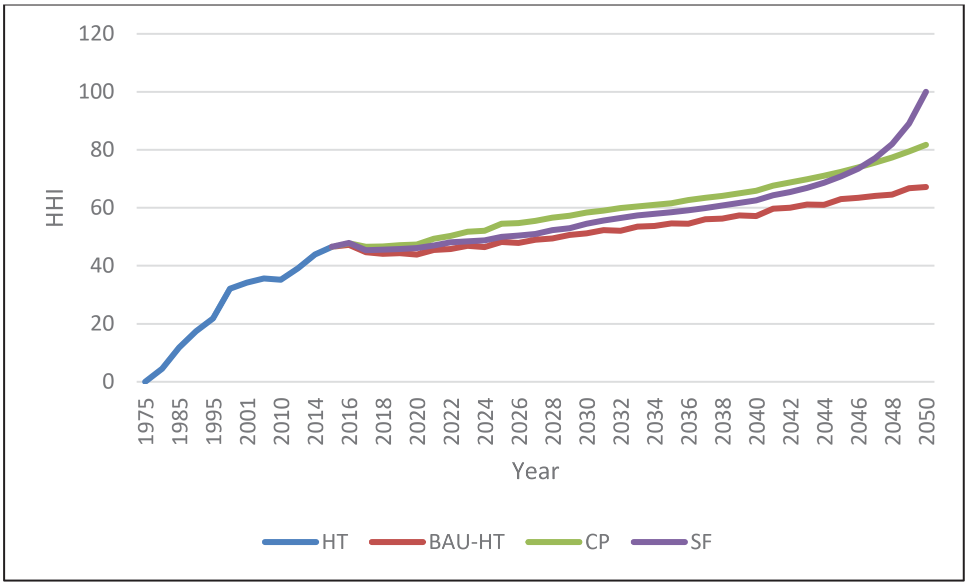


Figure 7-10: Revised normalised index-access to electricity (in %), 1975 – 2050

Source: Author's compilation

Similarly, a change in lifestyle practices means a large proportion of people are shifting from traditional firewood and kerosene to modern fuels (LPG) to meet their cooking needs, as can be seen in Figure 7-11. The HHI for access to electricity is calculated based on the normalised values of the proportion of modern cooking (LPG) consumed by the residential sector in a particular year over the period 1975 to 2050. As energy efficiency increases across the CP and SF scenarios compared to the BAU-HT scenario, people become increasingly aware of the potential benefits and cost savings and thus reduce their overall energy consumption (see Chapter 6, Section 6.2.2).

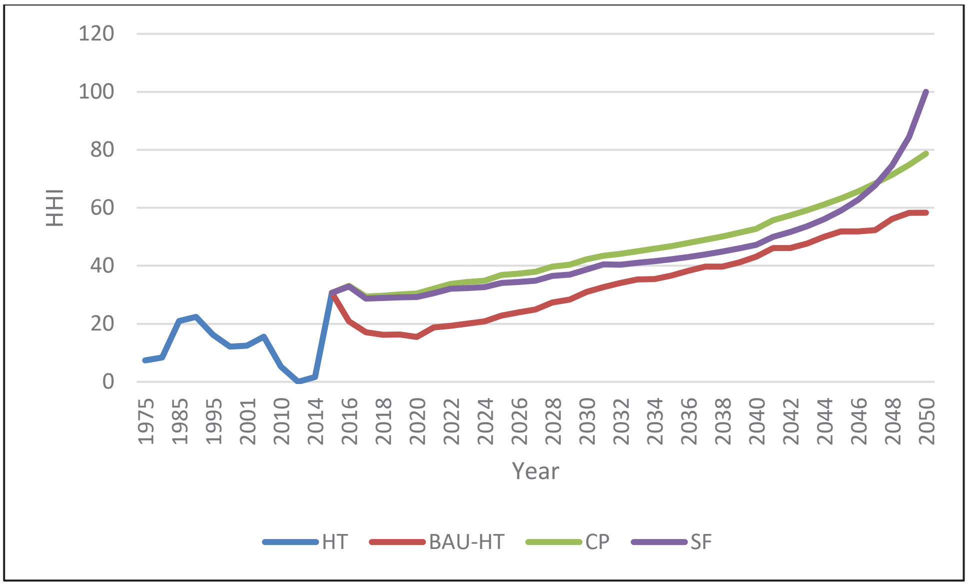


Figure 7-11: Revised normalised index-access to modern cooking (in %), 1975 – 2050

Source: Author's compilation

Although overall consumption in absolute terms decreases in the CP and SF scenarios compared to the BAU-HT scenario due to energy efficiency improvement measures (see Chapter 6, Section 6.2.1), the proportion of the population gaining access to modern energy sources increases along with the increase in population. This is a result of increased rates of urbanisation, rural electrification and improved lifestyle practices resulting from increased energy affordability, as can be seen in Figure 7-12. In the BAU-HT scenario, energy accessibility decreases from an HHI index of 39 in the base year 2015 to 36 by 2025, after which it shows a linear increase to 46 by 2035 and to 63 by 2050. In the CP and SF scenarios, there is an exponential increase to 46 and 42 respectively by 2025 and to 54 and 50 respectively by 2035. Long term, accessibility continues to increase to 80 in the CP scenario and 100 in the SF scenario by 2050. As can be seen in the long-term, the energy accessibility for the SF scenario increases at a rate faster than the CP scenario.

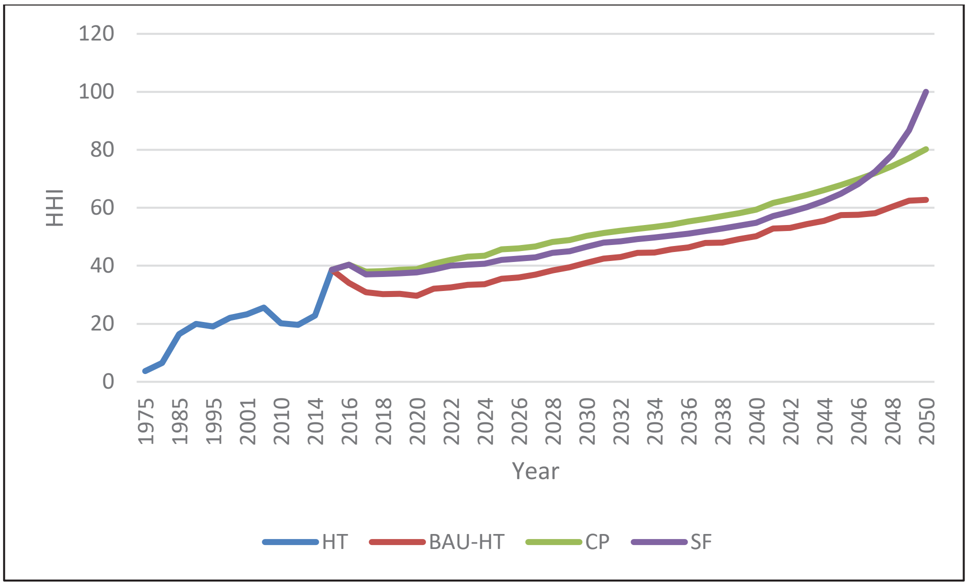


Figure 7-12: Revised composite index-energy accessibility (in %), 1975 – 2050

Source: Author's compilation

7.2.4 Revised energy reliability

Energy reliability is the ability of the electricity generation system to provide uninterrupted electricity. In this section, energy reliability is discussed in terms of generation fuel mix, transmission, distribution losses and the consumption of each fuel type as part of the TFC across the three alternative scenarios of BAU-HT, CP, and SF over the period 1975-2050.

The electricity generation mix as shown in the BAU-HT scenario is expected to change significantly in the future (see Chapter 6, Section 6.2.3). There will be a shift from fossil fuel-based sources such as coal to cleaner and more reliable sources such as nuclear and renewable energy. The diversification of the generation fuel mix means that nuclear and renewable fuels will play an important role in ensuring the security of energy supply, as shown in Figure 7-13. The HHI for the energy mix for electricity generation is calculated based on the normalised values for the proportion of various fuels such as coal, oil, natural gas, hydro, nuclear and renewable in the electricity generation mix in a particular year over the period 1975 to 2050. Additionally, as the overall demand for electricity declines as a result of energy efficiency improvements in the end-use sectors of the economy, electricity generation will be lower in the future in the CP and SF scenarios than that in the BAU-HT scenario.

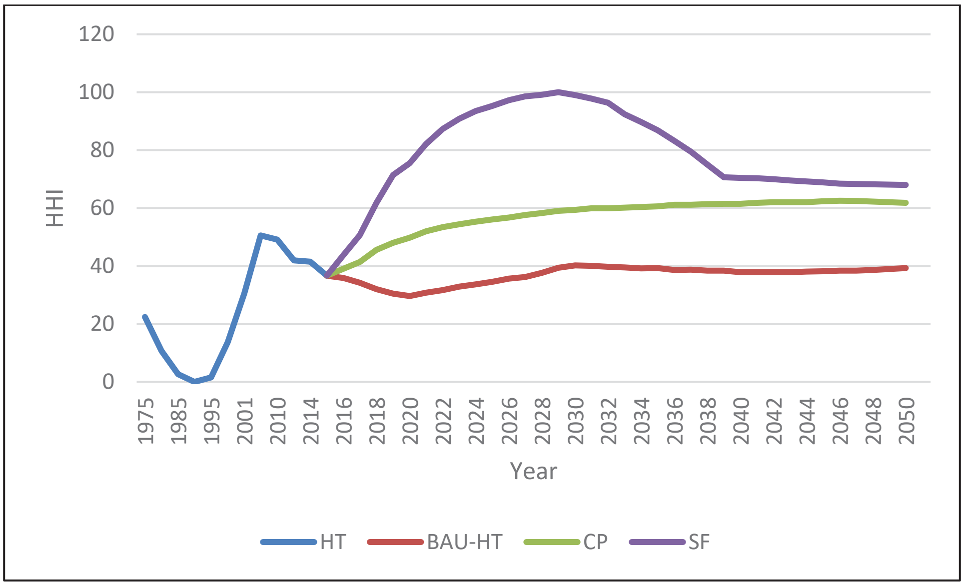


Figure 7-13: Revised normalised index-energy mix for electricity generation (in %), 1975 – 2050

Source: Author's compilation

The introduction of new and efficient technologies such as IGCC will not only result in a decrease in the share of coal in the total generation mix but also reduce T&D losses. Efficient technologies such as smart meters will further reduce AT&C losses caused by defective meters and meter reading errors. These energy efficiency improvement measures will collectively help to reduce the overall T&D losses and improve energy reliability, as shown in Figure 7-14. If no measures are taken to curb these losses, it can be observed that the losses will continue to increase under the BAU-HT scenario conditions. The HHI for the transmission and distribution (T & D) losses is calculated based on the normalised values for proportion of T & D losses in a particular year over the period 1975 to 2050.

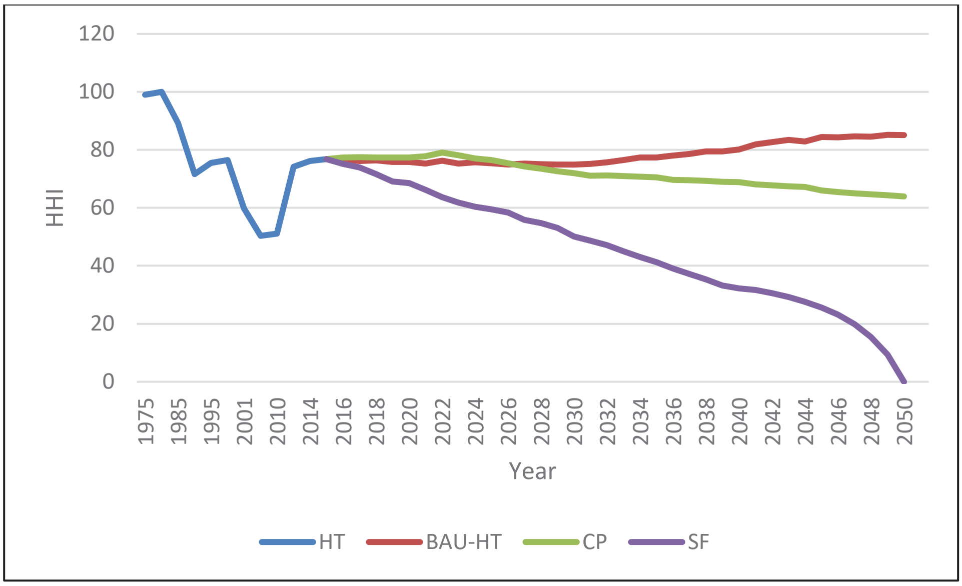


Figure 7-14: Revised normalised index-T&D losses (in %), 1975 – 2050

Source: Author's compilation

Further, improved diversity in the total fuel mix will help increase the energy reliability as demand will no longer concentrate on a single fuel, such as coal and oil. This is shown in Figure 7-15. The HHI for total final consumption is calculated based on the normalised values for proportion of various fuel sources including coal and lignite, crude petroleum, natural gas and electricity as part of the total energy consumption in a particular year over the period 1975 to 2050. Improved diversity will also reduce India's dependence on imports of coal and oil that are generally sourced from politically volatile and vulnerable regions. A rising share of renewable energy in the total fuel mix also indicates a transition to cleaner fuel sources, thus helping to curb GHG emissions (see Chapter 6, Section 6.2.2).

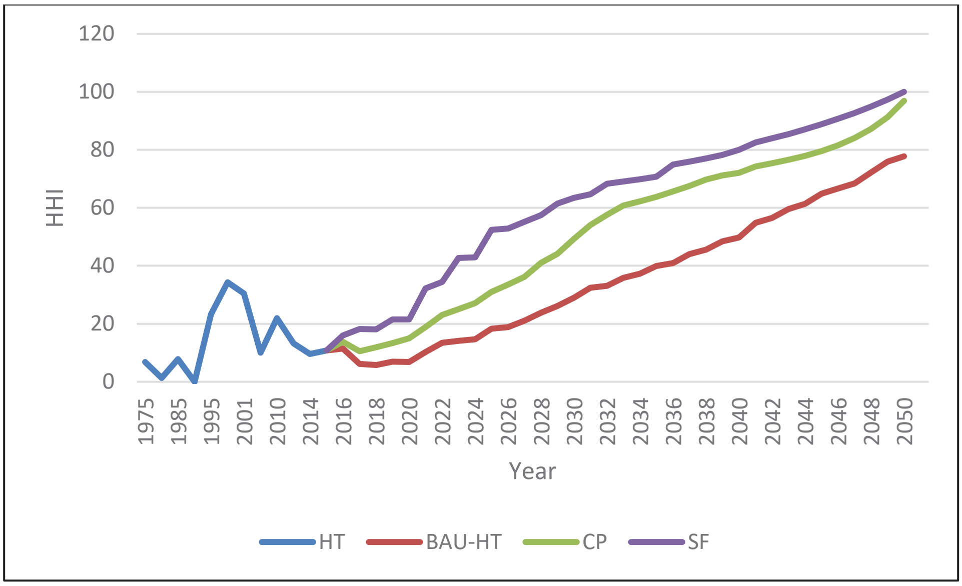


Figure 7-15: Revised normalised index–total final consumption (in %), 1975 – 2050

Source: Author's compilation

Increasing efforts to improve the diversity in the fuel mix in generation plants and in final consumption and to reduce T&D losses will collectively contribute to a corresponding increase in overall energy reliability. As a result, energy reliability in the SF scenario is the highest compared to the CP and BAU-HT scenarios over the period 2015-2050, as shown in Figure 7-16, reflecting the ambitious energy efficiency improvement measures taken. Energy reliability in the BAU-HT, CP and SF scenarios rises to 43, 55 and 69 by 2025, to 52, 64 and 66 by 2035 and to 56, 67 and 74 by 2050 respectively.

The composite index for energy reliability (in %) is determined by calculating the HHI for the normalised values in a particular year over the period 1975 to 2050 for the following:

1. the proportion of various fuels such as coal, oil, natural gas, hydro, nuclear and renewable in the electricity generation mix,

2. the proportion of transmission and distribution (T&D) losses,

3. the proportion of consumption each fuel including coal, lignite, crude petroleum, natural gas, and electricity as part of the total energy consumption.

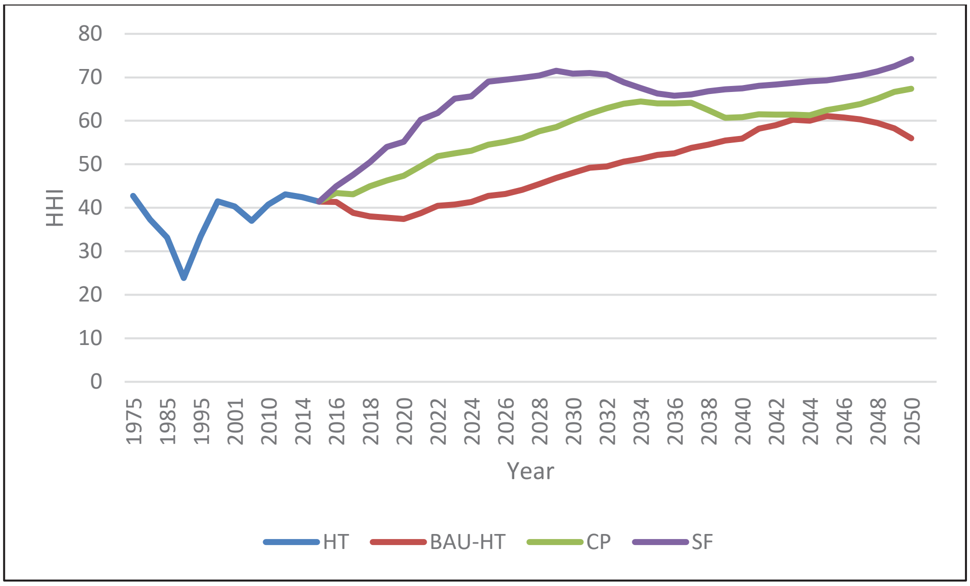


Figure 7-16: Revised composite index-energy reliability (in %), 1975 – 2050

Source: Author's compilation

7.2.5 Revised energy sustainability

To describe energy sustainability, the future trends of key GHG such as CO_2, CH_4 and NO_x on a per capita basis resulting from anthropogenic and non-anthropogenic activities related to the economy and population growth will be discussed across the three long-term scenarios of BAU-HT, CP and SF scenarios from 2015 to 2050.

As per the analysis, total CO_2 emissions in India will decrease with an increase in the population in the future according to the CP and SF scenarios. This will result from energy efficiency initiatives that reduce energy consumption, such as shifts in the iron and steel industry from coal-blast furnaces to DRI technologies (see Chapter 6, Section 6.2.6). As these initiatives continue to take effect into the future, emission intensities will fall at a faster rate, thus improving energy sustainability. As can be observed in Figure 7-17, the normalised values of CO_2 emissions per capita according to the SF scenario are greater than those in the BAU-HT scenario, indicating an increase in energy sustainability across the two alternative scenarios of CP and SF as compared to the BAU-HT scenario. The HHI for CO_2 emissions per capita (in CO_2 eq per capita) is calculated based on the normalised values of the emissions per capita for CO_2 in a particular year over the period 1975 to 2050.

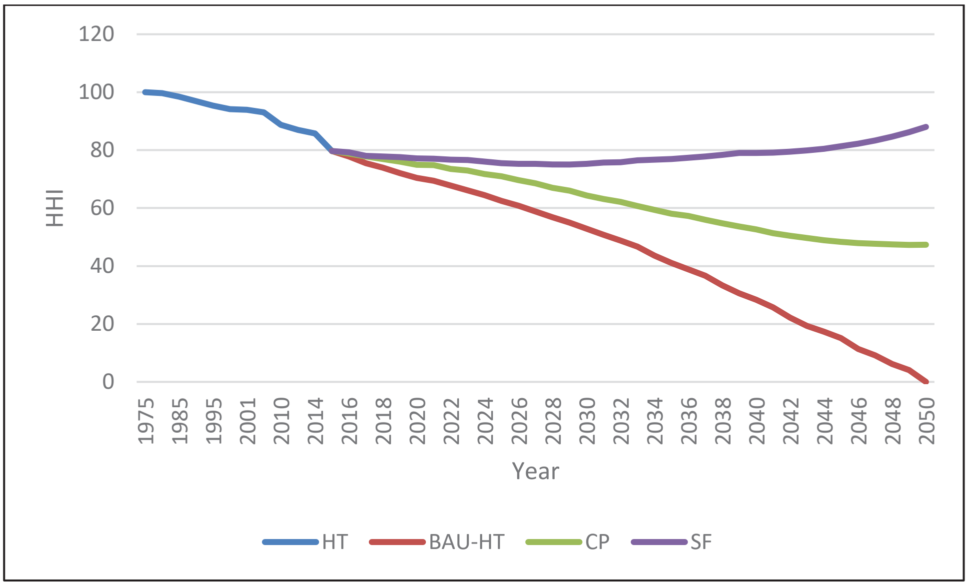


Figure 7-17: Revised normalised index-CO_2 emissions per capita (in CO2 eq per capita), 1975 – 2050

Source: Author's compilation

The largest contributors to CH_4 emissions are livestock such as cows and buffaloes, waste and fossil fuels. By adopting energy efficiency improvement measures, new technology can help to improve cattle feed and digesters. Further, use of efficient pump sets and tractors help better cultivation of rice paddies that would otherwise require high levels of water and warm weather. These collective efforts, especially in the agriculture sector, will help reduce the overall CH_4 emissions intensity in the future, thus improving the energy sustainability across the two alternative scenarios of CP and SF as compared to BAU-HT scenario as shown in Figure 7-18. The HHI for CH_4 emissions per capita (in CO_2 eq per capita) is calculated based on the normalised values of the emissions per capita for CH_4 in a particular year over the period 1975 to 2050.

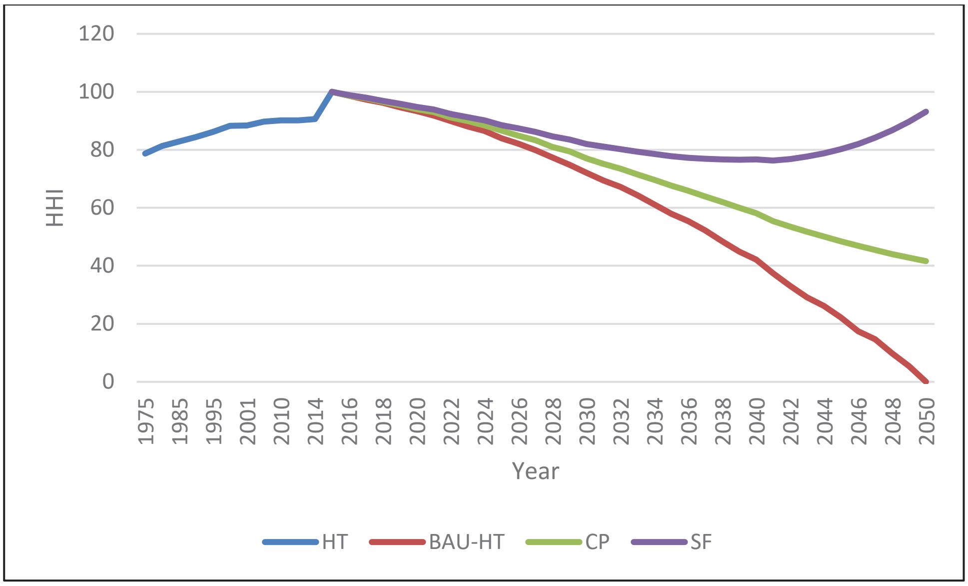


Figure 7-18: Revised normalised index-CH_4 emissions per capita (in CO2 eq per capita), 1975 – 2050

Source: Author's compilation

NO_x emissions can be reduced by improving agricultural and livestock practices, including energy-efficient fuel pump sets and tractors and better use of nitrogen-based and organic fertilisers. Further, new and efficient technologies in the manufacturing and construction industries can also contribute to lower emissions. Use of alternative renewable energy sources for electricity generation will reduce dependency on oil and gas, which in turn will help to greatly reduce NO_x emissions (see Chapter 6, Section 6.2.6). Such collective efforts to encourage and incorporate energy-efficient technology will help to reduce the overall NO_x emissions in the future and improve energy sustainability, as can be seen in Figure 7-19. Energy sustainability is highest in the SF scenario in the future compared to the BAU-HT scenario. The HHI for NO_x emissions per capita (in CO_2 eq per capita) is calculated based on the normalised values of the emissions per capita for NO_x in a particular year over the period 1975 to 2050.

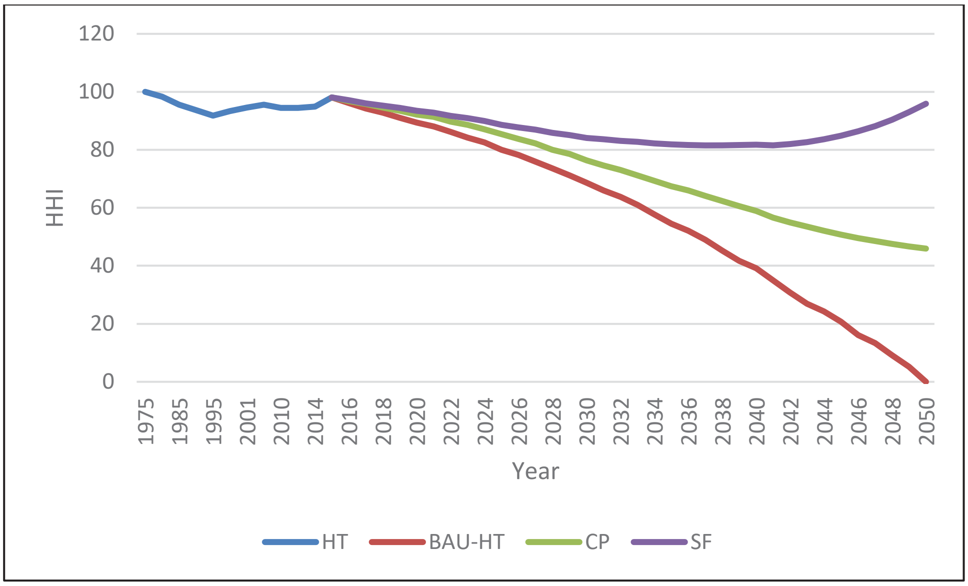


Figure 7-19: Revised normalised index-NOx emissions per capita (in CO2 eq per capita), 1975 – 2050

Source: Author's compilation

Overall GHG emissions will decrease in the future, as shown in Figure 7-20, as a result of increased efforts to adopt energy-efficient technologies such as and DRI technology in the iron and steel industry, increase in the use of renewable energy for power generation and switching to more efficient fuels such as biofuels in the transport sector. The composite index for energy sustainability (in CO_2 eq per capita) is determined by calculating the HHI for the normalised values of the emissions per capita for CO_2, CH_4 and NO_x in a particular year over the period 1975 to 2050. If historic practices continue in the future with no energy efficiency measures, however, the environment will be greatly degraded, and energy sustainability will become increasingly negative, as can be seen in the BAU-HT scenario (see Chapter 6, Section 6.2.6). In this scenario, the normalised values for energy reliability decline at an exponential rate from 75 by 2025, to 51 by 2035 and to 0 by 2050. In the CP scenario, energy reliability decreases slowly from 81 by 2025 to 64 by 2035 and to 45 by 2050. In the SF scenario, the energy reliability index reduces in the short to medium term from 93 in the base year 2015 to 84 by 2025 and to 79 by 2035, then increases slightly in the long-term to 82 in 2045 and 92 by 2050. As energy efficiency measures continue to improve in the future for the CP and SF scenarios, reduced energy consumption, diversity in the generation and final fuel mix with an increasing share of cleaner renewable resources will all collectively help to reduce GHG emissions while achieving economic growth and better living standards for the growing population in the future.

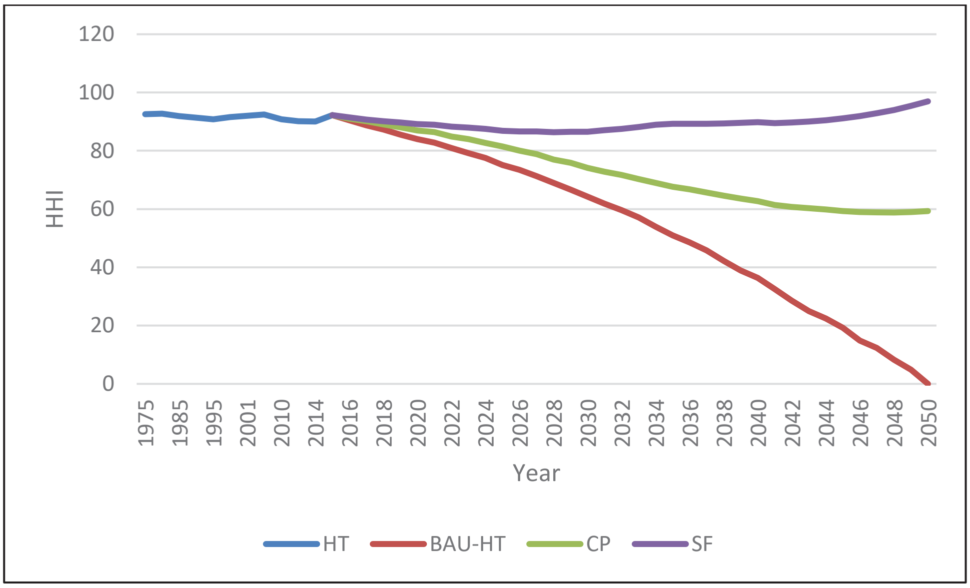


Figure 7-20: Revised composite index-revised energy sustainability (in CO2 eq per capita), 1975 – 2050

Source: Author's compilation

7.3 An Assessment of Energy Security for the Future

As explained in Chapter 2, the composite index for energy security was obtained by the linear aggregation of the weighted and normalised values of the individual indicators for the years 1975 to 2050. Energy security was assessed in three different composite indices which were aligned with the objectives of each of the long-term BAU-HT, CP and SF energy scenarios developed in this research. The trend analysis was carried out first by assigning equal weight to all the energy security attributes being considered to reflect the objectives of the BAU-HT scenario. In the second and third analysis of the trends was carried out by assigning unequal weights to the energy attributes to align them with the objectives of the CP and SF scenarios.

7.3.1 Composite index for energy security (CI-ES1: Equal Weights)

A composite index (HHI) of Energy Security (CI-ES1) is computed based on equal weights assigned to the normalised values of each of the key energy attributes of availability, affordability, accessibility, reliability and sustainability, as shown in Figure 7-21. Equal weight implies the recognition of an equal status for all indicators. Equal weights using an assumed value of 0.2 per attribute (there being 5 attributes), were assigned to each attribute.

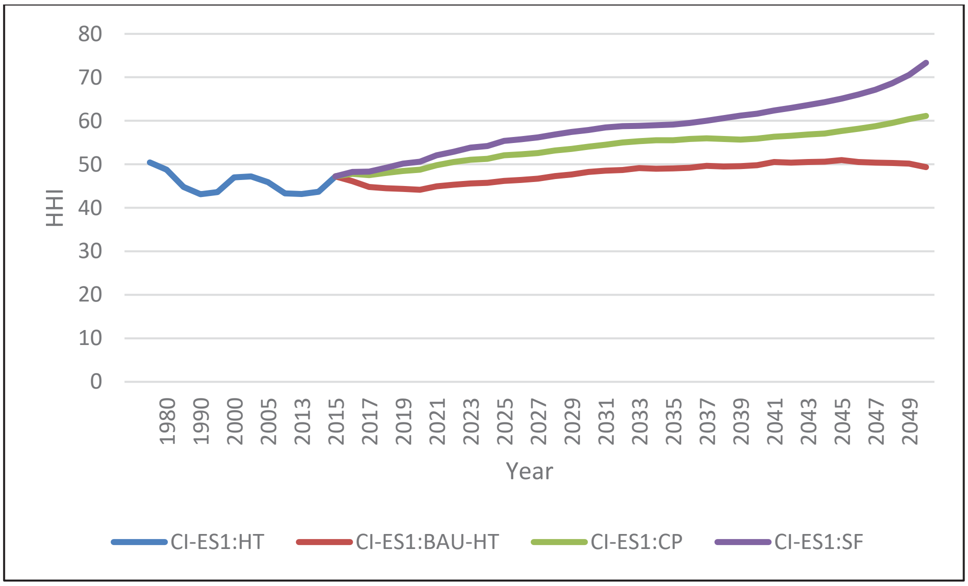


Figure 7-21: Revised composite index-energy security (CI-ES1), 1975 – 2050

Source: Author's compilation

As can be seen in Figure 7-21 above, the overall trend of energy security improves into the future in line with increasing energy efficiency improvements. If historic practices with no long-term energy efficiency improvement measures in place, that is, in the BAU-HT scenario, continue, the energy security index remains relatively constant at 48. As moderate efficiency measures are taken, the energy security index improves to 52 by 2025, to 56 by 2035 and to 61 by 2050 in the CP scenario. As more aggressive energy efficiency measures are put in action, the energy security index according to the SF scenario increases further to 55 by 2025, to 59 by 2035 and to 73 by 2050. This improvement in the energy security index across the alternative CP and SF scenarios is a result of introducing energy-efficient technologies such as DRI technology in the iron and steel industry, hybrid and electric vehicles with better fuel economy in the transport sector, efficient pump sets and tractors in the agriculture sector and efficient end-use electrical appliances in the residential and commercial sectors. These efforts cumulatively help to reduce the overall consumption of energy while achieving economic growth and improved standard of living conditions, thus reducing the production of and pressure to imports these resources; it also increases the diversity of the fuel mix and helps the transition away from fossil fuels to cleaner nuclear and renewable energy resources, thus reducing the adverse impacts on health and the environment in the future.

7.3.2 Composite index for energy security (CI-ES2: Unequal weights)

The objective of the CP Scenario is '*access to affordable prices*', which places greater emphasis on the attributes of affordability and availability. Accordingly, the second composite index (HHI) of energy security (CI-ES2) will be computed based on assigning greater weight to the normalised values of energy availability (0.35) and energy affordability (0.35) and equal weight (0.10) to the remaining three attributes of energy accessibility, energy reliability and energy sustainability, as shown in Figure 7-22.

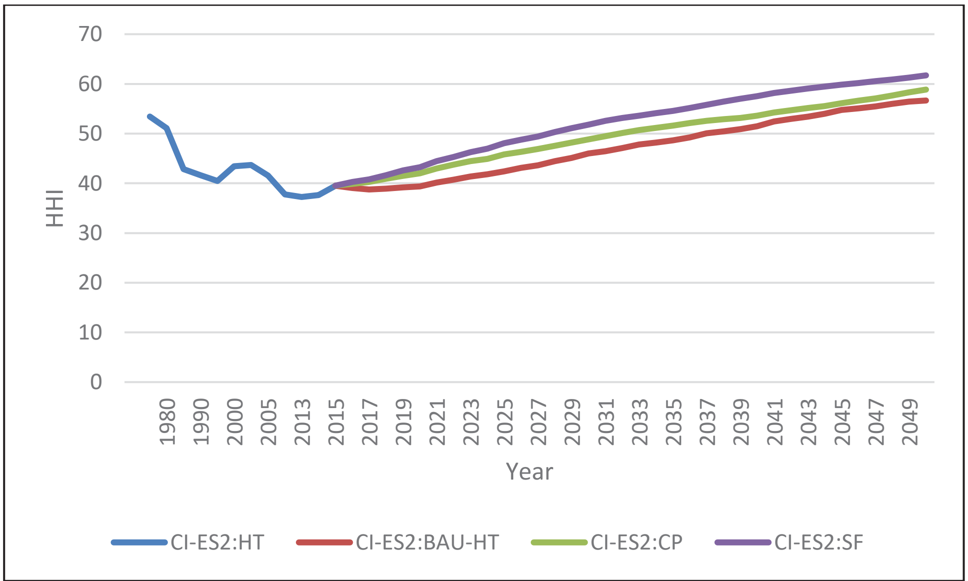


Figure 7-22: Revised composite index-energy security (CI-ES2), 1975 – 2050

Source: Author's compilation

According to this composite index, India is becoming more energy secure across all three scenarios in the future to 2050 compared to the historical trends from 1970 to 2014. All three scenarios - BAU-HT, CP and SF scenarios follow an overall similar trend but at different rates of improvement, 42, 46 and 48 respectively by 2025, 49, 52 and 55 respectively by 2035 and 57, 59 and 62 respectively by 2050. This indicates that as more energy efficiency improvement initiatives are put in action in the future, the more self-sufficient and hence energy secure the country will become.

7.3.3 Composite index for energy security (CI-ES3: Unequal Weights)

The objectives of the SF scenario are '*access to affordable, reliable and modern energy services*' and '*urgent action to combat climate change and its impacts*'. This places greater emphasis on the attributes of affordability and availability. Accordingly, the third composite index (HHI) of energy security (CI-ES3) is based on assigning higher weights to the normalised values of energy accessibility (0.30) and energy sustainability (0.30), a little less weight to energy reliability (0.20) and equal weights (0.10) to the remaining two attributes of energy availability and energy affordability, as can be seen in Figure 7-23.

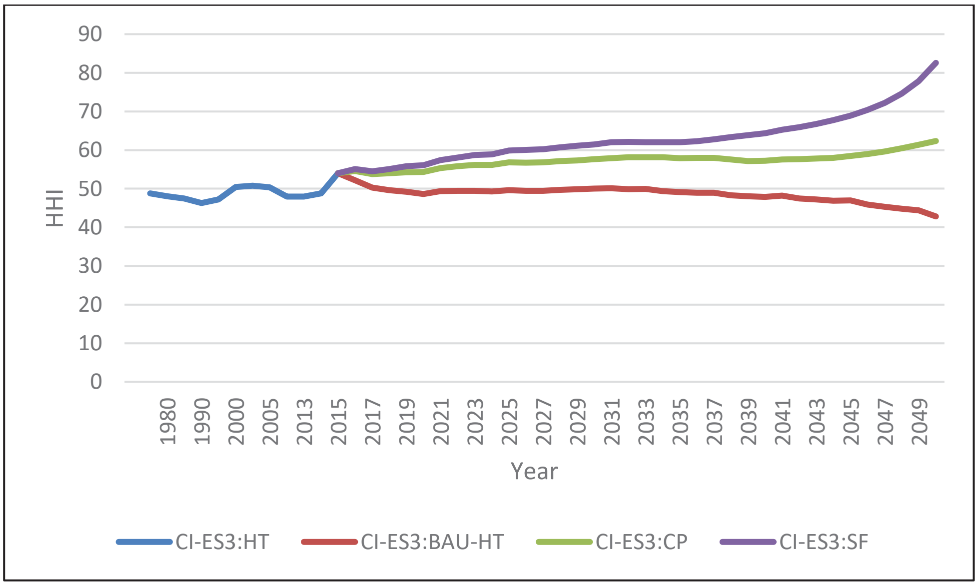


Figure 7-23: Revised composite index-energy security (CI-ES3), 1975 – 2050

Source: Author's compilation

If historical trends continue according to CI-ES3, India will become more energy insecure. As the trend in the BAU-HT scenario in Figure 7-23 shows, the index gradually decreases from 50 by 2025, to 39 by 2035 and to 43 by 2050. In the CP scenario, however, the country becomes gradually more energy secure as moderate energy efficiency improvement measures are put in place. The index rises from 54 in the base year of 2015, t0 57 by 2025, to 58 by 2035 and to 62 by 2050, indicating there is potential for technological innovations to attain better energy efficiency in the long term. In the SF scenario, India can expect to become energy secure at a faster rate as aggressive energy efficiency measures are put in action. Here, the index rises from 60 by 2025 to 62 by 2035, and to 83 by 2050.

7.4 Summary of Key Findings

This chapter examined the assessment of energy security for India in the future. The assessment was carried out by developing a composite index using equal and unequal weights for the attributes of energy accessibility, affordability, availability, reliability and sustainability in three different composite indices. A summary of the key findings is noted below, based on the recalculation of the energy attributes as a result of the data analysis:

- For the recalculated energy availability, the overall trend decreases in the future as a result of increasing efforts to introduce energy efficiency improvement measures across the BAU-HT, CP and SF scenarios of over the period 2015-2050. Comparing the behaviour of the attributes among the scenarios, energy availability increases in the BAU-HT scenario from 49 in 2025, to 59 in 2035 and to 80 in 2050; for the CP scenario energy availability increases from 56 in 2025, to 52 in 2035 and 55 in 2050; for the SF scenario energy availability increases in the short to medium term from 45 by 2025 to 49 by 2035 and decreases in the long-term to 25 by 2050.

- For the recalculated energy affordability, as more ambitious steps are taken to boost energy efficiency improvement measures in the future across all end-use sectors of the economy, energy consumption falls, and energy cost savings potentially increase. Energy affordability increases across all three scenarios from

29, 34 and 36 in 2025 to 37,43 and 51 by 2035 and to 48, 58 and 75 by 2050 in the BAU-HT, CP and SF scenarios respectively. In the CP and SF scenarios, cost savings are a lot higher compared to the BAU-HT scenario, where little to no effort is devoted to energy efficiency initiatives.

- For the recalculated energy accessibility, although overall energy consumption in absolute terms decreases due to an increase in energy efficiency improvement measures across the CP and SF scenarios compared to the BAU-HT scenario, the proportion of population gaining access to modern energy sources increases along with an increase in population, a result of the increased rate of urbanisation, efforts to boost rural electrification and improved lifestyle practices resulting from increased affordability. The energy accessibility index decreases in the short term from 39 in the base year 2015 to 36 by 2025, after which it shows a linear increase to 46 by 2035 and 63 in 2050 in the BAU-HT scenario. In the CP and SF scenarios, there is an exponential increase in the short-to-medium term, 46 and 42 by 2025 and 54 and 50 by 2035 respectively. In the long term, the accessibility index continues to increase to 80 in the CP scenario and 100 in the SF scenario by 2050.

- For the recalculated energy reliability, increasing efforts to improve diversity in the generation fuel mix and end-use consumption, along with efforts to reduce T&D losses, collectively help increase India's overall energy reliability. The energy reliability in the SF scenario is the highest compared to the CP and BAU-HT scenarios over the period 2015-2050, reflecting the ambitious energy efficiency improvement measures taken. Energy reliability in the BAU-HT, CP and SF scenarios rises to 43, 55 and 69 by 2025, to 52, 64 and 66 by 2035 and to 56, 67 and 74 by 2050 respectively.

- For the recalculated energy sustainability, overall GHG emissions decrease as a result of increased adoption of energy-efficient technologies such as DRI technology in the iron and steel industry, increases in the use of nuclear and renewable energy for power generation and switching to more efficient fuels such as biofuels in the transport sector. As seen in the BAU-HT scenario, if historic practices continue into the future with no energy efficiency measures, the environment will be greatly degraded, and energy sustainability will fall. Energy reliability declines at an exponential rate in this scenario from 75 in 2025 to 51 by 2035 and to 0 by 2050. In the CP scenario, energy reliability decreases slowly rate from 81 in 2025 to 64 by 2035 and 45 by 2050. In the SF scenario, the energy reliability index falls in the short term from 93 in the base year 2015 to 84 by 2025 but increases in the medium to long term to 92 by 2050.

- Using the composite index CI-ES1, all five energy attributes are given equal weights of 0.20 to align with the objectives of the BAU-HT scenario. If historic practices with no long-term energy efficiency improvement measures in place continue, in the BAU-HT scenario, continue, the energy security index remains relatively constant at 48. As moderate efficiency measures are taken, the energy security index improves to 52 by 2025, to 56 by 2035 and to 61 by 2050 in the CP scenario. As more aggressive energy efficiency measures are put in action, the energy security index according to the SF scenario increases further to 55 by 2025, to 59 by 2035 and to 73 by 2050.

- Using the composite index CI-ES2, unequal weights are assigned to energy availability (0.35) and energy affordability (0.35) and equal weights (0.10) to the remaining three attributes of energy accessibility, energy reliability and energy sustainability, to align with the objectives of the CP scenario. India becomes energy secure across all three scenarios in the future to 2050 compared to the historical trends from 1975 to 2014. The BAU-HT, CP and SF scenarios follow an overall similar trend but at different rates of improvement, 42, 46 and 48 respectively by 2025, 49, 52 and 55 respectively by 2035 and 57, 59 and 62 respectively by 2050. This indicates that as more energy efficiency improvement initiatives are put in action in the future, the more self-sufficient and hence energy secure the country will become.

- Using the composite index CI-ES3, unequal weights are assigned to energy accessibility (0.30) and energy sustainability (0.30), a little less weight to energy reliability (0.20) and equal weights (0.10) to the remaining two attributes of energy availability and energy affordability to align with the objectives of the SF scenario. The trend in the BAU-HT scenario, the index gradually decreases from

50 by 2025, to 39 by 2035 and to 43 by 2050. In the CP scenario, however, the country becomes gradually more energy secure as moderate energy efficiency improvement measures are put in place. The index rises from 54 in the base year of 2015, to 57 by 2025, to 58 by 2035 and to 62 by 2050, indicating there is potential for technological innovations to attain better energy efficiency in the long term. In the SF scenario, India can expect to become energy secure at a faster rate as aggressive energy efficiency measures are put in action. Here, the index rises from 60 by 2025 to 62 by 2035, and to 83 by 2050.

Chapter 8 : Policy Trade-offs and Implications

8.1. Introduction

In Chapters 6 and 7, the energy and economic impacts associated with the three long-term energy scenarios of BAU-HT, CP and SF for India were quantified using an energy-oriented input-output model. India's energy security for the 35 years from 2015 to 2050 was assessed on the basis of these scenarios to identify the long-term energy policies and strategies that would be needed to deal with the country's future energy challenges, such as increasing energy demand, reduced levels of GHG emissions and reducing dependency on imported fuels without compromising the economic growth targets.

This chapter aims to extend the analysis by providing a more complete policy perspective. A trade-off analysis is carried out, taking into account the policy implications associated with the different choices that arise from the scenario analysis. Section 8.2 discusses the policy trade-offs between key factors of economic growth, primary energy requirements, GHG emissions, energy diversity, energy import dependency, employment and trade balances. Section 8.3 is a summary of the key findings and concludes the chapter.

8.2. Policy Trade-offs

This section will discuss the trade-offs between the various key macroeconomic indicators that are important from the point of view of policy decision making.

- As shown in Figure 8-1, in the BAU-HT scenario, the GDP will increase by more than 8 times over the 35-year period, from US$2224 Bn in 2015 to US$18285 Bn in 2050. If current trends continue, primary energy requirements will increase 5 times from 1046.9 Mtoe in 2015 to 5632.1 Mtoe in 2050, and GHG emissions will increase by more than 5 times from 2779 $MtCO_2$ -e in 2015 to 15084 $MtCO_2$ -e in 2050.

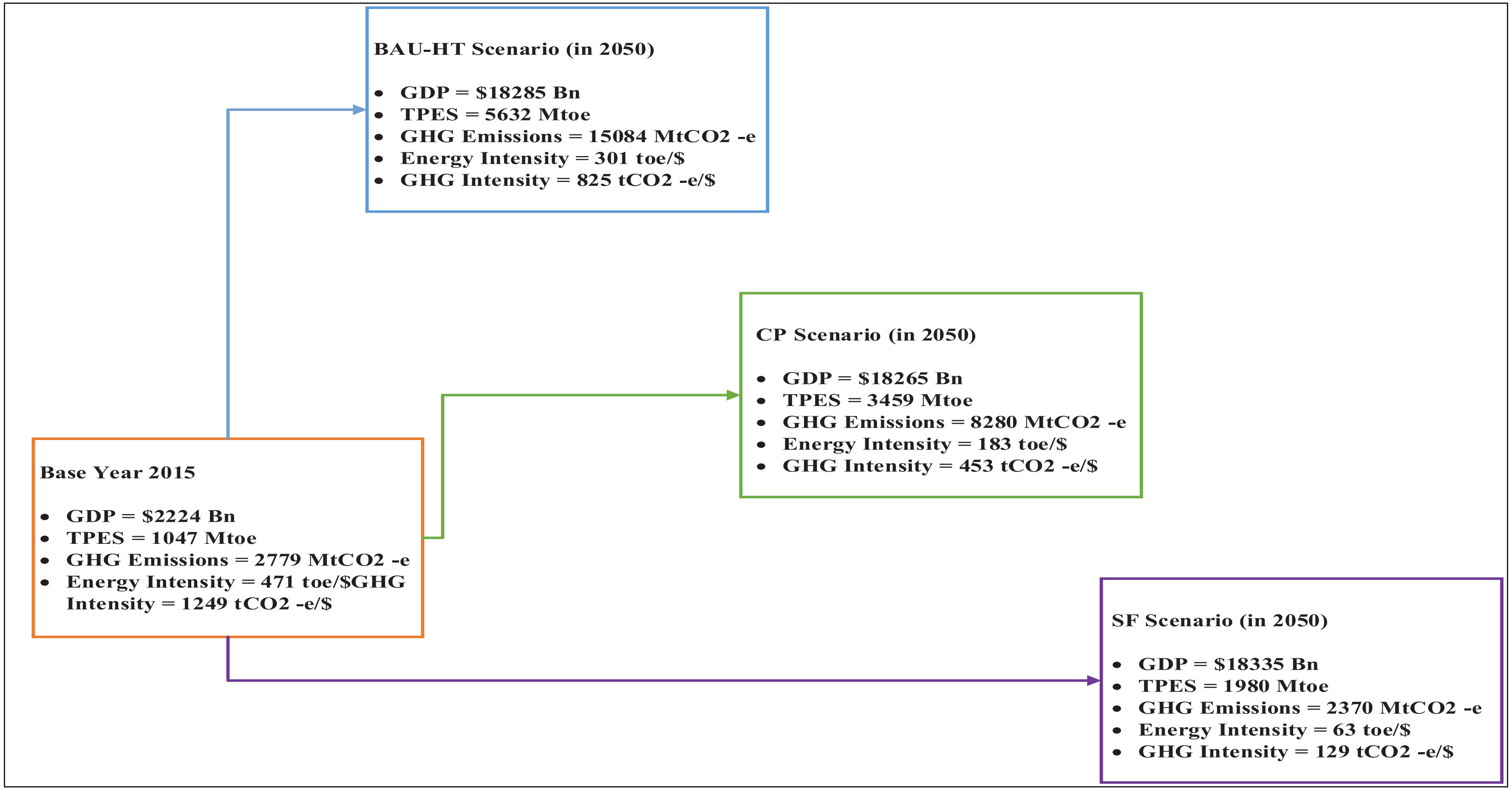


Figure 8-1: Summary of Key Macroeconomic Impacts in 2050

Source: Author's compilation

Note: Various values in this figure have been rounded-off into whole numbers – to facilitate exposition.

- The continuation of these trends to 2050 would see unappreciable impact on the energy mix. Coal will continue to be the dominant fuel (about 36% of the total), followed by oil at 32% of the total. The share of natural gas and nuclear would respectively be 4% and 2% of the total. Renewable energy will constitute about 25% of the total energy supply mix by 2050.

- The continuation of these trends to 2050 would see no significant impact on India's net energy import dependency. India will still be importing approximately 20% of its energy needs, with oil the dominant import fuel (about 40% of total energy imports). Oil will be followed by natural gas (22% of total energy imports) and coal (13% of total energy imports).

- India will become a net importer of goods and services if present trends continue to 2050. The country will have a trade deficit of \$539.2 Bn, with the manufacturing sector being the dominant sector with a deficit of \$665.9 Bn, followed by the energy industry, including mining, at \$533.9 Bn. On the other hand, transport, agriculture and commercial services sectors will be net exporters of goods and services, to the tune of \$181.8 Bn, \$47.1 Bn and \$431.7 Bn by 2050.

- There will be an increase in the number of jobs, reflecting a growth in population and an increase in personal wealth. Employment will increase from 601.2 Mn people in 2015 to 811.8 Mn people in 2050. However, employment by economic activity will remain relatively the same over the study period, with the agriculture sector constituting 55% of the total because of its high labour-intensive agricultural practices and minimal use of automation technology.

- To avoid adverse consequences likely to result if current energy policy trends continue (BAU-HT scenario), India will need to focus on new long-term energy strategies. These new strategies, as examined in this research through the CP and SF scenarios, reflect the nature of such adjustments at the macro level. The scenarios emphasise:

- reducing total primary energy demands
- diversifying the energy mix
- reducing dependency on imported energy sources
- improving both demand and supply-side efficiencies
- increasing the use of alternative fuels and technologies
- increasing diversity in electricity generation, in both technology and fuel mix, and
- reducing GHG emissions while promoting economic growth.

To achieve these macroeconomic goals, significant adjustments will need to be made at the micro level, that is, at the level of the individual sectors (agriculture, industry, transport, residential and commercial services) of the economy.

- By taking such efficiency measures, India’s primary energy consumption increases at a reduced rate of 3 times and 2 times from 2015 to 2050 in the CP and SF scenarios respectively as compared to 5 times for the BAU-HT scenario over the same period. Such energy efficiency improvement measures could reduce India’s total primary energy requirements relative to the BAU-HT scenario by 39% and 65% for the CP and SF scenarios respectively and the GHG emissions by 45% and 84% in the CP and SF scenarios respectively by 2050.

- The energy efficiency improvements are supported through increase in investments in efficient technologies across all key sectors of the economy which account for a decrease in the total primary energy requirements. The investments in the non-energy sectors are at a higher rate as compared to those in the energy sectors of the economy, for instance, in the CP scenario, investments in the non-energy sector increase at the rate 8.4% p.a. and in the energy sector - at the rate of 4.5% p.a., while in the SF scenario, investments in the non-energy sector increase at the rate of 8.5% p.a. and in the energy sector increase at the rate of 2.2% p.a. from 2015 to 2050.

- These goals can be achieved by increasing the share of nuclear power in the electricity generation mix from 3% in 2015 to 4% in the CP scenario and to 11% in the SF scenario by 2050. Coal-fired power plants would need to be replaced by gas-fired plants, which would increase the share of natural gas in the fuel mix from 5% in 2015 in the SF scenario to 17% by 2050, while the share of natural gas will remain constant at 5% from 2015 to 2050 in the CP scenario. These increases in the use of natural gas and nuclear power would increase the import of natural gas from 18% in the base year (2015) to 28% in the SF scenario by 2050. Uranium imports will increase from 12% in the base year (2015) to 13% for the CP scenario and 14% for the SF scenarios by 2050.

- In the SF scenario, the share of coal-fired power plants in total electricity generation will constitute 12% while the share of renewables would account for 60% by 2050.

- The impact of adopting energy efficiency policies on the GDP of the BAU-HT scenario would be miniscule − by 2050, GDP would have fallen by only 0.09% in the CP scenario and will increase by 0.27% in the SF scenario.

- The manufacturing and commercial services sectors have a high ranking in terms of their value-add, total industry output and employment generation. According to the CP scenario, the manufacturing and services sectors will have respectively contributed 19.5% and 50% of the total value added by 2050; in the SF scenario these sectors will have contributed 20% (manufacturing) and 51% (services) of the total value added to industry. In terms of the total industry output, the manufacturing and services sectors will respectively constitute 26.9% and 42.5% of the total industry output by 2050 in the CP scenario and 26.4% and 43.9% of the total industry output by 2050 in the SF scenario. In terms of employment, the manufacturing and services sectors respectively will constitute 14.5% and 24% of total employment by 2050 in the CP scenario and 15% and 25% of total employment by 2050 in the SF scenario. In terms of India's socio-economic development strategy, these sectors are key to successful industrialisation and currently account for a considerably large share (nearly 70%) of the GDP. Thus, if appropriate energy policies, such as those requiring improved building design and introducing efficient appliances such as LED lighting, efficient fans, and air-conditioning systems, refrigerators and so on, are applied in these sectors, there is potential for significant energy savings and hence improvement in energy security.

- Compared to other economic sectors, the agricultural sector is ranked in the middle in terms of its contribution (19%) to India's total industry output. However, the agriculture sector is characterised by its high contribution to income generation and employment, generating 55% of all employment in India. The agriculture value added is nearly 21% of the total value added to industry for both the CP and SF scenarios. The agriculture sector is expected to make a significant contribution to the country's energy diversity strategy by supplying inputs to biofuel production. Additionally, the government's efforts to boost renewable energy will bring more jobs and income in rural areas.

- The transport sector, particularly road and rail transport, is ranked low in terms of employment generation, accounting for about 4.3% of India's total employment figures. This is expected to continue into the future as a result of improved standards of living and changing lifestyle practices. This sector is, however, ranked low in terms of energy consumption; it accounts for 9% of total consumption in the CP scenario and 2% of the total in the SF scenario and its output contribution stands at about 8% of the industry total in both scenarios. The transport sector has advantages over other sectors in terms of its potential to improve energy intensity and reduce GHG emissions, supported by such measures as alternative fuels, improved vehicle fuel economy and better public transport infrastructure to reduce the number of vehicles on the roads.

- Both the CP and SF scenarios see job losses in the energy sector, because of declining energy demand. The total employment in the energy sector declines from 2.9% in the BAU-HT scenario to 2.2% and 1.2% of the total employment by 2050 for the CP and SF scenarios respectively. For example, the employment from the electricity sector will account for 0.7% in the CP scenario and 0.3% in the SF scenario of the total employment; these would, however, be offset by new jobs in the non-energy sectors, particularly in the industry sector. This implies that adopting energy efficiency policy measures would result in shifts in employment and salaries from energy to the non-energy sectors of the economy.

- In terms of India's trade balance, introducing higher energy efficiency targets would reduce trade deficits in both the CP and SF scenarios. Improvements in energy efficiency have the potential to make a positive impact on the energy industry (including electricity) by reducing energy imports and increasing energy exports. The transport and services sectors will be net exporters according to the scenario analysis, as a result of more clean fuel technology in the transport sector and more electricity generation from new and renewable energy sources. For instance, in the CP and SF scenario, transport sector will account for a trade balance of US$174 Bn and US$151 Bn respectively in 2050.

- This research has shown that the electricity sector, which is a major contributor to GHG emissions, would need significant transformation, specifically by increasing the diversity in its power generation fuel mix and shifting the technology from coal-based power plants to new and renewable energy. The industry sector would need to increase its focus on energy-intensive industries such as iron and steel, cement and non-ferrous metals, as these offer greater opportunities for energy savings from improved process technologies and efficiencies. The transport sector would need to mandate fuel efficiency standards and increased use of alternative fuels such as CNG and biofuels to reduce India's dependence on imported oil. The promotion of advanced technologies such as hybrid and EV cars, as well as improved public transport infrastructure, will help improve the overall energy efficiency of the transport sector. The agriculture sector will see a shift from labour-intensive practices to energy-efficient equipment such as efficient water pump sets and tractors. The residential and commercial services sectors, which are significant consumers of electricity, would need energy efficiency and conservation improvements in end-use appliances and building design and construction that focused on reducing energy consumption.

- To reduce overall GHG emissions and their adverse impact on the environment, India will need to increase its use of low-carbon energy resources, such as natural gas, nuclear and renewable energy. As India has limited indigenous natural gas reserves, it is dependent on imported sources. The use of nuclear and renewable energy in combination with other available domestic energy resources will help to enhance the security of its energy supply. While nuclear and renewable energy sources are clean in terms of GHG emissions, special care needs to be taken to increase the safety aspects of nuclear technology and the competitiveness of renewable energy. Among the other resources, coal is the only fossil fuel available domestically in abundance, but it has the disadvantage of being the largest source of GHG emissions, particularly CO_2 emissions. To take advantage of the availability of coal in a more sustainable way, it is important to shift existing coal combustion technologies to more efficient supercritical coal combustion technology or gasification-based IGCC technologies in the future, thereby improving efficiency and cost.

The key policy trade-offs are summarised as shown in Table 8-1. The representation is the percentage difference (growth or decline) for the BAU-HT, CP and SF scenarios for the years 2025, 2035 and 2050 with respect to the corresponding values for the base year 2015.

Indicators	2025			2035			2050		
	BAU-HT	CP	SF	BAU-HT	CP	SF	BAU-HT	CP	SF
GDP	xx	xx	xx	xxxx	xxxx	xxxx	xxxx xxxx	xxxx xxxx	xxxx xxxx
Employment	x	x	x	xx	xx	xx	x	x	x
Trade Balance	x	x	x	xx	xxx	xxx	xxxxx	xxx xxx	xxx xxxx
Primary Energy Demand	xx	xx	xx	xxx	xx	xx	xxxxx	xxx	xx
GHG Emissions	xx	xx	x	xxx	xx	x	xxxxx	xxx	x
Investments	xxx	xxx	xxx	xxx xxx	xxx xxx	xxx xxx	xxxx xxxx xxxx xxxx	xxxx xxxx xxxx xxxx	xxxx xxxx xxxx xxxx
Rebound Effect	x	x	x	x	xx	xx	xxx	xxxx	xxxxx

Table 8-1: Summary of major policy trade-offs

Source: Author's compilation

Legend: The number of 'x' is the percentage difference with respect to the corresponding values for the base year 2015. For example, Investments are 3% in 2025, 6% in 2035 and 16% higher in 2050 in each scenario as compared to the base year 2015.

8.3. Summary of Key Findings

This chapter has identified some key policy trade-offs that will be needed in order to improve the effectiveness of energy policies, and hence their ability to redress the energy security challenge in India. The summary of the key findings includes the following:

- If the trends resulting from its current energy policies continue, India by 2050 will experience a 5-fold increase in primary energy requirements and GHG emissions and will significantly increase its dependency by 17% on imported energy sources, primarily coal (13%) and oil (38%). The severity of the impacts of such outcomes can potentially be reduced by adopting appropriate policy strategies as described in the CP and SF scenarios. These scenarios emphasise increasing the diversity of the energy mix, improving demand and supply-side efficiencies, increasing the use of alternative fuels and technologies and reducing overall GHG emissions.

- The analysis has indicated that India would need to diversify its energy mix in the coming decades to reduce energy consumption and limit the GHG emissions. The outcomes from the two alternative scenarios of CP and SF scenario in this research demonstrate that energy efficiency improvement initiatives will have to be introduced on both the supply and demand sides, through the application of new and advanced efficient technologies. For instance, DRI in the iron and steel industry, hybrid car technology and increase use of alternative fuels such as CNG, ethanol and biofuels in the transport sector and IGCC technologies in power generation.

- Shift the energy system from current coal- and oil-based system to one which would be more diverse in energy resources such as nuclear and renewable energy. For instance, increase the share of renewable energy in power generation and introduction of solar panels in the residential sector.

- To achieve the policy goals set in the alternative CP and SF scenarios, India's economy would experience some positive as well as negative impacts. The impacts at the aggregate level, measured in terms of total output and employment, would be marginally negative. At the individual sectoral level, some sectors, particularly the energy sector, would endure negative impacts in terms of loss of employment. Some of the non-energy sectors (e.g. agriculture, manufacturing) on the other hand would benefit. The loss of income from the traditional energy sectors (coal, oil, gas, and electricity) could be compensated by the generation of employment in the non-energy sectors of the economy, mainly due to the increased use of renewable energy sources such as solar, wind and biomass, which are inputs produced within the country itself. This indicates a transfer of income and employment from the energy to the non-energy sectors (which do not show up at the aggregate level analysis) would have a positive impact on the domestic economy.

- The additional employment resulting from the increased use of renewable energy sources could also benefit rural areas. For example, increased demand for biomass could generate employment in the rural-based agriculture sectors. Similarly, the renewable energy plants such as wind and solar farms are usually installed in the rural areas. This could bring investment and jobs in these rural communities.

- This research has shown that through the alternative scenarios (CP and SF), could result in a significant lowering of the energy intensities in the economic sectors as compared to the BAU-HT scenario. For example, energy efficient improvement in the production technology should be promoted in sectors such as the iron and steel industry, chemical industry and the transport. Also, in sectors such as the construction and services efforts should be directed to reducing the input of energy intensive materials, otherwise even if efficient technologies are used the total energy consumption would not improve significantly because of the share high energy consumption by the inputs.

- In terms of cost competitiveness, introduction of energy efficient technologies requires high capital investment as seen from the results of the alternative scenarios – CP and SF scenario. For example, the investment in the non-energy sectors of iron and steel industry, chemical industry and transport sector would require more capital investment as compared to the energy sectors of coal, oil and natural gas. Electricity generation cost from fossil-fuel based plants is generally lower due to the lower investment cost and fuel cost as compared to the renewable energy plants. Further, fossil-fuel based plants are generally considered to be suitable to meet both base and peak load demands, whereas the renewable energy plants have the characteristics of being intermittent in nature and hence limited in terms of their ability to meet load demands reliably.

Chapter 9: Conclusion and Recommendations for Future Research

9.1 Introduction

This chapter discusses the objectives of this research, the summary of this research (including the research methodology), its main findings and some of its limitations. It also provides recommendations on how these limitations could be overcome in future research.

9.2 Research Objective

This research aimed to examine the role energy efficiency can play in redressing the energy security challenge in the context of India. Such challenges include meeting growing future energy demands while at the same time reducing dependency on imported energy and reducing GHG emissions, all while achieving economic growth.

9.3 Summary of the Research

The summary of the research is as follows:

- Review of the existing definitions of energy security and to establish an appropriate definition in the context of India to integrate the various themes of energy security. The review suggested that though extensive research has been conducted in this field, there is as yet no widely accepted definition of energy security. Based on this, a definition of energy security was developed in the context of this research, incorporating the key attributes of energy accessibility, affordability, availability, reliability and sustainability.

- Review of existing energy policies in India. The review suggested that the existing policies are narrow in their sectoral- or issue-specific, short-term perspectives, and in their fragmented and internally inconsistent viewpoints. This research argues that these policies, therefore, are incapable of addressing the long-term energy security challenge facing India. To address these limitations a deeper understanding of the nature of the challenges is needed in terms of the policy trade-offs which are critical from the point of view of policy decision-making. This is a difficult task due to the many interconnections and complex inter-relationships between energy, economy and environment - that are likely to have an impact on the policy decision-making. This can be achieved by developing a framework that will allow to capture these complex inter-relationships and linkages between the various sectors of the economy. This research has developed an analytical framework that comprises a scenario-based approach and a quantitative energy-oriented input-output model to determine the energy- and economy-wide impacts of the scenarios. Scenarios are developed to analyse the long-term impacts of energy efficiency to address the energy security challenge for India.

- The three scenarios developed in this research – BAU-HT, CP and SF – present different strategies for India for the study period 2015-2050. The outcomes of the CP and SF scenarios are better than those of the BAU-HT scenario in terms of all attributes. All three scenarios focus on five key variables that could transform India's energy sector. These variables are: diversity of energy supply mix, energy import dependency, technological advancement, socio-economic factors and GHG emissions. In addition, the issues arising from, for instance, ongoing talks at international level to reduce GHG emissions below a certain level were also taken into consideration in developing these scenarios.

- Analysis of these scenarios helped to assess the energy and economic impacts for the period 2015-2050. The results from each scenario were used to assess the impact on India's overall future energy security. The assessment was conducted by developing a composite index using equal and unequal weights for the revised energy security attributes to determine what constitutes energy security and how to measure it.

Salient features of the three long-term energy scenarios include:

- The BAU-HT scenario represents the continuation of current trends in energy policy. This scenario is characterised by no restriction on fossil fuels consumption in industries and power generation and no specific commitment to encourage renewable energy sources or to reduce GHG emissions. The level of commitment to environmentally-friendly energy production, socio-economic development, and technological breakthroughs is low.

- The CP scenario is based on the objectives of India's draft NEP 2017. This scenario is characterised by its moderate promotion of energy diversity, energy efficiency and renewable energy. In this scenario, some initiatives are taken to shift from a current high carbon-intensive fuel mix to a more diverse mix with higher proportions of new and renewable energy. It also aims to limit the consumption of fossil fuels and GHG emissions. Advanced and energy-efficient technologies are introduced in both the conversion and end-use sectors of the economy.

- The SF scenario is based on the objectives of the Sustainable Development Scenario introduced in the World Energy Outlook 2017. Compared to the CP scenario, the SF scenario is characterised by its higher level of urgency to boost energy diversity, energy efficiency and renewable energy. This scenario assumes there will be more restrictions on high energy-intensive technologies and a greater push to transition from fossil-based fuel sources to cleaner fuels such as renewable energy and biofuels.

- The scenario analysis indicates that as efforts to improve energy efficiency increase in the CP and SF scenario as compared to the BAU-HT scenario, the demand for primary energy demand decreases across the CP (3 times) and SF (2 times) scenarios as compared to the BAU-HT (5 times) scenario in 2050 with respect to the base year 2015. The decrease in energy demand contributes to a decrease in GHG emissions by 45% for the CP scenario and 84% for the SF scenario in 2050 as compared to the BAU-HT scenario.

- The efforts to transition from traditional conventional technology to more advanced energy efficient technologies come at a high cost of capital investment. The capital investment in the non-energy sectors (manufacturing, agriculture, transport) of the economy is higher (US$16123 Bn for the CP scenario and US$16642 Bn for the SF scenario in 2050) as compared to the energy (coal, oil, gas, electricity) sectors (US$344

Bn for the CP scenario and US$158 Bn for the SF scenario in 2050), indicating the replacement in technology and hence a decline in the demand for energy. Capital investment in the non-energy sector, for example, increase at the rate of 8.4% p.a. for the CP scenario and 8.5% p.a. for the SF scenario as compared to 8.3% p.a. for the BAU-HT scenario from 2015 to 2050, while capital investment in the energy sectors decrease at the rate of 4.5% p.a. for the CP scenario and 2.2% p.a. for the SF scenario as compared to 5.8% p.a. for the BAU-HT scenario over the same period.

- There is a rise in employment across the two alternative CP and SF scenarios as efforts to implement energy efficiency improvements grow. Employment increases in the non-energy sectors from 789 Mn people in the BAU-HT scenario to 807 Mn people in the CP scenario and 817 Mn people in the SF scenario, while in the non-energy sectors the employment decreases from 23 Mn people in the BAU-HT scenario to 18 Mn people in the CP scenario and 10 Mn people in the SF scenario in the year 2050.

- The results obtained through analysis of the BAU-HT, CP and SF scenarios were used to compute energy security in the future for India by assessing the five key energy attributes. Energy availability, accessibility, affordability, reliability and sustainability improves in CP and SF scenarios in the long term as compared to the BAU-HT scenario. This is a result of the steps are taken to encourage energy efficiency improvement across all end-use sectors of the economy, potentially leading to reduced energy consumption and increased energy cost savings. The greater diversity in the power generation fuel mix and final consumption and improvement in the electricity grid infrastructure reduces the T&D losses. In addition, the transition from traditional fuels to more clean energy sources (nuclear and renewable) decreases the overall GHG emissions.

Against the backdrop of the above findings, it can be seen that if historical trends were to continue in the future, the country will be increasingly energy insecure, the environment will be greatly degraded and there will be greater adverse health and climate conditions. However, as energy efficiency measures take effect, India will become significantly self-sufficient in energy and hence more energy secure in the future.

9.4 Recommendations for Future Research

In this section, some limitations of this research are presented and some recommendations made on how these limitations could be overcome in future research.

- This research focused on the macroeconomic impacts of energy efficiency. The policy settings, the characteristics of the end-use sectors and decision processes were examined at national level. It would be useful to carry out a similar analysis at state level. This would provide further legitimacy to broad generalisations, as they would be based on a consideration of the similarities and differences between the individual states and the national level.

- The input-output tables for India are developed by the MOSPI, usually at intervals of 5 years. These tables are, however, not in the same format from one interval to the next. The disaggregation of sectors has changed over the years. For instance, the 1968-69 tables were published with 60 sectors; subsequently, the tables from 1973-74 until 1998-99 consisted of 115 sectors. The current MOSPI input-output tables contain 130 sectors. In addition, the disaggregation of sectors is quite high in those sectors that are important for economy-wide impact analysis; the residential sector, for example, is still represented at aggregate levels. The evaluation of residential sector impacts on the economy can be better analysed if the sector can be disaggregated into urban and rural populations. This will allow better analysis of how the different consumption patterns of the population impact other sectors of the economy. The accuracy of the analysis also depends on the quality of the previous studies, such as aggregation and disaggregation of the economic sectors.

- One of the challenges in a study with a long-term perspective is to estimate and represent the evolution of the economic sectors realistically over the time period. Input-output models are static in nature and have their limitations because of their reliance on fixed technical coefficients. The technical coefficients were updated in this research based on the RAS method. However, economic sectors are diverse in nature and undergo significant changes over time. Dynamism in the projection could be introduced by using an input-output model with system dynamics models to study changes in behaviour over a time period.

- This research considered three scenarios for analysing the impact of energy efficiency improvements. There is potential to include additional scenarios reflecting a wide range of policy choices, in future research.

- The institutional dimension: i.e. what kind of institutions, organisations, rules, regulations and governance will need to be established to assess the impacts of the various scenarios and hence to implement the new policy strategies in place provides for a scope for future research.

- The current research focused on the energy sector and its impact on policy decision-making. However, it did not consider the impact the energy sector has on other scarce resources such as water and food. This research excludes the notion of the nexus relationship between energy-water-food and the impact of this nexus on policy decision-making. There is therefore scope for future research to extend this study to see the potential impact that energy efficiency improvement measures could have on water and food security and that an integrated, holistic approach may lead to better and more sustainable policy outcomes for India.

Appendices

Appendix A. Structure of Economic and Energy Sectors

A.1 Aggregation of Economic Sectors

Sector No.	Economic Sectors	IOT Sector No.
1	**Coal and Lignite**	27
2	**Crude petroleum**	29
3	**Natural Gas**	28
6	**Coal products**	64
7	**Oil products**	63
8	**Electricity**	107
9	**Paper manufacturing**	
	Paper and paper products	57
	Printing, publishing and allied activities	58
10	**Chemicals manufacturing**	
	Inorganic heavy chemicals	65
	Organic heavy chemicals	66
	Fertilizers	67
	Paints, varnishes and lacquers	69
	Pesticides, drugs and other chemicals	68, 70, 71, 72, 73
11	**Iron & Steel manufacturing**	
	Iron and Steel ferro alloys	77
	Iron and steel casting and forging	78
	Iron and steel foundries	79
12	**Non-ferrous metals manufacturing**	80
13	**Non-metallic minerals manufacturing**	
	Structural clay products	74
	Cement	75
	Other non-metallic mineral products	76

Sector No.	Economic Sectors	IOT Sector No.
14	**Non-energy intensive manufacturing**	
	Machinery	81-105
	Wood and wood products	55, 56
	Construction	106
	Textile and Leather	46-54, 59-60
	Food and Tobacco	40-45
15	**Non-energy mining**	
	Iron ore	30
	Other minerals	31-37
16	**Agriculture Sector**	
	Food crops	1-7
	Cash crops	8, 9, 11, 12, 13, 17
	Plantation crops	10, 14, 15, 16, 18
	Other crops	19-20
	Animal Husbandry	21-24
	Forestry and Logging	25
	Fishing	26
17	**Commercial Services**	
	Trade	116
	Hotels and Restaurants	117
	Real Estate	120
	Banking and Insurance	118-119
	Communication	115
	Education and Research	121
	Medical and Public Health	122
	Other Services	123-129
18	**Water Transport**	111
19	**Air Transport**	112
20	**Land Transport**	
	Road transport	110
	Rail transport	109

Note: The column on the left-hand-side of this Table represents sectoral classification in this research. The last column represents the sectoral classification codes taken from the input-output tables (IOT) from the Ministry of Statistics and Programme Implementation (MOSPI).

A.1 Disaggregation of Energy Sector

	Energy Sector
1	Coal
2	Oil
3	Gas
4	Electricity
5	Nuclear (Uranium)
6	Biomass
7	CNG
8	Methanol
9	Ethanol
10	Biodiesel
11	Coal-fired plant
12	Oil-fired plant
13	Gas-fired plant
14	Hydro-power plant
15	Nuclear power plant
16	Solar power plant
17	Wind power plant
18	Geothermal power plant
19	Biomass power plant

Appendix B. Input-output coefficients

B.1 Matrix of input-output technical coefficients (A)

	Energy Sector																	Non-Energy Sector											
	Energy Extraction						Energy Conversion											Industrial and Services									Transport		
	1	2	3	4	5.1	5.2	6	7	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8	9	10	11	12	13	14	15	16	17	18	19	20
D1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0037	0.0037	-	-	0.0004	0.0006	0.0016	0.0004	0.0000	-	-	0.0001	-	-	0.0001
D2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0377	0.0377	-	-	-	-	-	-	-	-	0.0000	-	-	-	-
D3	-	-	-	-	-	-	0.3441	-	0.0341	0.0255	-	-	-	-	-	-	-	-	0.0056	0.0032	-	-	0.0044	-	-	-	-	-	-
D4	-	-	-	-	-	-	-	0.0608	-	-	0.4939	-	-	-	-	-	-	-	0.0776	0.0466	0.0158	0.0053	0.0017	0.0413	0.0196	-	0.0117	0.0499	0.0898
D5.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6790	-	-	-	-	-	-	-	-	-	-	-	-
D5.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0275	-	-	-	-	-	-	-	-	-	-	-	-
D7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1225	-	-	-	-	-	-	-	-	-	-	-	-
D8.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D8.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0273	-	-	-	-	-	-	-	-	-	-	-	-
D8.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1418	-	-	-	-	-	-	-	-	-	-	-	-
D8.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D8.5	-	-	-	-	-	-	-	-	0.0722	0.0722	0.0744	0.0657	0.0657	0.0660	0.0638	0.0032	-	0.1258	0.0595	0.0743	0.1594	0.0397	0.0273	-	0.0359	0.0144	-	-	0.0103
D8.6	0.0016	0.0000	0.0009	0.0015	-	-	0.0006	0.0001	0.0030	0.0030	0.0033	0.0035	0.0035	0.0029	0.0052	0.0052	-	0.2023	0.0046	0.0005	0.0014	0.0046	0.0045	0.0005	0.0021	0.0037	0.0005	0.0018	0.0075
D8.7	0.0503	0.0360	0.0104	0.0757	-	-	0.0112	0.0069	0.0046	0.0046	0.0051	0.0054	0.0054	0.0045	0.0081	0.0081	-	0.0668	0.2166	0.0078	0.0321	0.0391	0.0435	0.0223	0.0325	0.0110	0.0855	0.1225	0.0343
D8.8	0.0000	0.0001	0.0000	0.0031	-	-	0.0000	0.0000	0.0007	0.0009	0.0001	0.0005	0.0007	0.0008	0.0005	0.0005	-	0.0014	0.0027	0.1139	0.0213	0.0228	0.0648	0.0009	0.0000	0.0142	0.0000	-	0.0000
D8	0.0000	0.0000	0.0001	0.0144	-	-	0.0001	0.0001	0.0004	0.0005	0.0000	0.0003	0.0004	0.0004	0.0003	0.0003	-	0.0004	0.0014	0.0442	0.0644	0.0068	0.0205	0.0043	0.0000	0.0001	0.0000	-	0.0000
D9	0.0019	0.0000	0.0008	0.0017	-	-	0.0002	0.0001	0.0074	0.0086	0.0082	0.0087	0.0100	0.0073	0.0130	0.0130	-	0.0027	0.0022	0.0004	0.0028	0.0791	0.0037	0.0005	0.0002	0.0058	0.0018	0.0545	0.0086
D10	0.0502	0.0662	0.0134	0.0569	-	-	0.0030	0.0006	0.0363	0.0400	0.0400	0.0424	0.0467	0.0355	0.0636	0.0636	-	0.0231	0.0210	0.0331	0.0431	0.0576	0.1775	0.0167	0.0077	0.0629	0.0405	0.0061	0.0649
D11	0.0000	0.0000	0.0000	0.0006	-	-	-	0.0000	-	-	-	-	-	-	-	-	-	0.0001	0.0013	0.0188	0.0418	0.0064	0.0060	0.0002	0.0000	0.0018	0.0000	-	0.0000
D12	0.0000	0.0000	0.0001	0.0004	-	-	0.0003	0.0001	0.0029	0.0029	0.0032	0.0034	0.0034	0.0029	0.0052	0.0052	-	0.0454	0.0360	0.0001	0.0005	0.0218	0.0389	0.0001	0.2519	0.0229	0.0013	0.0000	0.0152
D13	0.0409	0.1118	0.0811	0.3774	-	-	0.0874	0.0145	0.1344	0.1546	0.1482	0.1569	0.1805	0.1315	0.2352	0.2705	-	0.0929	0.0828	0.1487	0.1174	0.1408	0.1537	0.1111	0.0766	0.1147	0.1110	0.1319	0.1760
D14	0.0002	0.0003	0.0004	0.0012	-	-	0.0004	0.0004	0.0029	0.0029	0.0032	0.0034	0.0034	0.0028	0.0051	0.0051	-	0.0009	0.0008	0.0025	0.0020	0.0015	0.0007	0.0003	0.0010	0.0005	0.0004	0.0014	0.0027
D15	0.0003	0.0003	0.0007	0.0004	-	-	0.0002	0.0001	0.0004	0.0004	0.0005	0.0005	0.0005	0.0004	0.0008	0.0008	-	0.0037	0.0011	0.0002	0.0003	0.0018	0.0012	0.0001	0.0007	0.0009	0.0002	0.0006	0.0011
D16	0.0397	0.0191	0.0249	0.0653	-	-	0.0916	0.0024	0.0535	0.0535	0.0590	0.0625	0.0625	0.0523	0.0936	0.0936	-	0.0624	0.0356	0.0685	0.0627	0.0690	0.0490	0.0192	0.0250	0.0317	0.0351	0.0626	0.0468
D17	0.0005	-	-	-	-	-	0.2507	-	0.0772	0.0579	-	-	-	-	-	-	-	0.0016	0.0004	0.0035	0.0005	0.0001	0.0007	0.0001	0.0000	0.0002	-	-	-
D18	-	-	-	-	-	-	-	0.6710	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D19	-	-	-	-	-	-	-	-	-	-	-	0.1509	0.0981	-	-	-	-	0.0000	0.0127	0.0009	0.0005	0.0005	0.0002	-	0.0000	-	-	-	0.0000
D20	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0074	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

B.1 Matrix of input-output technical coefficients (A) (continued)

	Energy Sector																	Non-Energy Sector											
	Energy Extraction						Energy Conversion											Industrial and Services									Transport		
	1	2	3	4	5.1	5.2	6	7	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8	9	10	11	12	13	14	15	16	17	18	19	20
M1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0275	-	-	-	-	-	-	-	-	-	-	-	-
M3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1225	-	-	-	-	-	-	-	-	-	-	-	-
M4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0273	-	-	-	-	-	-	-	-	-	-	-	-
M7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1418	-	-	-	-	-	-	-	-	-	-	-	-
M8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M9	-	-	-	-	-	-	-	-	0.0722	0.0722	0.0744	0.0657	0.0657	0.0660	0.0638	0.0032	-	0.1258	0.0595	0.0743	0.1594	0.0397	0.0273	-	0.0359	0.0144	-	-	0.0103
M10	0.0016	0.0000	0.0009	0.0015	-	-	0.0006	0.0001	0.0030	0.0030	0.0033	0.0035	0.0035	0.0029	0.0052	0.0052	-	0.2023	0.0046	0.0005	0.0014	0.0046	0.0045	0.0005	0.0021	0.0037	0.0005	0.0018	0.0075
M11	0.0503	0.0360	0.0104	0.0757	-	-	0.0112	0.0069	0.0046	0.0046	0.0051	0.0054	0.0054	0.0045	0.0081	0.0081	-	0.0668	0.2166	0.0078	0.0321	0.0391	0.0435	0.0223	0.0325	0.0110	0.0855	0.1225	0.0343
M12	0.0000	0.0001	0.0000	0.0031	-	-	0.0000	0.0000	0.0007	0.0009	0.0001	0.0005	0.0007	0.0008	0.0005	0.0005	-	0.0014	0.0027	0.1139	0.0213	0.0228	0.0648	0.0009	0.0000	0.0142	0.0000	-	0.0000
M13	0.0000	0.0000	0.0001	0.0144	-	-	0.0001	0.0001	0.0004	0.0005	0.0000	0.0003	0.0004	0.0004	0.0003	0.0003	-	0.0004	0.0014	0.0442	0.0644	0.0068	0.0205	0.0043	0.0000	0.0001	0.0000	-	0.0000
M14	0.0019	0.0000	0.0008	0.0017	-	-	0.0002	0.0001	0.0074	0.0086	0.0082	0.0087	0.0100	0.0073	0.0130	0.0130	-	0.0027	0.0022	0.0004	0.0028	0.0791	0.0037	0.0005	0.0002	0.0058	0.0018	0.0545	0.0086
M15	0.0502	0.0662	0.0134	0.0569	-	-	0.0030	0.0006	0.0363	0.0400	0.0400	0.0424	0.0467	0.0355	0.0636	0.0636	-	0.0231	0.0210	0.0331	0.0431	0.0576	0.1775	0.0167	0.0077	0.0629	0.0405	0.0061	0.0649
M16	0.0000	0.0000	0.0000	0.0006	-	-	-	0.0000	-	-	-	-	-	-	-	-	-	0.0001	0.0013	0.0188	0.0418	0.0064	0.0060	0.0002	0.0000	0.0018	0.0000	-	0.0000
M17	0.0000	0.0000	0.0001	0.0004	-	-	0.0003	0.0001	0.0029	0.0029	0.0032	0.0034	0.0034	0.0029	0.0052	0.0052	-	0.0454	0.0360	0.0001	0.0005	0.0218	0.0389	0.0001	0.2519	0.0229	0.0013	0.0000	0.0152
M18	0.0409	0.1118	0.0811	0.3774	-	-	0.0874	0.0145	0.1344	0.1546	0.1482	0.1569	0.1805	0.1315	0.2352	0.2705	-	0.0929	0.0828	0.1487	0.1174	0.1408	0.1537	0.1111	0.0766	0.1147	0.1110	0.1319	0.1760
M19	0.0002	0.0003	0.0004	0.0012	-	-	0.0004	0.0004	0.0029	0.0029	0.0032	0.0034	0.0034	0.0028	0.0051	0.0051	-	0.0009	0.0008	0.0025	0.0020	0.0015	0.0007	0.0003	0.0010	0.0005	0.0004	0.0014	0.0027
M20	0.0003	0.0003	0.0007	0.0004	-	-	0.0002	0.0001	0.0004	0.0004	0.0005	0.0005	0.0005	0.0004	0.0008	0.0008	-	0.0037	0.0011	0.0002	0.0003	0.0018	0.0012	0.0001	0.0007	0.0009	0.0002	0.0006	0.0011

B.1 Matrix of input-output technical coefficients (A) (continued)

	Energy Sector																	Non-Energy Sector											
	Energy Extraction						Energy Conversion											Industrial and Services									Transport		
	1	2	3	4	5.1	5.2	6	7	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8	9	10	11	12	13	14	15	16	17	18	19	20
Capital (incl. land)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0377	0.0377	-	-	-	-	-	-	-	-	0.0000	-	-	-	-
Labour - Unskilled	-	-	-	-	-	-	0.3441	-	0.0341	0.0255	-	-	-	-	-	-	-	-	0.0056	0.0032	-	-	0.0044	-	-	-	-	-	-
Labour - Skilled	-	-	-	-	-	-	-	0.0608	-	-	0.4939	-	-	-	-	-	-	-	0.0776	0.0466	0.0158	0.0053	0.0017	0.0413	0.0196	-	0.0117	0.0499	0.0898
Natural Resources	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6790	-	-	-	-	-	-	-	-	-	-	-	-
Taxes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

B.1 Matrix of input-output technical coefficients (A) (continued)

	PFCE	GFCE	INV
D1	0.0001	-	-
D2	-	-	-
D3	0.0015	-	-
D4	0.0249	-	-
D5.1	-	-	-
D5.2	-	-	-
D6	-	-	-
D7	-	-	-
D8.1	-	-	-
D8.2	-	-	-
D8.3	-	-	-
D8.4	-	-	-
D8.5	0.0253	-	-
D8.6	0.0043	0.0109	0.0000
D8.7	0.0185	0.0153	0.0081
D8.8	0.0000	-	0.0158
D8	0.0000	-	0.0053
D9	0.0050	0.0023	0.0431
D10	0.0878	0.0297	0.2218
D11	0.0000	0.0000	0.0000
D12	0.3279	0.0178	0.0018
D13	0.3336	0.8555	0.5083
D14	0.0028	0.0004	0.0003
D15	0.0015	0.0018	0.0028
D16	0.0815	0.0255	0.0236
D17	0.0001	-	-
D18	-	-	-
D19	0.0000	-	-
D20	-	-	-
M1	0.0014	-	-
M2	0.0033	-	-
M3	0.0001	-	-
M4	0.0007	0.0016	0.0000
M6	0.0015	0.0018	0.0008
M7	0.0000	-	0.0031
M8	0.0000	-	0.0077
M9	0.0004	0.0001	0.0056
M10	0.0101	0.0078	0.0810
M11	0.0000	-	0.0000
M12	0.0133	0.0003	0.0000
M13	0.0096	0.0190	0.0110
M14	0.0023	0.0001	0.0000
M15	0.0036	0.0001	0.0000
M16	0.0019	0.0004	0.0004
M17	-	-	-
M18	-	-	-
M19	-	-	-
M20	-	-	-
Capital (incl. la	0.0362	0.0097	0.0594
Labour - Unsk	-	-	-
Labour - Skille	-	-	-
Natural Resour	-	-	-
Taxes	0.0029	-	-

B.1 Matrix of input-output technical coefficients (*A*) (continued)

	Export											
	Asia-7 Economies							Other Regions				
	PRC	Japan	Republic of Korea	India	Indonesia	Malaysia	Thailand	Other East Asia	Other South East Asia	Other South Asia	Central & West Asia	Rest of World
D1	-	-	-	-	-	-	-	-	-	-	-	-
D2	-	-	-	-	-	-	-	-	-	-	-	-
D3	0.0002	0.0345	0.0954	-	0.0000	0.0026	0.0347	0.0361	0.0003	0.0347	-	0.0056
D4	0.0004	0.1297	0.2454	-	0.0036	0.0769	0.0892	0.2462	0.0996	0.2236	-	0.0628
D5.1	-	-	-	-	-	-	-	-	-	-	-	-
D5.2	-	-	-	-	-	-	-	-	-	-	-	-
D6	-	-	-	-	-	-	-	-	-	-	-	-
D7	-	-	-	-	-	-	-	-	-	-	-	-
D8.1	-	-	-	-	-	-	-	-	-	-	-	-
D8.2	-	-	-	-	-	-	-	-	-	-	-	-
D8.3	-	-	-	-	-	-	-	-	-	-	-	-
D8.4	-	-	-	-	-	-	-	-	-	-	-	-
D8.5	-	-	-	-	-	-	-	-	-	-	-	0.0002
D8.6	0.0007	0.0002	0.0006	-	0.0025	0.0088	0.0024	0.0004	0.0016	0.0128	0.0040	0.0032
D8.7	0.0818	0.0739	0.0768	-	0.2332	0.1083	0.1237	0.0573	0.1221	0.1471	0.1506	0.0790
D8.8	0.0230	0.0393	0.0481	-	0.1298	0.0503	0.0507	0.0243	0.0208	0.0428	0.0058	0.0314
D8	0.0521	0.0185	0.0138	-	0.0518	0.1261	0.0822	0.0419	0.0537	0.0135	0.0003	0.0306
D9	0.0326	0.0826	0.0074	-	0.0060	0.0130	0.1784	0.2327	0.0661	0.0034	0.0053	0.0798
D10	0.0668	0.1267	0.1505	-	0.1508	0.1765	0.1694	0.0721	0.1419	0.2367	0.2017	0.2540
D11	0.4771	0.0970	0.0689	-	0.0062	0.0067	0.0051	0.0243	0.0027	0.0130	0.0008	0.0067
D12	0.0807	0.1250	0.0641	-	0.2213	0.1990	0.1078	0.0417	0.1559	0.2413	0.0879	0.0560
D13	0.1768	0.1987	0.1826	-	0.1720	0.2007	0.1259	0.1667	0.3038	0.0213	0.4776	0.2809
D14	0.0004	0.0589	0.0318	-	0.0018	0.0059	0.0059	0.0129	0.0154	0.0006	0.0057	0.0643
D15	0.0006	0.0051	0.0030	-	0.0029	0.0034	0.0038	0.0094	0.0020	0.0006	0.0118	0.0056
D16	0.0069	0.0099	0.0116	-	0.0183	0.0218	0.0211	0.0339	0.0143	0.0029	0.0486	0.0398
D17	-	-	-	-	-	-	-	-	-	-	-	-
D18	-	-	-	-	-	-	-	-	-	-	-	-
D19	-	-	-	-	-	-	-	-	-	-	-	-
D20	-	-	-	-	-	-	-	-	-	-	-	-
M1	-	-	-	-	-	-	-	-	-	-	-	-
M2	-	-	-	-	-	-	-	-	-	-	-	-
M3	-	-	-	-	-	-	-	-	-	-	-	-
M4	-	-	-	-	-	-	-	-	-	-	-	-
M6	-	-	-	-	-	-	-	-	-	-	-	-
M7	-	-	-	-	-	-	-	-	-	-	-	-
M8	-	-	-	-	-	-	-	-	-	-	-	-
M9	-	-	-	-	-	-	-	-	-	-	-	-
M10	-	-	-	-	-	-	-	-	-	-	-	-
M11	-	-	-	-	-	-	-	-	-	-	-	-
M12	-	-	-	-	-	-	-	-	-	-	-	-
M13	-	-	-	-	-	-	-	-	-	-	-	-
M14	-	-	-	-	-	-	-	-	-	-	-	-
M15	-	-	-	-	-	-	-	-	-	-	-	-
M16	-	-	-	-	-	-	-	-	-	-	-	-
M17	-	-	-	-	-	-	-	-	-	-	-	-
M18	-	-	-	-	-	-	-	-	-	-	-	-
M19	-	-	-	-	-	-	-	-	-	-	-	-
M20	-	-	-	-	-	-	-	-	-	-	-	-
Capital (incl. land)	-	-	-	-	-	-	-	-	-	-	-	-
Labour - Unskilled	-	-	-	1.0000	-	-	-	-	-	-	-	-
Labour - Skilled	-	-	-	-	-	-	-	-	-	-	-	-
Natural Resources	-	-	-	-	-	-	-	-	-	-	-	-
Taxes	-	-	-	-	-	-	-	-	0.0121	-	-	0.0001

B.2 Matrix of input-output energy coefficients (*F*)

	Energy Sector																	Non-Energy Sector											
	Energy Extraction						Energy Conversion											Industrial and Services									Transport		
	1	2	3	4	5.1	5.2	6	7	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8	9	10	11	12	13	14	15	16	17	18	19	20
D-PE-Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0000	-	-	-	-	-	0.0000	-	-	-	-	0.0000
D-PE-Crude Oil	0.0010	-	-	-	-	-	0.0257	-	0.1553	0.1165	-	-	-	-	-	-	-	0.0031	0.0009	0.0048	0.0009	0.0002	0.0010	0.0000	0.0000	0.0003	-	-	-
D-PE-Natural Gas	-	-	-	-	-	-	-	0.1829	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-PE-Uranium	-	-	0.1325	-	-	-	-	-	-	-	-	0.1504	0.0978	-	-	-	-	0.0046	0.0203	0.0022	0.0037	0.0011	0.0005	-	0.0003	-	-	-	0.0020
D-PE-Combustible RE	-	-	-	-	-	-	-	-	-	-	-	-	-	0.2490	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-PE-Non-combustible RE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0037	0.0037	-	-	0.0004	0.0006	0.0016	0.0004	0.0000	-	-	0.0001	-	-	0.0001
D-SE-Coal Products	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0377	0.0377	-	-	-	-	-	-	-	-	0.0000	-	-	-	-
D-SE-Oil Products	-	-	-	-	-	-	0.3441	-	0.0341	0.0255	-	-	-	-	-	-	-	-	0.0056	0.0032	-	-	0.0044	-	-	-	-	-	-
D-SE-Electricity	-	-	-	-	-	-	-	0.0608	-	-	0.4939	-	-	-	-	-	-	-	0.0776	0.0466	0.0158	0.0053	0.0017	0.0413	0.0196	-	0.0117	0.0499	0.0898
D-NE-Coal Products	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6790	-	-	-	-	-	-	-	-	-	-	-	-
D-NE-Crude Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-NE-Oil Products	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0275	-	-	-	-	-	-	-	-	-	-	-	-
D-NE-Natural gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1225	-	-	-	-	-	-	-	-	-	-	-	-
M-PE-Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M-PE-Crude Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0273	-	-	-	-	-	-	-	-	-	-	-	-
M-PE-Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1418	-	-	-	-	-	-	-	-	-	-	-	-
M-PE-Uranium	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M-SE-Coal Products	-	-	-	-	-	-	-	-	0.0722	0.0722	0.0744	0.0657	0.0657	0.0660	0.0638	0.0032	-	0.1258	0.0595	0.0743	0.1594	0.0397	0.0273	-	0.0359	0.0144	-	-	0.0103
M-SE-Oil Products	0.0016	0.0000	0.0009	0.0015	-	-	0.0006	0.0001	0.0030	0.0030	0.0033	0.0035	0.0035	0.0029	0.0052	0.0052	-	0.2023	0.0046	0.0005	0.0014	0.0046	0.0045	0.0005	0.0021	0.0037	0.0005	0.0018	0.0075
M-SE-Electricity	0.0503	0.0360	0.0104	0.0757	-	-	0.0112	0.0069	0.0046	0.0046	0.0051	0.0054	0.0054	0.0045	0.0081	0.0081	-	0.0668	0.2166	0.0078	0.0321	0.0391	0.0435	0.0223	0.0325	0.0110	0.0855	0.1225	0.0343

Unit: Mtoe/$Bn

B.2 Matrix of input-output energy coefficients (*F*) (continued)

				Export											
				Asia-7 Economies							Other Regions				
	PFCE	GFCE	INV	PRC	Japan	Republic of Korea	India	Indonesia	Malaysia	Thailand	Other East Asia	Other South East Asia	Other South Asia	Central & West Asia	Rest of World
D-PE-Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-PE-Crude Oil	0.0001	-	-	-	-	-	-	-	-	-	-	-	0.0058	-	0.0000
D-PE-Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-PE-Uranium	0.0006	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-PE-Combustible RE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-PE-Non-combustible RE	0.0001	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-SE-Coal Products	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-SE-Oil Products	0.0015	-	-	0.0002	0.0345	0.0954	-	0.0000	0.0026	0.0347	0.0361	0.0003	0.0347	-	0.0056
D-SE-Electricity	0.0249	-	-	0.0004	0.1297	0.2454	-	0.0036	0.0769	0.0892	0.2462	0.0996	0.2236	-	0.0628
D-NE-Coal Products	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-NE-Crude Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-NE-Oil Products	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-NE-Natural gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M-PE-Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M-PE-Crude Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M-PE-Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M-PE-Uranium	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M-SE-Coal Products	0.0253	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0002
M-SE-Oil Products	0.0043	0.0109	0.0000	0.0007	0.0002	0.0006	-	0.0025	0.0088	0.0024	0.0004	0.0016	0.0128	0.0040	0.0032
M-SE-Electricity	0.0185	0.0153	0.0081	0.0818	0.0739	0.0768	-	0.2332	0.1083	0.1237	0.0573	0.1221	0.1471	0.1506	0.0790

Unit: Mtoe/$Bn

B.3 Matrix of input-output carbon coefficients (*E*)

	Energy Sector																	Non-Energy Sector											
	Energy Extraction						Energy Conversion											Industrial and Services									Transport		
	1	2	3	4	5.1	5.2	6	7	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8	9	10	11	12	13	14	15	16	17	18	19	20
D-CO_2-Coal	0.0010	-	-	-	-	-	0.0257	-	0.1553	0.1165	-	-	-	-	-	-	-	0.0031	0.0009	0.0048	0.0009	0.0002	0.0010	0.0000	0.0000	0.0003	-	-	-
D-CO_2-Coal Products	-	-	-	-	-	-	-	0.1829	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-CO_2-Oil Products	-	-	0.1325	-	-	-	-	-	-	-	-	0.1504	0.0978	-	-	-	-	0.0046	0.0203	0.0022	0.0037	0.0011	0.0005	-	0.0003	-	-	-	0.0020
D-CO_2-Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	0.2490	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-CO_2-Combustible RE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0037	0.0037	-	-	0.0004	0.0006	0.0016	0.0004	0.0000	-	-	0.0001	-	-	0.0001
D-CH_4-Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0377	0.0377	-	-	-	-	-	-	-	-	0.0000	-	-	-	-
D-CH_4-Coal Products	-	-	-	-	-	-	0.3441	-	0.0341	0.0255	-	-	-	-	-	-	-	-	0.0056	0.0032	-	-	0.0044	-	-	-	-	-	-
D-CH_4-Oil Products	-	-	-	-	-	-	-	0.0608	-	-	0.4939	-	-	-	-	-	-	-	0.0776	0.0466	0.0158	0.0053	0.0017	0.0413	0.0196	-	0.0117	0.0499	0.0898
D-CH_4-Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6790	-	-	-	-	-	-	-	-	-	-	-	-
D-CH_4-Combustible RE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-N_2O-Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0275	-	-	-	-	-	-	-	-	-	-	-	-
D-N_2O-Coal Products	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1225	-	-	-	-	-	-	-	-	-	-	-	-
D-N_2O-Oil Products	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-N_2O-Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0273	-	-	-	-	-	-	-	-	-	-	-	-
D-N_2O-Combustible RE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1418	-	-	-	-	-	-	-	-	-	-	-	-
M-CO_2-Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M-CO_2-Coal Products	-	-	-	-	-	-	-	-	0.0722	0.0722	0.0744	0.0657	0.0657	0.0660	0.0638	0.0032	-	0.1258	0.0595	0.0743	0.1594	0.0397	0.0273	-	0.0359	0.0144	-	-	0.0103
M-CO_2-Oil Products	0.0016	0.0000	0.0009	0.0015	-	-	0.0006	0.0001	0.0030	0.0030	0.0033	0.0035	0.0035	0.0029	0.0052	0.0052	-	0.2023	0.0046	0.0005	0.0014	0.0046	0.0045	0.0005	0.0021	0.0037	0.0005	0.0018	0.0075
M-CO_2-Natural Gas	0.0503	0.0360	0.0104	0.0757	-	-	0.0112	0.0069	0.0046	0.0046	0.0051	0.0054	0.0054	0.0045	0.0081	0.0081	-	0.0668	0.2166	0.0078	0.0321	0.0391	0.0435	0.0223	0.0325	0.0110	0.0855	0.1225	0.0343
M-CH_4-Coal	0.0000	0.0001	0.0000	0.0031	-	-	0.0000	0.0000	0.0007	0.0009	0.0001	0.0005	0.0007	0.0008	0.0005	0.0005	-	0.0014	0.0027	0.1139	0.0213	0.0228	0.0648	0.0009	0.0000	0.0142	0.0000	-	0.0000
M-CH_4-Coal Products	0.0000	0.0000	0.0001	0.0144	-	-	0.0001	0.0001	0.0004	0.0005	0.0000	0.0003	0.0004	0.0004	0.0003	0.0003	-	0.0004	0.0014	0.0442	0.0644	0.0068	0.0205	0.0043	0.0000	0.0001	0.0000	-	0.0000
M-CH_4-Oil Products	0.0019	0.0000	0.0008	0.0017	-	-	0.0002	0.0001	0.0074	0.0086	0.0082	0.0087	0.0100	0.0073	0.0130	0.0130	-	0.0027	0.0022	0.0004	0.0028	0.0791	0.0037	0.0005	0.0002	0.0058	0.0018	0.0545	0.0086
M-CH_4-Natural Gas	0.0502	0.0662	0.0134	0.0569	-	-	0.0030	0.0006	0.0363	0.0400	0.0400	0.0424	0.0467	0.0355	0.0636	0.0636	-	0.0231	0.0210	0.0331	0.0431	0.0576	0.1775	0.0167	0.0077	0.0629	0.0405	0.0061	0.0649
M-N_2O-Coal	0.0000	0.0000	0.0000	0.0006	-	-	-	0.0000	-	-	-	-	-	-	-	-	-	0.0001	0.0013	0.0188	0.0418	0.0064	0.0060	0.0002	0.0000	0.0018	0.0000	-	0.0000
M-N_2O-Coal Products	0.0000	0.0000	0.0001	0.0004	-	-	0.0003	0.0001	0.0029	0.0029	0.0032	0.0034	0.0034	0.0029	0.0052	0.0052	-	0.0454	0.0360	0.0001	0.0005	0.0218	0.0389	0.0001	0.2519	0.0229	0.0013	0.0000	0.0152
M-N_2O-Oil Products	0.0409	0.1118	0.0811	0.3774	-	-	0.0874	0.0145	0.1344	0.1546	0.1482	0.1569	0.1805	0.1315	0.2352	0.2705	-	0.0929	0.0828	0.1487	0.1174	0.1408	0.1537	0.1111	0.0766	0.1147	0.1110	0.1319	0.1760
M-N_2O-Natural Gas	0.0002	0.0003	0.0004	0.0012	-	-	0.0004	0.0004	0.0029	0.0029	0.0032	0.0034	0.0034	0.0028	0.0051	0.0051	-	0.0009	0.0008	0.0025	0.0020	0.0015	0.0007	0.0003	0.0010	0.0005	0.0004	0.0014	0.0027

Unit: Mt CO2-e/$Bn

B.3 Matrix of input-output carbon coefficients (*E*) (continued)

				Export											
				Asia-7 Economies							Other Regions				
	PFCE	GFCE	INV	PRC	Japan	Republic of Korea	India	Indonesia	Malaysia	Thailand	Other East Asia	Other South East Asia	Other South Asia	Central & West Asia	Rest of World
D-CO_2-Coal	0.0001	-	-	-	-	-	-	-	-	-	-	-	0.0058	-	0.0000
D-CO_2-Coal Products	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-CO_2-Oil Products	0.0006	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-CO_2-Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-CO_2-Combustible RE	0.0001	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-CH_4-Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-CH_4-Coal Products	0.0015	-	-	0.0002	0.0345	0.0954	-	0.0000	0.0026	0.0347	0.0361	0.0003	0.0347	-	0.0056
D-CH_4-Oil Products	0.0249	-	-	0.0004	0.1297	0.2454	-	0.0036	0.0769	0.0892	0.2462	0.0996	0.2236	-	0.0628
D-CH_4-Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-CH_4-Combustible RE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-N_2O-Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-N_2O-Coal Products	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-N_2O-Oil Products	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-N_2O-Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D-N_2O-Combustible RE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M-CO_2-Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M-CO_2-Coal Products	0.0253	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0002
M-CO_2-Oil Products	0.0043	0.0109	0.0000	0.0007	0.0002	0.0006	-	0.0025	0.0088	0.0024	0.0004	0.0016	0.0128	0.0040	0.0032
M-CO_2-Natural Gas	0.0185	0.0153	0.0081	0.0818	0.0739	0.0768	-	0.2332	0.1083	0.1237	0.0573	0.1221	0.1471	0.1506	0.0790
M-CH_4-Coal	0.0000	-	0.0158	0.0230	0.0393	0.0481	-	0.1298	0.0503	0.0507	0.0243	0.0208	0.0428	0.0058	0.0314
M-CH_4-Coal Products	0.0000	-	0.0053	0.0521	0.0185	0.0138	-	0.0518	0.1261	0.0822	0.0419	0.0537	0.0135	0.0003	0.0306
M-CH_4-Oil Products	0.0050	0.0023	0.0431	0.0326	0.0826	0.0074	-	0.0060	0.0130	0.1784	0.2327	0.0661	0.0034	0.0053	0.0798
M-CH_4-Natural Gas	0.0878	0.0297	0.2218	0.0668	0.1267	0.1505	-	0.1508	0.1765	0.1694	0.0721	0.1419	0.2367	0.2017	0.2540
M-N_2O-Coal	0.0000	0.0000	0.0000	0.4771	0.0970	0.0689	-	0.0062	0.0067	0.0051	0.0243	0.0027	0.0130	0.0008	0.0067
M-N_2O-Coal Products	0.3279	0.0178	0.0018	0.0807	0.1250	0.0641	-	0.2213	0.1990	0.1078	0.0417	0.1559	0.2413	0.0879	0.0560
M-N_2O-Oil Products	0.3336	0.8555	0.5083	0.1768	0.1987	0.1826	-	0.1720	0.2007	0.1259	0.1667	0.3038	0.0213	0.4776	0.2809
M-N_2O-Natural Gas	0.0028	0.0004	0.0003	0.0004	0.0589	0.0318	-	0.0018	0.0059	0.0059	0.0129	0.0154	0.0006	0.0057	0.0643

Unit: Mt CO2-e/$Bn

B.4 Matrix of input-output labour coefficients (L)

	Energy Sector																	Non-Energy Sector											
	Energy Extraction						Energy Conversion											Industrial and Services									Transport		
	1	2	3	4	5.1	5.2	6	7	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8	9	10	11	12	13	14	15	16	17	18	19	20
Labour - Unskilled	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0000	-	-	-	-	-	0.0000	-	-	-	-	0.0000
Labour - Skilled	0.0010	-	-	-	-	-	0.0257	-	0.1553	0.1165	-	-	-	-	-	-	-	0.0031	0.0009	0.0048	0.0009	0.0002	0.0010	0.0000	0.0000	0.0003	-	-	-

Unit: Mn person per $Bn

Appendix C. Total outputs by sectors

C.1 Total output in the BAU-HT Scenario

	2025	2035	2050
Non-Energy Sectors			
Agriculture	1461	2846	6448
Non-energy Mining	68	129	288
Paper Manufacturing	61	113	244
Chemical manufacturing	433	768	1578
Iron and steel manufacturing	214	376	762
Non-ferrous metals manufacturing	85	153	324
Non-metallic minerals manufacturing	199	354	736
Non-intensive manufacturing	1325	2399	5139
Water transport	69	127	274
Air transport	22	40	85
Land transport	592	1071	2303
Commercial services	3264	6140	13708
Energy Sectors			
Coal	39	64	113
Crude Oil	50	81	146
Natural Gas	17	28	43
Nuclear	3	6	14
Combustible Renewable	1	2	2
Non-combustible Renewable	1	2	3
Coal Products	44	76	147
Oil Products	273	442	804
Electricity	278	465	834

Unit: US$ Billion

C.2 Total output in the CP Scenario

	2025	2035	2050
Non-Energy Sector			
Agriculture	1459	2812	6248
Non-energy Mining	68	128	282
Paper Manufacturing	60	110	229
Chemical manufacturing	427	761	1539
Iron and steel manufacturing	189	345	761
Non-ferrous metals manufacturing	83	145	291
Non-metallic minerals manufacturing	195	343	732
Non-intensive manufacturing	1297	2348	5008
Water transport	68	127	269
Air transport	21	39	83
Land transport	598	1104	2344
Commercial services	3279	6186	13966
Energy Sector			
Coal	30	44	57
Crude Oil	47	77	120
Natural Gas	16	23	25
Nuclear	2	4	4
Combustible Renewable	1	1	2
Non-combustible Renewable	2	3	5
Coal Products	40	66	110
Oil Products	258	423	660
Electricity	58	97	154

Unit: US$ Billion

C.3 Total output in the SF Scenario

	2025	2035	2050
Non-Energy Sector			
Agriculture	1453	2808	6227
Non-energy Mining	68	127	276
Paper Manufacturing	60	107	217
Chemical manufacturing	419	730	1419
Iron and steel manufacturing	204	346	761
Non-ferrous metals-manufacturing	82	139	269
Non-metallic minerals manufacturing	196	342	723
Non-intensive manufacturing	1303	2326	4897
Water transport	68	125	260
Air transport	21	38	80
Land transport	596	1097	2305
Commercial services	3294	6256	14253
Energy Sector			
Coal	22	15	8
Crude Oil	46	68	79
Natural Gas	16	21	6
Nuclear	4	7	5
Combustible Renewable	1	2	1
Non-combustible Renewable	3	6	4
Coal Products	37	52	74
Oil Products	253	377	433
Electricity	238	308	183

Unit: US$ Billion

Appendix D. Employment

D.1 Employment in the BAU-HT Scenario

	2025	2035	2050
Non-Energy Sector			
Agriculture	373	511	437
Non-energy Mining	2	3	3
Paper Manufacturing	3	4	3
Chemical manufacturing	18	26	24
Iron and steel manufacturing	9	12	11
Non-ferrous metals manufacturing	3	5	4
Non-metallic minerals manufacturing	8	11	9
Non-intensive manufacturing	54	72	63
Water transport	3	3	3
Air transport	1	1	1
Land transport	27	37	32
Commercial services	181	237	198
Energy Sector			
Coal	1	1	1
Crude Oil	2	2	2
Natural Gas	1	1	1
Nuclear	0	0	0
Combustible Renewable	0	0	0
Non-combustible Renewable	0	0	0
Coal Products	2	2	2
Oil Products	13	15	11
Electricity	10	12	8

Unit: Million person

D.2 Employment in the CP Scenario

	2025	2035	2050
Non-Energy Sector			
Agriculture	375	519	452
Non-energy Mining	2	3	3
Paper Manufacturing	3	4	3
Chemical manufacturing	18	26	24
Iron and steel manufacturing	10	14	12
Non-ferrous metals manufacturing	3	5	4
Non-metallic minerals manufacturing	8	11	9
Non-intensive manufacturing	55	74	64
Water transport	3	3	3
Air transport	1	1	1
Land transport	26	36	31
Commercial services	180	237	199
Energy Sector			
Coal	1	1	0
Crude Oil	2	2	1
Natural Gas	1	1	0
Nuclear	0	0	0
Combustible Renewable	0	0	0
Non-combustible Renewable	0	0	0
Coal Products	2	2	1
Oil Products	13	15	9
Electricity	10	11	6

Unit: Million person

D.3 Employment in the SF Scenario

	2025	2035	2050
Non-Energy Sector			
Agriculture	376	521	456
Non-energy Mining	2	3	3
Paper Manufacturing	3	4	3
Chemical manufacturing	19	27	26
Iron and steel manufacturing	10	14	12
Non-ferrous metals manufacturing	3	5	5
Non-metallic minerals manufacturing	8	11	10
Non-intensive manufacturing	55	75	66
Water transport	3	4	3
Air transport	1	1	1
Land transport	26	36	32
Commercial services	181	238	201
Energy Sector			
Coal	1	0	0
Crude Oil	2	2	1
Natural Gas	1	1	0
Nuclear	0	0	0
Combustible Renewable	0	0	0
Non-combustible Renewable	0	0	0
Coal Products	2	2	1
Oil Products	12	13	6
Electricity	10	11	3

Unit: Million person

Appendix E. Total primary energy demand

E.1 Total primary energy demand in the BAU-HT scenario

	2025	2035	2050
Coal	716.1	1167.7	2021.4
Oil	657.9	1014.1	1699.7
Natural Gas	83.1	138.0	218.5
Nuclear	28.1	56.4	122.3
Renewables	443.6	789.1	1567.7

Unit: Mtoe

E.2 Total primary energy demand in the CP scenario

	2025	2035	2050
Coal	551.6	796.5	992.6
Oil	599.4	929.4	1212.1
Natural Gas	72.4	100.3	98.8
Nuclear	21.3	31.8	39.0
Renewables	433.6	714.1	1115.5

Unit: Mtoe

E.3 Total primary energy demand in the SF scenario

	2025	2035	2050
Coal	429.5	307.7	130.2
Oil	584.4	789.6	538.3
Natural Gas	78.9	112.2	39.8
Nuclear	32.3	64.4	44.7
Renewables	432.1	644.2	451.5

Unit: Mtoe

Appendix F. Total final energy demand

F.1 Total final energy demand in the BAU-HT scenario

	2025	2035	2050
Agriculture	59	109	231
Industry	395	582	745
Transport	172	251	401
Residential	462	857	1827
Commercial	38	66	121
Coal	156	236	316
Oil	356	562	2150
Natural gas	52	73	365
Renewables	420	754	1514
Electricity	142	239	1945
Total	**1127**	**1864**	**3324**

Unit: Mtoe

F.2 Total final energy demand in the CP scenario

	2025	2035	2050
Agriculture	52	79	86
Industry	313	430	449
Transport	122	176	185
Residential	445	747	1212
Commercial	35	58	98
Coal	111	148	163
Oil	292	443	548
Natural gas	46	65	66
Renewables	393	643	1005
Electricity	126	192	247
Total	**968**	**1491**	**2029**

Unit: Mtoe

F.3 Total final energy demand in the SF scenario

	2025	2035	2050
Agriculture	50	69	36
Industry	333	356	72
Transport	116	154	71
Residential	409	597	451
Commercial	33	49	54
Coal	128	129	64
Oil	276	369	176
Natural gas	46	53	1
Renewables	369	518	367
Electricity	122	158	78
Total	**941**	**1226**	**685**

Unit: Mtoe

Appendix G. Electricity generation fuel mix

G.1 Electricity generation fuel mix in the BAU-HT scenario

	2025	2035	2050
Coal	1776.5	2930.3	5258.3
Oil	39.5	50.3	34.1
Natural Gas	139.4	290.9	587.9
Nuclear	106.8	213.0	456.8
Renewables	254.2	396.1	614.3

Unit: TWh

G.2 Electricity generation fuel mix in the CP scenario

	2025	2035	2050
Coal	1373.8	2024.3	2518.9
Oil	20.2	49.7	76.5
Gas	119.6	158.9	145.5
Nuclear	81.0	121.3	145.0
Renewable	448.1	792.6	1212.6

Unit: TWh

G.3 Electricity generation fuel mix in the SF scenario

	2025	2035	2050
Coal	993.8	595.1	171.2
Oil	26.4	26.9	14.1
Gas	199.2	401.5	239.4
Nuclear	125.9	255.4	155.1
Renewable	698.7	1440.6	856.7

Unit: TWh

Appendix H. GHG emissions

H.1 GHG emissions in the BAU-HT scenario

	2025	2035	2050
CO_2	5132	8367	14641
CH_4	87	155	310
N_2O	41	71	134

	2025	2035	2050
Agriculture	106	195	413
Industry	794	1162	1414
Transport	541	793	1285
Residential	636	1179	2514
Services	58	101	182
Electricity	2606	4322	7762

Unit: MtCO2 -e

H.2 GHG emissions in the CP scenario

	2025	2035	2050
CO2	4081	6107	7990
CH4	81	132	205
N2O	36	57	84

	2025	2035	2050
Agriculture	94	142	154
Industry	568	740	749
Transport	377	548	582
Residential	613	1029	1667
Services	54	88	148
Electricity	2003	2953	3748

Unit: MtCO2 -e

H.3 GHG emissions in the SF scenario

	2025	2035	2050
CO2	3529	3610	2264
CH4	77	108	76
N2O	33	43	30

	2025	2035	2050
Agriculture	90	124	64
Industry	654	639	240
Transport	360	477	227
Residential	563	822	620
Services	51	74	81
Electricity	1440	914	334

Unit: MtCO2 -e

Appendix I. GDP

I.1 GDP by expenditure approach

	2025			2035			2050		
	BAU-HT	CP	SF	BAU-HT	CP	SF	BAU-HT	CP	SF
Private consumption	2575	2583	2578	5055	5061	5066	11465	11440	11490
Government expenditure	454	456	456	866	871	874	1940	1957	1972
Investment	1450	1456	1457	2506	2518	2533	5419	5491	5570
Exports	1011	981	982	1836	1786	1746	3870	3730	3567
Imports	1116	1115	1105	2039	2036	2005	4409	4353	4264

Unit: US$ Billion

I.2 GDP by income approach

	2025			2035			2050		
	BAU-HT	CP	SF	BAU-HT	CP	SF	BAU-HT	CP	SF
Payment for capital service	2885	2918	2923	6195	6253	6326	16223	16477	16800
Payment for labour	1195	1194	1199	1588	1588	1595	1343	1345	1350
Payment for natural resources	44	41	41	76	72	65	151	131	104
Indirect taxes	251	208	206	365	286	227	569	313	81

Unit: US$ Billion

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