VIF Task Force Report

India's Energy Transition in a Carbon-Constrained World

Vivekananda International Foundation

Vivekananda International Foundation: Task Force Report

‘India’s Energy Transition in a Carbon-Constrained World’

Final Report

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3, San Martin Marg | Chanakyapuri | New Delhi - 110021
Tel: 011-24121764 | Fax: 011-66173415
E-mail: info@vifindia.org
Website: www.vifindia.org
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Task Force Members

Dr. Anil Kakodkar, Former Chairman, Atomic Energy Commission and Secretary, Department of Atomic Energy.

D.P. Srivastava, former Ambassador and Distinguished Fellow, VIF (Coordinator, VIF Task Force).

Sri. R.P.Singh, Former Chairman, Power Grid Corporation of India.

Sri Anil Kutty, IAS (Retired) Former JS, Ministry of Power, CMD AP Transco and Chairman AP Discoms.

Sri Upendra Tripathi, IAS (Retired), Former Secretary MNRES.

Sri Anand Mohan Tiwari, IAS (Retired), Former CMD, GNFC, GSFC.

Sri Sujit Gulati, IAS (Retired).

Ms. Manju Gupta, ex NPCIL, former President and MD of Areva India.

Dr. Anupam Khanna, Former Chief Economist, Shell International, UK and former Director General (Policy Outreach) NASSCOM.

Dr. Umesh Chandra Kulshreshta, Professor and Former Dean, School of Environmental Sciences, JNU.

Dr. Prakash Rao, Deputy Director, Symbiosis Institute of International Business.

Dr. Vasundhara Sen, Faculty, Symbiosis Centre for Management and Human Resources Development.

Dr. Sitakanta Mishra, Associate Professor, Pandit Deendayal Energy University.

Research Associates

Hennashka Israni, MA, Economics, University of Pune, M.Sc. International Relations, London School of Economics and Political Science.

Garima Maheshwari, M. Phil and Ph.D. in Climate change issues, Jawaharlal Nehru University.

Hardik Jani, M.E. - Mechanical Engineering (Energy), Ph.D. - Study on Hybrid Renewable Energy, Research Associate (Suzlon Energy Limited), School of Technology, Pandit Deendayal Energy University, Gandhinagar, Gujarat, India.

Prabha Shankar, B.Tech, IIT Guwahati, Young India Fellow, Ashoka University, Masters Student, Computational Science and Engineering, University of Munich, Germany.

Ketan Srivastava, B.Tech, A. P. J. Abdul Kalam University, UP, MBA, Energy and Infrastructure Management, School of Petroleum Management, Pandit Deen Dayal University, Ahmedabad.

PK Khup Hangzo, Masters degree Strategic Studies, S. Rajaratnam School of International Studies, Nanyang Technological University, Singapore. Associate Fellow, VIF.

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Foreword

The risks of climate change have been brought to the surface with the extreme weather conditions in the past few years. This has given rise to worldwide debates on the necessities of energy transition. At the 26th meeting of the Conference of Parties (COP 26) at Glasgow, Prime Minister Modi committed that India will achieve the net zero emission status by 2070. This is a landmark decision. It implies that India will have to decarbonize its growing economy in the next fifty years. A shift away from coal and fossils fuels will imply deep structural changes in the economy.

India's energy transition is bound to be a complex task. To study its implications, the Vivekananda International Foundation set up a task force headed by Dr. Anil Kakodkar, Former Chairman of the Atomic Energy Commission. Ambassador D.P. Srivastava, Distinguished Fellow, Vivekananda International Foundation, coordinated the work of the Task Force. It included a multi-disciplinary team of experts from power, environment, renewable energy and nuclear power sectors. The Task Force engaged IIT Bombay to assist it with mathematical modelling. I would like to thank all members of the Task Force for their contributions to the discussions.

The report of the Task Force has come up with a number of key findings. Power sector accounts for only 45 percent of India's emissions. Therefore, the goal of net zero emission will not be attainable without going beyond the power sector to include transport, residential uses and industry. India has legitimate aspiration to achieve higher standards of living for its people quickly. This requires raising the per capita consumption of energy even as we enhance the efficiency of energy use and incorporate renewable energy sources in the overall energy-mix. Energy transition cannot be at the cost of the wellbeing of our people.

The mathematical modelling by the IIT Bombay team has brought out that an energy generation-mix with preponderance of renewables has the highest transition cost. The model estimates that the energy transition to net zero emission in 2070 will cost more than USD 11 trillion. This amounts to raising more than USD 220 billion per annum for nearly five decades. The global commitment of

developed countries is USD 100 billion per annum. Actual disbursement has fallen short of even this modest figure, as noted by the Glasgow conference. Much of these resources for India's energy transition would therefore have to come from domestic resources.

A significant conclusion of the Task Force is that India will have to ramp up nuclear power in tandem with the phasing down of coal. The Task Force report points out that the use of renewables for the production of green energy adds to the cost of electricity generation cost and land. Nuclear power could provide a more efficient and cost-optimum solution. Post-Fukushima, public skepticism about nuclear power had increased, but the situation is changing as more and more countries are considering a return to nuclear energy given the recent climate events. There is a rethink on nuclear energy underway even in Western countries where there has traditionally been strong public sentiment against it. The US, China, UK and France have announced financing of R&D for HTGCR (High Temperature Gas Cooled Reactor). The Task Force suggests that nuclear power should also be included in the hydrogen policy for the production of green hydrogen.

I would like to thank Dr Anil Kakodkar for guiding the Task Force. Ambassador DP Srivastava deserves our appreciation for putting together the report and managing the work Task Force energetically and enthusiastically over the last nine months. We gratefully acknowledge with appreciation the support of the Nuclear Power Corporation of India Limited (NPCIL) and Shri DS Chaudhary, Director, for their support and encouragement.

New Delhi-110001

Director

Date : 26th May, 2022.

Dr. Arvind Gupta

Vivekananda International Foundation

Introductory Comments

Humanity is facing an existential crisis as a result of climate change threat arising from unabated emission of greenhouse gases from human activities. Carbon-di-oxide emitted from energy related activities is the most significant threat among them. Currently there is an intense discussion on global action to reduce carbon emission to net zero in a manner that restricts the warming above the temperature that existed in pre-industrialized era to 1.5° C. Decarbonizing global energy systems is in itself a major challenge involving use of clean energy resources and new technologies to meet various energy demands. The challenge is much bigger for a country like India because her development aspirations are yet to be realized. India needs to simultaneously grow and decarbonize her energy infrastructure. This report attempts a discussion on India's Energy Transition in the Carbon-Constrained World.

Solar, wind, hydro, biomass and nuclear energy are essentially the key components of clean energy basket for a country like India. Most of these energy sources primarily produce electricity. Share of electricity in the energy use on the demand side is thus expected to sharply increase as a result of transition to net zero. However, in addition to electricity, one would also need to supply heat energy as well as process feed to several industries. Hydrogen would be the energy carrier to do this without causing emission of carbon-di-oxide. Hydrogen would also complement electricity in transportation sector in a significant way. Production of hydrogen without carbon-di-oxide emission would however require use of clean energy either directly or through use of electricity. The later route which would enhance the share of electricity in the energy basket on the demand side even further is likely to dominate at least in the short run as a result of better advancement of technology for electrolysis as compared to direct thermo-chemical splitting of water.

It thus appears that in the net-zero scenario, electricity would be the dominant part of overall energy system with a smaller contribution coming from bioenergy primarily for decentralized production and use in kitchens and agriculture. A significant part of electricity would be consumed for production of hydrogen to be used in industry and transportation. Going forward, it is likely that

hydrogen would be produced directly leveraging heat from solar and nuclear energy. Electricity would however remain all-pervading source of energy spanning domestic, commercial, industrial, transport, agriculture and other segments of energy use.

There is a general misconception that the entire energy needs to support a quality of life of our people comparable to those in advanced countries of the world can be sourced through renewable energy. India is a relatively population dense country. There are thus limits to per capita availability of renewable energy which is very diffused in nature. A large component of nuclear energy in our clean energy mix is thus inevitable. More ever as the studies have shown the average cost of delivered electricity would substantially rise in a net zero scenario in absence of a significant share of nuclear energy.

In spite of the best efforts, total decarbonization of the energy sector appears difficult particularly in hard to abate industries. Use of fossil energy may thus continue to a limited extent. Deployment of CCUS technologies at the requisite scale would then be necessary to meet the net zero goal. Clearly a significant cost element would be inevitable.

Clean energy transition involves deployment of technologies, many of which are far from being mature. It is also possible that new technologies would appear on the horizon as we go along. Aggressive R&D and technology development efforts are therefore necessary to ensure that the energy transition moves along the optimum path appropriate to Indian conditions. Full clarity is needed in terms of destination and pathway to be followed to meet the energy security and decarbonization targets at each point of time as we move along. Rather than being hostage to vendor driven policies, we should be able to drive policies that keep the investments and prices at minimum possible level. This would require an integrated and balanced approach to different clean energy sources and related technologies to meet the energy needs of Indian people.

This report discusses different aspects of energy transition in India and in other prominent countries. The report is also informed by a modelling work done by IIT Bombay specifically for this report. Reports by other groups have also been valuable inputs to this discussion.

I would like to express my gratitude to VIF for the opportunity to engage in this discussion and to all colleagues on the task force for their valuable contributions.

Anil Kakodkar
Chairman of the Task Force

List of Abbreviations

AD	–	Accelerated Depreciation
AERB	–	Atomic Energy Regulatory Board
AF	–	Adaptation Fund
APPC	–	Annual Power Purchase Cost
APS	–	Announced Pledges Scenario
ARDP	–	Advanced Reactor Demonstration Program
ARENH	–	Accès Régulé à l'Electricité Nucléaire Historique
ARPA-C	–	Advances Research Projects Agency for Climate
ARPA-E	–	Advanced Research Projects Agency for Energy
BASIC	–	Brazil, South Africa, India and China
BARC	–	Bhabha Atomic Research Centre
BAU	–	Business as Usual
BCD	–	Basic Customs Duty
BCM	–	Billion Cubic Meters
BESS	–	Battery Energy Storage System
BNEF	–	Bloomberg New Energy Finance
BRICS	–	Brazil, Russia, India, China, and South Africa
BSUoS	–	Balancing Services Use of System
BU	–	Billing Unit
BUR	–	Biennial Update Report
BWR	–	Boiling Water Reactor
C&I	–	Commercial and Industrial
CAGR	–	Compound Annual Growth Rate
CAPEX	–	Capital Expenditures
CBDR-RC	–	Common but Differentiated Responsibilities and Respective Capabilities
CBG	–	Compressed Bio Gas
CBRD	–	Common but Differentiated Responsibilities
CBTE	–	Cross Border Trade of Electricity
CCS	–	Carbon Capture and Storage
CCUS	–	Carbon Capture Use and Storage

CDM – Clean Development Mechanism

CEA – Central Electrical Authority of India

CEEW – Council on Energy Environment and Water

CER – Certified Emission Reduction

CERC – Central Electricity Regulation Commission

CFA – Central Financial Assistance

CfD – Contract for Difference

CGD – City Gas Distribution

CO2 – Carbon Dioxide

COD – Commercial Operation Date

COP26 – 26th Conference of Parties to the UNFCCC

COPs – Conference of Parties

CRS – Congressional Research Service

CSIR – Council of Scientific and Industrial Research

DAE – Department of Atomic Energy

DACS – Direct Air Capture and Storage

DDUGJY – Deen Dayal Upadhyaya Gram Jyoti Yojana

DFC – Development Finance Corporation

DG – Director General

DISCOM – Distribution Company

DOE – Department of Energy (United States)

DPR – Detailed Project Report

DRDO – Defense Research and Development Organisation

DSM – Demand Side Management

E-Amrit – Accelerated e-Mobility Revolution for India's Transportation

EC – European Commission

EDF – Électricité de France

EIT – Economies in Transition

EMR – Energy Market Reform

EU – European Union

EUR – Euros

EV – Electric Vehicle

FAC – Forrest Advisory Committee

FACT – Forest, Agriculture and Commodity Trade

FDI – Foreign Direct Investment

FID – Final Investment Decision

FIT – Feed in Tariff

FPO – Farmer Producer Organizations

GBI – Government Based Incentive

GCF – Green Climate Fund

GDP – Gross Domestic Product

GEF – Global Environmental Facility

GFANZ – Glasgow Financial Alliance for Net Zero

GHGs – Greenhouse Gas Emissions

GLOFs – Glacial Lake Outburst Floods

GOI – Government of India

GST – Goods and Services Tax

GST-ITC – GST Input Tax Credit

Gt – Gigatonne
GW – Gigawatt
GWh – Gigawatt Hour
HP – Horse Power
HTGR – High Temperature Gas Reactor
HTR – High Temperature Reactor
HTSE – High Temperature Steam Electrolysis
IAEA – International Atomic Energy Agency
IEA – International Energy Agency
IEEFA – Institute for Energy Economics and Financial Analysis
IMF – International Monetary Fund
INDC – Intended Nationally Determined Contributions
InSTS – Intra State Transmission System
IPCC – Intergovernmental Panel on Climate Change
IRIS – Infrastructure for Resilient Island States
IT – Information Technology
IOT – Internet of Things
ITMO – Internationally Transferred Mitigation Outcomes
KWh – Kilowatt Hour
KV – Kilo Volts
LCOE – Levelized Cost of Electricity
LDCs – Least Developed Countries
LDCF – Least Developed Countries Fund
LNG – Liquefied Natural Gas
LT-LEDS – Long-term Low Greenhouse Gas Emission Development Strategies
LULUCF – Land Use, Land Use Change and Forestry
L&D – Loss & Damage
MIT – Massachusetts Institute of Technology
MMSCMD – Million Metric Standard Cubic Meter per Day
MMTPA – Million Metric Tonnes Per Year
MNRE – Ministry of Renewable Energy
MoEF – Ministry of Environment, Forrest and Climate Change
MOP – Ministry of Power
MoPNG – Ministry of Petroleum and Natural Gas
Mt – Megatonne
MU – Million Units
MVA – Million Volt-Amps
MW – Megawatt
MWe – Megawatt Electric
MWh – Megawatt Hour
NABARD – National Bank for Agriculture and Rural Development
NAFCC – National Adaptation Fund on Climate Change
NAPCC – National Action Plan on Climate Change
NBWL – National Board of Wildlife

NCQG – New Collective Quantified Goal

NDC – Nationally Determined Contributions

NGG – Natural Gas Grid

NGHM – National Green Highways Mission

NITI Aayog – National Institute for Transforming India

NOME – Nouvelle Organisation du Marché de l'Electricité

NOX – Nitrogen Oxides

NPCIL – Nuclear Power Corporation of India Limited

NPP – Nuclear Power Plant

NZ – Net Zero

NZE – Net Zero Emissions

O&M – Operations and Maintenance

OECD – Organization for Economic Co-operation and Development

OPEC + – Organization of the Petroleum Exporting Countries

OSOWOG – One Sun One World One Grid

PBI – Procurement Based Incentive

PHWR – Pressurized Heavy Water Reactor

PLF – Plant Load Factor

PLI – Production Linked Incentive

PM-KUSUM – Pradhan Mantri Kisan Urja Suraksha evem Utthan Mahabhiyan

PNGRB – Petroleum and Natural Gas Regulatory Board

PPA – Power Purchase Agreement

PPAC – Petroleum Planning and Analysis Cell

PRAAPTI – Payment Ratification and Analysis in Power procurement for bringing Transparency in Invoicing of generators

PSA – Power Supply Agreements

PSP – Pumped Storage Plants

PTC – Production Tax Credit

PV – Photovoltaic

R&D – Research and Development

RAB – Regulated Asset Based Model

RE – Renewable Energy

REC – Renewable Energy Certification

REE – Rare Earth Minerals

REPP – Renewable Energy based Power Plants

RES – Renewable Energy System

RLNG – Regasified Liquefied Natural Gas

RMB – Renminbi

ROW – Right of Way

RPG – Renewable Power Generator

RPO – Renewable Purchase Obligation

RST – Resilience and Sustainability Trust

RTE – Réseau de Transport d'Électricité

SAARC – South Asian Association for Regional Cooperation

SATAT – Sustainable Alternative Towards Affordable Transportation

SCF – Standing Committee on Finance

SCCF – Special Climate Change Fund

SDG – Sustainable Development Goal

SDRs – Special Drawing Rights

SDS – Sustainable Development Scenario

SECI – Solar Energy Corporation of India

SERC – State Electricity Regulatory Commission

SIA – Social Impact Assessment

SMR – Small Modular Reactors

SOX – Sulfur Oxides

STEPS – Slated Policies Scenario

STU – State Transmission Utilities

TWh – Terawatt Hour

UAE – United Arab Emirates

UDAY – Ujwal DISCOM Assurance Yojna

UK – United Kingdom

UN – United Nations

UNCED – United Nations Conference on Environment and Development

UNEP – United Nations Environment Programme

UNECE – United Nations Economic Commission for Europe

UNFCCC – United Nations Framework Convention for Climate Change

USA – United States of America

VAT – Value Added Tax

VGF – Viability Gap Funding

VHTR – Very High Temperature Reactor

VIF – Vivekananda International Foundation

VRE – Variable Renewable Energy

WTO – World Trade Organization

WUA – Water User Associations

ZEC – Zero Emissions Credit

Executive Summary

Climate change is an existential threat for mankind. The risk has been underlined by extreme weather events in different parts of the world in past few years. Glasgow Climate Pact mentions that 'limiting global warming to 1.5 degrees C requires rapid, deep and sustained reductions in global greenhouse emissions, including reducing global carbon dioxide emissions'[1]. Moving towards a low carbon economy entails accepting stringent emission standards. Most developed countries have agreed to reach the target of Net Zero Emission by 2050; China by 2060. Prime Minister Modi announced that India will achieve this by 2070. Fossil fuels currently account for 79% of global energy basket. The world has to transition away from fossil fuels to emission free sources of energy in a few decades. Both in terms of scale and speed, such a transformation has never before taken place in history. The age of coal has lasted more than two centuries. The oil era, begun a century ago is still continuing. Within months of Glasgow conference, the focus is again shifting to energy security. Geo-politics threatens to trump the climate agenda, as the Ukraine crisis has shown.

This study by Vivekananda International Foundation Task Force brings out the energy choices available to India keeping in mind her development perspective. Historically, economic growth depended upon the use of energy. Since the beginning of the industrial revolution, this meant burning of fossil fuel. Developed countries have followed this route and attained higher standards of living. They also have much higher per capita emissions. China started on this path later but has quickly caught up and surpassed the West. Today, it is the world's largest emitter. For these countries, emission reduction does not pose the kind of problems developing countries will face. The latter are yet to complete their industrialization and infrastructure development. They have to accept more stringent emission standards while moving up the development trajectory.

According to the International Energy Agency (IEA), 90% of the electricity generation will have to be based on renewables to reach the target of Net Zero Emission by 2050, with the balance 10% coming from nuclear power.[2] The share of electricity in the energy basket will have to increase from 20% at present to 50% during this period. The IEA report candidly admits that there is a pathway

till 2030, 'but in 2050, almost half the reductions come from technologies that are currently at the demonstration or prototype stage.'[3] Is it possible to lay down a roadmap with any degree of certainty, when no firm assessment of technology or cost is available?

Achieving net zero emission requires de-carbonization of the entire economy, not simply power sector. Power sector accounts for around 40 per cent of emission and 20 per cent of energy at world level. This will, therefore, require much greater efforts than the IEA report has suggested. Most of the energy will have to be converted to electricity generated from non-emitting sources – renewables and nuclear power. This report examines different technology choices. Solar and wind power have low, generation cost, but generates power with high degree of variability resulting in high systems costs. Nuclear power involves high capital expenditure upfront (primarily because of long gestation periods and resulting higher financing costs) but generates dispatchable power with much higher plant load factor. Hydrogen will play a major role in supplementing energy needs of industry and transportation segments and could also be an important storage solution. Emission free (Green) hydrogen could be produced using either renewables or nuclear power. Adoption of electrolysis route for hydrogen production would significantly increase the share of electricity as a part of total energy needs besides leading to higher energy cost for hydrogen production. Concentrated solar thermal and high temperature nuclear reactors on the other hand would obviate the need of having to go through electricity for hydrogen production through direct thermo-chemical splitting of water to produce hydrogen leading to a higher energy efficiency although the technology development for this purpose is somewhat trailing behind electrolysis. Land use requirements in case of renewable energy is a major constraint for most of the countries. In a country like India, where additional energy requirements are the largest and population the densest among the large countries, there is also a question of adequacy of available renewable energy to meet total energy needs thus needing a much larger share of nuclear energy as compared to the prevalent perception. Battery technology does not offer grid level storage solution and is limited in time. While they may offer a reasonable choice for decentralized or microgrid systems, one would need thermal, hydro or chemical (for ex. hydrogen) energy storage supplemented by flexible generation solutions.

Glasgow Conference

There have been two major outcomes of the Glasgow conference. At the Paris Conference in 2015, the agreement was to contain temperature rise within 2 degrees above the pre-industrial levels. The goal of keeping it below 1.5 degrees was the desired objective to be pursued. At Glasgow, this has been mainstreamed. A lower threshold means a smaller carbon budget to share. This increases the pressure for accepting more stringent emission standards. The second result is endorsing the concept of Net Zero Emission. This is a relative concept, which implies achieving a balance between emissions and sink of a given country by a chosen deadline. This essentially implies that the task of addressing a global problem has been reduced to implementation at the national level.

PM Modi announced at Glasgow that India will achieve 500 GW of 'non-fossil fuel' by 2030. He also stated that India will need financing of 1 trillion dollars till 2030.[4] Since then GOI has

announced updated INDCs on 3rd August where the country will achieve about 50 percent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030.[5] So far contribution of developed countries has been marginal. The UN Secretary General stated that the Glasgow Conference outcome: 'reflect the interests, the conditions, the contradictions and the state of political will in the world today'.[6] His remarks underline the difficulty of political leaders, who have to convince their electorate to make immediate sacrifices for a distant goal. The governments of major economies in turn are not willing to sacrifice energy security. In the run-up to Glasgow, President Biden gave a call for OPEC + countries to increase their oil production. Earlier, in the summer Chancellor Angela Merkel had concluded an agreement for supply of Russian gas via the Nordstrom II pipeline.

Renewables

The renewables promise low emission and low operating costs, since fuel cost is nil. However, they have very high systems cost consisting of 'balancing power' and transmission costs. Being an intermittent source of power, they need a balancing power, when the wind is not blowing, or the sun is not shining. This is provided by gas in Europe and coal in India. On the other hand, when there is a surge in renewable generation, thermal power plants have to be backed down. Maintaining a standby capacity and operating it at sub-optimal level, adds to inefficiency and cost of the system. As large wind or solar power plants are located in remote location, this also entails high transmission costs.

With increasing share of renewables in the grid, systems costs go up. MIT and OECD studies have pointed out that relying exclusively on renewables to meet lower emission standards increases costs 'disproportionally'. To optimize costs, the grid must include nuclear. The MIT study has validated this model for USA and China. The VIF study looks at the problem in the Indian context.

The cases of UK and Germany are instructive. Both countries have a high share of renewables in their electricity generation-mix – 39.97% for UK and 40.9% for Germany. The dropping of wind speed in the North Sea in early November 2021 resulted in sharp hike in electricity prices in Europe. The UK was worst affected, where wholesale electricity prices shot by five-fold. Germany was partly sheltered from negative effects of this phenomenon as it could draw electricity from the regional grid. The UK being an island nation does not have this facility.

Renewable energy is expensive. Germany has the highest electricity tariff in the world:

	Germany	France	USA	China	India
Electricity Tariff US$ per kWhr	0.37	0.22	0.15	0.09	0.08

Source: Statista. (2020). *Household Electricity Prices Worldwide in December 2020, By Select Country*. https://www.statista.com/statistics/263492/electricity-prices-in-selected-countries/

As chapter 4 of this report points out, Germany's high tariff is not a coincidence. It has high dependence on wind power and is phasing out nuclear power. It continues to depend upon gas,

a fossil fuel. Chancellor Merkel, before she demitted her office, remarked that this could lead to increase in German emission levels. Can India afford Germany's Green strategy, which has increased both cost and emission level? India, like UK, does not have access to a regional grid. Most of our neighbors are energy deficit. Bhutan exports electricity, but the scale cannot meet the requirement of even one state in India.

Clean, Firm Power

A series of extreme weather events ranging from California, Texas to North Sea in Europe has brought the focus to firm, clean power. The output of solar and wind power is weather dependent, and unpredictable. A study commissioned by the Environmental Defense Fund and the Clean Air Task Force on energy choices for California has brought interesting findings. The State has decided to make all its electricity carbon free by 2045. The study pointed out that 'Periodic large-scale weather patterns extending over 1,000 kilometers or more, known as dunkelflaute (the German word for dark doldrums), can also drive wind and solar output to low levels across regions.'[7] This is beyond the capacity of batteries to cope; they can supply power only for a few hours. To deliver clean power reliably using wind or solar power requires building excess capacity. This flows from low plant load factor, and unpredictability of renewable electricity generation. In turn, this increases generation as well as transmission costs.

Modelling done by energy experts from Princeton University, Stanford University and Energy and Environmental Economics found that to meet 100 GW of peak demand, 500 GW of capacity would be required if only wind or solar power is used. This will result in 65% increase in tariff over today's rates. On the other hand, any generation-mix of nuclear and other clean, firm power sources 'could deliver a 100% carbon-free electricity supply with generation and transmission supply costs of about 7-10 cents per kilowatt-hour, which compares well with current average of 9 cents per kilowatt-hour.'[8]

To achieve lower emission standards, coal may have to be 'phased-down'. It has to be replaced with a source of energy, which like coal can provide stable, base-load power. Renewables cannot supply stable power as they are intermittent. The nuclear power, however, raises the issues of high capital cost and storage and disposal of nuclear waste. The report examines these issues in detail in chapters 9 and 11 on nuclear power.

Nuclear

Climate change has given nuclear power - a source of emission-free energy, a new lease of life. The US, UK, EU, and Japan are considering retaining and enhancing the share of nuclear power in their generation mix. Nuclear power contributes to lower emissions at affordable cost. It is also a source of clean, firm energy. The rising geopolitical tensions in Europe over the Ukraine issue has also underlined the importance of nuclear power as critical for energy security.

Renewables versus Nuclear: Cost and Emissions

Renewables have a lower plant load factor of 20-22 percent, as against 80-90 percent for nuclear power plants. Thus, a nuclear power plant of same capacity would generate more than three times the electricity produced by a Solar PV plant. A comparison of capital cost should take into account total electricity generated, and not simply the capacity. As mentioned earlier, renewables also have very high systems costs, including cost of balancing power and transmission.

The tariff of Solar PV power plants has kept dropping and was as low as Rs. 1.99 per kWhr in some of the recent tenders. As against this, the average tariff of nuclear power plants in 2019 was Rs. 3.43 per kWhr. However, this does not take into account cost of balancing cost and cost of stranded thermal power plants. This has been estimated by the Forum of Regulators as Rs. 2.12 per unit. Taking this nuclear power tariff of Rs. 3.43 per kWhr is more competitive than Solar power tariff of Rs. 1.99 + Rs. 2.12 = Rs 4.11per unit.

At present, the cost of 'balancing power' is 'socialized'. These are borne either by DISCOMS to be passed on to the consumers or thermal power plants, which are backed down. Currently, renewables account for around 9-10 per cent of India's total generation. As the salience of renewables in the grid will increase, this cost will go up. Proportionately, the capacity of the thermal sector to absorb this cost will go down since the share of coal-based power plants in the grid decreases. The cost of balancing power estimated by the Forum of Regulators does not include the transmission cost, which is very high in case of renewables. If this is factored in, the balance of advantage will shift further in favor of nuclear power.

According to a recent report by the United Nations Economic Commission for Europe (UNECE) on 'Life Cycle Assessment of Electricity Generation Options', nuclear power has the lowest emission as compared to other sources:

	Nuclear	Solar PV	Wind	Gas	Coal
Emission Levels g CO_2 eq./kWh	5.1–6.4	8.0–83	7.8–16	403–513	751–1095

Source: UNECE. (2021). Life Cycle assessment of Electricity Generation Options. https://unece.org/sites/default/files/2021-10/LCA-2.pdf

There are fears of nuclear accidents imperilling civilian lives. After Fukushima, Japan had stopped operation of its nuclear power plants. They are being started again. Japan's new Prime Minister Kishida announced that 'It's crucial that we re-start nuclear power plants'.[9] There is a growing realization in the US that nuclear power plants are essential for reaching the goal of Net Zero Emission. Some of the plants which were to be closed down, have received 20 years extension as well as financial assistance. PM Johnson's 10 Point Action Plan for Net Zero Emission also included support for R&D in the nuclear sector.

The share of nuclear power in electricity generation in India (3%) is far behind those of other major economies – US (20%), EU (20%). China plans to commission 150 new nuclear reactors over the next 15 years boosting its share in generation to 10%. In the US, UK and many other countries, private sector is allowed to own and operate nuclear power plants. In UK and UAE even foreign companies are allowed to do so.

Under the Atomic Energy Act of India, majority private equity holding in nuclear power plants is not allowed. Therefore, capital for expansion of nuclear power will have to be provided by the Government, unless the Act is amended. Internal accruals will not be sufficient for a rapid ramp-up. An immediate step could be the grant of 'must-run' status to nuclear power on par with renewables. This is a facility to ensure continued operation of the plant, whose output cannot be ramped up and down easily. It is important particularly at a time when the demand is low and there is pressure to compete with other sources of fuel, which have lower operating cost.

Coal

Days before the Glasgow conference was to end, the US and China announced reaching a bilateral climate deal. This included the phrase 'phasing-down' of coal. The phrase suggested that they were not willing to accept 'phasing-out' of coal. This formulation was later adopted in the Glasgow summit. Though India got the blame, the two biggest emitters had already agreed to this formula. The stress on 'phasing-down' of coal ignores the fact that gas, a fossil fuel, remains an important part of energy consumption and electricity generation in developed countries.

China accounts for 50.5% of the world's coal consumption; India comes a distant second with 11.3% of global consumption.[10] The Glasgow Climate Pact has called for 'accelerating efforts towards phasedown of unabated coal power'.[11] This is part of a process over time. The term 'unabated coal power' refers to the use of coal without CCUS technologies. The world has to indeed accelerate efforts to develop and deploy such technologies. At this stage, these are not commercially viable and are not deployed on a scale even in developed countries. In the meantime, the US, EU and China have increased the use of coal. 'Coal supplied 23% of US electricity production from the start of the year through mid-June, up from 17% in the same period of 2020, according to a Wood Mackenzie analysis of preliminary EIA data.' [12]'Coal-fired power generation surged by around 20% in the U.S. and the European Union following steep, pandemic-related declines in 2020.' [13]

'China's coal consumption is expected to increase 4% to 4,130 million metric tons in 2021 – surpassing the record set in 2013.'[14] The Chinese increase in coal consumption is not a temporary phenomenon. It has invested heavily in building new coal plants before the window closes. According to IEA, the Chinese government approved further increase in coal-based power plants and '37 GW was authorized in 2020 – three times more than in 2019.'[15] The emissions from these plants will continue beyond 2050.

Germany intended to retain lignite and coal till 2037. The new government with participation of the Greens Party announced bringing forward phasing out of coal from 2038 to 2030. But this

commitment has been diluted by inserting a caveat. 'A coal phase-out will happen **ideally** by 2030 – with the newly inserted word 'ideally' blunting Green ambitions by marking the whole project as tentative.'[16] Germany's decision to phase out coal, and also shut down nuclear power plants, could have the paradoxical result of increasing emissions as it steps up import of gas.

India depends on coal for 71% of its electricity generation. This share will have to be gradually reduced as we move towards low carbon economy. The power crisis in China and India last year was a reminder of complexity of the transition. If a temporary upsurge in commodity coal prices could cause a major hike in electricity prices, any abrupt phasing down of coal could cause massive disruption. Currently, a heat wave is sweeping India. The rise in demand for air conditioning, and coal shortage, has again underlined the delicate balance. Increased reliance on renewables would expose India to weather uncertainties.

Gas

While the role of nuclear power in any pathway to a low carbon economy cannot be ignored, building up a nuclear power plant takes minimum of 5-6 years. Creating a fleet of plants will take longer. In the transition period, gas could be a bridging fuel. The government is committed to increase gas usage from present 6% of the energy basket to 15% by 2030. Imported RLNG is expensive. But gas has a role in providing energy security in the interim period till sufficient generating assets based on renewables and nuclear are built up. In order to be able to compete with other fuel forms, gas has to be brought under GST.

Hydropower

Hydropower provides an ideal solution for 'flexible' generation. It can be ramped up or down quickly to provide balancing power for renewables. As the share of renewables in India's grid goes up, this factor will assume increasing importance. Hydro-power potential however will be affected by climate change, which has an impact on glacier melt, monsoon pattern and river flows. India has a hydro-power potential of 145.32 GW. Against this, the installed capacity is only around 51.34 GW or 35.33% of the total potential. Availability of hydropower can be augmented through sub-regional cooperation between Bhutan, Nepal, and India. Bhutan has a potential of 36.9 GW, while its actual installed capacity is only 2.33 GW. Nepal has a potential of 83 GW, while the installed capacity is 1.2 GW. Co-operation between these three countries can earn Nepal and Bhutan substantial revenue, while considerably adding to hydro-power available to India.

Incentives for the nuclear sector

The EU and UK explicitly recognize the concept of carbon price. This pushes up the price of electricity generated by fossil fuels and creates an arbitrage in favor of nuclear power. The carbon price will continue to rise inexorably as emission norms become more stringent in Europe. This will provide

a long-term, built-in incentive for nuclear power, along with renewables, in Europe. India does not have the concept of carbon-price. The incentives given to renewables, like 'must-run' status, free inter- state transmission and Renewable Purchase Obligations (RPO) are not provided to nuclear power even though it produces least emission amongst different fuel forms. If the sector has to expand, nuclear power has to be given parity with renewables.

The US does not recognize the concept of carbon price at the Federal level, though states like California have a carbon market. Some of the US States provide Zero Emission Credit. The US also provides tax credit. Under the recently enacted Infrastructure Act, the Biden Administration has authorized a USD 6 Billion program 'designed to preserve the existing nuclear fleet and prevent premature shutdowns of nuclear power plants. This provision is anticipated to preserve immense amounts of carbon free electricity.'[17] The relief to the nuclear power plants is based on the fact that nuclear energy is a source of emission-free electricity. The Infrastructure Act also 'contains funding approvals for Department of Energy's Advanced Reactor Demonstration Projects and authorizes US$3.2 billion through FY 2027 for the advanced reactor demonstrations.'[18] Most of the US States have regulated markets, which 'offer power plants protection from rising costs.' The States where the power sector has been de-regulated are providing Zero-Emission Credits of $17.54/MWh, paid by the distribution utilities.[19] This is more than 21% percent of the wholesale price of $ 83.35 per MWh of electricity in the state and provides a major relief to the sector.[20]

EDF, a government owned company, has monopoly of nuclear power generation in France. While EDF has to sell 25% of electricity at regulated prices to retail consumers, it is free to sell the balance 75% of its output in the wholesale market, which is outside the regulated price system (ARENH). As wholesale price of electricity is higher, this arrangement gives EDF considerable margin. Increasing carbon prices in future would ensure that the premium for nuclear power, which is emission-free, will continue. The government also provides capital for expansion of capacity. Recently, President Macron announced construction of 6 nuclear power plants by EDF. Financing for Euro 50 billion project is expected to be provided by the French government.

UK follows the system of Contract for Difference (CfD) with an agreed 'strike price' for purchase of electricity. This provides long term (15 years) price support to private operators building nuclear power plants. The Operator is reimbursed the difference between market price and the agreed strike price, in case the market price goes down below the strike price. If, however, market-price is higher than the strike price, the Operator pays the difference to the Government. This arrangement also covers off-shore wind power and implicitly recognizes the parity between the two in terms of providing emission-free electricity.

US, UK and France are also providing help for R&D activities, such as development of Small Modular Reactors (SMRs) and High Temperature Gas Reactors (HTGRs). These innovations are needed to bring down upfront capital costs and also for hydrogen production. The European Commission (EC) has proposed inclusion of nuclear power in the 'Green Taxonomy' or 'taxonomy

for sustainable finance.'[21] Interestingly, the Commission has also accepted inclusion of gas in Green Taxonomy. If EC's proposal is accepted, this will imply that nuclear sector enjoys easy finance terms on par with the renewables. The Indian Government also needs to provide finance for rapid scaling up of nuclear power sector.

Mathematical Modelling

The mathematical modelling for the VIF study has been done by IIT Bombay. The objective of modelling was to find the most cost-optimum solution for India's energy transition to the net zero emission stage by 2070. The modelling includes, apart from BAU, 5 different scenarios – R95N05, R60N10, CCS30, R50N20CCS30, R40N35CCS25 and R05N95 (R –Renewable, N-Nuclear, CCS-Carbon Capture and Storage). In all five scenarios, IIT Bombay were asked to examine 10% of electricity delivered as Hydrogen. In addition, they were asked to examine two other scenarios with higher share of green hydrogen in the energy mix at the net zero emissions stage. It may be noted that these are hypothetical scenarios. The results of the mathematical modelling are discussed in the following paragraphs.

Hydrogen Economy

Growth of renewables depends upon finding a storage solution. Currently, battery storage is too costly (USD 200 Per KWhr). It has a duration of 4-6 hours which cannot cope with supply disruption of longer period. Long term inter-seasonal variation could be met by hydrogen production. The recently announced Hydrogen policy of the GOI defines Green Hydrogen/Green Ammonia as 'Green Hydrogen/Green Ammonia produced by way of electrolysis of water using renewable energy'. This is a somewhat restricted definition, and excludes not only Blue Hydrogen, but also production of Green Hydrogen using nuclear power.

It is also worth bearing in mind that hydrogen production based on renewables involves dual conversion – first produce electricity and then use it to produce hydrogen. Technologies for direct splitting of water through thermo-chemical route, using the heat from sun or a nuclear reactor are under development. These would by-pass the need to produce electricity at intermediate stage. This would lead to saving in energy and costs. China, Japan, US and UK are funding R&D for High Temperature Gas Cooled Reactors, which promise the use of such more efficient processes. At this stage, when technology and cost estimates have not matured, there is a need to have a flexible approach and explore all options. This has implications in terms of realising better economy as well as restricting the size of electricity system in the overall net zero energy system in the country. Such developments therefore need to be incentivised rather than excluding them from the definition of green hydrogen.

Green hydrogen is more expensive than either Blue hydrogen or Grey hydrogen. It is also two to three times costlier than natural gas. While incentivising production of green hydrogen is an

important policy action, it is equally important to promote use of hydrogen at the demand end. Policies for such a promotion effort to start with, should disregard the colour of hydrogen. Switch over to green hydrogen can be mandated at an appropriate stage taking into account cost of green hydrogen and competitiveness of industry engaged in green production.

Even the developed countries are experimenting with a variety of options. The British PM Johnson's 10 Point Action Plan mentions production of 'low carbon hydrogen'. Japan and Germany are keeping open the option of importing Hydrogen due to lack of enough land for producing Green Hydrogen using renewables at home. Land availability is a problem in India too. India's Hydrogen Roadmap of 2006 included various options, including Blue Hydrogen or producing Green Hydrogen using nuclear power.

Production of green Hydrogen using electricity solely from renewables will significantly increase the SPV installed capacity due to the low efficiency of the electrolyser, losses involved in the two-stage conversion, and losses involved in the transportation and storage of H_2. Use of high temperature reactors for thermos-chemical splitting of water offers a more efficient solution. In case the choice is narrowed to Green Hydrogen, this will push up the costs. A careful view has to be taken whether the argument of stranded assets justifies overlooking intermediate solutions.

Apart from cost, there is a severe constraint in terms of land available for production of green hydrogen through electrolysis of water using renewables energy. The mathematical modelling done by IIT Bombay for the VIF study found that there is simply not enough land available. The details are discussed in the section on Land. This phenomenon is not limited to India and is the reason why Germany, whose preferred model is reliance on renewable energy, has decided to enter into agreement with foreign countries to produce green hydrogen overseas.

Finance

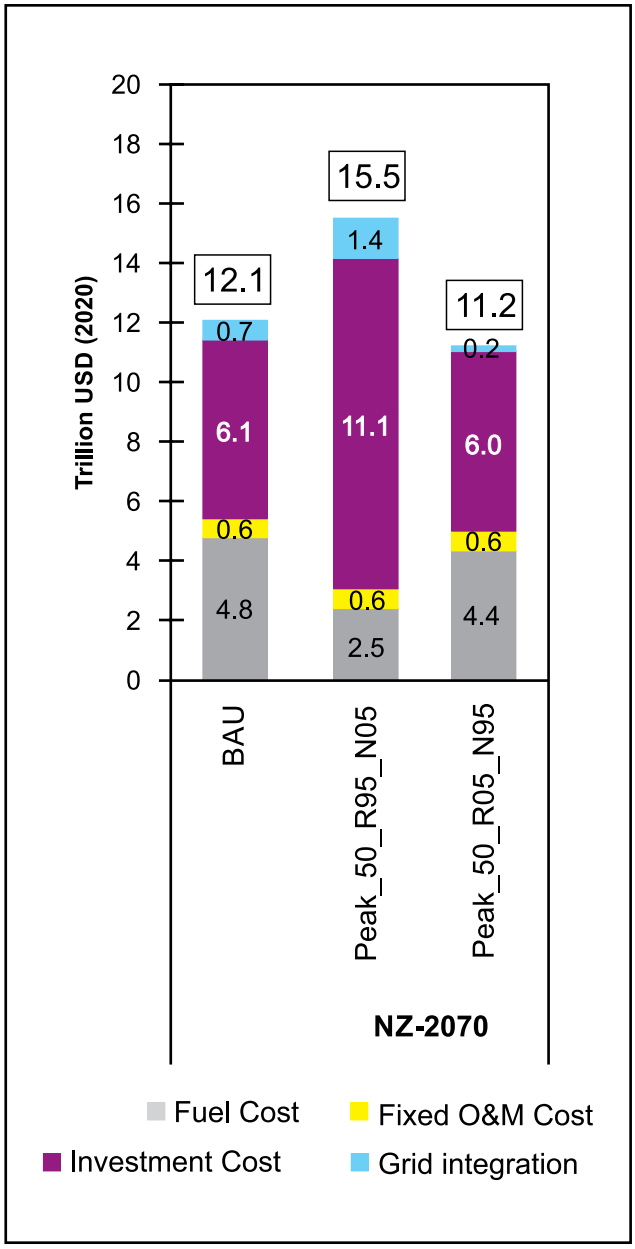
Energy transition of this scale in a short time frame of 50 years (2070) would require massive resources. The IEA had projected that the 'total annual energy investment surges to $ 5 trillion by 2030'[22]. A recent report by McKinsey says, 'Capital spending on physical assets for energy and land-use systems in the net-zero transition between 2021 and 2050 would amount to about $275 trillion, or $9.2 trillion per year on average'.[23] Not only this envisages a substantially higher annual outlay than the IEA projection, it also covers entire transition period up to 2050. PM Modi's demand for developed countries to provide $ 1 trillion per annum to developing countries appears very reasonable in comparison. The commitment of $ 100 billion per annum made by developed countries so far pales into insignificance compared to the scale of resources needed.

To date, even this lower target of USD 100 billion has not been reached. The contribution received so far from international sources has been paltry. The Global Environment Facility and Green Climate Fund have provided grants to a total of only US$ 165.25 million to India. The corresponding domestic mobilization from our sources amounts to US$ 1.374 billion. Since most of the resources

will have to be generated by DISCOMs, restoring their financial health is important. Unfortunately, after showing initial improvement, DISCOM losses have started mounting again. They are now in excess of Rs. 1,56,000 crores. This is at current, low level of per capita consumption. The losses will go up as per capita consumption increases unless better financial discipline is maintained. This requires political consensus in a federal structure.

According to modelling done by IIT Bombay, the cost of the energy transition to net zero stage till 2070 will be $ 12.1 trillion in the BAU case. Of the five scenarios chosen for this study, the cost of transition is highest in case of the renewable heavy (R95N05) scenario - $ 15.5 trillion (Figure 1). It is the least in the scenario where nuclear power has a predominant share in the generation mix (R05N95) - $11.2 trillion. Both scenarios correspond to 2050 as the peaking year. Spread over nearly 5 decades, this amounts to nearly $ 224 billion per annum.

Figure 1: Net zero in 2070 with 10% green H2 demand— Cost of power sector transition under different scenarios.



Source: Figure 18 of IIT Bombay, Mathematical Modelling for the VIF Task Force Study – India's Energy Transition in a Carbon Constrained World. (Annexed)

Rising carbon- price

Most new technologies are expensive and at the present stage of development not viable. To make them commercially viable, it is suggested that carbon-price should be introduced. This would make fossil fuels more expensive and create a dis-incentive for their use. There is strong move in the EU to suggest a Border Adjustment Tax to equalize carbon price between Europe and other countries, so that European industries do not shift to lower cost destinations. Though the move did not succeed in Glasgow, the pressure will continue. Whatever the rationalization, such a move will undermine the basic premise on which success of decarbonization drive rests. Higher electricity prices will make the energy transition more painful both in political and economic terms. It will also render Indian industry uncompetitive. *The carbon prices in EU have increased in one year from Euro 32.72 per ton in December 2020 to Euro 90.75 per ton by the end of December 2021.*[24]

India does not accept the concept of carbon price. Nor is there any agreement at international level. The US position differs from EU with regard to carbon price. It has not accepted the concept at federal level, though some of the states like California apply it. If this position changes in future, pressure will mount. Such pressure could also come through unilateral measures. Applying the concept will change the cost matrix between renewables and nuclear on one hand, and fossil fuels on the other hand. This will also change the relative advantage of gas versus coal.

Land

Renewables have a much larger land footprint than nuclear power plants. A recent report of RTE, the French government company has the same conclusion. A team of experts from Stanford and MIT have done a study in the context of a proposal to shut down Diablo Canyon nuclear power plant. Their report mentions that while the existing nuclear power plant takes up 900 square acres, the solar power plant of comparable capacity would require 90,000 square acres.

India has total surplus land area in the country as 2,00,000 square kms. according to a report by Prof. Sukhatme. According to the mathematical modelling done for this study, India will need 14,680 GW of solar if we rely mostly on renewables (R95N05). This would require total land area of 4,12,033 square kms. The land requirement will be substantially reduced to 1,83,565 square kms. in case we rely mostly on nuclear power (R05N95).

The above estimate of land required is based on 10% of electricity delivered as hydrogen. The requirement will go up steeply in case the share of green hydrogen produced using renewables is increased. If the share of electricity generation by hydrogen in the energy mix is increased to 25%, still the land requirement will be further increased to 13,13,500 square kms. There is simply not enough land available for scaling up renewable capacity to meet the demand for electricity at net zero emission.

Disorderly Transition

A disorderly energy transition would have enormous cost for the world, and exhaust resources needed for an orderly transition. The rise in fossil fuel prices since last year illustrates the problem. Moving towards a low carbon economy should reduce demand, and price of oil and gas. Ironically, the world witnessed a sharp increase in the price of both. The increase in prices diverted resources needed for transition to low carbon economy to meeting the immediate import bill.

The priority has shifted to maintaining energy security. The present phase may pass. But the problem can be repeated in the future on a larger scale, unless phasing out of fossil fuels is coordinated with ramping up of clean energy.

The increase in oil and gas prices is partly a function of demand-supply situation, and partly geopolitical considerations. Economic recovery after the pandemic boosted demand. This was combined with the policy of OPEC countries of restricting crude oil production to keep prices high.

The trend was reinforced by political uncertainties arising from Libyan and Iranian situation, and lately Ukraine crisis. While fossil fuels have to be phased out in the long run, consumer behaviour takes time to change. It is necessary to maintain demand-supply balance in the meantime. The call by IEA for freezing investment in new fossil fuel supply may have had the unintended consequence of contributing to worsening of the situation. It made the oil companies more cautious about investment in the oil and gas sector; the previous year had already witnessed major cuts. The oil prices have soared to USD 92.87 (OPEC Basket) as of 13th February 2022. Since then, Brent crude oil price has shot up to $ 120 per barrel. Gas prices had seen an upward trend since the beginning of 2021. The trend has picked up momentum after Ukraine crisis broke out on 24th February.

The surge in oil and gas prices have led to huge increase in import bill of consuming countries. In India's case, this will double the annual oil import bill of USD 100 billion approximately. There have been parallel increase in the import bill of coal and LNG. PM Modi had stated at Glasgow Conference that India will need USD 1 trillion by 2030 for moving towards low carbon economy. This works out to USD 100 billion per annum. The increase in oil and gas bill exceeds this amount. This makes it very difficult to find resources for India's energy transition, which is just beginning. The problem of oil and gas sector may be repeated on a much larger basis unless nuclear power is ramped up in tandem with phasing down of coal.

Tariff

In order to encourage progressive electrification of economy, which is critical to attain net zero emission status, it is essential that the electricity tariff (delivered cost of electricity without going into fiscal issues) remains low. A number of studies have mentioned that there will be increase in tariff in the initial phase when carbon cost has to increase to drive out fossil fuel. However, once the renewables have replaced fossil fuel, the electricity price will come down. This is a fallacious argument. The McKinsey report brings out that there will be a 20-25 increase in overall tariff in the initial phase. This as well as further trajectory of predicted tariff is based on the assumption that ways are found to overcome the intermittency of renewable power and build flexible, reliable, low-cost grids. As the share of the renewables in the grid increases, the renewables operational cost will indeed come down. However, there are two other components of the delivered cost – renewables capital cost and grid costs which actually increase sharply. The overall tariff remains elevated registering an increase of 20%.

There is a view that the energy transition will produce winners and losers. The sectors which depend upon fossil fuel extraction or use will suffer, while the sectors linked to generation and use of renewables will gain. However, if there is a sharp increase in the overall tariff, there will be no winners. The choice of generation-mix is important to moderate the costs. Otherwise, the overall cost to the economy will increase, it will be difficult to electrify new sectors and net zero emission will remain an elusive goal. As per the mathematical modelling by IIT Bombay, the ex-bus price of

electricity will increase more than three times from about 50 USD/MWh in 2020 to 164 USD/MWh at the NZE stage in 2070 in a renewable heavy scenario (R95N05).

Development Imperative

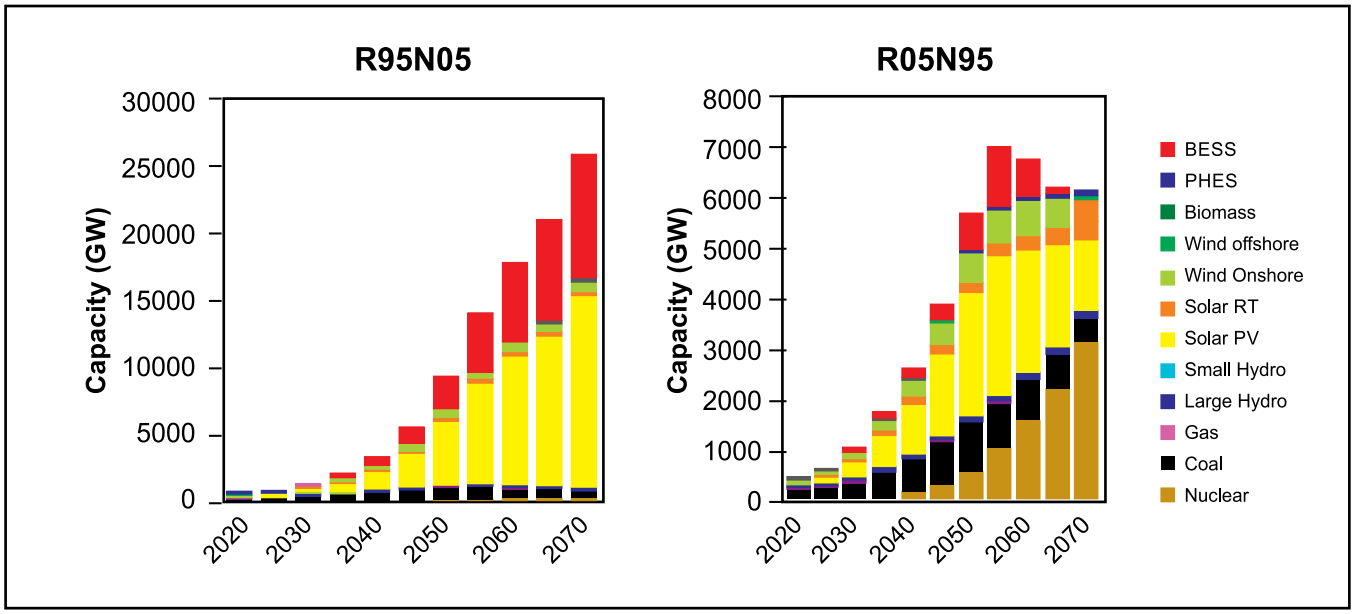
Developed countries have not only exhausted 80% of the carbon space, they continue to use up a disproportionate share of the meagre space left. The per capita annual territorial GHG emissions in 2030 will be highest for US (12.1 tons), followed by China (9.4 tons), Japan (6.6 tons), EU (5.3 tons), UK (3.6 tons) and India (2.2 tons).[25] Acceptance of Net Zero Emission, does *not* mean c*onvergence* of emission trajectories. This is a *relative* concept where each country equalizes *its respective* emissions and carbon absorptions by a timeline of its choice. The level at which this equilibrium will be reached will be different for each country.

There is a clamor for accepting early peaking to avoid stranded assets. This argument overlooks its impact on growth. 'Peaking' of emissions is easier for developed countries, who have completed infrastructure development and industrialization. In case of developing countries, this would cut-short the development trajectory. According to an OECD study, India's growth is to continue till 2060 when it catches up with China in terms of share in world GDP. [26]An early 'peaking' would depress the development trajectory.

Achieving Net Zero Emission requires de-carbonization of the entire economy, rather than simply power generation. This will be done by replacing fossil fuel by electricity generated from renewables and nuclear with Hydrogen providing energy for hard to abate sectors. Electricity currently accounts for 24% of primary energy consumption in India according to NITI Ayog figures. *Electrifying other sectors will increase this demand by three to four times*. India has chosen 2070 as the date for attaining NZE. Over a period of half-century, living standards cannot remain stagnant. *Any projection of power consumption will also have to reflect people's aspirations for better standards of living*. More electricity will be needed to respond to *impact of climate change* in sectors ranging from irrigation, drinking water, to heating and cooling of homes and work places.

According to the mathematical modelling by IIT Bombay, the generation requirement at net zero stage in 2070 for renewable heavy scenario (R95N05) will be 30,839 TWh. The corresponding figure for the scenario where nuclear has a preponderant share (R05N95) will be 24,470 TWh. An approach relying mostly on renewables requires not only higher generation, but much higher increase in capacity due to the low plant load factor, and unpredictability of climate conditions. R95N05 for instance would require 14680 GW of Solar with 284 GW of Nuclear to reach net zero emission stage as against much smaller capacity of 3036 GW of solar and 3139 GW of Nuclear in R05N95. The huge capacity build up required in case of renewable heavy high pushes up the cost as well as land requirement in R95N05 scenario. The striking contrast between the two scenarios in terms of capacity build-up required is clear from Figure 2 below.

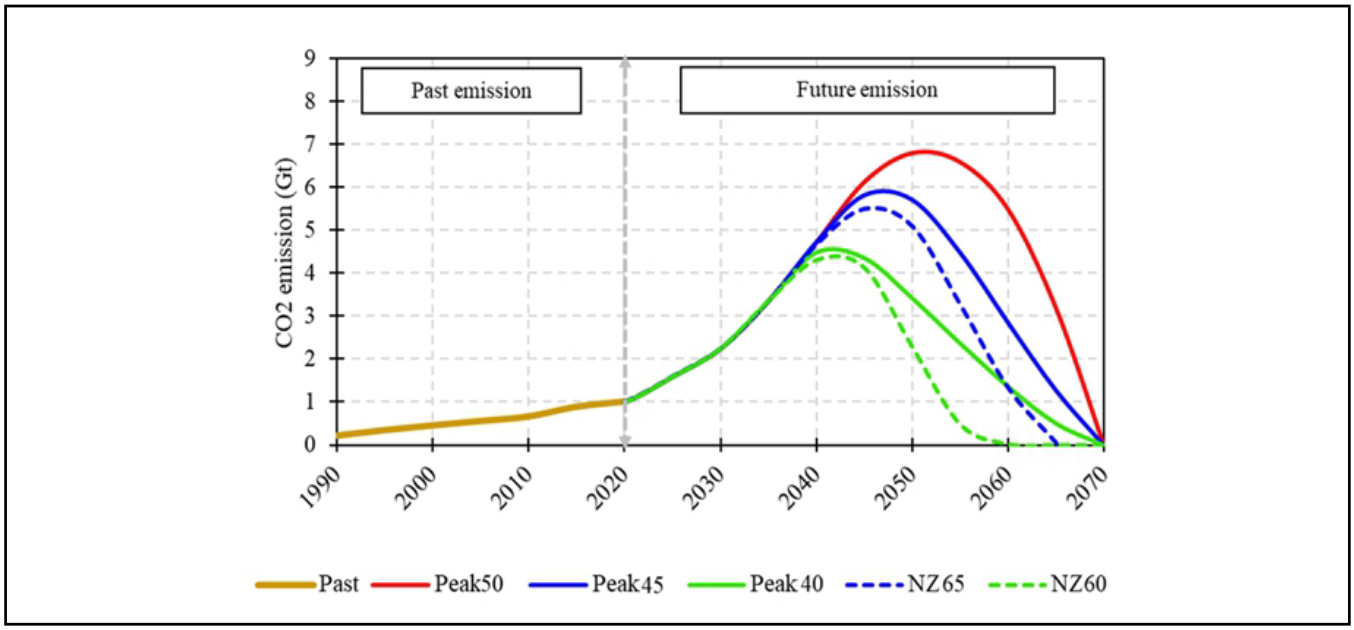
Figure 2: Net zero in 2070 with 10% green H2 demand - Installed capacity under different scenarios.



Source: IIT Bombay, Mathematical Modelling for the VIF Task Force Study – India's Energy Transition in a Carbon Constrained World. (Annexed)

The modelling has covered three permutations of net zero years and peaking years NZE 2070 with peaking in 2050, NZE in 2065 with peaking in 2045 and NZE in 2060 with peaking in 2040. The future CO2 emission trajectory is shown below (Figure 3):

Figure 3: CO2 emission trajectory— Scenarios with different peaking and net zero year



Source: IIT Bombay, Mathematical Modelling for the VIF Task Force Study – India's Energy Transition in a Carbon Constrained World. (Annexed)

According to modelling by IIT Bombay, despite the rising trajectory, India's per capita emission at the peak level in 2050 will be 6.8 tons (as against 13.2 tons in BAU scenario). This is below China's per capita emission in 2019 of 7.3 tons. The Chinese per capita emission will continue to rise to reach 8.9 tons per capita in 2030. China has accepted a peaking of emissions in 2030, but not announced any downward trajectory beyond that date.

The modelling has an interesting finding about the impact of an early net zero year and early peaking on the cost of energy transition. Early peaking leads to higher upfront capital investment in renewable and storage. The cost of transition in the three cases are: $15.5 trillion, $16.1 trillion, $16.7 trillion respectively. While delayed peaking may lead to some stranded assets, there are also costs of early peaking. Compressing the transition schedule increases investment.

Moving towards low carbon economy will require huge increase in electricity generation. This will increase from 1265 TWhr in 2020 according to NITI Ayog figures to 2518 TWhr in 2030 as per CEA's projections. This will amount to doubling of generation and require a CAGR of 7.13%. According to mathematical modelling done by IIT Bombay, requirement of electricity generation from clean sources would be higher in case the target is reaching net zero emission in 2070:

• Electricity Generation (2020): 1265 TWh (NITI Aayog Dashboard)
• Electricity Generation (2030): 2518 TWh (CEA's 2030 Projections)
• Electricity Generation (2070): 24470 TWh (IIT Bombay - R05N95)
• CAGR from 2020 to 2030: 7.13%
• CAGR from 2030 to 2070: 5.84%
• CAGR from 2020 to 2070: 6.1%

Creating new generation capacity and strengthening the grid will require massive resources. Most of these will have to be mobilized through domestic effort. Foreign investment will not come in unless there is assured payment. This requires restoring the financial health of DISCOMs. To respond to the aspiration of better standards of living, more energy in the form of electricity is needed. Neither the Central government, nor State governments can bear the financial burden alone. The task requires cooperative efforts within our Federal structure. While implementation is spread over decades, the policy makers need to make fundamental choices now.

Key Recommendations

- India's per capita electricity consumption to be ramped up to 20,559 kWh (R95N05) to 16,313 kWh kWh (R05N95) per capita by 2070 to cater to a low carbon economy which includes e-mobility, supplying process heat to industry and hydrogen production.

- Renewables share in the economy to grow, but systems costs including balancing costs and transmission charges to be taken into account for deciding the tariff structure of the renewables, and its share in the grid.
- Nuclear as a source of non-fossil, stable base-load power has to be a significant part of India's energy matrix to optimize cost and lower emission. According to mathematical modelling done by IIT Bombay, India's energy transition to Net Zero Emission stage by 2070 would cost $ 11.2 trillion in a nuclear dominated scenario (R05N95), while the cost in case of a renewable dominated scenario (R95N05) would be 28% more at $ 15.5 trillion.
- The land requirement must be taken into account in making different energy mix choices.
- Major economies are retaining coal in the generation mix in the short to medium terms, while China is building new coal-based power plants. India should explore options for minimizing emissions, such as super-critical technology with higher efficiency and CCUS.
- Need for rapid ramp-up of nuclear power to decarbonize Indian economy. Nuclear power should be given incentives on par with renewables, including 'must-run' status and GST status.
- As ramping up of nuclear power will take time, in the interim there is need for gas as a bridging fuel in India's transition to a low carbon-economy. Gas based power plants could be utilized to provide peaking power to wind or solar power plants. In the long run some nuclear power capacity should operate in load follow mode. Hydrogen and electricity cogeneration should also enable some flexing capability.
- Need for a flexible approach to hydrogen production as technologies have not matured. The options should include nuclear energy for producing hydrogen.
- Government to provide funding for R&D to develop SMRs, HTGRs and load-following reactors, which can be ramped up or down to support renewables.
- Hydropower could be basis for enhanced regional cooperation between India, Nepal and Bhutan as well as meeting India's need for clean energy.

These recommendations relate to broad objectives and course of action. This report avoids the temptation of laying down 'pathways'. To do so assumes investment decisions which are yet to be made. Many of the technologies like Battery storage, CCUS and Hydrogen have still not matured. It is hoped that this report could be the basis for an informed debate on addressing an extremely complex issue.

D.P. Srivastava

Co-ordinator, VIF Task Force for
India's Energy Transition in a Carbon-Constrained World

26.5.2022

Chapter 1 : Development Imperative, Climate Change and Energy Choices

The concern for climate change has spurred an intense debate on energy transition to a low carbon economy. While the developed world has contributed most to global warming, its consequences will be felt by all countries. The worst affected will be those least equipped to deal with it. Ignoring their development imperative would leave millions in poverty. Since the industrial revolution, growth has been predicated upon burning of fossil fuel. It will not be easy to break out of this paradigm. Those who advocate de-growth for the sake of preserving ecology ignore the inequity inherent in such an approach. The transition to a low carbon economy will require enormous investment. Finding such resources is particularly challenging at this stage. Even before the global economy could recover from the pandemic, it is confronted with a third oil price shock.

During the Glasgow Summit, Prime Minister Modi enhanced India's commitment to clean energy and said that India will reach its non-fossil energy capacity to 500 GW by 2030. He added that India will meet 50 percent of its energy requirements from renewable energy by 2030. India will reduce projected emissions between now and 2030 by 1 billion tonnes. The country will also reduce carbon intensity of its economy by less than 45%. He also announced that India will reach the target of net zero by the year 2070.[27]

Moving towards lower carbon economy would entail a major transition. At present, coal accounts for 71% of her electricity generation. The recent heat wave showed how precarious the situation is. India's peak power supply touched a record level of 207 GW on 29th April with increased demand for air conditioning.[28] This shows how climate change could strain her power system.

India needs more energy to complete her infrastructure development. The national power grid was completed only recently. In April 2018, 'Leisang in Manipur became the last village to be added to the national power grid.'[29] Though this was indeed a moment to be proud of, India's per capita electricity consumption remains at 1/3rd of the global average. This points to the complexity

of the challenge posed by climate change. The transition to a low-carbon economy involves the diversification of energy sources. This has to be achieved while moving up the development trajectory.

The Glasgow Conference on climate change was preceded by two major developments. The slowing down of winds in the North Sea in September 2021, and the spike in gas prices led to an unprecedented increase in the price of electricity in Europe. In China and India, coal shortages threatened the power supply. Ironically, the year which brought renewed focus on climate change and clean energy ended with a sharp increase in the price of fossil fuels, and call for increased production. This points to the complexity of energy transition. The cost of disorderly transition would be high.

The Glasgow Summit had two key outcomes. It mainstreamed the idea of Net Zero Emissions. There is also greater acceptability of the idea of limiting the temperature increase to within 1.5 degrees above the pre-industrial level. At the Paris Conference in 2015, the agreement was to limit the temperature increase to 2 degrees Celsius above the pre-industrial level. Lowering of the threshold has the result of reducing carbon space and strengthening of emission standards.

Amongst the sectoral outcomes of the Glasgow Summit was the recommendation to 'phase-down' coal. The summit did not accept 'phasing out' of coal. Coal accounts for 71% of India's electricity generation. If the country is to maintain its development trajectory, phasing down of coal has to be in tandem with increase in generation based on non-fossil sources of energy. These are: renewables and nuclear power. Solar power is an obvious choice for India. The potential of wind power is limited to the coastal states. It is also seasonal. India has already achieved 100 GW in terms of installed capacity. The renewables, however, are intermittent and need to be balanced with stable base-load power. This can either be provided by coal or nuclear in India's case. Given the climate concerns, the share of coal in the energy basket cannot be increased. Hence, the role of nuclear power as a clean, non-fossil source of base-load power assumes significance. There is a positive convergence between the growth of renewables and nuclear power.

International Energy Agency (IEA) report, Net Zero Emission and Equity

The IEA report titled Net Zero by 2050 states that technologies are available for emission reduction up to 2030. This still leaves unanswered the question of finance. However, the biggest uncertainty lies in the next phase of de-carbonization. The IEA report admits 'But in 2050, almost half the reductions come from technologies that are currently at the demonstration or prototype phase.' It lists three key areas: 'advanced batteries, hydrogen electrolyzers, and direct air capture and storage.[30]' That these technologies will mature in time and will be cost-effective is a major leap of faith. This cannot be a credible pathway based on what is known to science today.

The concept of Net Zero Emission puts developed and developing countries in a straightjacket despite their widely varying energy, and emission records. India is projected as the third biggest

emitter in absolute terms. This methodology ignores that in terms of per capita emission, India is at the bottom of the list amongst major economies. India's per capita emission in 2030 will be less than 1/3rd of the US (30.7%) and about 45% of the Chinese per capita emission. This would be clear from Table 1.

Table 1 : Per capita annual territorial GHG emissions based on minimum targets

(tonnes of CO2 equivalent, excluding LULUCF)

Emission levels	2019[a]	2030[b]**
US*	16.06	13
Canada	15.41	12
China	7.10	9
Japan	8.72	7
EU	6.41	5.1
India	1.91	4

Source: [a]Ritchie, H. and Roser, M. (2020). *CO_2 and Greenhouse Gas Emissions*. https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions.

[b]UNEP. (2020). *Emissions Gap Report 2020*. https://www.unep.org/emissions-gap-report-2020

*Projections for the US are based on 2025 projections.

**Approximate projections.

Share of Fossil Fuel

The IEA report suggests that 'no additional new financial decisions should be taken for new unabated coal plants, the least efficient coal plants are phased out by 2030'.[31] While asking developing countries to phase out coal, most developed economies still retain a high share of fossil fuel in their energy basket. In most cases, gas has replaced coal. This is also partly the cause of the current hike in European electricity prices. In Germany, the share of fossil fuel in electricity generation is 40.9%. Of this gas accounts for 15.4%, while the rest is made up of hard coal (9.4%) and mineral oil products (0.8%).[32] In the case of the UK, the share of fossil fuel in electricity generation is 39.97%, with natural gas accounting for 40.1%.[33] A study by Agora Energiewende notes that 'Since 2015, although coal generation halved, (-340 TWh), only half of that was replaced by wind and solar (176 TWh).[34]

Germany and UK have made contrasting energy choices. While Germany has decided to phase out nuclear, the UK is building new nuclear power plants and has even allowed foreign investment. Germany will retain the use of coal (lignite) till 2037, while the UK decided to phase out coal by 2024. Chancellor Merkel towards the end of her term decided to go ahead with the Nordstrom II pipeline, which will import an additional 55 BCM gas per annum. This was done despite the opposition of European neighbors and reservations on part of the US, though Biden Administration eventually

acquiesced in the decision. Germany preferred energy security to climate concerns or geo-politics. After the Ukraine crisis erupted, this has been put on hold. However, Germany continues to import gas from Russia through the Nordstrom I pipeline. Europe's dependence on Russian gas imports is the reason that gas has not been included in the sanctions announced against Russia.

The Challenge of Renewables

The recent hike in electricity tariff in Europe demonstrates the volatility and cost of systems based on the high incidence of Variable Renewable Energy (VRE). Natural gas prices were increasing since early this year. The sudden dropping of the wind in the North Sea led to the loss of wind power production. The effect was most pronounced in the UK, though it was felt in the entire European energy market. 'Prices for power to be dispatched the next day rocketed to £285 a megawatt-hour in the U.K. when wind speeds dropped.'[35] 'That is equivalent to $395 a megawatt-hour and marked a record on figures going back to 1999.' [36] There was a sharp jump in electricity prices in Germany also, which reached 131 Euros a megawatt-hour. Germany was relatively protected as it has access to the regional grid and piped gas from Russia.

The impact of the jump in electricity tariff in Europe is continuing to be felt. 'European Central Bank President Christine Lagarde this month referred to energy markets as one of the main forces driving inflation higher'.[37] At least Two UK energy retailers went out of business leaving 'a combined 94,000 gas and power customers stranded'.[38] 'National Grid asked Électricité de France SA to restart its West Burton A coal power station in Nottinghamshire. That won't be possible in the future: The government has said all coal plants must close by late 2024'.[39] The problem of the unpredictability of renewables and volatility of imported gas prices has long-term implications for the energy model on which Europe is basing its ambition to attain Net Zero Emission by 2050. Wind accounts for 21.06% of the UK's electricity generation, while the share of natural gas is 40.1%.[40] In the case of Germany, wind accounts for 20.3% of electricity generation, while natural gas's share is 15.4%.[41] Thus, these two sources account for nearly 60% and 40% respectively of power production in these two countries. Sustained volatility or disruption cannot be easily made up from other sources.

Fatih Birol, IEA Executive Director told the Financial Times that 'There is an inaccurate campaign that's saying we're seeing the first crisis caused by clean energy and that this can become a barrier for further policy action to address climate change. But this is definitely not true.'[42] He claimed that 'the current energy market disruption was due to a confluence of factors, including an "unsustainable recovery" from pandemic, weather conditions and significant gas supply outages.'[43] It is indeed true that an increase in gas prices is a factor in the current crisis. The upward trend in gas prices pre-dates the dropping of North Sea wind and fall in wind power generation. However, this does not mean that wind power has played no role in the steep hike in electricity prices. This is partly implicit in Mr. Birol's statement, which refers to 'weather conditions'. The five-fold increase in electricity price took place in September, much before the onset of winter. Therefore, the increase in electricity price did not take place due to the paucity of gas to meet

the heating requirement. It took place because gas is used to supplement wind power and meet balancing or peaking requirements. The sudden drop in wind speed over the North Sea resulted in a sharp drop in the generation, which led to a spike in gas demand. This took place at a time when the international market for gas was tight and led to a jump in prices. Paradoxical, though it may sound, there is a symbiotic relationship between renewables and gas. Increasing penetration of wind power in the grid rests on the availability of fossil fuel. The recent events have underlined the fragility of the model.

The recently released World Energy Outlook by IEA has made an oblique reference to the Texas crisis of February 2021. But it has tip-toed around the ongoing problem in Europe, which has left thousands of consumers stranded in the UK and a series of bankruptcies of power companies unable to cope with the requirement to sell electricity at regulated prices, while the wholesale price of the purchase has gone up steeply. It, however, acknowledges that growing salience of wind and solar energy poses a challenge to Europe's grid stability in the future:

> 'Such vulnerabilities may become more pronounced: in the APS, installed capacity and annual generation from natural gas in both the United States and European Union are lower by 10-25% in 2030, whereas the peak level of weekly gas-fired power generation actually increases by 10-15% relative to 2020, reflecting a much more substantial role for natural gas in balancing variable renewables.'[44]

Renewables are important as a source of emission-free energy. But it is disingenuous to talk about it as a problem in the distant future while ignoring its current dimension which is in full public glare. The challenge posed by VRE will of course get worse as grid penetration increases beyond current levels as acknowledged by the IEA report. This calls into question a key assumption underlying the IEA report on Net Zero Emissions by 2050. The report assumes that 'Electricity accounts for almost 50% of total energy consumption in 2050'. It also assumes that 'By 2050, almost 90% of electricity generation comes from renewable sources, with wind and solar PV together accounting for nearly 70%. A substantially higher percentage of electricity in the overall energy basket, as well as renewables' share in electricity generation would sharply increase volatility.[45]

Integration Cost of Variable Renewable Energy

Angela Merkel before she demitted office admitted that Germany's decision to phase out nuclear has made it difficult to meet its climate commitments.[46] Reliance on North Sea winds has costs, which are not reflected in the tariff. This includes balancing costs, which already exceeded Euro 900 million per annum by 2016.[47] In addition, there are considerable costs involved in laying the grid infrastructure. As the salience of VRE increases, the grid integration costs will go up steeply.

An MIT study titled – The Future of Nuclear Energy in a Carbon Constrained World, has brought out that without the contribution of nuclear power, 'the cost of achieving deep decarbonization targets increases significantly[48]. This has relevance for India as we ramp up the share of renewables

in the grid by 2030. With this, the cost of renewable integration will also go up. According to a report by the Forum of Regulators, the cost of VRE integration in the grid, which is not reflected in the present tariff structure of renewables, is Rs. 2.12 kWhr per unit. This includes balancing cost of Rs. 1.10 per kWhr and stranded assets cost of Rs. 1.02 per kWhr.[49] This is borne by the DISCOMs, and eventually passed to the consumers. As India ramps up the renewable capacity from 100 GW at present to 450 GW, this will impose an enormous burden.

Ramping up renewable capacity from 100 GW at present to 450 GW by 2030 will also entail expanding the grid with dedicated transmission lines to carry renewable power. According to an estimate by the Power Grid Corporation, the cost of laying the grid to cover additional renewable capacity (350 GW) will work out to Rs. 2,27,500 Cr (Rs. 2.275 Trillion). If the IEA's prescription for 90% of electricity generation through renewables is accepted to achieve Net Zero Emission target, the cost will be of a much higher magnitude. It will have repercussions across the entire economy and socio-political fabric and will not be limited to a particular sector alone.

To optimize the cost, renewables will have to be supplemented with nuclear power. The alternative will be exorbitant whether we chose a renewable-only solution or the European model of depending upon imported gas as the preceding paragraphs have shown.

According to a CEA estimate, the share of renewables in India's power generation will increase from 9.2% at present to more than 31% (Solar 19%, Wind 12%) by 2029-30. With this, the cost of renewable integration will also go up. To optimize this cost, without increasing emission, the share of nuclear has to increase. As mentioned earlier, with an almost similar energy profile China is aiming at increasing the share of nuclear to 10% by 2030. The share of nuclear power in the US (20%) and EU (20%) is 10 times higher than its share in India's energy basket (2%).

Winds are changing

The hike in electricity prices in Europe was triggered by a drop in wind speed and an increase in gas prices. It has occasioned a change in Europe's mood. President Macron of France had announced earlier that he would 'shut 14 reactors and cut nuclear's contribution to France's energy mix from 75 to 50 percent by 2035.' [50]He said on 11th October 'We will continue to need this technology.[51] In February 2022, he announced a major buildup of France's huge nuclear power program, pledging to construct up to 14 new-generation reactors and a fleet of smaller nuclear plants as the country seeks to slash planet-warming emissions and cut its reliance on foreign energy.[52] French consumers pay much less for electricity than other EU countries. German households pay 50 percent higher prices than their French counterparts and are above the EU average.

France and many of the Central European countries want nuclear power to be included in the Green Taxonomy to benefit from 'sustainable finance' to be provided by the EU. Recently, France, Poland, Hungary, Slovakia, Bulgaria, Croatia, Romania, and Slovenia said 'To win the climate

battle, we need nuclear power.'[53] The statement added 'It is, for us all, a crucial and reliable asset to a low carbon future'.[54] 'The European Commission has now taken steps to include nuclear energy as a *transitional* activity in the taxonomy by adopting a Complementary Delegated Act (CDA).'[55]

Perhaps the most significant is the statement by Japan's new Prime Minister Fumio Kishida: 'It's crucial that we re-start nuclear power plants.'[56] He made the statement in parliament in response to a question by 'Yukio Edano, leader of the main Constitutional Democratic Party of Japan (CDPJ), on the government's policy for sustainable energy and if nuclear power would be part of the plan.'[57] While France and Central European states have been votaries of nuclear power, Japan had closed down nuclear power plants in the wake of the Fukushima incident. The anti-nuclear sentiment has always been strong in that country due to memories of Hiroshima and Nagasaki. Indeed, the process of re-starting the nuclear power plants was started by the previous Japanese government itself. 'The Fifth Basic Energy Plan approved by the Japanese Cabinet in July 2018, calls for nuclear energy to account for 20%-22% of the country's power generation by 2030. [58] Nuclear power is also included in the Sixth Basic Energy Plan approved recently. The process has now accelerated in the wake of climate concerns.

The UK government released an Energy White Paper captioned 'Powering our Net Zero Future' in December 2020. It contained Prime Minister Boris Johnson's Ten Point Plan. The plan included nuclear power along with wind energy as part of the UK's drive towards a Net Zero future. It said 'Nuclear power provides a reliable source of low-carbon electricity.'[59] The paper added 'Our analysis suggests additional nuclear beyond Hinkley Point C will be needed in a low-cost 2050 electricity system of very low emissions.'[60] The British model not only seeks to revive nuclear power but allows foreign companies to build nuclear power plants. The Chinese company CGTN was part of EDF led consortium to build the Hinkley Point C nuclear power plant. Another Chinese company General Nuclear Power Group (GCN) was to be a minority partner in the Sizewell nuclear power plant. Though the participation of Chinese companies in the project is being reviewed by the UK government, the sector remains open to foreign participation.

The UK Government has released an updated document 'Net Zero Strategy: Build Back Greener' in October 2021. This builds on the previous year's document. It has added that the UK will 'bring at least one large scale nuclear project to the point of Final Investment Decision by the end of this Parliament.' It has also started discussions to explore the potential of High-Temperature Gas Reactors (HTGRs).

The nuclear tariff is fixed on the basis of a system Contract for Difference (CfD). This system also applies to offshore wind power, though the rates are different. Under this arrangement, the government pays the difference between the contract price and the market price in case the market price dips below the agreed strike price. However, if the market price is above the strike price, the operator pays the difference to the government. In its essence, the arrangement provides a long-term price guarantee to the company producing nuclear power or offshore wind power.

Bill Gates in his book *How to Avoid A Climate Disaster* has examined the world's energy options for transition to a low carbon economy. It is a remarkable work. Unlike other studies which tell us about the goals and timelines to be followed, Gates has also discussed *how* to achieve them. He has looked at various technologies available and dispassionately examined their potential to meet the target of Net-Zero Emission. As the founder of one of the world's largest tech companies, who can have better credentials to tell us if these are workable options? He says 'Coal plants are not like computer chips'.[61] 'Unfortunately, no. computer chips are an outlier.'[62]

He adds:

> 'Nor have solar panels become a million times better. When crystalline silicon solar cells were introduced in the 1970s, they converted about 15 percent of the sunlight that hit them into electricity. Today, they convert around 25 percent. That's good progress, but it's hardly in line with Moore's Law.' [63]

This caution about the limits of technology has to be borne in mind while evaluating options and timelines suggested by IEA and a plethora of other Think Tanks. The IEA report has candidly admitted that 50 percent of technologies needed to make the transition from 2030 to Net Zero Emission in 2050 do not exist. Given this fact, mathematical models which claim to predict the share of different fuels in pathways to net-zero future, hardly represent scientific rigor.

Gates has also pointed out that de-carbonization of electricity production is only a small part of the problem. Electricity represents only 20 percent of the energy basket. Decarbonization of other sectors of the economy is more difficult even if the share of electricity in the net-zero stage goes up to 50 percent as envisaged in the IEA report. He has discussed the problems of steel and cement production. These two alone accounts for 10 percent of global emissions. Posing the question 'What's Your Plan for Cement?' he says that 'the question is just a shorthand reminder that if you're trying to come up with a comprehensive plan for climate change, you have to account for much more than electricity and cars.'[64]

Another key question raised by Bill Gates is *'How Much Space Do You Need?'* This is linked to the issue of land use, which is increasingly one of the most contentious issues the world over, especially in developing countries. He points out that next to fossil fuels, nuclear power is one of the densest forms of energy-requiring much less space than either solar or wind. Nuclear power can provide 500-1000 watts per square meter as against 5-20 watts per square meter for solar and a mere 1-2 watts per square meter for wind power. [65]In other words, for the same energy output, solar would need 100 times space, while wind power will need 500 times space.[66]

On nuclear fission, Bill Gates says:

> 'It's the only carbon-free energy source that can reliably deliver power day and night, through every season, almost anywhere on earth, that has been proven to work on a large scale.
>
> No other clean energy source comes even close to what nuclear already provides today.'[67]

Renewables, particularly solar power has to play a major role in India's energy basket in the future. India has taken major steps to move towards a clean energy future. The Indian government's actions have been acknowledged by the IEA in its World Energy Outlook, 2021:

> 'There have been some notable examples of developing economies mobilizing capital for clean energy projects, such as India's success in financing a rapid expansion of solar PV in pursuit of its 450 GW target for renewables by 2030.'[68]

While ramping up the share of renewables, the systems costs in terms of providing balancing power and grid infrastructure have to be borne in mind. This has to be accompanied by a balanced energy basket. The role of nuclear power in providing stable, base-load power cannot be ignored. As the MIT study noted, its inclusion in the energy mix will help optimize the cost of transition to a low-cost economy.

As Bill Gates has pointed out, invoking Moore's law to claim that battery costs will become affordable in the foreseeable future does not work. This also applies to hydrogen as a storage solution, which is not an energy-dense medium and is difficult to store and transport safely. Hydrogen also involves a two-stage conversion – use of electricity to produce hydrogen through electrolysis and burning of hydrogen to produce electricity. This inevitably leads to a loss of energy.

There is growing pressure from the EU to impose a carbon tax. The carbon cost in the EU has increased in one year from Euro 32.72 per ton in December 2020 to Euro 90.75 per ton by the end of December 2021.[69] The EU industry fears that this may lead to the shifting of industries to countries where there is no carbon tax, or it is lower. There are demands from the EU industries to impose a carbon tax to equalize costs between domestic manufacture and imports. The European Commission has proposed a Carbon Border Adjusted Mechanism. It claims that this is designed in compliance with WTO rules. This claim is yet to be tested; at present WTO rules have no such provision. There is, however, no denying that pressure is continuing to build up for environment conditionalities on India's trade with EU. India has at present a coal cess of Rs. 400 per tonne. The Glasgow Conference did not accept the idea of carbon tax, but this does not mean that the idea has been dropped by its supporters.

Nuclear power is included in the Biden Administration's Clean Energy Standard. The goal is to generate 80% clean electricity by 2030 and 100% by 2035. Recently, US Energy Secretary Jennifer Granholm in her address to the IAEA said that 'We know the continued deployment of nuclear energy is essential to confronting climate change.'[70] Addressing a press conference with DG, IAEA, she stated 'Nuclear is a key technology for the Member States as they aim to lower their emissions, grow their economies, and ultimately combat climate change in a truly sustainable way.'[71] The role of nuclear power in moving towards clean energy has also been endorsed by the EU and UAE. The latter is rich in hydrocarbon resources. Yet, it has decided to invest in nuclear power as a source of clean energy.

Nuclear power will remain a major part of the energy mix of the US (20%), EU (20%), and China (10%) in the future. [72] This is substantially higher than India, where nuclear power accounts for less than 2% of generation at present.

Land use

Renewables have a much larger land footprint than nuclear power plants. RTE, a French government company has come out with recommendations for France's energy transition. The report mentions that 'Renewable energy development raises concerns about the use of land and the limitation of other uses.'[73] A similar concern is voiced in the US context by a team of experts from Stanford and MIT. They have reviewed a proposal to shut down Diablo Canyon nuclear power plant. Their report mentions that while the existing nuclear power plant takes up 900 acres, the solar power plant of comparable capacity would require 90,000 acres.[74]

Land is an even more critical issue in case of India. India has 16% of the world population and 2% of the land area. Land will be an even bigger constraint on energy choices in India as compared to France or USA. According to the Sukhatme report the total surplus land area in the country for generation of solar energy is 2,00,000 square kms. According to mathematical modelling done by IIT Bombay for the VIF study, land area required for reaching net zero stage by relying upon renewables heavy scenario (R95N05) would 4,12,033 square kms. This will be substantially reduced to 1,83,565 square kms. in case India takes the option where nuclear power has a preponderant share in the generation-mix (R05N95). Lower plant load factor of renewables, and unpredictability, increases the generation capacity required in case of renewables as compared to nuclear or thermal power. For instance, R95N05 scenario requires 14,680 GW of solar capacity, as against 3036 GW of solar in R05N95 scenario. This inevitably pushes up land requirement and cost. Both these scenarios are based on delivering 10% of electricity as green hydrogen at Net Zero Stage. The land requirement will go up steeply in case the share of green hydrogen produced using renewables is increased in the energy-mix.

The problem of finding vast tracts of land for basing solar or wind farms will become worse if we rely exclusively on renewables to produce hydrogen. Germany, which is a proponent of clean energy, proposes setting solar power plants in Morocco and Australia to produce hydrogen. Land constraint is the major factor behind this decision.

Finance

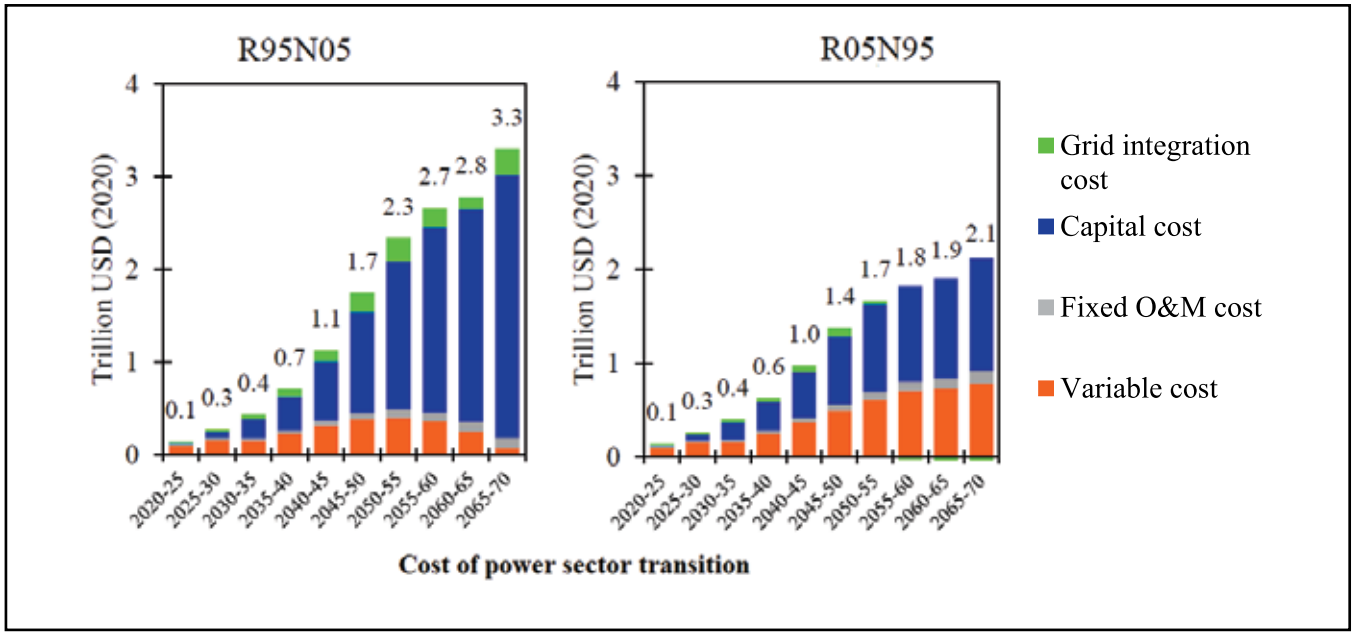
According to the McKinsey report, 'spending on physical assets for energy and land-use systems in the NGFS Net Zero 2050 would rise to about 9.2 trillion annually, or about $3.5 trillion more than today.'[75] This is substantially higher than the IEA estimate of $ 5 trillion per annum. The requirement of $3.5 trillion additional funding on annual basis is also 3.5 times the demand of $1 trillion per annum for developing countries voiced by PM Modi at the Glasgow Conference. The OECD commitment to provide $100 billion per annum to developing countries as climate finance pales into insignificance compared to this estimate.

The McKinsey report also states that while developed countries would spend about 6 percent of their combined GDP from 2021 to 2050, developing regions would need to spend 'substantially larger share of national GDP.' The report estimates that 'in the Net Zero 2050 scenario, India's capital requirement would be 11 percent of GDP, compared to the global average of about 7.5 percent of GDP.'[76]

According to modelling done by IIT Bombay, the cost of India's energy transition to net zero stage till 2070 will be $ 12.1 trillion in the BAU case. It will go up in case we take the renewable heavy (R95N05) route to $15.5 trillion. The cost will be least where nuclear power has predominant share in the generation mix (R05N95) - $11.2 trillion. This amounts to nearly $224 billion per annum till 2070.

The model is based on peaking of emissions in 2050. The largest share of cost of energy transition takes place between 2050 and 2070. This accounts for $11 trillion out of a total of $15.5 trillion in renewable heavy scenario (R95N05). This accounts for $7.4 trillion out of a total cost of $11.2 trillion in nuclear heavy scenario (R05N95). This is clear from the phasing of costs given in the Figure 4 below:

Figure 4: Net zero in 2070 with 10% green H2 demand — Cost of power sector transition



Source: IIT Bombay, Mathematical Modelling for the VIF Task Force Study – India's Energy Transition in a Carbon Constrained World. (Annexed)

Actual commitments made by developed countries fall below the threshold they had set themselves. According to OECD Secretary-General Mathias Cormann, climate finance in 2019 amounted to $ 78.3 billion. This was $ 21.7 billion short of the goal of $ 100 billion per annum the developed countries had pledged to provide to developing countries.' Even within the existing

target, the share of the grant is less than 1/3rd. The OECD statement notes that '...the share of grants in overall public climate finance was 27% in 2019, while loans (both concessional and non-concessional) represented 71%.'[77] According to an estimate by Sri Rajiv Kumar, Vice Chairman, NITI Ayog, India needs 'an outlay of $2.5 trillion on climate adaptation and mitigation projects'.[78]

The target of $ 100 billion per annum finance is linked to the previous milestones, which have since been revised. 'The goal of $100 billion per annum finance to be provided to developing countries was formalized at COP16 in Cancun, and at COP21 in Paris, it was reiterated and extended to 2025.'[79] It was thus pegged to the goal of containing temperature rise above pre-industrial levels to 2 degrees Celsius. With lowering of the threshold to 1.5 degrees Celsius at Glasgow, there will be more stringent emission norms, and higher financial requirements. Even the lower threshold agreed earlier has not been met. The Glasgow Conference outcome document noted:

> 'with deep regret that the goal of developed country Parties to mobilize jointly USD 100 billion per year by 2020 in the context of meaningful mitigation actions and transparency on implementation has not yet been met.'[80]

As far as India's additional announcements are concerned, further climate financing to the tune of approximately US $1 trillion by 2030 would be required.[81] India has so far received very little funding from international sources. Most of the climate action has been financed from domestic sources as underlined by Sri Sushil Kumar Modi, Minister for Environment, Forest and Climate Change:

'As regards India's climate actions are concerned, it has so far been largely financed from domestic resources. As per India's Third Biennial Update Report (BUR) to the UNFCCC in February 2021, the domestic mobilization fully overshadows the sum total of international funding. During 2014 to 2019, while Global Environment Facility and Green Climate Fund have provided grants to a total of only US$ 165.25 million, the corresponding domestic mobilization amounts to US$ 1.374 billion.'[82]

Multilateral development banks have not provided sufficient resources for energy transition. 'The World Bank's Climate Investment Fund has supported 26 gigawatts of clean power since 2008'.[83] The Global Climate Fund set up after the Paris Conference, 'as of October 2021 had financed just 190 projects around the world, with a cumulative commitment of $ 10 billion'.[84]

Since resources from either developed countries or international institutions has not materialized so far on any appreciable scale, we will have to finance new projects with our own resources. This requires DISCOMs to be in excellent financial health. Delay in payment to Operators will be a disincentive for fresh funds to flow in from private sector. Sri R.K. Singh, Minster for Power said 'They (RE producers) are very important in the context of COP26 (India's target of 500 GW RE by 2030). No investment will come if they find that power is not paid for.' [85]After showing initial

signs of recovery, DISCOMs losses have started mounting again. The Minster for Power in a written reply to the Lok Sabha stated: 'Discoms have not been able to pay the generation companies for the power procured, and the outstanding payments to generation companies are estimated to be in excess of Rs 1,56,000 crore. The outstanding dues to renewable generators are around 11 months of revenues.'[86]

Disorderly transition

The energy transition would require sustained investment over a period of time. An orderly transition would require that phasing out of fossil fuel takes place in tandem with ramping up of renewables and nuclear. Mismatch in demand-supply could result in energy shortages and a sharp rise in price. The cost of disruption could far exceed the investment required for energy transition in such a case. We are witnessing the paradox that the fossil fuels, which need to be replaced by clean energy, now command premium price. There has been remarkable upsurge in price of oil, gas and coal in the past few months.

The IEA report 'Net Zero by 2050' envisaged freeze in investment in new oil and gas fields coupled with declining trends of demand and prices of fossil fuels. It mentioned that 'Beyond projects already committed as of 2021, there are no new oil and gas fields approved for development', and 'no new coal mines or mine extensions are required.'[87] The report mentioned 'Oil demand never returns to its 2019 peak', and 'it declines from 88 million barrels per day (mb/d) in 2020 .'[88] It foresaw that 'oil price drops to around USD 35/barrel in 2030 and USD 25/barrel in 2050.'[89] The reality turned out to be different. Even before the Ukraine crisis had erupted, the oil prices had soared to USD 92.87 (OPEC Basket) by 13th February 2022. According to a subsequent IEA report, the global supply reached '98.7 million barrels per day' in January 2022. [90]This is already higher than the 2019 level of 95 million per day.[91] The crude production is still rising.

The increase of crude oil price, and India's import bill took place even before the Ukraine crisis erupted in February 2022. This was a function of demand-supply before geopolitics intervened. The OPEC + group of countries have followed a policy of limiting monthly increase in production to 0.4 million barrels per day. This has kept the supply below demand level. However, this was not the only reason for sharp hike in prices. Fall in demand during the pandemic had led to massive cuts in investment in exploration and production of oil and gas in 2020. The IEA's call for freezing investment in new oil fields reinforced this trend. Without new investment, it is difficult to find replacement oil to compensate for declining production. According to Saudi ARAMCO chief executive Amin Nasser 'substantial investment is needed to arrest global supply that is declining by as much as 7 percent a year'.[92] Investment needs will be greater to find replacement for Russian oil in case secondary sanctions are imposed against that country. The Oil Majors will invest $75 billion in upstream production this year. 'That is an increase on last year but still well below the $100 billion spent in pre-pandemic 2018 – and steeply below the 2013 boom year of $200 billion.'[93]

India imported 4.6 million barrels per day of crude oil in December 2021.[94] The Indian basket crude price averaged $84.67 barrels during January 2022 as against $ 54.79 barrels in January 2021.[95] According to a rough, back of the envelop calculation, $1 per barrel increase in crude price translates into more than $ 1.68 billion or 12,768 crores in annual import bill assuming daily import at current (December 2021) level. There has been an increase of $ 30 per barrel during 1-year period up to January 2021. After the Ukraine crisis erupted in February, the price of Indian basket has shot up to $112.59 per barrel registering an increase of $44 per barrel over year-on-year basis.

Crude oil prices had started rising around April-May 2021. By October, the Indian basket of crude had climbed up from $61 in April to $83 per barrel in October 2021. Between October 2021 till January 2022, it had climbed further to $112 per barrel.[96] The increase of nearly $60 per barrel in the price of Indian basket, and assuming current level of consumption is maintained, would mean an increase of $96 billion over one-year period, doubling the annual import.

The gap between continued demand for fossil fuel, and falling supply, has led to a disorderly transition. PM Modi had projected a demand for $1 trillion for India for a period of 10 years up to 2030. The cost of $ 96 billion in annual import bill is nearly 10 times the cost of energy transition. The hike in import bill on account of increase in coal prices is still sharper. This increase has diverted resources needed for changing the generation-mix to lower carbon technologies. Unless phasing-down of coal takes place in tandem with increase in nuclear power, what we are witnessing today, will be repeated on a much larger scale for an extended period. The demand-supply imbalance would produce crippling power shortage and rise in electricity prices, which will dwarf the scale of present crisis.

Way Forward

Increased per capita consumption

The per capita electricity consumption has to rise sharply if India is to attain NZE. Lowering emissions requires replacing fossil fuel with electricity generated by renewables or nuclear power. This is a daunting challenge. At present fossil fuels account for 89 percent of primary energy consumption globally. Electricity is only 20% of the energy basket globally; in India's case it accounts for around 24% as per NITI Ayog figures. In terms of emission, power sector in India accounts for 45.73% (1147 MT) of total emission (2508 MT) with the remaining accounted for by industrial sector (30.38%), transport (13.44%), buildings (6.54%), energy and agriculture (3.91%).[97] De-carbonisation of economy would require going beyond electricity generation to cover transport, industry and other sectors of the economy. This will increase requirement for electricity. The CAGR of electricity generation in the past cannot be a guide for future demand.

While India has attained 100% grid connectivity, the level of rural electrification is low. At present electrification of a village is deemed complete if 10% of the households are electrified. As NITI Ayog says:

'There is also a need to redefine the concept of 'Electrification', as occurs in the DDUGJY, to include stages of electrification in a village, with the village being deemed completely electrified if and only if ALL households of a village have an electricity connection, which witnesses reliable supply of electricity at least for a set number of hours.'[98]

The electrification of villages would increase demand for electricity for the rural sector. There is also the need to bridge the regional disparities in electricity consumption. There is a huge variation in the per capita consumption of electricity (PCE) within India (Table 2):

Table 2: Per capita consumption of electricity (PCE) within India

State	Consumption Level
Gujarat	2279 units (high level of industrialisation and urbanization)
Punjab	2028 units (high level of agriculture consumption and urbanisation)
Chhattisgarh	2016 units (industry)
Eastern region (Bihar, W. Bengal, Orissa)	695 units
North East (7 sister states, Assam)	392 units (average)

Source: CEA. (2021). *All India Electricity Statistics, General Review 2021.*

With the rapid spread of electricity network in the eastern region and the north east, there will be a spurt in electricity consumption resulting in quick rise in the national average.

The rise in per capita electricity consumption reflects aspirations for a better standard of living. As incomes go up, demand for better housing, heating and cooling goes up – concept of an 'all electric home' with IT infrastructure, new gadgets like robots, IOT etc. Temperature control at home and in place of work will not simply be a matter of life-style choice for the rich. With extreme weather conditions, this will be the requirement of daily life. This will include both increased requirement of cooling and heating. The heat wave sweeping over India illustrates the point. With temperatures soaring, demand for air-conditioning has gone up, straining the system to the limit.

Climate change will affect both power generation and consumption. Melting glaciers will affect river flow. There will also be change in monsoon pattern. This could adversely affect hydro-power generation. Falling ground water level will increase the need for electricity for pumping water. The effect will be uneven due to India's varied geography. According to recently released IPCC report, 'hydropower production is projected to increase by up to 25% by the end of the 21st century due to increased temperature and precipitation'. 'However, hydropower production is projected to decline in plants located in snow-dominated rivers due to earlier snowmelt.'[99]

The Prime Minister has announced increase in the share of manufacturing in GDP to 30% from the present 13-14%. This is essential to generate employment as well as address the problem of chronic trade deficit. This however, will increase the need for energy for the industrial sector. Is it possible to avoid this by shifting to a service economy? In the digital age, a service economy also has a huge electricity requirement. The server banks for data storage or cloud computing need vast amounts of electricity. Unlike the developed countries, India still needs considerable infrastructure development. This includes road-building program, inland waterways development, building storage dams to 'cushion' water flows into planes, physical desilting/drainage of dams, river basins to increase carrying capacity. The infrastructure development will be spread over decades and generate demand for raw material, and energy for mining and production for steel and cement. Total volume of electricity generation as well as per capita consumption will increase as a result.

As per the mathematical modelling by IIT Bombay, per capita electricity consumption at net zero stage will vary from 20,559 kWh for R95N05 to 16,313 kWh in R05N95 case. Higher electricity consumption generated from non-fossil fuel is needed not only to ensure energy security, but to attain net zero emission. Otherwise, burning of fossil fuel either for power generation, or transport and industry will add to emissions.

Peaking

The journey towards Net Zero would involve 'peaking' of emissions before they begin to decline. EU, USA and Japan have already crossed this stage and announced cuts below their respective emission levels in 1990, 2005 and 2013 respectively. China has announced peaking in 2030. This means its emissions will continue rising for another decade, though it already accounts for the highest national emission level. At 10.17 billion ton per annum, the Chinese emission level is twice the US emission, which is the next bigger emitter. Interestingly, China has not announced any reduction beyond this year.

Applying the concept of 'peaking' prematurely to developing countries freezes in place historical inequities and would depress their development trajectory. 'Peaking' of emission, just as Net Zero stage is not based on the convergence of emission levels. Different countries would 'peak' at different levels. Early 'peaking' would also impact on their growth. In case of India, an OECD report mentions:

'China's share of world output peaks during the 2030s at about 27% and declines slowly thereafter, while India's share keeps rising. Each accounts for a fifth to a quarter of the world economy in 2060.'[100]

Accepting 'peaking' before 2050 would impact on India's growth trajectory. While we are committed to a clean environment, this would amount to imposing an unequal cost. According to

the modelling done by IIT Bombay, early peaking may lead to higher upfront capital investment in renewables and storage as seen in Table 3 below.

Table 3: Capital investment in renewables and storage for different peaking and net zero years

Cost - $ Trillion

Scenario	R95N05	R95N05	R95N05
Net-zero year	2070	2070	2070
Peaking year	2050	2045	2040
Cost of transition to net zero power sector	$15.5	$16.1	$16.7

Source: IIT Bombay, Mathematical Modelling for the VIF Task Force Study – India's Energy Transition in a Carbon Constrained World. (Annexed)

According to modeling done by IIT Bombay, India's per capita emission at the peak level in 2050 will be 4.53 tons. This is below the per capita emissions of China (7.3 tons), US (16.1 tons), EU (6.5 tons) in 2019. China has announced the peaking of emissions in 2030; it has not mentiona ed downward trajectory beyond that date. At their peak, Chinese emissions will be 8.9 tons. The US and EU will reduce their respective per capita emissions to 9.4 tons and 4.1 tons in 2030.

Increase in Cost and Tariff

The success in de-carbonization of the economy to reach the goal of Net Zero Emissions depends upon keeping power tariff (delivered cost of electricity) low. High tariff will be a dis-incentive for E-mobility or switching the industry from fossil fuel to electricity. This makes it imperative that the generation-mix chosen should optimize cost. High renewable penetration makes the grid more unpredictable and increases the costs. Some increase in tariff is inevitable as thermal power will have to be phased-down and new generating assets – either renewable or nuclear power will have to be created. The renewable route will increase the systems costs. This is discussed in greater detail in chapter 4 on VRE and the Future of the Grid as well as chapter 6 on Net Zero Emission and Future of India's Power Sector.

India's energy transition will be a very complex task. It requires political consensus in a Federal structure. It also requires restoring the health of the power sector. The energy transition will require massive resources, and there are limits to the budgetary support the governments can provide. While we must tap renewables, particularly solar, their high systems costs have to be borne in mind in deciding their share in the energy mix. This has to be complemented with nuclear as a source of clean, base-load power. This is critical in ensuring that the costs are affordable. Without this, it will not be possible to increase the share of electricity in the economy, which is critical to decarbonizing the economy. The country will need adequate transition time. While India is committed to making the contributions it has voluntarily undertaken, it cannot afford to compromise on its development

priorities. It is hoped that this study will contribute to making an informed decision by our policymakers. The Ukraine crisis is re-drawing the global energy map, and has sharpened focus of governments to ensuring energy security. The high cost of disruption will drain away resources needed for an energy transition to a low carbon economy.

IEA Reports

The IEA has brought out a number of reports on the subject of climate change lately. This is a welcome change on the part of the organization which was created in 1974 with the stated mandate to preserve the stability of international oil supplies. The reports are rich in useful data. It has advocated the adoption of the Net Zero Emission target by all countries and laid down pathways to achieve this target based on mathematical modeling. But the assumptions on which these reports are based need to be looked at more closely. Some of these are stated.

The IEA report Net-Zero by 2050 – A Roadmap for the Global Energy Sector says:

> 'Most of the global reductions in CO_2 emissions through 2030 in our pathway come from technologies readily available today. But in 2050, almost half the reductions come from technologies that are currently at the demonstration or prototype phase. In heavy industry and long-distance transport, the share of emissions reductions from technologies that are still under development today is even higher.'[101]

> 'The biggest innovation opportunities concern advanced batteries, hydrogen electrolyzers, and direct air capture and storage. Together, these three technology areas make vital contributions to the reductions in CO_2 emissions between 2030 and 2050 in our pathway'.[102]

As the report admits, half the technologies that are needed to reduce emission to net-zero level in 2050 are currently at the demonstration or prototype phase. These include technologies in three key areas – advanced batteries, hydrogen, and electrolyzers. Therefore, to allocate to them share in energy-mix on the basis of mathematical modeling is rather impressionistic. It creates an illusion of certainty where none exists.

While including in mathematical model technologies, which are yet to be proven cost-effective, IEA reports have shied away from acknowledging the cost of providing 'flexibility in generation in a future grid, where the renewables will have a 90% share. The renewables being intermittent, requires creating additional generating assets to back them up. According to World Energy Outlook 2021 by IEA, this requirement will be 'over 170 GW in India (from 40 GW) by mid-century'.[103] This is half the size of India's current grid. An informed discussion of options requires transparency in cost assumptions.

How to Avoid A Climate Disaster by Bill Gates

Bill Gates makes a passionate plea for urgent action to avert climate change. But he has displayed a refreshing candor in acknowledging the limitations of technology. He not only suggests the goals to be pursued but also *how* to achieve them. He has posed some key questions. One of these is *What's Your Plan for Cement?* He points out that the production of steel, cement, and plastic accounts for 31 percent of global emissions. This is larger than the share of electricity, which is 27%.[104] In the case of steel and cement, the manufacturing process itself produces carbon-di-oxide. This cannot be averted even if coal or gas is replaced by electricity as a source of heat in production.

Bill Gates keeps returning to the question *How Much Is This Going to Cost?* The cost will be a key factor in the choice of pathways to the energy transition. He has mentioned the MIT study, which points out that an approach solely based on renewables will be extremely costly. This is so not only for developing countries but also for the rich world. Germany and Denmark, which rely upon renewables to provide nearly half the generation have the highest electricity tariff. According to a Bloomberg item, this reached 38 billion dollars in 2020.

Bill Gates has pointed out that unfortunately, the coal plant is not a chip. Nor does Moore's Law apply to batteries. Their costs have come down, but this is nothing of the scale of chips. As the man who founded and ran one of the world's largest technology companies, he is uniquely placed to understand technology.

Bill Gates has analyzed the reason why renewable power is expensive. He says that 'The main culprits are our demand for reliability and the curse of intermittency.'[105] 'The sun and the wind are intermittent sources.[106] 'But our need for power is not intermittent.'[107] This requires either supplementing renewable power with other sources of energy when the sun is not shining and the wind is not blowing. Or the power produced when the weather conditions are alright is stored in batteries. He has argued that this is 'prohibitively expensive.[108]

Bill Gates has advocated nuclear power as the best bet for the de-carbonizing economy while keeping the costs down. Nuclear power is emission-free, reliable technology, 'that has been proven to work on a large scale.'[109] It is much more energy-dense than renewables and takes much less material to build.[110]

Chapter 2 : Climate Change

Climate change has emerged as one of the major challenges facing humanity. The concentration of Greenhouse Gases (GHGs) in the earth's atmosphere has been rising steadily since the Industrial Revolution, leading to a rise in average global temperature. According to World Meteorological Organization, in 2019, the average global temperature was 1.1 degrees Celsius above the pre-industrial levels. The impacts of climate change will be wide-ranging, spanning both sudden disasters as well as slow-onset events. Developing and least developed countries and small island states are particularly vulnerable to the impacts of climate change.

In particular, India is the world's fifth-most climate vulnerable country, witnessing increasing levels of hydrological, cyclonic, and drought events both inland and along its coasts. As per the latest assessment report of Indian government, India's average temperature has risen by around 0.7°C during 1901–2018, and by the end of the 21st century, average temperature over India is projected to rise by approximately 4.4°C relative to the 1976–2005 average.[111] Given the urgency of climate change and India's high degree of climate vulnerability, the country has emphasized on a fair and equitable process and outcomes of climate negotiations.

Climate Negotiations in Perspective

United Nations Framework Convention for Climate Change (UNFCCC) has been the key climate regime for international negotiations on climate change. Beginning in 1992 with the formation of the United Nations Framework Convention for Climate Change (UNFCCC), the mechanisms and outcomes of global climate governance have evolved in accordance with various stages of climate negotiations. These have been mainly conducted within the ambit of one of the UNFCCC's key institutions viz. the Conference of Parties (COPs). Plurilateral groupings like Major Economies Meeting, BRICS, BASIC, G20 etc. have also exercised influence on the course of negotiations within the COP. The outcome is also affected by bilateral agreements and domestic processes of major economies. A case in point is the decision to 'phase-down' coal at the Glasgow Conference, which was preceded by a bilateral deal between USA and China. This in turn originated from an earlier decision of the Chinese government. Details are discussed in following paragraphs of this chapter.

Through the medium of the COPs, the global climate negotiations have traversed a significant trajectory spanning key mechanisms such as the UNFCCC, Rio Declaration (1992), the Kyoto Protocol (1997), the Paris Agreement (2015) and Glasgow Summit outcome.

Through the negotiations and outcomes at successive COPs, global climate governance has come to be undergirded by the foundational approach of climate justice, rooted in the core principles of historical responsibility of developed countries for their cumulative emissions, the principle of equity, and the principle of Common But Differentiated Responsibilities and Respective Capabilities (CBDR&RC). These principles have formed the core substance of climate treaties negotiated under the UNFCCC.[i]

UNFCC

These can be defined as under:

First, the principle of responsibility for cumulative Greenhouse Gas emissions is central to the idea of distributing or apportioning the responsibility for climate action in accordance with the share of individual countries in contributing to the cumulative global emissions since industrialization. The principle clearly implicates the developed countries whose historical emissions have contributed to the accumulation of greenhouse gases in the atmosphere.

Second, interwoven with these principles is the framework of equity in the distribution of mitigation responsibilities, wherein developing countries like India have emphasized their low per capita current emissions, as well as low historical emissions and low cumulative emissions, as important determinants of equity considerations.

Third, in sync with the notion of historical responsibility is the CBDR&RC principle which acknowledges different capabilities and differing responsibilities of individual countries in addressing climate change. The principle again implicates the more capable developed countries, particularly in issues regarding early mitigation action, climate finance and technology transfer.

These principles have played an important role in shaping the outcomes of global climate negotiations and the key climate treaties. The key contention of negotiations has been the scope and nature of mandatory emission reduction targets for countries participating in the UNFCCC. These key agreements and understandings have been briefly discussed as under.

Kyoto Protocol:

Beginning with the Berlin Mandate (1995) of the first COP, the approach of making reductions of greenhouse gas emissions mandatory for developed countries was advocated. This Mandate led the adoption of a legally-binding treaty at the third COP in the form of the Kyoto Protocol. The Protocol instituted legally binding targets for developed countries and advanced Economies-In-Transition (EIT).

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i Under the UNFCCC, countries were divided in two main groups viz. developed countries and Economies-in-Transition (for whom emission reductions targets were mandatory) and developing countries (for whom emission reduction targets were not mandatory).

The Kyoto Protocol entered into force in 2005. Its first commitment period was between 2008 and 2012, wherein 5.2% emissions reduction on an average was to be achieved by developed countries and economies-in-transition relative to their 1990 level of emissions. The EU-15, at the time, committed to reduce emissions by 8% relative to 1990 levels. This 8% target was distributed among the EU member states.

The Protocol target was regarded as a vastly insufficient target to meet the threshold of keeping global warming below 2 degree Celsius. Moreover, the Protocol also excluded from its ambit emissions from shipping and aviation. The targets were also affected by the US's refusal to adopt the Protocol and by Canada's withdrawal from it in 2011.

The developing countries did not have mandatory mitigation targets but could participate in the Protocol through the Clean Development Mechanism, wherein emitters could fund green projects in developing countries in order to meet their emissions reductions targets.

Despite adopting a mandatory approach, the Protocol provided for flexibility mechanisms for the developed countries, such as voluntary choice of base year for emissions reductions, joint implementation, and market mechanisms. These flexibility mechanisms have provided sufficient leeway to the developed countries in achieving their targets. Besides, the financial crisis of the late 1990s and of 2007-08 resulted in reduction in emissions and facilitated in meeting the overall commitments under the Protocol.

In the implementation of the first commitment period of the Kyoto Protocol by 37 developed countries and Europe, the emissions of developed countries reduced by 6% on an average (including United States) between 1990 and 2008.[112] Between 2008 and 2012, the emissions of 36 developed countries that effectively participated in the Kyoto Protocol (excluding US and Canada) reduced by 24.2% relative to the 1990 level.[113] EU has been able to meet its emission targets under the first commitment period, in terms of reduction in annual emissions. In the period 2008-2012, emission levels in the 15 EU member states fell by an average of 12.2% against 1990 levels.

Under the second commitment period of the Kyoto Protocol (2013-2020), under the Doha Amendment to the Kyoto Protocol, the average emissions reduction target was set at 18% reduction by 2020 relative to 1990 levels. Countries like Japan, Russia and New Zealand did not participate in this period. In the second commitment period (2013-2020), EU-29 committed to a 20% reduction in emissions compared to 1990. However, the Doha Amendment never entered into force till 2020.

The performance of developed countries under the Doha Amendment resulted in only 14.8% emissions reduction by 2019 relative to base year.[114] Within this group, non-EIT developed countries (viz. core industrialized countries) witnessed an emissions reduction of only 3.7% by 2019 relative to base year, indicating that core emissions reductions within the developed country grouping had been achieved mainly by EIT countries and very little by industrialized or developed countries.[115]

Diluting the Protocol

A key concern during the Kyoto Protocol implementation phase was negotiating a successor to the Protocol. The developed countries viewed the Kyoto Protocol unfavourably due to its imposition of mandatory mitigation targets on developed countries. In order to dilute this, subsequent climate negotiations began to institutionalize a voluntary approach, in contrast to Kyoto Protocol's mandatory-targets approach.

Under the UNFCCC aegis, the Copenhagen Accord of 2009 institutionalised a voluntary approach of meeting climate pledges. Countries like US and Canada pledged 17% economy-wide mitigation targets relative to 2005 levels. Copenhagen commitments were recognized under the subsequent Cancun Agreement as non-binding commitments.

This approach was given further accommodation in subsequent climate conferences under the UNFCCC, leading up to the Paris Agreement. During this phase, climate finance to the tune of $100 billion annually was also committed by developed countries in 2010, which remained unmet. The Green Climate Fund was also setup to facilitate climate mitigation and adaptation in developing countries.

The Paris Agreement (2015)

In 2015, a new international climate treaty, the Paris Agreement, was institutionalized. Under the Agreement, countries submit their own nationally-determined emissions reductions targets to the UNFCCC, with the goal of preventing global warming above 2 degree Celsius and with the aim to attempt to keep it below 1.5 degree Celsius. Countries also submit voluntary, non-mandatory 'long-term low greenhouse gas emission development strategies (LT-LEDS)', which are complement their Nationally Determined Contributions (NDCs).

Under the Agreement, a global stock-take, every five years, with the first one scheduled for 2023, becomes a platform for assessing progress in the implementation of countries' climate progress. In terms of climate finance, the developed countries accepted, formally, the target of $100 billion a year by 2020 as a minimum. The Glasgow summit outcome 2021 decided that a new goal for climate finance would be quantified prior to 2025.

The Paris Agreement continues the post-Kyoto voluntary approach to country targets. It has cemented the erosion of the equity-based and historically-rooted distinction between developed and developing countries. Consequently, by institutionalizing a voluntary regime based on nationally-determined commitments, it follows the trajectory of dilution of climate commitments over the successive COPs. Although the Paris Agreement has established a new architecture for binding actions, under which the developed countries have to take lead in making deep and rapid reductions in their emissions, they have failed thus far.

Key Outcomes of The Paris Agreement (2015)

- Limiting global warming to below two degrees Celsius, aiming for 1.5 degrees Celsius, by the end of the century, and achieving 'peaking' of global emissions and 'climate neutrality'

(Art. 4) by the second half of the century. As per Article 2.1 (a) of the Paris Agreement, the Agreement aims at, "Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change." (UNFCCC, p. 4).

- Five-year review cycle with parties submitting revised targets and Nationally Determined Contributions (NDCs) to reflect 'highest possible ambition' and progression over past commitments.
- Flexibility and self-determination of targets in accordance with 'national circumstances.'
- 'Global Stocktake' every five years to communicate transparency in Monitoring, Reporting and Verification (MRV) by the parties.
- Including climate finance in NDCs and meeting the commitment of $100 billion annually by 2020 by developed countries, in addition to ratcheting up finance ambition.
- Provide for market and non-market approaches.
- Global goal on adaptation and strengthen national adaptation efforts.
- Strengthen efforts to address loss & damage, including through the Warsaw International Mechanism, on a cooperative basis.

Glasgow Climate Conference and Its Outcomes

The Glasgow Conference held at the 26th COP in 2021 has further institutionalized the idea of nationally-determined ambition. Further making recourse to the climate emergency facing humanity, it has legitimized a new regime of Net Zero Emissions (NZE) as a universal panacea applicable to all countries without any differentiation.

First, the Glasgow summit outcome "Reaffirms the Paris Agreement temperature goal of holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels."[116] This effectively legitimizes it as a recognizable benchmark goal in further global negotiations on climate change.

Second, it is for the first time that any climate change outcome document makes a reference to mitigating the use of coal and fossil fuels. The Glasgow summit outcome talks about 'phasedown of unabated coal power and phase-out of inefficient fossil fuel subsidies'.[117]

Third, updated individual commitments (NDCs) and Net Zero Emission targets were submitted by more than 150 countries.

In terms of NZE, the pact stated that "limiting global warming to 1.5 °C requires rapid, deep and sustained reductions in global greenhouse gas emissions, including reducing global carbon dioxide emissions by 45 per cent by 2030 relative to the 2010 level and to net zero around midcentury, as well as deep reductions in other greenhouse gases."[118]

In terms of NDCs, the pact welcomed the "new or updated nationally determined contributions, long-term low greenhouse gas emission development strategies and other actions that demonstrate progress towards achievement of the Paris Agreement temperature goal." It also urged "Parties to revisit and strengthen the 2030 targets in their nationally determined contributions as necessary to align with the Paris Agreement temperature goal by the end of 2022, taking into account different national circumstances."

Fourth, the Glasgow conference saw some main pledges, declarations and statements being signed by countries, such as the Breakthrough Agenda, Declaration on Forests and Land Use, Global Coal Pledge, Global Methane Pledge and China-US Climate Declaration, among others.

Fifth, rules for carbon trading – pending since the 2018 Katowice conference – were finalized. In case of carbon markets, under Article 6 of the Paris Agreement, the first contestation was over the developing country demand that extra carbon credits leftover from the past – from the time of Kyoto Protocol – should be allowed to be carried forward and traded. This was agreed for CERs generated by projects registered up to the cut-off year of 2013.The second demand – mainly of developed countries – was that systems should ensure that there is no double-counting of emissions.

Finally, the two-year Glasgow–Sharm el-Sheikh work programme on the global goal on adaptation was initiated at COP26. It was decided that the institutional arrangements, scope, objectives, modalities and activities of the work programme would be finalized by the time of COP28.

Evaluating Outcomes

The negotiation outcomes reflect the further institutionalization of the voluntary emission reduction approach as agreed under the Paris Agreement, as well as Net Zero Emission schedules which provide considerable leeway to the countries in undertaking mitigation. These outcomes can be evaluated as shown in Tables 4 and 5:

Table 4: Emissions Profile of Major Economies

Country	Cumulative Emissions (1750-2019) (in billion tonnes of carbon dioxide equivalent)	Per capita emissions in 2019 (in tonnes)	Total annual emissions in 2019 (billion tonnes)	Size of the economy (in trillion US Dollars)
China	220	7.1	10.17	15
United States	410.2	16.06	5.28	22
European Union (EU-28)	364.8	6.41	3.29	15
India	51.9	1.9	2.63	2.7
Japan	64.5	8.7	1.11	5.4

Source: Ritchie, H., and M. Roser. 2020. *Our World in Data*. Accessed 2021. https://ourworldindata.org/emissions-by-sector#citation.[119]

Table 5: Current and Projected Emissions

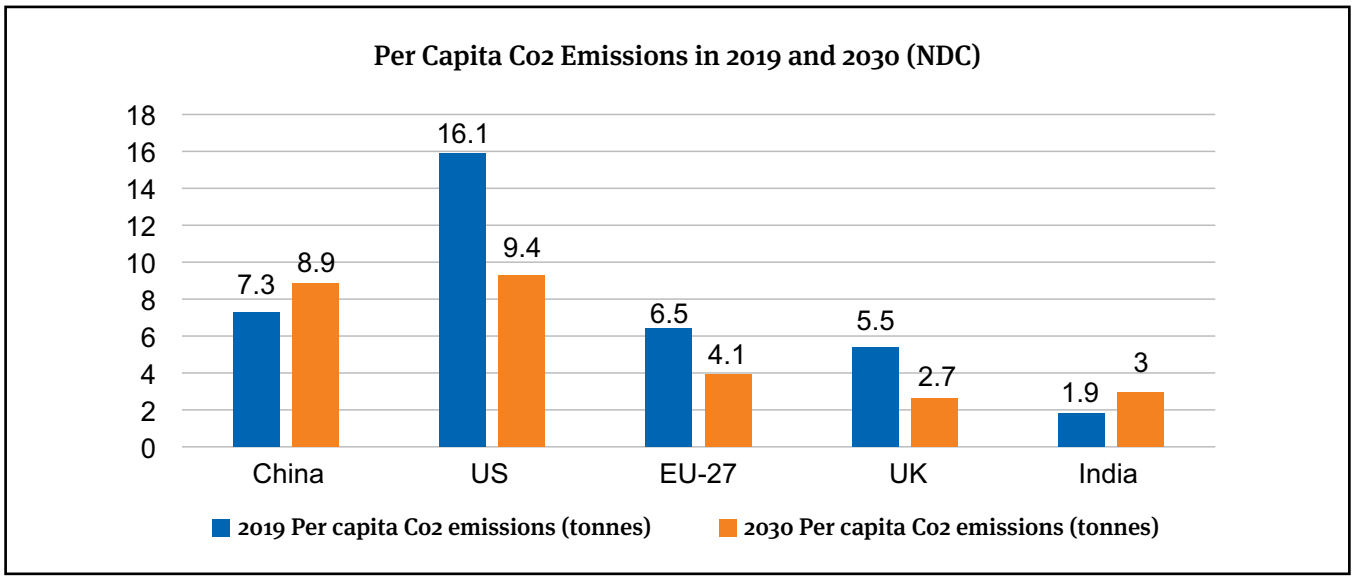
Country	2020 Emissions GtCO2	2030 Emissions GtCO2*
China	10.67	13.2-14.5
United States	4.71	2.7
India	2.44	3.84-4.02
Japan	1.03	0.92
Germany	0.65	0.47
United Kingdom	0.33	0.27

*Estimates deduced from projections given by Climate Action Tracker, based on current policy projections and written NDC commitments submitted

First, the Glasgow legitimization of the 1.5 degree temperature goal will have a bearing on a much tighter remaining global carbon space and how it should be fairly apportioned.

As per estimates, collectively, developed countries have used an additional carbon space of about 25.1 GtCO2eq than their estimated emission allowances for the pre-2020 period, while the estimated emissions gap in 2030 based on current policies for achieving the 1.5°C goal is around 34 GtCO2eq.[120] Under the current NZE pledges, carbon budget of 1.5°C would be surpassed by 33% by 2050.[121] Figure 5 demonstrates the per capita CO2 emissions by different countries.

Figure 5: Per capita CO2 emissions by different countries



Source: Down to Earth and Center for Science and Environment. (2021). *Carbon Budget Target 2030: How It Ends*. https://www.downtoearth.org.in/news/climate-change/carbon-budget-target-2030-how-it-ends-79873

Second, the conference saw disagreements between developed and developing countries, as the initial draft agreement, at the behest of developed countries, made a reference to 'phase out' of coal – which developing countries, like India, see as critical to their economies and in serving in social subsidies like cooking gas for the poor[122] – and phase-out of 'inefficient fossil fuel subsidies' rather than phase-out of fossil fuels or the entirety of fossil fuel subsidies. Ironically, this was first mentioned as part of the 'U.S.-China Joint Glasgow Declaration on Enhancing Climate Action in the 2020s' in the language that "China will phase down coal consumption during the 15th Five Year Plan and make best efforts to accelerate this work."[123]

The developing countries also perceived that the developed countries displayed a lack of sincerity and equity while talking about mitigating fossil fuel use, as fossil fuels like oil and gas are more important to their economies as compared to coal. Even in terms of coal, as per the latest data, U.S. coal-fired generation is set to increase by 22% more in 2021 than in 2020, which is also the first year-on-year increase in coal-fired generation since 2014.[124] These included sectoral declarations and statements including the Global Methane Pledge, Glasgow Leaders' Declaration on Forests and Land Use, The Global Forest Finance Pledge, Green Grids Initiative, Glasgow Financial Alliance for Net Zero, Global Coal to Clean Power Transition Statement, The Global Action Agenda for Innovation in Agriculture, Breakthrough Agenda, Clydebank Declaration for Green Shipping Corridors, and, the COP26 Declaration on Accelerating The Transition To 100% Zero Emission Cars and Vans.

India at Glasgow

India's announcements at COP26 Summit by PM Modi marked one of the watershed moments of the Glasgow conference. The PM announced new climate commitments for India in the form of the five nectar elements or 'Panchamrit':

First, India will reach its non-fossil energy capacity to 500 GW by 2030.

Second, India will meet 50 percent of its energy requirements from renewable energy by 2030.

Third, India will reduce the total projected carbon emissions of one billion tonnes annually by 2030.

Fourth, by 2030, India will reduce the emissions intensity[ii] of its economy by little less than 45 percent.

Fifth, by the year 2070, India will achieve the target of Net Zero. These '*panchamrits*' will be an unprecedented contribution of India to climate action.[125]

Since the Glasgow climate conference, the Government of India has announced updated NDCs

ii Emission intensity is defined as the total amount of greenhouse gas emissions emitted for every unit of GDP.

on 3rd August 2022 where the country will achieve about 50 percent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2050, and reduce emissions intensity of its GDP by 45 percent by 2030.[126]

Interpreting the Targets

First, India's present installed renewable energy capacity, including nuclear, is 156.8 GW, constituting 40.1% of the total installed electricity capacity of 390.8 GW.[127] According to projection scenarios by Central Electricity Authority (CEA), by the year 2029-30, non-fossil fuel based installed capacity will be around 64% of the total installed capacity and non-fossil fuels will contribute around 44.7% of the gross electricity generation.[128]

Second is meeting 50% of the country's energy requirements from Renewable Energy by 2030. In 2020-21 the share of energy from renewables, including large hydropower and nuclear, in total energy consumption was 5.4%.[129]

Third, reducing total carbon emissions by 1 billion tonnes by 2030 is the first time that the country is presenting targets in terms of reduction in projected emissions levels rather than in terms of emissions intensity. India's current carbon emissions are around 2.88 Gt and are projected to be around 4.48 Gt by 2030 in a Business-As-Usual scenario, making the goal of 1 billion ton emissions reduction by 2030 achievable through an ambitious 22% decrease in emissions.[130]

Fourth, reduction in carbon intensity of the economy – emissions per unit of the GDP – by 45% by 2030 would mean working on attaining higher level of energy efficiency in all industries including carbon-intensive sectors such as transport, cement, and iron and steel, among others. India has already achieved a 28% reduction in its emissions intensity by 2020 compared to 2015,[131] and is well on the path to achieve a 40% reduction in emissions intensity by 2030.[132]

Fifth, achieving Net Zero Emissions by 2070 will be challenging without the provision of hefty climate finance in order to decarbonize sectors like power, industry and transport.

Viability and Effectiveness of NZE Regime

The key highlights of the climate regime after Glasgow Conference has been the institutionalization of the NZE goal. In real terms, the debate around NZE can be addressed substantively with reference to the extent to which carbon neutrality targets help in keeping global warming below 1.5 degree Celsius, and whether existent economies and technologies make it a feasible proposition to achieve.

On both the counts, the available evidence is scant at best. In its 2018 report, the IPCC had emphasized that to keep global warming below 1.5 degree Celsius, the world must become carbon neutral by 2050. It had also emphasized that to adhere to the 1.5-degree Celsius threshold, by 2030 global emissions need to be 45% lower than 2010 level. In the light of the latter, NZE targets will

be effective only if they are complemented by deeper mitigation schedule through the respective NDCs of countries. In this context, accountability for fulfilling short-term 2030 mitigation schedules becomes much more important than emphasis on long-term mid-century goals like NZE, for evaluating progress.

There are three key immediate unanswered questions in an NZE regime in which individual countries declare their NZE schedule without agreeing to a common foundational consensus. These are:

First, countries have not specified or agreed upon the scope of NZE viz. what greenhouse gases are covered for reduction. The paradox is that emissions of gases like carbon dioxide are essentially 'stock' emissions that remain in the atmosphere for thousands of years and, therefore, present initiatives towards carbon neutrality cannot compensate for or cover the emissions already existent.[133]

For other GHGs like methane there are no requisite technologies to make them compatible with removal from the atmosphere in sync with NZE.[134]

Second, from the perspective of viability, it is important to assess whether commitments are compatible, in an equitable and fair manner, with the remaining global carbon budget. As per IPCC's Sixth Assessment Report, between 1850-2019, 2390 Gt of carbon dioxide was emitted. The remaining carbon budget for limiting global warming to 1.5 degree Celsius is 460 Gt of carbon dioxide, with a 50% chance of emitting.[135]

As per estimates, at the current trajectory of emissions this budget will be exhausted in the next seven to eleven years,[136], as shown by various studies.[137]

If we calculate the global carbon budget in accordance with the 2 degree Celsius threshold, then we have a global carbon budget of 1150 Gt which would be likely exhausted in the next 25 years. As per the Paris Agreement, while 2C is the agreed threshold, 1.5C is the desirable goalpost to be pursued. While the de jure standard of measurement of global carbon budget is 2C, 1.5C has become the de facto standard, in face of a mounting climate emergency.

This is also important from the point of view of fairness, as NZE goals raise the question about how fair is to developing countries to declare their NZE goals in sync with industrialized nations with high per emissions.

Third, the modalities to achieve NZE have not been agreed upon and are likely to be contentious, but without them these goals would yield little returns. These modalities revolve around how to achieve NZE – by reduction, removal or carbon offsets.[138]

In other words, as Sagar, et al. (2021) have explained, "The use of "net" zero potentially allows countries to keep emitting today while relying on yet-to-be-developed and costly technologies to absorb emissions tomorrow. Its focus on long-term targets displaces attention from meaningful short-term actions that are credible and accountable."[139] Indeed, NZE provides a way for countries

to achieve carbon neutrality even at the current level of emissions or even by increasing emissions and provides a relief to developed countries whose burden would be shared globally.[140]

NZE and Climate Justice: A Trade-Off?

The institutionalization of NZE raises critical questions about climate justice. It not only dilutes the principle of historical responsibility but also that of equity, as it leads to disproportionate division of the global carbon budget. Around 80% of the carbon space has already been consumed by mainly developed countries since 1850, and even China is fast gathering pace to meet the developed countries' emission levels[141]. According to Sanwal (2021), "By contributing over 60% of global cumulative emissions, with just one-fourth of the global population, North America and Europe are responsible for nearly 970 billion tonnes of carbon emissions"[142]

The debate around NZE has substantively marginalized the question of principles of the existent climate regime and the pre-2020 commitments made by developed countries therein, with reference to climate finance, technology transfer, and meeting the countries mitigation targets. The metrics of performance with regard to these parameters has been underwhelming.

China's Climate Record

Despite being a late industrializer and counting itself as a developing economy, China bears substantial historical responsibility for contributing to climate change. China has contributed about 12.7% or 200 billion tonnes of global cumulative carbon dioxide emissions since 1751. In contrast, India's global cumulative emissions stand at 48 billion tonnes, thereby absolving it of any historical responsibility for climate change.

Presently, China's share in the total annual global emissions was 10.17 billion tonnes in 2019, accounting for about 20% of global emissions, while US's was 5.28 billion tonnes, accounting for 10% of global emissions. Despite having a comparable population, China's per capita emissions stood at 10.5 tonnes, thrice that of India's 1.9 tonnes per capita. It is projected that China's per capita emissions will overtake North America by 2030.[143]

China is also heavily reliant on coal power and has coal output almost three times that of the rest of the world. In 2020, China added 38.4 GW of dirty coal capacity and approved another 36.9 GW.[144]

Unlike US and other developed economies, China's targets also do not provide a long-term mitigation schedule. While the country's emissions peaking target is 'before 2030', it has not provided a schedule for emissions reduction beyond 2030. According to estimates, the "1.5°C-consistent goal would require China to reduce its carbon emissions and energy consumption by more than 90 and 39%, respectively, compared with the "no policy" case."[145] Much of China's pledges made up to 2030 also do not demand a stringent mitigation schedule, and are achievable without giving up much.

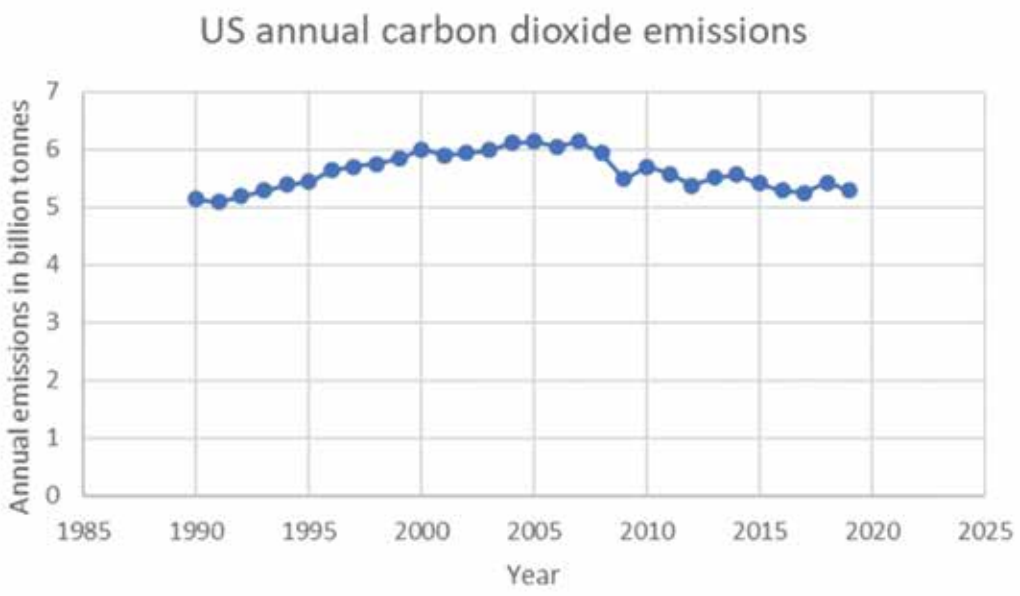
This clearly demonstrates that China's climate neutrality target becomes more of a way of deferring emissions reductions to a future date instead of undertaking a mitigation schedule.

United States' Climate Record

The United States, under the Biden Presidency, has been spearheading the global NZE movement. However, the US's record in terms of historical responsibility, mitigation and fossil fuel use has been less than desirable, as:

First, in real terms, the emissions of US have shown only a minor decline. In 2019, US emissions were 5.28 billion tonnes. In 1990, they were 5.13 billion tonnes. In terms of annual emissions share, US's share of global annual emissions was 14.72% in 2019. In 1990, this figure was 22.6%. Between 1990 and 2019, the decline in annual emissions has been 2.8% as seen in Figure 6.

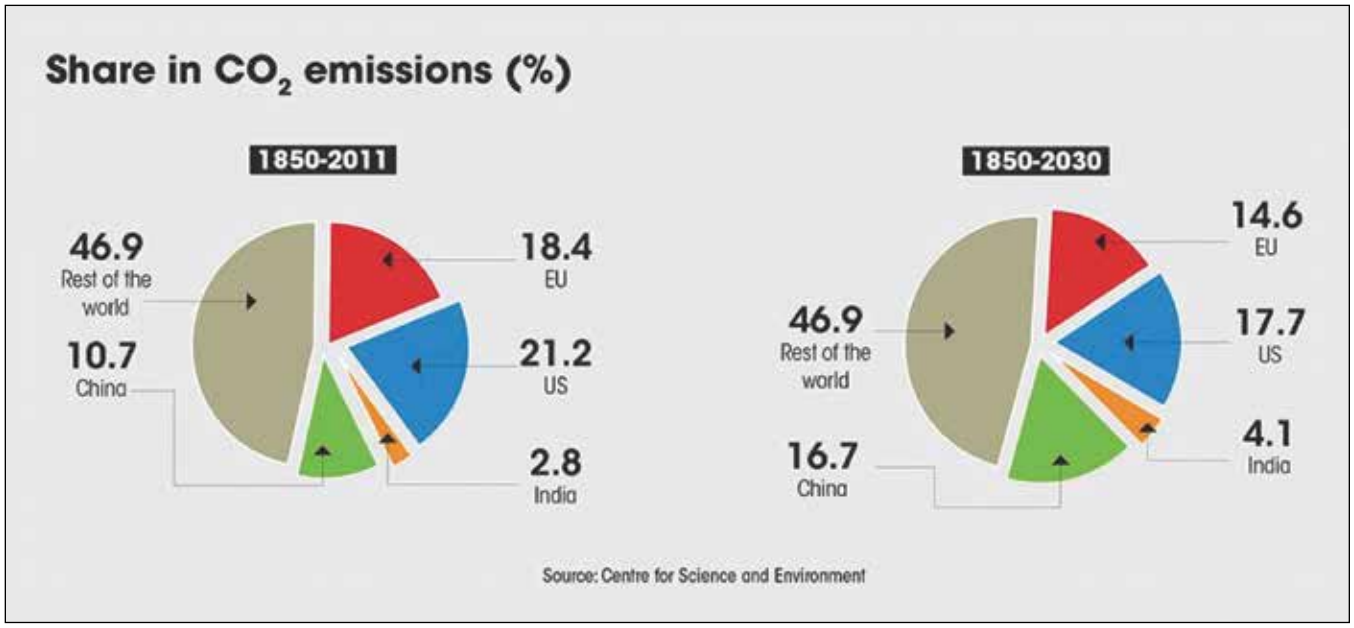
Figure 6: Annual CO_2 emissions by the United States



Source: VIF Task Force.

Second, in terms of historical responsibility and apportioning carbon budget, in 2018, the US, with 4.3% of the world population has been responsible for 25 per cent of cumulative emissions since 1850, while the EU with 6.8 per cent of the population has been responsible for 18.4 per cent. India, with 17.8 per cent of the population, has been responsible for only 2.8 per cent, while China, with 18.3 per cent of the world's population has been responsible for 10.7 per cent as seen in Figure 7.[146]

Figure 7: Share in cumulative CO2 emissions



Source: Gopalkrishnan, T and Subramanian, K. (2019). *Climate Emergency CoP 25: Developed Countries Have Largely Consumed World's Carbon Budget*. https://www.downtoearth.org.in/factsheet/climate-emergency-cop-25-developed-countries-have-largely-consumed-world-s-carbon-budget-68221

It is also projected that by 2030, this inequity will remain, with a lion's share of carbon budget being cornered by developed countries and China.

Even if the US did reach carbon neutrality by 2050 assuming a steady linear decline in emissions, its cumulative emissions between 2018 and 2050 would be 106 Gt of carbon dioxide which is equivalent to 22% of the remaining global carbon budget. As per this data, if the US has to stick to its fair share of carbon budget, it should ideally reach carbon neutrality by 2025 – and would still owe a carbon debt of 470 Gt of carbon dioxide to the world based on principle of historical responsibility for past emissions.[147] By a similar rationale, the EU should ideally reach NZE by 2033 and would owe the world a carbon debt of $9.3 trillion for past emissions.[148]

Europe and Canada's Record

Besides the performance of United States, the trajectory of other developed countries like Europe and Canada also raises questions about climate justice within an NZE context. Europe, despite announcing the European Green Deal in 2019 and announcing NZE targets within a legal framework, continues to witness a situation wherein member states' individual policies run counter to climate protection. As a whole, European countries subsidize the fossil sector by more than 137 billion Euros per year, with Germany topping the list at €37 billion per year, followed by the UK at €19 billion, Italy at €18 billion and France at €17.5 billion.[149]

The present state of play complicates not only EU's commitments to its Green Deal, but also its climate targets of achieving NZE by 2050 and reducing emissions by 55% by 2030 relative to 1990 levels. The latest EU commitments also include proposals for a higher share of renewables – from 32% to 40% – and increased energy efficiency, with at least 50% of hydrogen used in the industry to be generated from renewables. While the EU has overall reduced its emissions by around 34% between 1990 and 2020, it may not be able to meet its new pledges unless member states also implement mitigation policies.

Other developed countries like Canada – which also withdrew from the Kyoto Protocol in 2011 – also do not display the commensurate degree of climate action despite much rhetoric. Recently, Canada updated its NDC to commit to reduce its emissions by at least 40-45% below 2005 levels by 2030, up from the previous target of 30%. However, in order to be compliant with Paris Agreement, this target needs to amount to around 54% emissions reduction. Significantly, Canada also does not limit itself to domestic mitigation pathway and takes the route, in its NDC, of possible recourse to supporting mitigation efforts abroad through the use of internationally transferred mitigation outcomes (ITMOs), counting them as its own mitigation achievements.

Despite scaling up of its climate pledges and rhetoric, the Canadian government does not intend to reduce its oil and gas production, with more oil and gas expected to be produced in 2050 than in 2019, with the country emitting around 200 megatonnes of CO2 equivalent in 2050. Its 2021-2050 oil and gas production will, as per estimates, exhaust 16% of the world's remaining carbon budget, thereby rightly earning the country the title of a 'carbon bomb'.[150]

Thus, major economies like US, EU and Canada, despite being historical polluters and despite much climate rhetoric, are yet far behind in achieving their climate targets. This becomes especially significant in the context of a fast-constricting carbon space available.

In its recent publication on 1.5 Degree Lifestyles, the German think-tank, Hot or Cool Institute, brings out the issue of fair apportioning of the remaining carbon space, emphasizing that climate justice and equity should be made the mainstay of decisive action in terms of converging on a 'fair consumption space.' The report estimates that the lifestyle carbon footprint per person is extremely high in developed countries and needs to be reduced commensurately in order to reach a carbon footprint target of 0.7 tCO_2e by 2050, with intermediary targets of 2.5 and 1.4 tCO_2e by 2030 and 2040, respectively, with the need to reduce footprints in high income countries by 91-95%, in upper middle income countries by 68-86% and in lower middle income countries by 76%, by 2050.[151] The report recommends systemic and behavioural changes to converge on 2.5 ton footprint target for 2030.

NZE Regime and India

In terms of per capita emissions, India lags far behind the developed countries and China, and needs space for emissions to advance its developmental trajectory. Even in terms of share in

absolute greenhouse gas emissions, India (7%) is far behind China (28%), United States (14%) and European Union (10%).[152]

In terms of stated national commitments in NDCs, India is well on its way to exceed its Paris commitments. The country has achieved 24% of its emissions intensity reduction (between 2005-2016) as a proportion of its GDP in line with its commitment to a 33-35% reduction by 2030, its share in renewables is 37.9% relative to its target of 40% share in renewables-based electricity and the forest cover has increased by 15000 sq. km. between 2014 and 2020.[153]

This climate-compliant record should be assessed alongside the fact that India neither shares historical responsibility for past emissions and neither has high per capita emissions at present. Its high degree of vulnerability to climate change, especially in agrarian, coastal and other sectors further alienates an untested NZE regime from it. Furthermore, the country needs emissions space to grow in line with its fair share of carbon budget.

Mid-century targets declared by some countries are clearly inadequate in containing global warming in view of the fast-depleting carbon space and developed countries should strive to bring down their per capita emissions to the global average by 2030. Moreover, India has always insisted that NZE cannot become a way for developed countries to renege on their pre-2020 commitments and on the commitment to provide $100 billion climate finance annually.

Presently, 137 countries have made submissions on their Net Zero targets. Amongst these, the major developed economies (and China) that have made submissions are indicated in Table 6 below.

Table 6: Major Countries' NZE Schedule

Country	Net Zero Emissions Target Year	Emissions peaking Year[a]	Per capita emissions in peaking year (ton)[b]	Current Per Capita Emissions (ton) in 2019[b]	Current Total Emissions in 2019 (billion ton)[b]	Approximate Projected Total Emissions By 2040 ($MtCO_2$ eq.)[c]
European Union	2050 (in law)	1979	8.16	6.41	3.29	2000
Japan	2050 (in law)	2004	10.01	8.72	1.11	800
United States	2050 (in policy)	2007	20.39	16.06	5.28	4800
China	2060 (in policy)	2030	9.3	7.10	10.17	12000

Sources: *a. CEEW. (2021). Peaking and Net Zero for India's Energy Sector CO_2 Emissions. p.6. https://www.ceew.in/publications/how-can-india-attain-net-zero-emission-by-2050*

b. Hannah Ritchie and Max Roser. (2020) - CO_2 and Greenhouse Gas Emissions https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions

c. C2ES. (2021). Global Emissions. https://www.c2es.org/content/international-emissions/

India committed to achieve NZE by 2070, but has not declared a peaking year for emissions. From the table above, it is clear that different economies have different peaking years and peaking levels. The peak year for emissions is interlinked with the economic growth trajectory of the country in question, with countries with a relatively high growth, signified by high per capita emissions, expected to peak earlier than those countries that start from a low base with low per capita emissions and with still substantial gap to cover in terms of economic development. India's high economic growth rates compared to other countries after their peaking years signifies that India still has to achieve substantial level of economic development to reach the peak. It is one of the reasons India has, so far, not disclosed a peak year for its emissions, as it still has substantive development gap to cover.

In terms of peaking levels, compared to the developed countries' projected emissions levels as seen in the table, the approximate projected total emissions levels of India by 2040 would be 4100 MtCO2eq. compared to China's triple the number as a developing country, while per capita emissions of India would be only 3.02 MtCO2 in 2040 and 3.71 MtCO2 in 2050.[154] [155] Even if it is assumed that India peaks its emissions between 2040 to 2050, India's emissions per capita in the peaking year would be much lower than those of developed countries and China (as seen in table above), reflecting the inequity in pursuing development.

From the point of view of the NZE transition, the developed countries have also been vague about disclosing their emissions level post-2050, opting instead to deploy the language of 'net zero' which, in effect, simply means offsetting the release and absorption of emissions. This perpetuates existing asymmetries among developed and developing countries in terms of access to the global atmospheric commons.

Climate Finance: An Unmet Commitment

Despite the constant emphasis in the negotiations on historical responsibility, equity and CBDR-RC, action by developed countries has been mainly lax. This is reflected in the issue of climate finance. The climate finance mechanism under the UNFCCC has two main agencies viz. Global Environmental Facility (GEF) and the subsequently established Green Climate Fund (GCF). Special funds under the GEF have also been established viz. Special Climate Change Fund (SCCF), the Least Developed Countries Fund (LDCF) and the Adaptation Fund (AF). In 2010, the Standing Committee on Finance (SCF) was also established to assist the COP.

Despite these mechanisms, the promise to mobilize $100 billion annually has not been met, as developed countries are still short of $20 billion. Even these are figures released by OECD and are conservative estimates, as, due to reporting manipulations and accounting differences some previous OECD reports on climate finance have also been rejected by developing country representatives. For instance, in 2013–2014, the OECD claimed an annual average of USD 57 billion of total public and private climate finance, while the Indian Ministry of Finance pointed to loopholes in their methodology and asserted that only USD1–2.2 billion should be counted. Similarly in case

of the 2020 OECD report, Oxfam estimated only USD 19–22.5 billion in public finance specifically targeting climate action from 2017–2018, a third of what was reported by developed countries.[156]

Moreover, the share of loans in climate finance has increased to 74%, while the share of grants has decreased to 20% between 2013-18, with only one-fifth of such finance being allocated to adaptation, with the major share being given to mitigation.[157] In terms of fair shares, according to a study, while Germany, Japan and the UK are paying 40-45% of their fair share, Australia, Canada and the USA contributed less than 5% of their fair share in 2017-2018.[158]

Despite this supply-side lacuna, on the demand side, the need for climate finance will only grow. As per UNEP estimates, developing countries currently need $70bn a year to adapt to climate change. This is expected to rise to $140-$300bn a year by 2030. Africa alone needs an estimated $3 trillion to implement its adaptation plans by 2030, while LDCs need $200bn from 2020 to 2025 and again from 2025 to 2030. Between 2014-18, they received less than 3% of their demand.[159] The adaptation gap between available resources and the looming climate emergency is underscored by the latest IPCC report that reinforces the climate emergency facing the planet and the vulnerability of developing countries like India to climate change.

Even the Glasgow summit outcome made little headway in terms of finance. While it noted with "deep regret" that rich countries had failed to commit the climate finance of $100 billion a year by 2020 as promised in 2009 – with the estimated shortfall being more than half[160] – they deferred it further till 2023. This failure of developed countries to meet the climate finance pledge has come despite their exhortation to the developing countries to scale up their climate commitments even in the absence of commensurate finance. At Glasgow, it was decided to launch a structured process on the new collective quantified goal (NCQG) for finance that will complete its work by 2024 and will be included under the COP, as per demands of developing countries like India.

Despite the demands of least developed countries to scale climate finance to USD 1.3 trillion per year between 2025 and 2030, the COP failed to achieve consensus on this. A new commitment was made that developed countries would double the finance provided for climate adaptation from 2019 levels by 2025. This would raise the adaptation funding to $40 billion annually compared to $20 billion in 2019. This is much less than the UN estimates of at least $70 billion annually and set to rise in future to around $130-300 billion annually.[161]

It was also decided to establish an ad-hoc work programme from 2022 to 2024 to negotiate a new collective quantified goal on climate finance beyond 2025. For this purpose, three biennial high-level ministerial dialogues will be held. The finance deficit has been underscored by the assessment of the UNFCCC's Standing Committee on Finance, according to which developing countries would require nearly $6 trillion up to 2030, including domestic funds, to support less than half of the actions in their NDCs.[162]

The Glasgow consensus is also heavily relying on mobilizing climate finance from private sources. Ahead of COP26, the Glasgow Financial Alliance for Net Zero (GFANZ) was launched in April 2021, jointly by the United Nations and the UK COP26 presidency. It has 450 financial institutions spanning banks, asset management firms, insurance companies, pension funds etc.

with an estimated total of $130 trillion of assets.[163] However, most of this funding, constituting bank asset base, is not fresh funding and un-allocatable. This vigorous corporate mobilization of climate finance, under the aegis of UN, represents the developed countries' attempt to dilute and divert responsibility for financial mobilization from themselves to private entities.

Additionally, the International Monetary Fund (IMF) announced that its recent $650 billion allocation of Special Drawing Rights (SDR)[iii] would include a Resilience and Sustainability Trust (RST) of up to $50 billion, in order to work towards a 'new climate economy'.[164]

Pledges were also made towards the Adaptation Fund – focused solely on adaptation and being 100% grant-based – by individual countries, amounting to USD 356 million, which is double the amount pledged at COP24, but still well-short of the demand for rising adaptation finance.

Emissions Gap, Commitments and The Need to Scale Ambition

Updated NDCs were submitted by various countries to the UNFCCC in the run-up to COP26 as seen in Table 7. Between 2020-2021, UNFCCC released its analysis of updated NDCs, stating these actions would not be sufficient to keep global warming in check even if all the stated commitments in the NDCs are met. To keep the target within reach, global emissions would need to be reduced by 45% from 2010 levels by 2030. The current national pledges of countries are on course to see global warming between 2.5°C and 2.7°C by the end of the century.

Table 7: Key Countries with Updated NDC Submissions to UNFCCC

Country	Original NDC	Updated NDC
United States	Reduce GHG emissions by 26–28 per cent from 2005 levels by 2025	Reduce GHG emissions by 50–52 per cent from 2005 levels by 2030
China	• Peak CO_2 emissions around 2030 • Reduce CO_2/gross domestic product (GDP) by 60–65 per cent from 2005 levels by 2030 • Increase the share of non-fossil fuels in primary energy consumption to around 20 per cent by 2030 • Increase forest stock volume by around 4.5 billion m3 by 2030	• Peak CO_2 emissions before 2030 • Reduce CO_2/GDP by 65 per cent from 2005 levels by 2030 • Increase the share of non-fossil fuels in primary energy consumption to around 25 per cent by 2030 • Increase forest stock volume by around 6 billion cubic metres in 2030 • Increase the installed capacity of wind and solar power to 1,200 GW by 2030
Japan	Reduce GHG emissions by 26 per cent from 2013 levels by 2030	Reduce GHG emissions by 46 per cent from fiscal year 2013 levels by fiscal year 2030, with efforts to reduce by 50 per cent
EU-27	Reduce GHG emissions by at least 40 per cent from 1990 levels by 2030 (applied originally to EU28 collectively)	Reduce net GHG emissions by at least 55 per cent from 1990 levels by 2030

iii It is an international reserve asset created by the IMF in 1969 to supplement the official reserves of member countries.

United Kingdom	Contribution to EU28-wide emissions target: reduction target of at least 40 per cent	Reduce GHG emissions by at least 68 per cent from 1990 levels by 2030
Canada	Reduce GHG emissions by 30 per cent from 2005 levels by 2030	Emissions 40–45 per cent below 2005 levels by 2030
India	• Reduce emissions/GDP by 33–35 per cent from 2005 levels by 2030 • Increase the share of non-fossil fuels in primary electricity production to 40 per cent (conditional)	N/A

Source: UNEP. 2021. *Emissions Gap Report 2021*.
https://www.unep.org/resources/emissions-gap-report-2021

At the opening session of COP26, Germany pledged to reduce carbon emissions by 65 percent compared to 1990 levels by 2030, and to be greenhouse gas-neutral by 2045.[165] The latest pledges reduce the projected 2030 emissions by only 7.5%, compared to 30% that is needed for 2°C and 55% that is needed for 1.5°C.[166]

IPCC Report and its Outlook for India

The first and the second parts of the IPCC Sixth Assessment Report released in 2021 and 2022 respectively provide a basis for the physical science of climate change and adaptation action, while the third part of IPCC assessment report has covered the 'Mitigation of Climate Change'. According to IPCC, of the 1.1C global warming seen since the pre-industrial era, less than 0.1C has been contributed by natural factors, with the earth likely to cross the 1.5°C threshold by 2040 and the remaining global carbon budget to be exhausted in about a decade. IPCC estimates that around 3.3 to 3.6 billion people live in contexts that are highly vulnerable to climate change.[167]

India will be affected by erratic monsoon patterns and heatwaves stress, with predicted increase in heat extremes and annual mean temperature over Asia expected to be rising by 1-2°C relative to 1850-1900 period in case of 1.5°C to 2°C global warming. In parts of the Indian subcontinent, the projected changes in mean precipitation at 1.5°C global warming range from a 10-20% decrease to a 40-50% increase.

Since the 1950s, according to IPCC, heavy precipitation events have increased in India while the amount of moderate rainfalls has seen a decline due to 'anthropogenic aerosol forcing'. It is predicted that by mid-21st Century, international transboundary river basins in India could face severe water scarcity. India will also face decreasing crop production – in crops such as

rice and maize – and occurrence of pests and invasive species. Intensity and frequency of heatwaves over India are expected to increase. Indian cities such as Kolkata, Chennai, Bombay and Ahmedabad are particularly vulnerable as climate change hotspots. In Bombay sea-level rise damages amount to US$49-50 billion by 2050 and could increase by a factor of 2.9 by 2070. India has a high share in coastal cities in Asia that are particularly vulnerable to sea-level rise and flooding events.

Climate change is also projected to impact India's health infrastructure. For instance, the report draws a positive link between El Niño intensity and malaria incidence in a single year in India. It also talks about energy scenarios, projecting that in India, hydropower production will increase by up to 25% by the end of the 21st century due to increased temperature and precipitation, but is projected to decline in plants located in snow-dominated rivers. There is also projected to be a decrease in coal power plants' annual usable capacity factor due to water shortages.

In addition to climate impacts, the latest IPCC assessment also refers to the present and potential adaptation scenarios for India. A case in point is the Ahmedabad city, which has developed annual Heat Action Plans, building regulations to minimize trapping heat, advisories about managing heat stress, and instituting cool roofs policy. Another example is the reference made to public works programs such as MGNREGA which should take into account climate risk in planning to increase community resilience to climate change. In terms of energy adaptation in India, the report states that solar pumps can replace diesel and electric pumps, potentially reducing 8-11% of India's carbon emissions attributable to groundwater pumping while also boosting agricultural productivity.

Climate Impacts and India's Domestic Approach

India is amongst the most vulnerable countries to the impacts of climate change. In particular, sectors like water and agriculture will be impacted by climate change severely. Climate change impact on irrigation and hydropower in India span variable monsoon and temperature patterns. The 6th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) refers to monsoon variability, heatwave stress and heavy precipitation events in India. In the context of variability in seasonal mean rainfall, increase in extreme precipitation during monsoon and extreme variability in rainfall and extreme weather events in different parts of the country are likely to increase. This will lead to floods and drought. Indirect impacts of climate change on water resources may precipitate in potential conflict situations. For instance, China's dam construction activities may lead to disputes over control of stream flow exercised by the upstream country, leading to potential situations of both scarcity and flooding in a downstream country like India.

Within the agricultural sector, climate change adversely impacts output by about 4-9% every year, leading to around 1.5% loss in GDP annually.[168] Around 60% of the net cultivated area is rainfed and sensitive to climatic variability.[169] Irrigated area accounts for nearly 48% of the 140 million hectare agricultural land.[170] Rising water requirement in irrigation has resulted in a decline in India's per capita water availability. The per capita annual water availability has declined from 5,177 cubic metre (cm) in 1951 to 1,508 cm by 2014, and is likely to reduce further to 1,465 cm and 1,235 cm by 2025 and 2050, respectively, compounded by the impacts of climate change.[171] It is projected that climate change may lead to increase in the water requirement for irrigation for paddy in the Cauvery delta by 8 and 14% during mid and end of century respectively as a result of increase in Potential Evapotranspiration.[172]

Climate change will also adversely impact hydropower in India. Hydropower is an important part of India's renewable energy mix. In 2020, around 163.5 terawatt-hours of electricity production came from hydropower. However, new evidence sheds light on the impact of climate change on hydropower generation. Hydropower is sensitive to the changes in the streamflow due to corresponding changes in precipitation patterns. Wet seasons may see less overall energy generation compared to other seasons. A study found that, in India, seven large hydropower projects experienced a significant warming and a decline in precipitation and streamflow between 1951–2007 and all the hydropower projects are projected to experience a warmer and wetter climate in the future.[173] The increasing evidence reflects that hydropower, a critical renewable resource is sensitive to climate change, especially in a country like India which has made hydropower a key part of its renewable electricity production.

With increasingly constrained carbon space overshadowing the debate on fair global allocations of the atmospheric commons, India finds itself faced with the paradox of being amongst the most climate-vulnerable countries on the planet without having contributed to the problem, but without bright foreseeable prospects of getting a fair allocation. With climate justice considerations now in the background due to the rising discourse of climate emergency guided by the western countries, India is in the process of reviewing workable alternatives that can contribute to climate action while protecting its economic and developmental prerogatives at the same time.

A key part of meeting the NZE target could be through adaptive and mitigative actions. India's National Action Plan on Climate Change (NAPCC) has three missions focused on adaptation. These are National Water Mission, National Mission for Sustainable Agriculture and National Mission for Sustaining the Himalayan Ecosystem. Additionally, the National Mission for a Green India is focused on a mix of both mitigation and adaptation. In 2015, India formed the National Adaptation Fund for Climate Change (NAFCC) whose implementing agency (registered under the Kyoto Protocol) is the National Bank for Agriculture and Rural Development (NABARD). The aim of NAFCC is to meet the cost of climate resilience for vulnerable states and union territories, and is focused mainly on community or publicly-steered developmental activities that intersect with climate change in fields

such as agriculture and water.[174] Of these adaptive and mitigative actions, including community-steered programmes, forms an important part. These community-based programmes are occurring at rural, urban and peri-urban levels.

Adaptation, in India, is occurring in several geographical and sectoral domains. In urban landscape, Indian cities – exhibiting high degree of climate vulnerability coinciding with modes of urbanization – are undertaking adaptation measures of different kinds, such as mainstreamed and strategic adaptation, and, reactive and planned adaptation, in response to rising climate vulnerability. These measures generally converge on the framework of sectoral risk assessments and actions, albeit short term and mostly reactive in nature.[175] Climate-resilient interventions in the field of agriculture, water resources, energy, and infrastructure have been undertaken by national, state and district level adaptive planning policies. They have also been mainstreamed with employment generation policies and Sustainable Development Goals (SDGs) in generating community-level adaptive action.

Besides adaptation, an important part of the mitigation and adaptation landscape in India is the forestry sector, regarding which India has also made commitments in its NDC. Indian commitments regarding its carbon sink include expanding efforts to create an 'additional carbon sink' of 2.5 to 3 billion tonnes of CO2 equivalent by 2030. As of 2021, the total carbon stock in country's forests is estimated to be 7,204 million tonnes, with an increase of 79.4 million tonnes in the carbon stock of country as compared to the 2019 assessment.[176]

Besides adaptation and mitigation actions, finance also forms an important part of meeting India's overall climate commitments, especially those announced at COP26, with the Prime Minister emphasizing that for effective climate action climate finance commitments should be as closely tracked as climate mitigation commitments.

As per India's NDC, the country requires around US$2.5 trillion between 2015 and 2030 for implementing adaptation measures in various sectors such as agriculture, forestry, fisheries, water resources, energy and agriculture, besides requiring additional funding for disaster risk reduction. It is also estimated that an additional $1 trillion will be required for achieving additional commitments by 2030.[177] While the domestic adaptation finance has consistently increased and around 21 centrally sponsored government schemes (with a value of USD 740 billion in 2013-14) directly deal with climate adaptation, yet there is a huge gap requiring to be filled.[178] Of the USD 100 billion annually committed to developing countries, the Green Climate Fund mobilized only USD 10.3 billion, with finance for India amounting to only USD 177 million out of which only USD 78 million is grant-based.[179]

So far climate finance mobilization has been largely domestic. As per India's Third Biennial Update Report (BUR) to the UNFCCC in February 2021, between 2014 and 2019, while Global Environment Facility and Green Climate Fund have provided grants of total $165.25 million, the corresponding domestic mobilization amounts to $1.374 billion.[180]

As per estimates, India would need $200 billion per year in 2020s and 2030s to be able to become net zero by 2070, with expenditure increasing progressively as the low-cost technologies are exhausted.[181] Much of this mobilization would also depend on the developed countries fulfilling their climate finance commitments, which have been deferred to 2023.

In the recent winter session of the Parliament, the government informed the Rajya Sabha that "India expects developed countries to provide climate finance of US $1 trillion per year to the developing countries. As far as India's additional announcements are concerned, additional climate financing to the tune of approximately US $1 trillion by 2030 would be required".[182]

Despite the gap between climate finance supply and demand, international agreements to mobilize USD 100 billion every year for climate adaptation has not been forthcoming, thereby dimming the prospects of concrete implementation of adaptation measures.

Imperative of Climate Action

The imperative of climate action has been reinforced in recent times yet again in India. While already vulnerable to the impacts of climate change on various fronts, India has seen its tangible impact on its national power infrastructure in recent times. In 2022, unusually early onset (since April) of prolonged high temperatures of mid-to-high 40s (degrees Celsius) has led to a rise in heatwaves as well as strained the country's power grid. The latter was due to rise in electricity demand across economic sectors – in the wake of the post-COVID19 recovery – and due to apportioning of limited coal stockpiles as well as due to rise in international prices since coal crisis began in China last year.

The crisis underscores not only the country's heightened vulnerability to impacts of climate change across socio-economic sectors, but also the need to transition to address how to bring climate resilience and adaptation measures to the key economic sectors. This requires not only macro-level adaptation and resilience measures, but also micro-level interventions that can make the interim transition more smooth.

Chapter 3 : Energy Profile of Major Economies

The fossil fuels constituted 67% of the final energy consumption of the world in 2020, while the share of electricity in the energy basked stood at 19.1%.[183] These two factors taken together underline the difficulty in achieving deep de-carbonization. Achieving Net-Zero emission would require not only switching to non-fossil fuel for electricity generation, but also increasing their share in the energy basket overall. The latter is a much bigger task, as electricity generation is only 1/5th of the energy-mix. As Bill Gates has pointed out in his book *How to Avert a Climate Disaster*, some of the manufacturing processes like steel and cement produce carbon di-oxide as a byproduct. Reducing carbon foot-print in the industry would go beyond replacing hydro-carbons by electricity for supplying heat.[184]

The fossil fuels account for more than two-thirds of electricity generated world-wide.[185] They remain an important source of electricity generation of developed countries and China. In case of the US, fossil fuel provided 60% of electricity generated (Coal 22%, Gas 38%). The use of coal for power generation 'will rise by almost 20 percent' this year according to the US Energy Information Administration.[186] Fossil fuels account for 44.3% of German electricity production, including lignite, gas and hard coal. Germany will continue to use lignite (coal) till 2037. Fossil fuels account for about 63% of electricity generation in Japan.

Coal accounts for 63% of electricity generation in China, and 71% of electricity generation in India. China is the largest coal consuming country in the world. Its annual consumption is 4319 billion tonnes per annum accounting for 50.5% of the world consumption. India comes a distant second with 966 billion tonnes per annum or 11.3% of world coal consumption. The US is the third largest coal consumer with 731 billion tonnes per annum or 8.5% of the world consumption. [187]

Though the share of solar and wind has risen fast in recent years, they provided only 9% of electricity production in 2020, behind nuclear (10.2%) and hydro-power (17%) [188] The IEA's suggestion that this could be ratcheted up to 90% by 2050, while increasing the share of electricity in the energy-mix to 50%, raises serious questions about viability of the proposition. While the

need for urgent action to address the problem of climate change is undeniable, there is need to explore all options. There cannot be a single pathway to de-carbonization of the economy. There is need for factoring in the political will also. During the past few months, Biden Administration has made public calls to OPEC to raise oil production. China's decision to authorize new coal based power plants on a large scale through 2019, increase in US consumption of coal and Germany's decision to go ahead with Nordstrom 2 pipeline suggests that shift away from fossil fuels would not be easy.

The following section attempts to unpack the share of fossil and non-fossil fuels sources in the energy mix and electricity generation of the major economies as per the latest available figures.

1. **United States:** Fossil fuels account for the largest share in the energy basket of the US.

   In terms of the overall primary energy production basket, 79% of the total share comprises of fossil fuel based sources, followed by Renewables at 11% and Nuclear Power at 9%.[189]

   Of the fossil fuel sources for electricity generation, 2021, Natural Gas was the largest with a 38% share followed by Coal (22%) and Petroleum less than (1%). Nuclear Energy accounts for one-fifth (19%) of the US electricity production. Renewable sources also contribute to a 20% share with Wind Energy being the largest source at 9.2%, followed by Hydropower at 6.3%, Solar Power at 2.8%, and Biomass and Geothermal Power Plants at 1.3% and 0.4% respectively.[190]

2. **United Kingdom:** In 2020, Natural Gas accounted for the 40% of the total UK energy production, forming an important component of the energy mix.

   In terms of electricity generation specifically, renewable sources accounted for the highest share in the of the UK with a total of 39.7%. Of the share in renewables, wind energy provided for the highest share of 21.06%. Nuclear power contribution fell, accounting for 15.3%, taking the total share of non-fossil fuel based sources to 55%. The fossil fuel share in the energy basket for electricity generation comprised of a total of 44.8%, with Natural Gas being the primary fuel (40.1%) in the generation mix.[191]

3. **Germany:** In terms of total energy production in 2019, coal accounted for 26.27%, dry natural gas at 4.23%, petroleum and other liquids at 1.82% and Nuclear and renewables at 67.69% respectively.[192]

   Renewable or non-fossil fuel based sources comprise of a total of 40.9% of the total share in Germany's electricity mix for 2021. Within the non-fossil fuels based sources of energy the primary component is Wind Power (20.3%) followed by Solar Energy (8.5%). Nuclear Energy comprises of 11.9% of the total share, with a possibility in future decline owing to the recent policy of phasing out of nuclear power plants. Of the total of of the fossil-fuel share, lignite

attributes to 18.7%, followed by natural gas at 15.4% and hard coal and mineral oil products at 9.4% and 0.8% respectively.[193]

4. **France:** In 2019, the total share of Nuclear and Renewables in the energy production mix of France accounted for 99.41%. [194]

   Nuclear power is the leading source of electricity generation in France, contributing to 69.1% of the total. In February 2022, French President Macron announced a major buildup of France's huge nuclear power program, pledging to construct up to 14 new-generation reactors and a fleet of smaller nuclear plants as the country seeks to slash planet-warming emissions and cut its reliance on foreign energy.[195] Renewable sources account for 21.9% of the total production mix. Fossil-fuel based sources only account for about 9% of the share, one of the lowest in comparison to other major economies.[196]

5. **Denmark:** The fossil-fuel based sources (crude oil and natural gas) account for 50.25% of the total share in the energy production mix as of 2020. Renewable sources attributed to 46.25% of the total share in the energy mix.[197]

   Specifically, as regards to electricity generation, wind accounts for 46% of the total share followed by biofuels at 22%, coal at 22%, natural gas at 7%, solar at 3% and oil at 1% respectively. Denmark does not produce electricity from nuclear power sources, owing to a law passed in 1985 prohibiting the use of nuclear power for the purposes of generation of electricity. It however, imports nuclear power, but in minimal capacity.[198]

6. **Russia:** In 2018, natural gas dominated the total energy production at 40% of the total share. This was followed by petroleum at 37.62%, coal at 16.35% and nuclear and other renewables as 6% respectively.[199]

   As of 2020, Russia's electricity mix majorly comprises of fossil-fuel sources. Natural Gas has the highest percentage share at 45%, followed by coal 14%. Of the non- fossil fuel sources, Hydropower accounts for 20%. Nuclear Energy provides for 20% of the generation mix.[200]

7. **India:** Coal continues to dominate the energy production of the country at 77.2% of the total share, followed by crude oil at 8.79%.[201]

   In terms of electricity generation mix in 2020-21, Coal accounted for 71.47%, Gas 3.72%, and Oil 0.01% out of the total. The balance was provided by the non-fossil sources including Hydro 10.95%, Solar 4.40%, Wind 4.38%, Nuclear 3.13%, Bio-mass 1.08%, Mini Hydro 0.75%, and Other at 0.12%.[202]

8. **China:** According to IEA report, 'Despite impressive growth in renewables since 2000, China remains heavily dependent on fossil fuels, which met around 85% of the country's total

primary energy needs in 2020 – coal alone for about 60% and oil for about a fifth. China is by far the largest coal-consuming country in the world, the 3 billion tonnes of coal equivalent it burned in 2020 making up more than 50% of the world market. The report further states that the Chinese government approved further increase in coal based power plants and '37 GW was authorized in 2020 – three times more than in 2019.' [203]

In terms of electricity generation, coal has the largest share in the non-renewables, accounting for 63% of the total share. Natural Gas contributes to 3.2% of the total share in 2020. Hydropower and renewables provide for 17% and 11% in the generation mix. The contribution of Nuclear Power to the electricity mix stands at 4.7%.[204]

9. **Japan:** As per the draft Strategic Energy Plan of Japan LNG has the maximum share in the energy mix for the FY 2019-20 at 37%. This is followed by coal at 32% and oil at 7%. With a view to reduce GHG emissions by 2030 the plan expects Japan's renewables to account for 22-24%, with nuclear at 22-20%, LNG 27%, coal 26% and oil 3% for the FY 2030-31. [205]

   Fossil fuels form the largest share with a contribution of coal at 30.65% and gas at 32.07% of the total electricity generation in Japan. This is followed by renewables at 26.10%. Nuclear energy has the lowest share in the energy mix, with 6.32% of the total share.[206]

10. **South Korea:** The primary component of South Korea's electricity mix is of fossil-fuels with coal accounting for 34.6% and gas 29.2% of the total generation mix. Nuclear Power constitutes 26.1%, whereas renewables are at the lowest share of about 8.3% in the energy basket for electricity production.[207]

A sharp increase in the share of renewables in the energy-mix would also raise the cost of renewable integration in the grid. This is covered in the next chapter.

Chapter 4 : Future of grid and the problem of Variable Renewable Energy (VRE)

> 'So if solar and wind represent a big part of our electricity mix and we want to avoid major outages, we are going to need other options for when the sun isn't shining and the wind isn't blowing. Either we need to store excess electricity in batteries (which I will argue in a moment is prohibitively expensive), or we need to add other energy sources that use fossil fuels, such as natural gas plants that run only when you need them. Either way, the economics won't work in our favour. As we approach 100 percent clean electricity, intermittency becomes a bigger and more expensive problem.'
>
> – Bill Gates,
> *How to Avoid A Climate Disaster*[208]

As the world moves towards a low carbon economy, the salience of renewables in the grid is bound to increase. This however brings in its wake a whole range of problems relating to balancing costs. When the sun is not shining or the wind is not blowing, the balancing power is provided by coal or gas. Slowing down of the Northern Sea Winds and rising gas prices have led to five-fold increase in electricity prices in Europe. The crisis is continuing, and is likely to worsen as winter months will increase the demand of gas and electricity for heating. This has underlined the fragility of the model based on a combination of intermittent renewable energy, and imported gas. The UK's problem is worse, as being an island nation, it does not have access to a regional grid which Germany enjoys. This also holds out a lesson for India, as the share of renewables in India's grid goes up. We do not have access to a regional grid; most of our neighbours are energy deficit. Bhutan and Nepal are an exception. But their hydro-power exports do not meet India's scale yet.

The sharp hike in electricity prices in Europe may be of recent origin. There are also different schools of thought about origins of the problem – whether the hike is a result of increased reliance on renewables or it has resulted from volatility in the price of imported gas. If it is the former, this calls into question the entire model being built up by IEA to achieve Net Zero Emission. If renewables did not need balancing power, gas price hike would not have affected the electricity prices to such an extent. But even before the onset of the present crisis, German and Danish electricity prices

were the highest in Europe. These are two countries relying most on renewables. Indeed, German prices are highest worldwide as Table 8 shows.

Table 8: Electricity prices worldwide

Country	Electricity Price (Household) (Dec. 2020) (US$/kWh)[209]	Electricity Price (March 2021) (US$/kWh)[210]	
		Household	Business
Germany	0.37	0.372	0.244
Denmark	0.34	0.35	0.241
United Kingdom (UK)	0.26	0.275	0.239
Japan	0.26	0.246	0.185
France	0.22	0.209	0.146
United States (US)	0.15	0.15	0.109
China	0.09	0.086	0.99
India	0.08	0.077	0.114

Sources: Statista. (2020). *Household Electricity Prices Worldwide in December 2020, By Select Country.* https://www.statista.com/statistics/263492/electricity-prices-in-selected-countries/GlobalPetrolPrices.com. (2021). *Electricity Prices.* https://www.globalpetrolprices.com/electricity_prices/

The figures in the Table 8 pre-date the recent gas price hike. Growth in the share of renewables requires corresponding increase in the balancing power. In Europe, this is supplied by gas. Thus, there is the paradoxical result that quest for clean energy brings in its wake more demand for fossil fuel. Europe is replacing coal with gas, which remains a substantial share of its energy basket. A study by Agora Energiewende notes that 'Since 2015, although coal generation halved, (-340 TWh), only half of that was replaced by wind and solar (176 TWh).[211] In case of Germany, the share of gas in her energy basket will go up further with phasing out of nuclear power plants and Nordstream 2 coming on stream.

German Feed-in Tariff

Germany provides Feed-in tariff for renewable power. The cost is included in the tariff. At 6.5 Euro Cent/kWhr, this amounts to 20% of the total tariff charged to the consumers in the household sector.[212] Though it is a rich country, there is strong financial discipline. The Grid charges of 7.8 Euro Cent/kWhr, or 24% of the tariff is also passed on to the consumers.[213] In case of renewables, grid charges are considerable, as most of the locations for the wind and solar power are in remote areas.

The first German Feed-in Tariff, also called Erneuerbare-Energien-Gesetz (EEG) (Renewable Energy Sources Act), was introduced in 2000 and has been amended every four years to incorporate

necessary policy changes. The policy has been crucial in increasing the market share of renewable energy sources and has shown massive improvement in this direction. In 2000, the market share of renewable energy was 6.2%, 23.7% in 2012, about 28% in 2014 while in 2020 more than 50% of the electricity generated was through renewables. Growth at this rate ensures that more than 80% of the electricity can be generated by renewable sources by 2030. [214]

Rising Balancing Cost of Renewables in Germany and UK

The case of Germany and UK illustrate the difficulty inherent in increasing the share of renewables in the Grid. Both have committed to the goal of the Net Zero Emission target. Germany has decided to phase out nuclear by 2022, though it will retain coal for much longer till 2038. The UK has decided to phase out coal, but commission new nuclear power plants. Both rely to a large extent on wind power, which contributes to 23.7% of German power production while it accounts for 24% in the case of the UK. A study by Michael Joos and Iain Staffell shows that 'The cost of wind and solar has declined substantially in the last decade, such that the levelised cost of electricity (LCOE) for onshore wind and large solar is now lower than gas and nuclear'. It adds:

> 'However, LCOE does not tell the whole story: To accommodate VRE output while enforcing high standards for the security of supply, costs are incurred in other parts of the system, mainly for holding and operating reserve and backup plants to manage variability and uncertainty of VRE output. These are so-called system integration costs.' [215]

The study poses the questions: 'Do VRE generators bear the costs that they cause elsewhere in the system to a sufficient extent in current market arrangements? If not, how could market arrangements be changed to internalize these costs?' The answer to both questions is negative. In the case of Germany, 'Costs for the grid reserve and RES curtailment are socialized via grid fees, which in Germany are paid for only by consumers.' In the case of the UK, 'The costs for congestion management are socialized via the Balancing Services Use of System (BSUoS) charge, which is paid for by all suppliers and generators on a pro-rata basis.'

The balancing costs are increasing both in case of Germany and UK. In the case of Germany, they exceed Euro 900 million by 2016 as a study by Michael Joos and Ian Staffell has brought out. [216] In the case of the UK, the costs had reached 1.2 billion pounds by 2016.[217]

The study further notes 'Balancing costs are relatively low even at higher penetration levels up to 40% of electricity demand'. 'However, integrating higher levels of VRE (e.g. > 50% of demand) will require a transformation of the power system with large scale deployment of alternative flexibility options such as demand-side management (DSM) and storage to maintain cost efficiency as well as the transformation of power markets to provide and remunerate short-term flexibility sufficiently.'[218] It also adds 'It is also important to note that while most VRE integration literature focusses on balancing costs, these make up a smaller part of energy bills than costs of grid infrastructure.'[219]

Germany's New Renewables Energy Act 2021

The New Renewables Energy Act 2021 came into effect on January 1, 2021 weeks after the last-minute changes in December 2020, and was approved by the Bundestag (the Federal Parliament of Germany). The most important change under the new Act is that part of renewable surcharge, also called EEG surcharge of 6.67 ct/kWh (20% of the total cost per kWh) will be borne by the federal budget. This will increase the budgetary support provided by the German government to the renewable sector to about 11 billion euros. The government will use the revenues from CO2 pricing of transport and heating systems to meet this. Though the amount may be recouped by the Government, this adds cost to the economy. The cost of renewables in Germany has gone up steeply. 'The money channeled to green energy rose to almost 31 billion euros ($38 billion) in 2020, a 13% jump from a year earlier', according to data published by the country's grid operators. 'Green power's share of Germany's energy mix rose to 46% last year from about 43% in 2019'. This is cost to consumers; German government plans to cover 1/3rd of this cost in budget; the consumers nevertheless will have to pay the remaining 2/3rd. [220]

MIT Study

An MIT study 'The Future of Nuclear Energy in a Carbon-Constrained World' has noted that as we move towards a lower emission target, sole reliance on renewables will sharply escalate the cost. The inclusion of nuclear will help optimize the cost:

> 'At lower carbon targets when nuclear technology is not allowed as an option, electricity generation must come from renewables as the only other completely low-carbon option. Due to the intermittent nature of wind and solar generation, large amounts of installed renewables and battery storage capacity are needed to ensure that the system is always able to meet demand. The large investments needed to install this additional capacity increase the total system cost. This represents an opportunity for nuclear technology, as the installed capacity needed to meet demand using nuclear generation is much less than the build-out required for renewables'.[221]

VRE or Clean, Firm Power?

A series of extreme weather events ranging from California, Texas to North Sea in Europe has swung the pendulum away from VRE to 'clean, firm power'. A study commissioned by the Environmental Defense Fund and the Clean Air Task Force on energy choices for California has brought interesting findings. The State has decided to make all its electricity carbon free by 2045. A group of energy system experts from Princeton University, Stanford University, and Energy and Environmental Economics modelled California's electricity requirements and costs of different options. The output of solar and wind power is weather dependent, and unpredictable. 'Periodic large-scale weather patterns extending over 1,000 kilometers or more, known as dunkelflaute (the German word for dark doldrums), can also drive wind and solar output to low levels across regions.'[222] This

is beyond the capacity of batteries to cope; they can supply power only for a few hours. The study estimated that 'California's peak demand for electricity will increase from 50 gigawatts today to 100 gigawatts midcentury.'[223] The study found that 'reliably generating' this demand load using solar and wind power 'would require building the system upto nearly 500 gigawatts of power generating capacity.'[224] This is nearly half of US's total grid size today, and five times California's peak demand in 2045.

The high capacity required to reach a given generation level flows from low plant-load factor and unpredictability of renewable energy, which is weather dependent. 'This excess capacity would be expensive.'[225] The study estimated that 'wholesale electricity rates would increase by about 65% over today if renewable energy and currently available storage technologies alone were to be used to meet demand in 2045.'[226] The study mentions 'Nuclear power can provide a very large amount of energy steadily in a small footprint.'[227] The study found that any combination of nuclear, and other clean sources 'could deliver a 100% carbon-free electricity supply with generation and transmission supply costs of about 7-10 cents per kilowatt-hour, which compares well with current average of 9 cents per kilowatt-hour.'[228]

IEA Reports

The IEA, which has been advocating sharp increase in the share of electricity to reach Net Zero emission level, has hinted at the magnitude of the problem with the increase in the share of renewables in the power grid. Curiously, it has shied away from indicating the cost or investment required. This amounts to seriously under-estimating the cost of renewables. While energy transition to a low carbon economy is indeed an unexceptionable goal, this needs full transparency to ensure that right choices are made amongst different options available.

> 'A major question is how to manage the potential for increased variability on both the demand and supply sides of the energy equation. The variability of electricity supply will be affected by rising shares of wind and solar PV, putting a huge premium on robust grids and other sources of supply flexibility.' [229]

The report adds further:

> 'Without effective policies to prepare for and manage these fluctuations, the daily variation of demand could increase on the basis of announced pledges to 270 gigawatts (GW) in the European Union (from 120 GW today) and over 170 GW in India (from 40 GW) by mid- century.' [230]

The above estimate of 170 GW of flexibility required in India's case by mid-century has huge financial implications. This will be the additional generation capacity, which will have to be created as a back-up for growth of renewables. This capacity will be lying idle or have to be run at sub-optimal level when renewable energy is available. To put it in perspective, this additional capacity to be used only as a stand-by for renewables is nearly 50 percent of India's current capacity of 330 GW.

The increased cost of creating and maintaining additional generation capacity as a stand-by facility would have to be matched by increase in the grid capacity to evacuate renewable power from remote locations. Just as renewable generation capacity has low PLF of around 20-28 percent (as against 70 percent for nuclear), the grid utilization for evacuation of renewables is also low adding to the cost of operation. This may not exceed 20-25 percent of grid capacity. In India, renewables are exempted from inter-State transmission charges. This means that this cost is 'socialised' – either borne by the government or other sectors.

The IEA report sketching out the Net Zero scenario in 2050, states:

> 'By 2050, China, India, European Union and United States all reach Phases 5 or 6 in their energy transitions in the APS, and also in the STEPS (except for China, which comes close). Phases 5 and 6 have not yet been reached by any country. These phases are characterised by longer periods (from days to seasons) of mismatch between VRE generation and demand. During those periods, if VRE generation is inadequate to meet demand it has to be supplemented by sufficient dispatchable sources of generation, withdrawals from long-term storage systems, or measures to manage demand.' [231]

Bill Gates in his book 'How To Avert a Climate Disaster' has underlined the problem of intermittency of renewables:

> 'In short, intermittency is the main force that pushes the cost up as we get closer to all zero-carbon electricity'. It is why cities that are trying to go green still supplement solar and wind with other ways to generate electricity, such as gas-fired powered power plants that can be powered up and down as needed to make demand, and these so-called peakers are not zero-carbon by any stretch of the imagination.'[232]

VRE and electricity tariff

Some of the recent studies have mentioned that energy transition would result in higher electricity tariff (delivered price of electricity) as high carbon price will be used to drive the consumer choice from fossil fuels to renewable energy. The increase in carbon price is necessary to bridge the price differential and make the battery or CCUS technologies commercially viable. However, once the renewables replace the fossil fuels, the tariff will come down as the former have nil fuel cost. This view is based on flawed assumption and does not take into account grid costs which will increase. A recent study by McKinsey points out that the delivered cost of electricity has three components – generation operating costs, generation capital costs and additional grid costs. The report mentioned that:

'Operating cost for generation could drop by more than 60 percent relative to 2020 as the energy mix shifts to renewables. Some of the reduction in operating and other costs for generation would be offset by an increase in the operating and other costs associated with grid flexibility, transmission and distribution. As a result, delivered cost of electricity would still be about 20 percent higher in 2050 than 2020 levels.'[233]

Thus, energy transition will lead to inevitable increase in tariffs.

Indian Experience

VRE integration in the grid: Balancing and Stranded Costs

In 2017, the renewable integration cost for Tamil Nadu were estimated at Rs. 1.57 per KWhr (Table 9). This was Rs. 1.45 per KWhr for Gujrat (Table 10). As balancing cost and grid costs are not part of the renewable tariff structure in India, nor are they borne by the promoter, they have to be absorbed by the DISCOMs. This cost could be absorbed or disguised as long as there is low grid penetration; renewables account for around 10 percent of power generation in India currently. It will not remain so once the renewables become the dominant part of the energy-mix.

A report by CEA, published in 2017 presented the impact of spread over renewable energy (RE) based power generation and associated cost for the states of Gujarat and Tamil Nadu. [234] In 2017, the day-time penetration of RE was 34% and 12% for Tamil Nadu and Gujarat respectively. [235] Currently, the overall national average RE penetration (whole day) is 8.2%. In Tamil Nadu and Gujarat, the shares of RE (wind + solar) power generation are 18% and 14% respectively.[236]

Table 9. Grid integration cost of renewable generation ₹/kWh) – Tamil Nadu

Sr. No.	Cost description	Cost value (₹/kWh)
1	Total balancing charge for the Central Generating Stations (CGS) Coal and gas based station (fixed +fuel charge) (₹/kWh) - Spread over renewable generation	0.20
2	Total balancing charge for Tamil Nadu Coal based station (fixed + fuel charge) (₹/kWh) - Spread over renewable generation	0.03
3	Impact of DSM per kWh (₹/kWh) - Spread over renewable generation	0.35
4	Impact on tariff (₹/KWh) for Tamil Nadu DISCOM for backing down Coal generation assuming solar and wind at ₹4/kWh and coal fuel charge at ₹2.0/kWh- Spread over renewable generation (Considering 25% on account of renewables)	0.5
5	Stand by charge (₹/kWh) - Spread over renewable generation	0.23
6	Extra transmission charge (₹/kWh) - Spread over renewable generation	0.26
Total	**Total Impact - Spread over renewable generation (₹/kWh)**	**1.57**

Source: Central Electricity Authority (CEA). (2017). *Report of the Technical Committee on Study of Optimal Location of Various Types of Balancing Energy Sources/Energy Storage Devices to Facilitate Grid Integration of Renewable Energy Sources and Associated Issues*. https://cea.nic.in/wp-content/uploads/2020/03/report.pdf

Table 10: Grid integration cost of renewable generation (₹/kWh) – Gujarat.

Sr. No.	Cost description	Cost value (₹/kWh)
1	Total balancing charge for CGS Coal and gas based station (fixed + fuel charge) (₹/kWh) - Spread over renewable generation	0.24
2	Total balancing charge for Gujarat Coal and Gas based station (fixed + fuel charge) (₹/kWh) -Spread over renewable generation	-
3	Impact of DSM per kWh (₹/kWh) - Spread over renewable generation	0.12
4	Impact on tariff (₹/KWh) for Gujarat DISCOM for backing down Coal generation assuming solar and wind at ₹ 4/kWh and coal fuel charge at ₹ 2.0/kWh - Spread over renewable generation (Considering 25% on account of renewables)	0.5
5	Stand by charge (₹/kWh) - Spread over renewable generation	0.33
6	Extra transmission charge (₹/kWh) - Spread over renewable generation	0.26
Total	**Total Impact - Spread over renewable generation (₹/kWh)**	**1.45**

Source: Central Electricity Authority (CEA). (2017). *Report of the Technical Committee on Study of Optimal Location of Various Types of Balancing Energy Sources/Energy Storage Devices to Facilitate Grid Integration of Renewable Energy Sources and Associated Issues*. https://cea.nic.in/wp-content/uploads/2020/03/report.pdf

The Forum of Regulators (FOR) report on "Analysis of factors impacting retail tariff and measures to address them" published in April 2021 mentioned, "As in the case of transmission assets, the fixed cost of stranded generation assets is being paid for by the consumers without getting any benefit. Surplus energy of this magnitude (129251.18 MU across 12 states of India) and resultant costs (in the range of Rs. 1.34/kWh) are a matter of great concern. Further, the cost of balancing renewables has been estimated to be in the range of Rs. 1.10/kWh by CEA. In addition, the additional stranded capacity cost (incremental fixed charge) estimated on account of RE integration is in the range of Rs. 1.02/kWh."[237] According to this estimate, the cost of VRE integration in the grid works out to Rs. 1.10 + Rs. 1.02 = Rs. 2.12 per kWhr. This neutralizes the tariff difference between renewables on one hand and thermal and nuclear on the other hand. In fact, if renewable tariff is taken at Rs. 2-2.5 per unit, this will make them more expensive than nuclear power tariff which stood at Rs. 3.43 per unit in 2019.

The installed capacity of the renewables is to be increased from 100 GW currently to 450 GW by 2030. This additional tariff of Rs. 2.12 per kWhr on account of VRE grid integration, applied to increase in renewable generation, will impose huge financial burden on DISCOMs.

Ramping up renewable capacity from 100 GW at present to 450 GW by 2030 will also entail expanding grid. According to an estimate by the Power Grid Corporation, the estimated cost shall be about Rs. 2,27,500 Cr. (Rs. 2.2275 Trillion), considering cost of about Rs 650 Cr./GW for establishment of new transmission system.

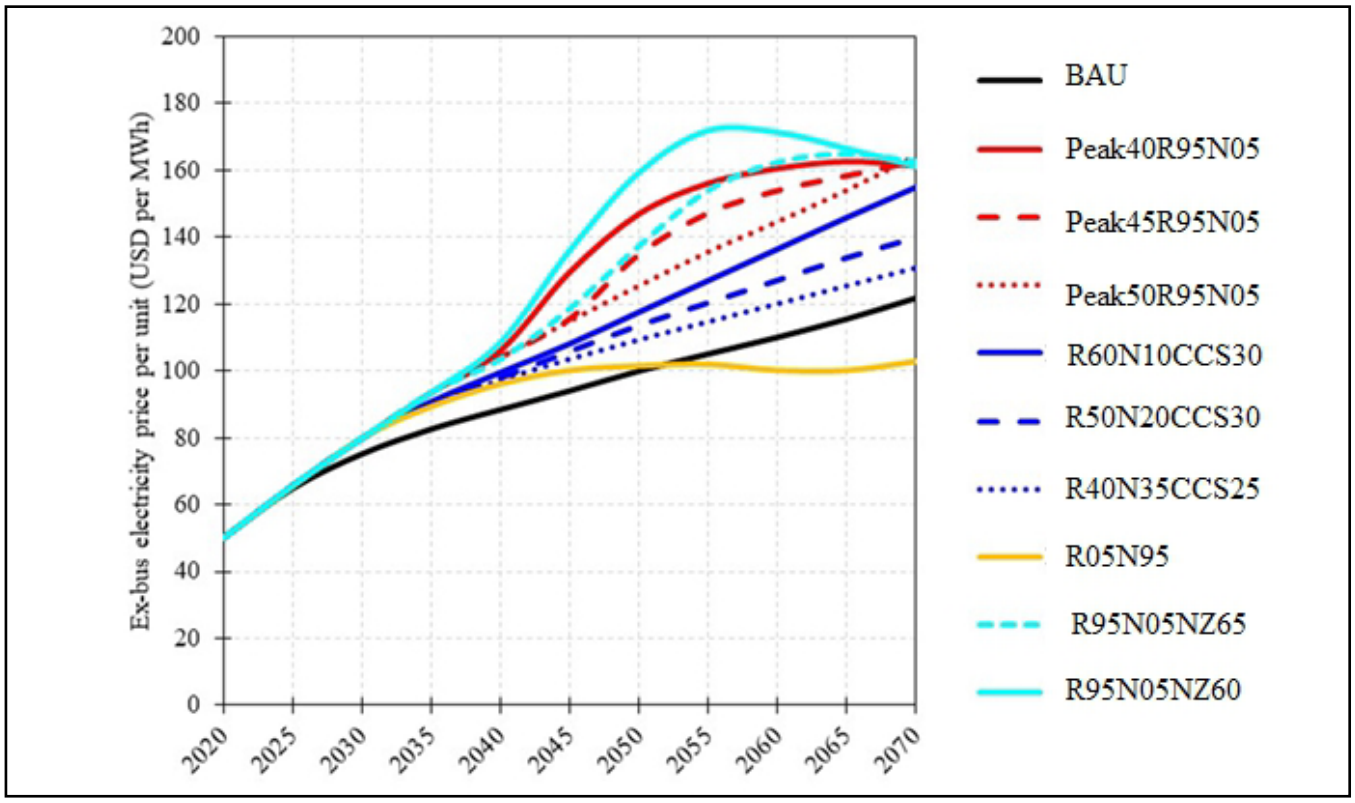
The case for regional grid in South Asia

India does not have access to a regional grid at present. Most of our neighbours are energy deficit with the exception of Nepal and Bhutan. Nepal has huge hydro potential with very little demand. During 2021-22, 2025 and 2035, Nepal is expected to have net exportable surplus power of about 5.7GW, 13.2GW and 24.9GW respectively. This clean energy may be utilized to facilitate integration of large RE capacity in In India in near future. The allocation of power from Bhutan to India is about 2070MW. Bangladesh can draw power from hydro projects in Nepal through an Indian entity in line with CERC CBTE Regulations. Co-operation in the energy sector could be a win-win situation for both countries.

Net Zero Emission, price of electricity and grid integration cost

As we approach the net zero stage in 2070, the cost and tariff of electricity will go up sharply as shown in the Figure 8.

Figure 8: Net zero in 2070 with 10% green H2 demand— Grid cost of electricity under different scenarios



Source: IIT Bombay, Mathematical Modelling for the VIF Task Force Study – India's Energy Transition in a Carbon Constrained World. (Annexed)

According to the mathematical modelling done by IIT Bombay, the grid cost of electricity will rise from 50 USD/MWh in 2020 more than 3 times to about 164 USD/MWh at the NZE stage in 2070 in the scenario where renewables have preponderant share in the generation-mix (R95N05). Early peaking (say 2040 or 2045) will initially increase the same price to stabilize at about 162 – 163 USD/MWh. However, a high nuclear scenario (R05N95) will stabilize the price much earlier to about two times the current price at $103 per MWh. The cost of electricity increases in each scenario, though the rise is the sharpest in case of a renewable high scenario.

Mathematical modelling by IIT Bombay has also brought out that grid integration cost goes up by 2070 to $ 1.4 trillion in R95N05 scenario as against $0.2 billion in R05N95 scenario. The combination of higher generation capacity and higher grid integration cost will make the delivered cost of electricity highest in the case of a renewable high scenario.

Chapter 5 : India's Power Sector

India's power sector is facing challenges due to over-capacity and stressed assets. CEA report mentions that 'after the enactment of Electricity Act 2003 generation has been delicensed which has given impetus to the generation capacity addition and led to huge coal-based generation capacity addition during 11th and 12th plan.'[238] It states further, 'huge capacity addition in the recent years has raised concerns related to under-utilization of the coal-based capacities leading to stressed assets in the sector'.[239] A third reason could be that load projection is based on the estimate of GDP growth. Slow-down of the Indian economy in the wake of the global financial crisis brought down demand. The sector already under stress will face the greatest pressure due to rising climate concerns. India is on track to meeting its Intended Nationally Determined Contributions (INDC)s pursuance of the Paris Conference of 2015. However, moving toward the goal of Net Zero Emission will require vast resources. Assistance from developed countries has fallen short of their commitment consistently. Therefore, restoring the health of the power sector is important to attract the huge investment needed for the energy transition.

Our dilemma is that investment in energy transition has to be made at a time when we have stressed assets in the power sector. This makes it difficult to justify the fresh investment. The private sector investments will come if the DISCOMs are in good health. The government launched the UDAY scheme to improve the financial situation of the DISCOMs. However, their liability has again started going up as seen in Figures 9 and 10.

The need to expand generation capacity goes beyond the current phase. India has accepted the goal of Net Zero Emission by 2070. Lowering the carbon footprint would require the electrification of new sectors of the economy, which will lead to the expansion of the grid size. Renewables have to be backed up by a stable source of power when the sun is not shining and the wind is not blowing. They are also intermittent and the most land-intensive source of energy. The extreme weather events in India earlier this year also brought out the need for additional capacity which is not weather dependent. The surge in demand strained the existing grid. In the wake of the Ukraine war, many countries in Europe are returning to coal.

Figure 9: Financial losses of Indian DISCOMs over the years

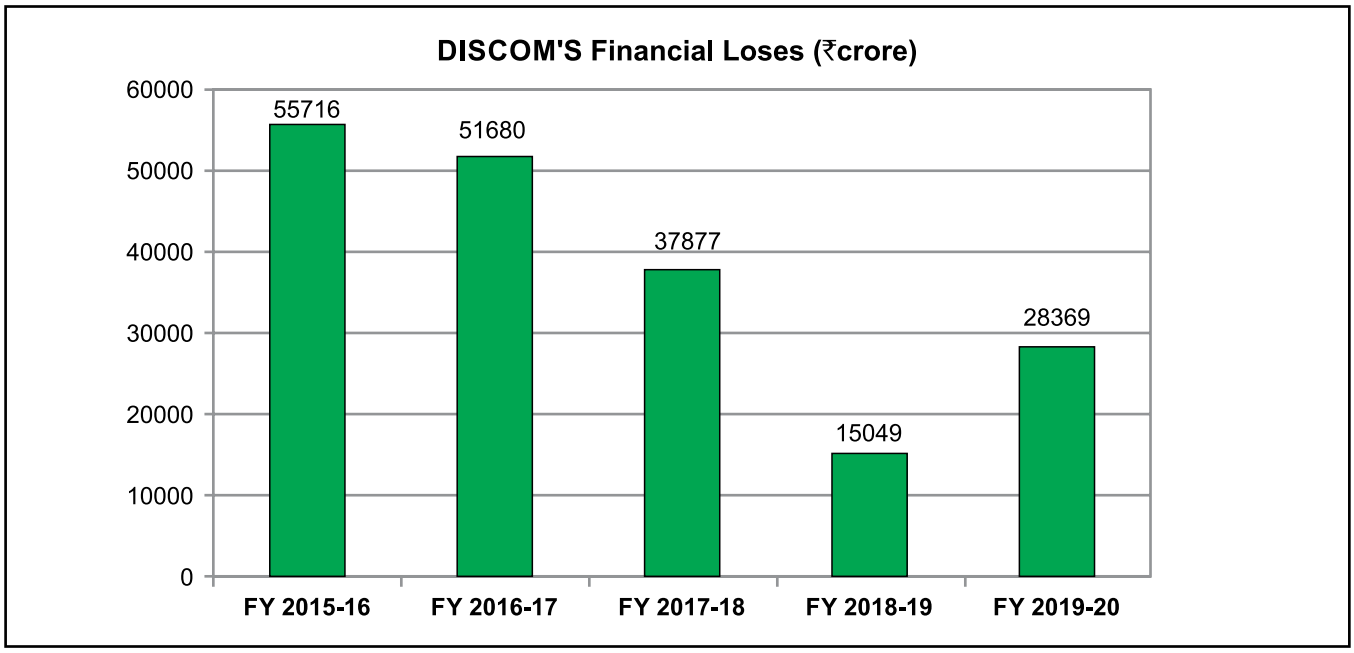


Image: VIF India.

Source: Financial Express. (2020). *Uday 2.0: Govt. May Impose Stricter Penalties on Non-complying Discoms Under the New Scheme.* https://www.financialexpress.com/industry/uday-2-0-govt-may-impose-stricter-penalties-on-non-complying-discoms-under-new-scheme/1837058/

Figure 10: Aggregate Technical & Commercial (AT&C) losses in India

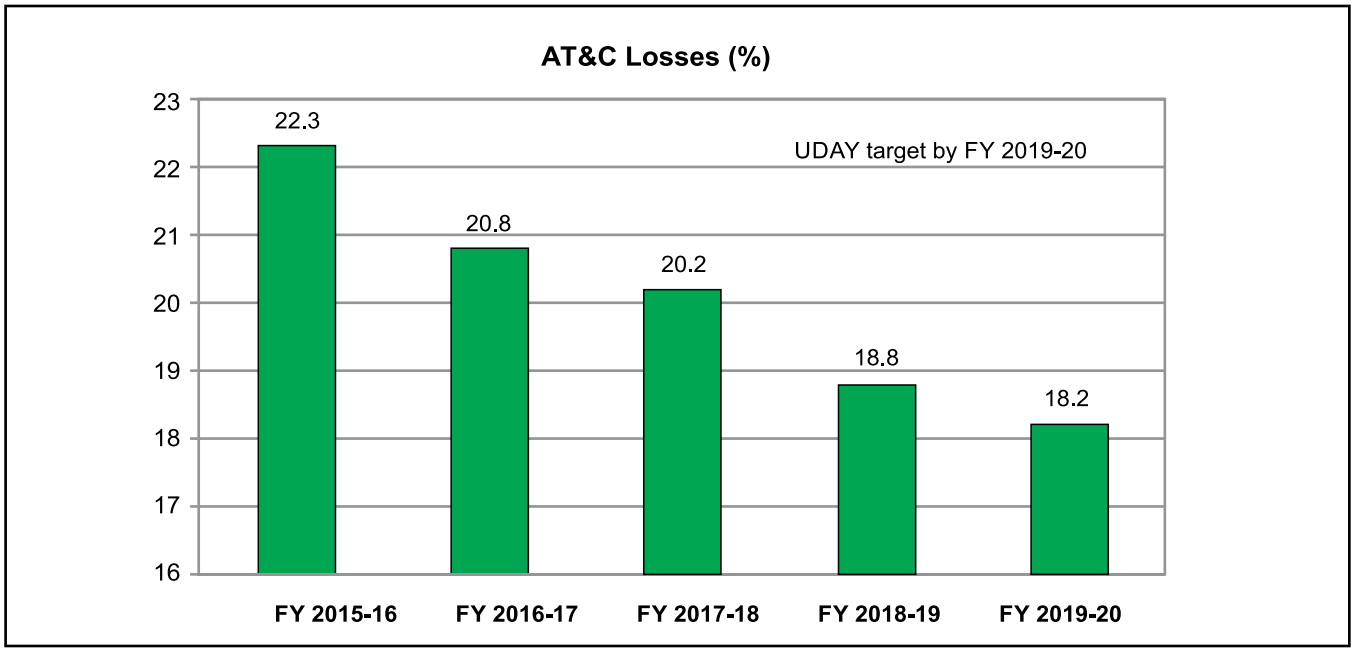


Image: VIF India.

Source: Financial Express. (2020). *Uday 2.0: Govt. May Impose Stricter Penalties on Non-complying Discoms Under the New Scheme.* https://www.financialexpress.com/industry/uday-2-0-govt-may-impose-stricter-penalties-on-non-complying-discoms-under-new-scheme/1837058/

According to ICRA, the power industry continues to confront substantial issues, with most DISCOMs incurring annual losses - the total loss is anticipated to reach Rs. 90,000 Crore in FY 2020-21.[240] Because of these accumulating losses, DISCOMs are unable to pay for generators on time - an amount of 67,917 crores was overdue as of March 2021, as per Ministry of Power, PFC Consulting, 2020.[241] In order to counteract the losses, the GoI has announced financial support of Rs. 90,000 Crore to revive the DISCOMs. The amount of overdue payments to the generators has since increased further.

The Power Minister R K. Singh stated in the parliament that the financial situation of the majority of state government-owned distribution corporations is gravely concerning since the Power DISCOMs owe generation firms (gencos) more than 1.56 lakh crore. "Discoms have not been able to pay the generation companies for the power procured, and the outstanding payments to generation companies are estimated to be in excess of Rs 1,56,000 crore. The outstanding dues to renewable generators are around 11 months of revenues. Therefore, reforms have been deliberated upon in consultation with the states and all stakeholders."[242]

The PLF of coal-based plants has reduced to 56.01 % during 2019-20 from 78.6 % during 2007-08.[243] The CEA report, therefore, sounds a note of caution that 'there is an increasing need to plan capacity addition optimally in view of the limited availability of fuel resources for generation, new sources of generation and environmental concerns.' India has huge reserves of thermal coal; the availability of imported gas at an affordable price is an issue. India is also endowed with abundant sunshine and must make full use of solar power. However, solar power is intermittent and requires a balancing power. The distant location of the solar or wind power plants adds to the cost of creating grid infrastructure. Balancing requires operating thermal plants supplying balancing power at sub-optimal capacity, which generates systems costs. The German and the UK's example of relying upon wind power has thrown up its own set of problems as the cost of electricity has sky-rocketed with the dropping of wind speed. This happened, despite Germany and UK (to a lesser extent) enjoying support from being part of the robust European grid with access to Nuclear and Hydropower. India is more like Australia – which is also facing solar integration issues. The problem has been compounded by the (depletion in production from on-shore gas wells and short-fall in the supply of gas from the KG Basin coupled with the high cost of imported gas (LNG). There are therefore no easy solutions.

In most parts of India, clear sunny weather is experienced 250 to 300 days a year. The annual radiation varies from 1600 to 2200 kWh/m2, which is comparable with radiation received in the tropical and sub-tropical regions. The equivalent energy potential after accounting for availability of land and its utilization factor is about 3200 TWh of energy per year. The touchstone of selecting the energy source has to be not simply the generation cost, but the final cost to the consumer.

In a country, where the per capita energy consumption is 1/3rd of the global average, we need to make full use of a diversified energy basket. The electricity demand will grow. Dr. Grover has noted 'In the coming decades, growth in electricity generation will be due to two factors: structural changes in the energy sector leading to a preference for the use of electricity in place of fossil

fuels; and growth in energy demand due to improvements in the standard of living, urbanization, demands of industry, commerce, agriculture, transportation, etc.'[244]

Generation Capacity

The sector wise installed capacity in India is shown in Table 11. As of 28 February 2022, India has a total installed electricity capacity of 395.60 GW as seen in Table 12.[245] Of this, 106.37 GW (26.88%) is accounted for by renewables (hydro, solar, wind and bio). Among renewables, hydropower accounted for the largest share - 51.36 GW or 12.98% of India's total electricity installed capacity. It also accounted for 48.28% of its total installed renewable energy capacity. Within the hydropower sector, large hydropower (those having installed capacity above 0.02 GW) accounted for /46.52 GW or 90.57% of India's total hydropower capacity and 11.76% of its total installed electricity capacity. Small hydro power (those having installed capacity below 25 MW) on the other hand accounted for 4.83 GW or 9.42% of India's total hydropower capacity and 1.22% of its total installed electricity capacity.

Table 11: Sector wise installed capacity

Sector	MW	% of Total
Central Sector	97,637	25.2%
State Sector	1,03,876	26.8%
Private Sector	1,85,376	47.7%
Total	**3,86,888**	

Source: Central Electricity Authority (CEA)

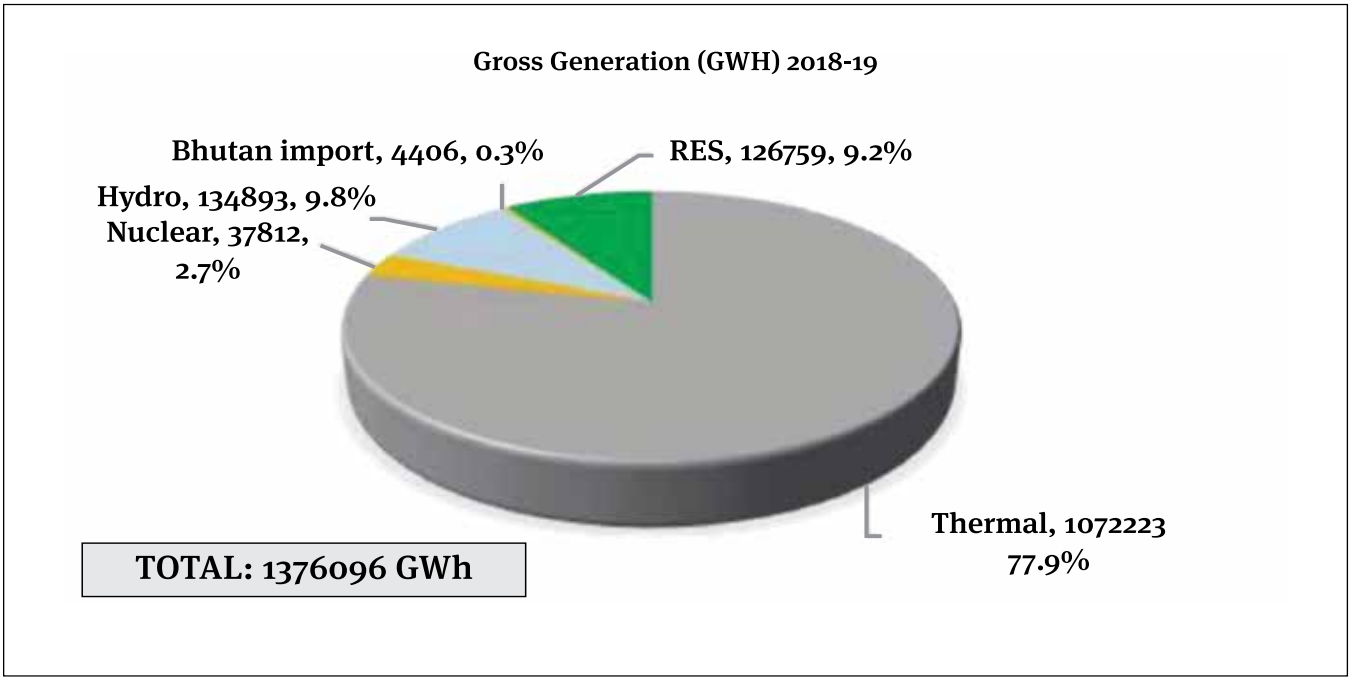
Table 12: India's total installed electricity capacity (as on 28 February 2022)

	Energy sources	Installed capacity	Share in total installed electricity capacity
Thermal	Coal	203,899.50 MW/203.89 GW	51.54%
	Gas	24,899.51 MW/24.89 GW	6.29%
	Lignite	6,620 MW/6.62 GW	1.67%
	Diesel	509.71 MW/0.50 GW	0.12%
	Total	235,928.72 MW/235.92 GW	59.63%
Nuclear		6,780 MW/6.78 GW	1.71%
Renewable	Hydro	51,364.42 MW/51.36 GW	12.98%
	Solar	50,777.77 MW/50.77 GW	12.83%
	Wind	40,129.78 MW/40.12 GW	10.14%
	Bio	10,627.18 MW/10.62 GW	2.68%
	Total	106,374.63 MW/106.37 GW	26.88%
Total		**395,607.86 MW/395.60 GW**	

Source: Central Electricity Authority (CEA). (2022). All India Installed Capacity in (MW) of Power Stations (as on 28 February 2022).

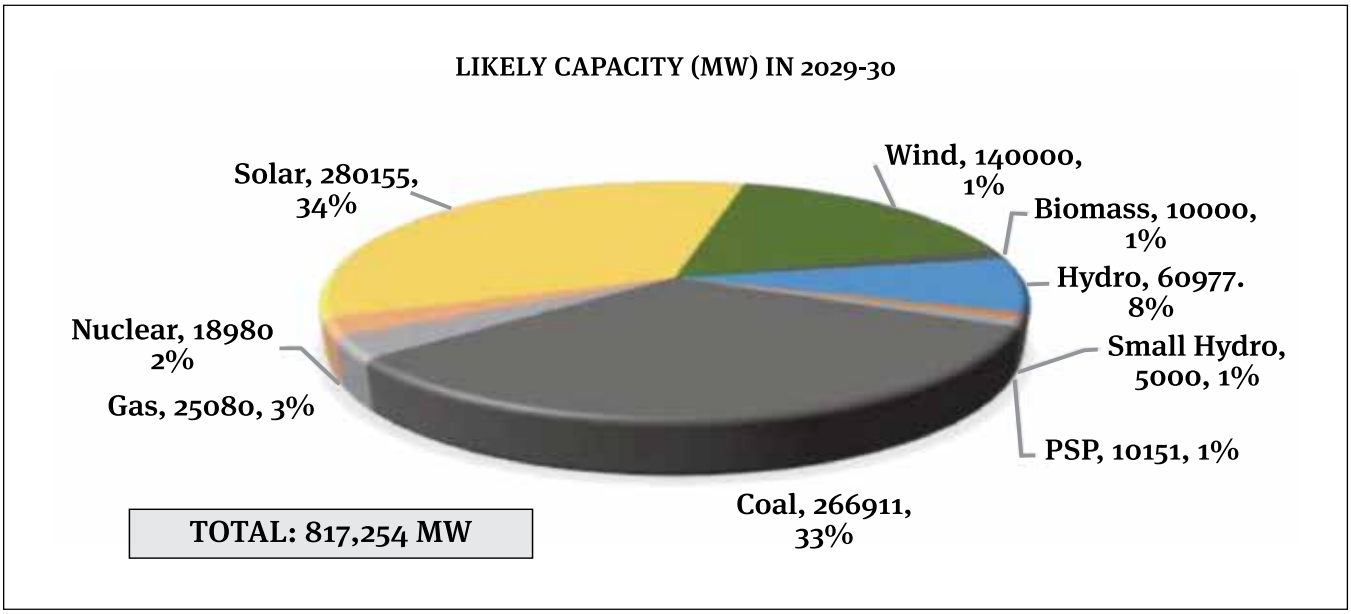
The total present gross electricity generation mix of India is 13,76,096 GWh as shown in Figure 11. The projected energy capacity mix of India in 2029-30 is 817,254 MW as shown in Figure 12.

Figure 11: Present gross electricity generation mix of India



Source: CEA. (2020). Report on Optimal Generation Capacity Mix for 2029-30. https://cea.nic.in/old/reports/others/planning/irp/Optimal_mix_report_2029-30_FINAL.pdf

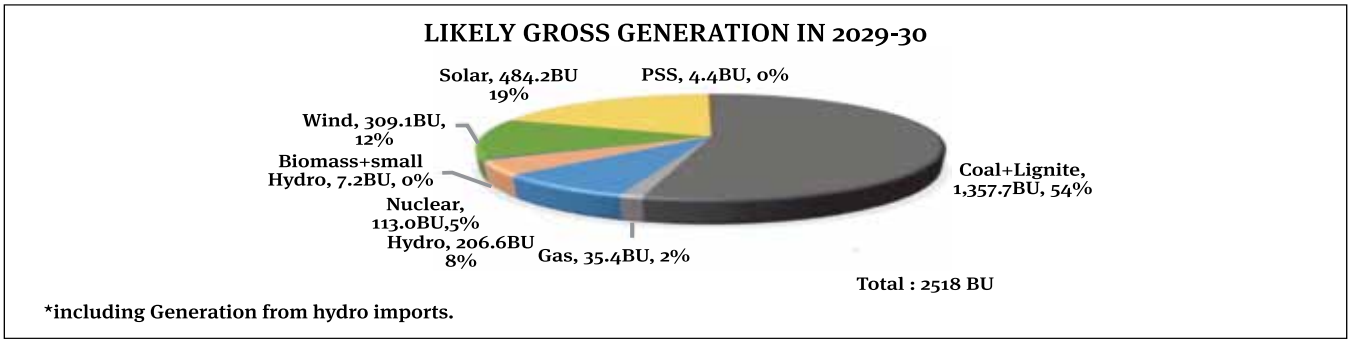
Figure 12: Projected energy capacity mix of India in 2029-30



Source: CEA. (2020). Report on Optimal Generation Capacity Mix for 2029-30. https://cea.nic.in/old/reports/others/planning/irp/Optimal_mix_report_2029-30_FINAL.pdf

The projected gross electricity generation (BU) during the year 2029- 30 is likely to be 2,518 BU comprising 1,393 BU from Thermal (Coal, Gas, and Lignite), 801 BU from RE Sources, 207 BU from Hydro, 4.4 BU from PSS and 113 BU from Nuclear as shown in Figure-13.

Figure 13: Projected gross electricity generation mix of India in 2029-30



Source: CEA. (2020). Report on Optimal Generation Capacity Mix for 2029-30. https://cea.nic.in/old/reports/others/planning/irp/Optimal_mix_report_2029-30_FINAL.pdf

It can be seen from the above results that in the year 2029-30, non-fossil fuel (solar, wind, biomass, hydro & nuclear) based installed capacity is likely to be about 64% of the total installed capacity and non-fossil fuels contribute around 44.7% of the gross electricity generation during the year 2029-30.

Projected Achievements of INDCs by 2030

Installed capacity and share of non-fossil fuel

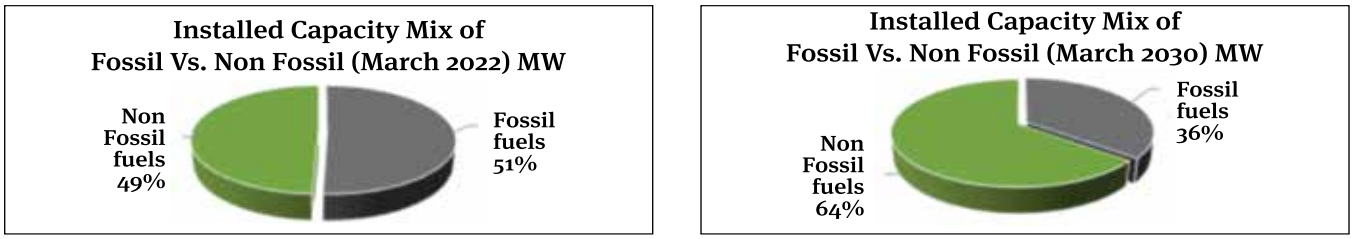
As per the INDC target announced in the run-up to the Paris Conference, the percentage of non-fossil fuel in installed capacity is to be 40% by 2030. Table 13 gives the percentage of non-fossil installed capacity by the end of 2029-30. In March 2022, the percentage of non-fossil fuel in installed capacity was 49% as seen in Figure 14. Studies for the year 2029-30 show that it is likely to increase to 64% in March 2030:

Table 13 : Likely Installed Capacity mix of Fossil and Non-fossil* fuels

Year	Installed Capacity (MW)	Installed Capacity of Fossil Fuel (MW)	Installed Capacity of Non-Fossil Fuel (MW)	% of Non-Fossil Fuel in Installed Capacity
March, 2030	8,17,254	2,91,991	5,25,263	64%

Source: CEA. (2020). Report on Optimal Generation Capacity Mix for 2029-30. https://cea.nic.in/old/reports/others/planning/irp/Optimal_mix_report_2029-30_FINAL.pdf

Figure 14: India's present and projected installed capacity mix for fossil and non-fossil energy

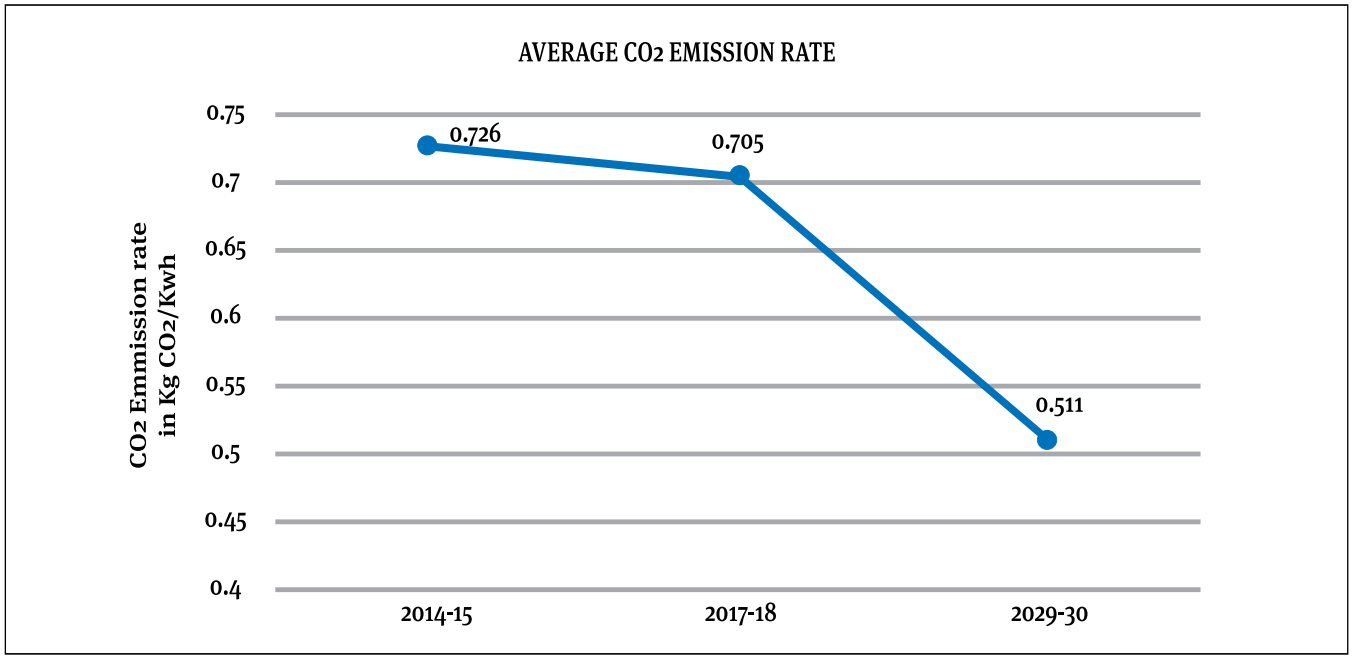


Source: CEA. (2020). Report on Optimal Generation Capacity Mix for 2029-30. https://cea.nic.in/old/reports/others/planning/irp/Optimal_mix_report_2029-30_FINAL.pdf

Average CO2 emission rate

The average emission factor kgCO2/kWh from the total generation including renewable energy sources in the base case scenario (40% of India's total installed capacity by the year 2030 based on non-fossil fuel sources) has been estimated and is shown in Figure-15. The average emission rate is likely to reduce to 0.511 kgCo2/kWh by the year 2029-30 from 0.705 kg/kWh in the year 2017-18.

Figure 15: India's average CO2 emission rate over the years with 2029-30 projection



Source: CEA. (2020). Report on Optimal Generation Capacity Mix for 2029-30. https://cea.nic.in/old/reports/others/planning/irp/Optimal_mix_report_2029-30_FINAL.pdf

Increase in the battery cost projections by 2030 to $100/kWh and $125/kWh

According to the CEA report, the cost trajectory for battery energy storage system (BESS) is assumed to be reducing uniformly from Rs. 7 Cr/MW in 2021-22 to Rs. 4.3 Cr/MW (with a basic battery cost of $75/kWh) in 2029-30 for a 4-hour battery system in the base case study. However, there are several uncertainties associated with influencing this cost trend like currency fluctuations, trade limitations, raw material availability, etc. Therefore, additional scenarios with higher battery costs (basic battery cost of $100/kWh and $125/kWh) compared to the base case study have been analyzed.

Increase in the battery cost projections by 2030 to $100/kWh

The results of likely installed capacity in this scenario are given in Table 14:

Table 14: Projected installed capacity in India by 2029-2030 for battery cost of $100/kWh

Fuel Type	Capacity (MW) in 2029-30	Percentage Mix (%)
Hydro*	61,657	7.51%
PSP	11,151	1.36%
Small Hydro	5,000	0.61%
Coal + Lignite	2,70,111	32.88%
Gas	25,080	3.05%
Nuclear	18,980	2.31%
Solar	2,79,550	34.03%
Wind	1,40,000	17.04%
Biomass	10,000	1.22%
Total	**8,21,529**	
Battery Energy Storage	22,970 MW/91,880 MWh	
*Including Hydro Imports of 5856 MW		

Source: CEA. (2020). *Report on Optimal Generation Capacity Mix for 2029-30*. https://cea.nic.in/old/reports/others/planning/irp/Optimal_mix_report_2029-30_FINAL.pdf

Increase in the battery cost projections by 2030 to $125/kWh

The result of likely installed capacity in this scenario is given in Table 15:

Table 15: Projected installed capacity in India by 2029-2030 for battery cost of $125/kWh

Fuel Type	Capacity (MW) in 2029-30	Percentage Mix (%)
Hydro*	61,657	7.56%
PSP	11,151	1.37%
Small Hydro	5,000	0.61%
Coal + Lignite	2,80,511	34.37%
Gas	25,080	3.07%
Nuclear	18,980	2.33%
Solar	2,63,775	32.32%
Wind	1,40,000	17.15%
Biomass	10,000	1.23%
Total	**8,16,154**	
Battery Energy Storage	14,670 MW/58,680 MWh	
*Including Hydro Imports of 5856 MW		

Source: CEA. (2020). Report on Optimal Generation Capacity Mix for 2029-30. https://cea.nic.in/old/reports/others/planning/irp/Optimal_mix_report_2029-30_FINAL.pdf

Thermal Power

G-20 understanding was that they will not finance international thermal projects. However, Variable Renewable Energy (diurnal solar and seasonal wind energy) will require steady power for providing grid support as well as energy generation during adverse weather events. Hence, as the overall energy requirement increases, an additional, steady, round-the-clock supply would also be required. A significant proportion of this additional capacity would have to be based on nuclear (which is a zero-GHG emitter but has no capability of load variation as of now) and gas or 'dirty' coal - the only affordable resource available within India.

There is a general feeling that coal must be avoided at all costs as it is extremely polluting. No doubt, gas is more benign compared to coal as it produces about 40% less carbon emissions from gas for producing the same quantity of electricity. However, the case for gas does not fully reflect the net greenhouse gas effects of gas – from extraction to burner-tip - due to leakage of methane. The Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report from 2013 has said that 'methane heats the climate by 28 times more than carbon dioxide when averaged over 100 years and 84 times more when averaged over 20 years'.

Most developed countries are using gas as the bridge fuel (towards Net Zero / complete renewable), stating that it is much cleaner than 'dirty' coal. This luxury is not available to India on account of the prohibitive cost of gas. Deliberately, China has continued to build new coal-based power plants. Hence, in spite of the commitment to achieve NZE by 2070, coal-based power will have to continue to be a major part of the generation mix, though its share will have to be steadily brought down over time in a planned manner. Definitely, the new coal plants should be based on ultra-critical technology to increase efficiency and reduce emissions. A provision could also be made in the design for installation of CCS (Carbon capture and sequestration) should the technology become economically viable in the future.

Simultaneously, plans should be put in place for accelerating the installation of nuclear power plants in the country. As explained earlier, 'firm, round the clock power, not dependent on weather ' is required to not only steady the grid (vital as the proportion of Variable Renewable Energy increases in the grid), equally important, required to tide over adverse weather events like prolonged fog, cloud cover, rains etc. A ready-made solution being loosely talked about is the storage of solar energy in batteries. This is prohibitively expensive and even though, intense research has been going on for the past few decades on developing cheap batteries, no solution is in sight.

Battery Storage

In his book 'How to avoid a climate disaster' Bill Gates writes about a thought experiment on how much battery storage would be required to supply full power to a city like Tokyo if is fully dependent on renewable energy and is without RE generation for a period of 3 days while a tropical storm passes over it. He calculates a requirement of storage of 3122 gigawatt-hours

of electricity in 14 million batteries costing about USD400 billion resulting in an annual cost (averaged over the lifetime of batteries) of USD27 billion.

Clearly under current technologies, full back-up even for a full day is unaffordable and inevitably, VRE requires backup power generation capacity based on either fossil fuels or nuclear energy.

The desirable solution would be to use emission-free nuclear power – with the surplus energy being used for some other activity – say desalination of water for coast-based nuclear power plant or the nuclear power to be stored in some other forms – like green hydrogen. This hydrogen can then be used for a variety of applications in refineries, steel plants, transportation, and even for regenerating electricity.

Tariff of Nuclear Power Plants

The latest tariff values of nuclear power plant obtained from NPCIL operating stations are given in Table 16.

Table 16: Latest Tariff for NPCIL Operating Stations (May-21)

Station	Type of Reactor	Date of Commencement of Commercial Operation.	Power Rating in MW	Tariff (Rs./kWh)
TAPS-1&2	BWR	Unit-1 : 28/10/1969 Unit-2 : 28/10/1969	160	2.41
TAPS-3&4	PHWR	Unit-3 : 18/08/2006 Unit-4: 12/09/2005	540	3.35
RAPS-2	PHWR	Unit-2 : 01/04/1981	200	3.31
RAPS-3&4	PHWR	Unit-3: 01/06/2000 Unit-4: 23/12/2000	220	3.31
RAPS-5&6	PHWR	Unit-5: 04/02/2010 Unit-6: 31/03/2010	220	3.89
MAPS-2	PHWR	Unit-2: 21/03/1986	220	2.57
NAPS-1&2	PHWR	Unit-1: 01/01/1991 Unit-2: 01/07/1992	220	3.01
KAPS-1&2	PHWR	Unit-1: 06/05/1993 Unit-2: 01/09/1995	220	2.29*
KGS-1 &2	PHWR	Unit-1: 16/11/2000 Unit-2: 16/03/2000	220	3.42
KGS-3&4	PHWR	Unit-3: 06/05/2007 Unit-4: 20/01/2011	220	3.42
KKNPP-1&2	BWR	Unit-1: 21/12/2014 Unit-2: 31/03/2017	1000	4.09**

** Revision is due and revised tariff for the period 2017-22 is yet to be notified*
*** Average Tariff during the FY 2020-21: Re. 3.47 per unit*
Source: Nuclear Power Corporation of India Limited

Tariff comparison between thermal, nuclear, and renewables

The average tariff for nuclear power of Rs. 3.43 per unit (Table 17) compares favorably with recent solar power tenders which include storage. These ranged from Rs. 4.04/kWhr (Greenco) to Rs. 4.30/kWhr (Renew Power).

Table 17: Tariff comparison of Thermal, Renewables and Nuclear

Thermal[a]	Nuclear[b]	Wind without storage[c]	Solar without storage[d]	Solar with storage[e]
Rs.3.25/kWhr	Rs. 3.47/kWhr	Rs. 2.69/kWhr	Rs. 1.99/kWhr	Rs. 4.04 – Rs. 4.30k/kWhr

a. Adani Power, Jindal Power, GMR Energy and 12 other bidders.
b. Average nuclear tariff for 2019
c. ReNew Power, Sembcorp's Green Wind Infra Energy, Evergreen Anupam Renewables
d. NTPC, Torrent Power, Aljomaih Energy and Water Co., Aditya Birla Renewables
e. Greenco, ReNew power.

However, it is worth noting that the mentioned nuclear tariff is of the delivered cost i.e. demand side; whereas the wind and solar tariffs are on the generation side and do not include the considerable costs attributable to grid transmission (since most of the solar generation will happen on wastelands located far away from load centers), grid stability and grid integration, energy security (firm, back-up generation support required during adverse weather events, etc). Adding these costs to the tariff would enormously escalate the renewables tariff. Hence, the demand side nuclear tariff is more lucrative than the renewables, unlike the widespread perception.

Thermal Tariff for the project awarded to Adani Power, Jindal Power, GMR Energy, and Essar Power (total 12 bidders) (Rs. 3.25/kWh).

The average tariff for nuclear power in the year 2019 was Rs. 3.43/kWh (Table 10 above).

Wind Tariff (without storage) of Rs. 2.69/kWh for the project awarded to ReNew Power Ventures Pvt. Ltd, Sembcorp's Green Wind Infra Energy, and Evergreen's Anupavan Renewables.

Solar Tariff (without storage) of Rs. 1.99/kWh for the project awarded to NTPC (200 MW), Torrent Power (100 MW), Aljomaih Energy and Water Company (80 MW), and Aditya Birla Renewables (120 MW) in Gujarat. Renewables tariff with storage awarded to Greenco (Rs. 4.04/kWh) and Renew Power (Rs. 4.30/kWh). Storage was limited to 9 hrs only.

Different sectors of electricity generation have shown different rates of growth over the last decade (Table 18). The total electricity generation in India grew with a CAGR of 5.17% (2010-11 to 2019-20) with 1598.417 TWh electricity generation in 2019-20.

Table 18: Sector-wise annual gross generation rate of electricity in India.

(utilities and non-utilities combined) (in GWh)

Year	Thermal				Hydro	Nuclear	Renewable	Total
	Steam	Diesel	Gas	Total				
CAGR 2010-11 to 2019-20 (%)	6.02 %	-7.49 %	-5.19 %	4.80 %	3.14 %	5.87 %	13.47 %	5.17 %

Source: Energy Statistics India 2021.

The renewable energy sector exhibited a gigantic CAGR of 13.47%; whereas the Hydro and nuclear sectors achieved CAGRs of 3.14% and 5.87% respectively. The overall thermal electricity generation expanded by 4.80% while having negative growth in diesel and gas-based electricity generation.

The slow-down of the economy in the wake of global financial crisis affected the growth of electricity demand. This was reinforced by the impact of the pandemic on the economy. Post-pandemic recovery, and the recent heat wave, has underlined the need for more power. With a total installed capacity of 395 GW, the power sector was under strain to cope with a peak load of 207 GW. As we move towards a low carbon economy, the demand for electricity generated from non-emitting sources will pick up. The demand will be reinforced by the need to bring more sectors under electrification.

Chapter 6 : Net Zero Emission and the Future of the Indian Power Sector

Achieving Net Zero Emission would drive up India's power requirement very steeply, as most of the energy will have to be derived in the form of electricity from emission-free sources – renewables, hydro and nuclear. The scale of generation required would bear no relation to the past trends shown in the previous chapter. The growth figures of the past include the power sector only; at present, electricity is only 24% of the Indian energy basket. While moving towards decarbonization, other sectors like agriculture, industry, and transport will also have to be decarbonised primarily involving use of electricity. This will result in the future growth of the electricity sector at a rate far above the historical trends. Assuming a CAGR of 4%, India's annual energy requirements by 2070 are estimated to be 33912 TWh with a per capita energy consumption of 21195 kWh. The majority of this would be in the form of electricity.

Sufficiently large electricity system is thus required not only to provide for India's energy security but attain the goal of Net Zero Emission. The challenge of providing electricity on such a vast scale would be clear from the following Tables 19 and 20:

Table 19: Projected electricity generation in India based on CEA's 2030 projections and IIT Bombay's net zero 2070 mathematical model

Year	Electricity Generation
2020	1265 TWh*
2030	2518 TWh** (CEA's 2030 Projections)
2070	24,470 TWh*** (R05N95)

Sources: * NITI Ayog Dashboard
** CEA's 2030 Projections
*** Our projection is based on mathematical modelling done by IIT Bombay (R05N95) scenario, which is the most cost-optimum scenario. Electricity generation required in renewable high scenario (R95N05) is higher.

There will be a sharp increase in demand of electricity which minimises demand and cost:

Table 20: Projected CAGR for electricity generation in India based on CEA's 2030 projections and IIT Bombay's net zero 2070 mathematical model

CAGR of electricity generation from 2020 to 2030	7.13%
CAGR of electricity generation from 2030 to 2070	5.84%
CAGR of electricity generation from 2020 to 2070	6.1%

In case India relies mainly on renewables to meet the target of net zero emission, the generation required will be substantially higher at 30,839 GW.

The exact size and composition of the **generation mix** would depend upon two broadly different approaches. An approach relying exclusively or largely on renewables to meet a given peak demand will need much higher generation capacity due to the low PLF and inherent variability of solar or wind power. The size and cost could be significantly reduced by including nuclear power in the generation mix. In addition, since the green hydrogen production needs would inevitably be a large part of the overall energy basket, the electricity demand would also depend upon the process adopted for hydrogen production. Green hydrogen produced through the alternative of adopting electrolysis route using renewable energy will increase the requirement of generation capacity much above the level needed for hydrogen production using nuclear power. There is thus importance to accelerating development of thermochemical route for splitting water to produce green hydrogen which is expected to be much more energy efficient besides moderating the electricity generation capacity needs. Sources of high temperature heat required in this context (high temperature reactors as well as concentrated solar thermal plants, both of which are well within the domestic capability) also need to be developed.

The mathematical modelling by IIT Bombay has brought out generation capacity, per capita electricity consumption and cost of transition to net zero by 2070. Table 21 below makes clear that most cost optimum solution is R05N95 with preponderant share of nuclear with cost of energy transition limited to $11.2 trillion. The cost keeps going up as the share of renewables increases - $13.1 trillion for 40%, $13.6 trillion for 50%, $14.4 trillion for 60% and $15.5 trillion with 95% renewable penetration. The increase in cost of transition becomes clear from the next two sets of figures on capacity and generation-mix.

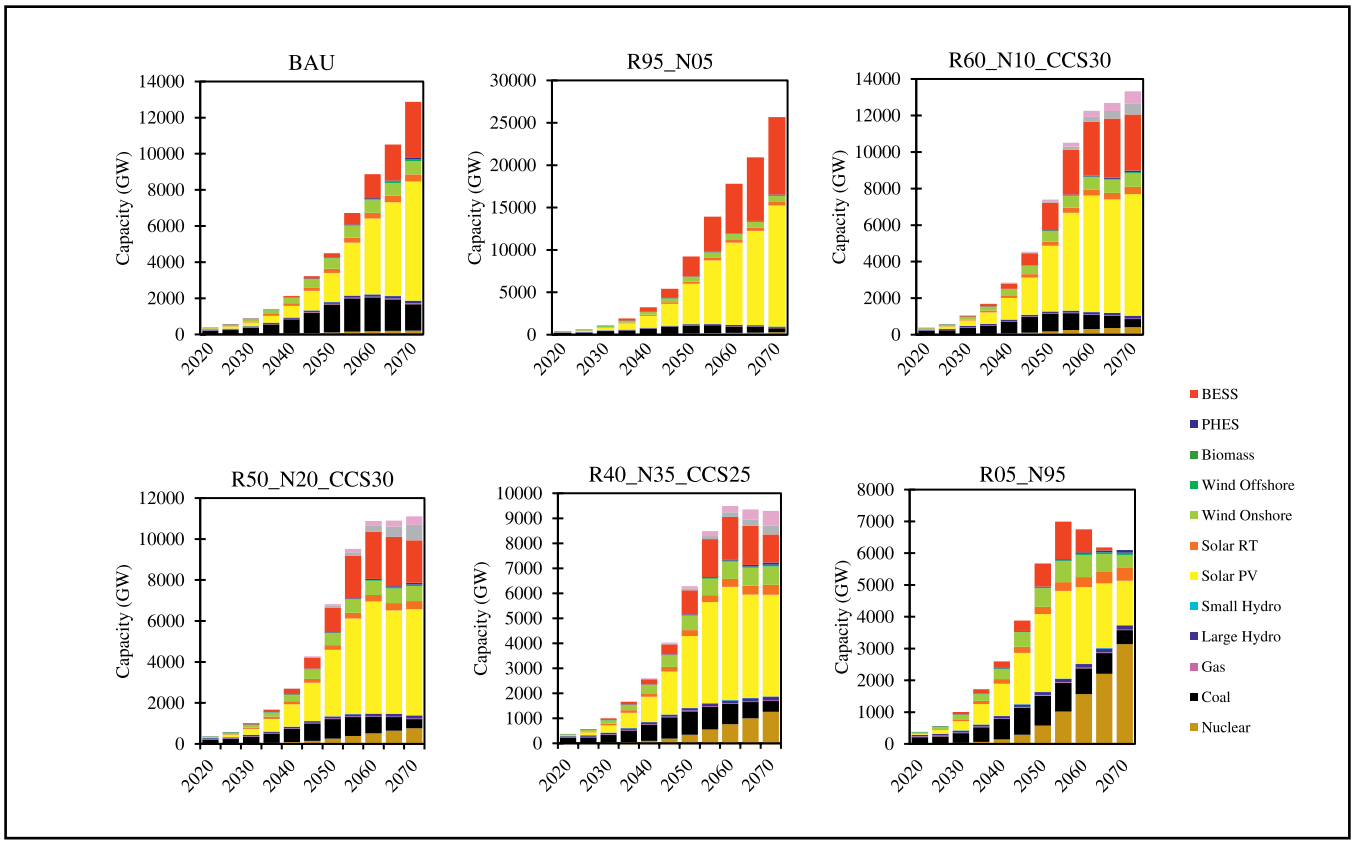
Table 21: Summary of results from scenario analysis (1 USD ≈ 74 INR)

Scenarios	BAU	Net-zero 2070				
		R95N05	R60N10_CCS30	R50N20CCS30	R40N35CCS25	R05N95
Net-zero year	—	2070				
Peaking year	—	2050				
Generation in 2070 (TWh)	27147	30839	25996	25531	25086	24470
Per-capita electricity consumption (kWh)	18098	20559	17331	17021	16724	16313
VRE penetration by generation in 2070 (%)	54	92	57	47	37	4
Maximum solar capacity (GW)	6985	14680	7057	5787	4841	3036
Maximum wind capacity (GW)	800					
Maximum coal capacity (GW)	1874	975	961	958	942	940
Stranded coal capacity in 2070 (GW)	—	484	452	451	437	438
Maximum nuclear capacity (GW)	215	284	406	763	1258	3139
CCS capacity (GW)	—	—	1269	1178	944	—
Maximum storage capacity (TWh)	3798	10621	3894	2925	2073	1438
Maximum H2 electrolyser capacity (GW)	381 GW (for the production of 64 MT of green H2)					
Cost of transition to net-zero power sector (Trillion USD)	12.1	15.5	14.4	13.6	13.1	11.2
Investment in new technology (Trillion USD)	6.1	11.1	8	7.4	6.7	6
Ex-bus electricity price in 2020 (USD per MWh)	50					
Ex-bus electricity price in 2070 (USD per MWh)	122	164	155	140	131	103
Peak annual CO2 emission (Gt) (peaking year)	13.2 (2060)	6.8 (2050)				

Source: IIT Bombay, Mathematical Modelling for the VIF Task Force Study – India's Energy Transition in a Carbon Constrained World.

IIT Bombay has modelled installed capacity under different scenarios as shown in Figure 16 below. The graph shows largest capacity is required in the scenario (R95N05); the smallest capacity is required in (R05N95). Low PLF of renewables requires a larger capacity for the same generation. In R95N05 scenario, 14680 GW of solar with 284 GW of nuclear is required. In contrast, R05N95 scenario requires 3036 GW of solar and 3139 GW of nuclear. This increases the cost as well as land requirement steeply in case of renewable high scenario. Despite larger fleet of nuclear reactors, the latter option is cheaper. Larger solar capacity also increases the size (and cost) of storage solution. At present, battery storage does not last beyond few hours and cannot cope with unpredictable weather over extended period and area.

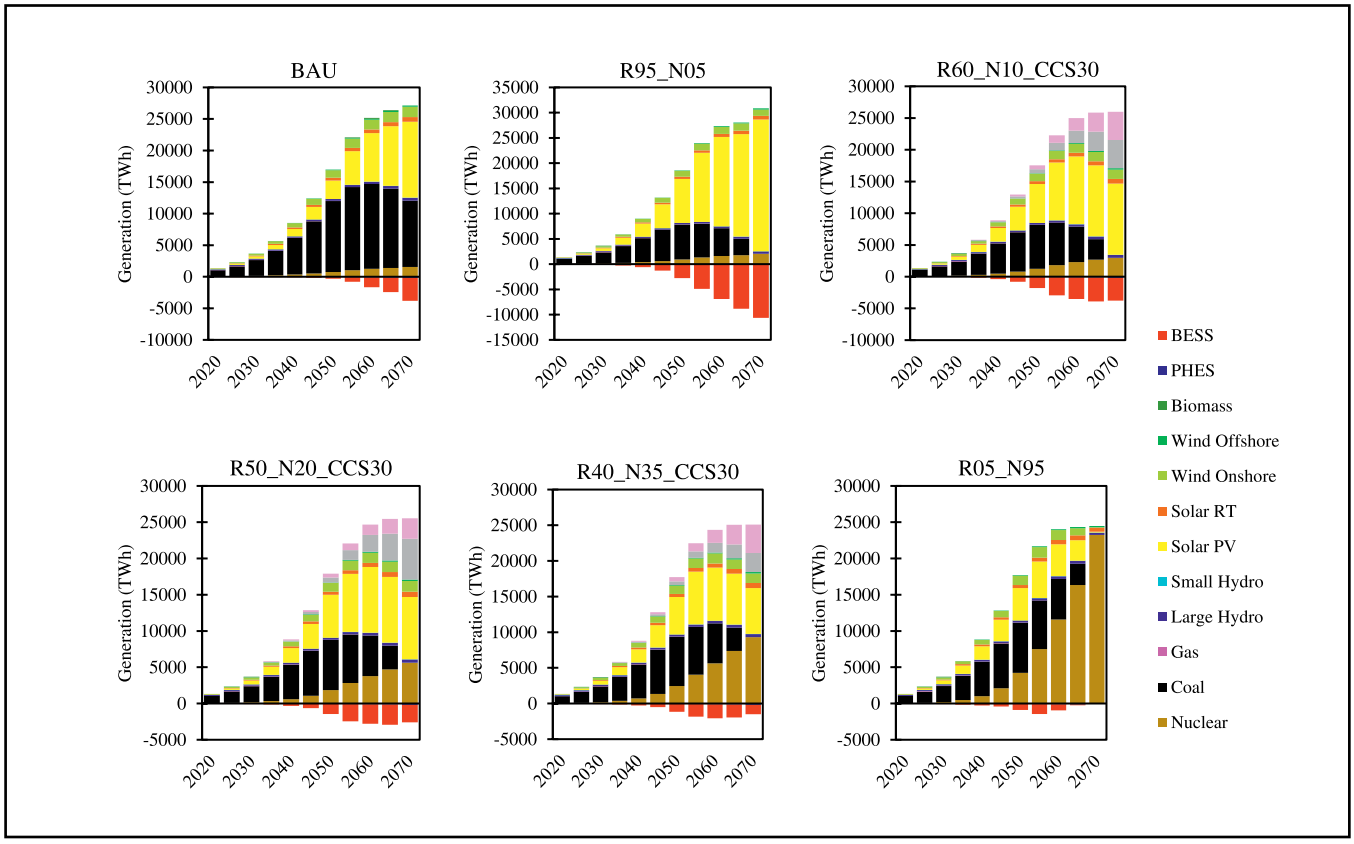
Figure 16: Net zero in 2070 with 10% green H2 demand — Installed capacity under different scenarios



Source: IIT Bombay, Mathematical Modelling for the VIF Task Force Study – India's Energy Transition in a Carbon Constrained World. (Annexed)

IIT Bombay has also modelled generation-mix under different scenarios as shown in Figure 17 below. R95N05 scenario requires 30839 TWh of generation, while R05N95 scenario requires 24470 TWh only. Thus, reliance on renewables to provide predominant share of electricity increases the generation required by almost 26%.

Figure 17: Net zero in 2070 with 10% green H2 demand - Generation under different scenarios



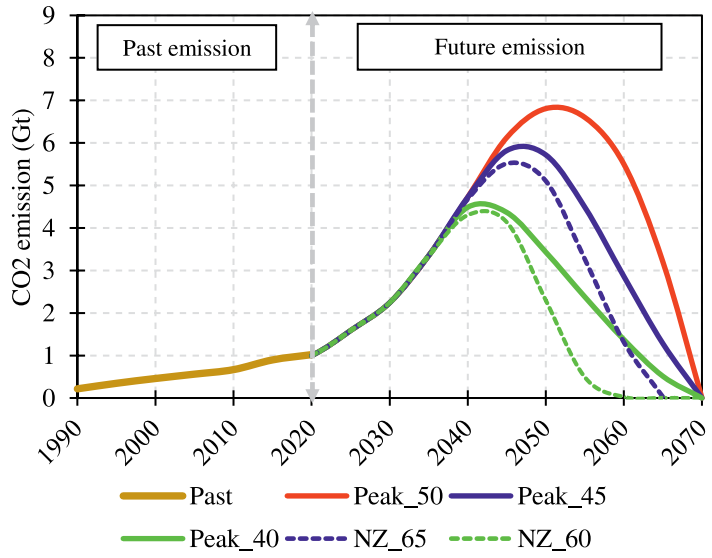
Source: IIT Bombay, Mathematical Modelling for the VIF Task Force Study – India's Energy Transition in a Carbon Constrained World. (Annexed)

This phenomenon where high dependence on renewables to achieve low emission targets increases the costs was also brought out by a MIT model in 2018. This report is discussed in detail in chapter 10 on nuclear power. Not all energy uses can be met by electricity. For hard to abate sectors like steel and cement, hydrogen will be needed. It is both a fuel carrier and a storage solution. Production of green hydrogen using renewables increases demand for electricity, and costs. This is discussed further in the chapter on Hydrogen economy.

Net Zero Emission

India has committed to achieving net zero emissions by 2070. IIT Bombay has modelled net zero in 2070 with peaking in 2050 as a hypothetical scenario. Apart from BAU and net zero in 2070, the graph below (Figure 18) also shows two other hypothetical scenarios of net zero in 2065 and 2060.

Figure 18: CO2 emission trajectory - Scenarios with different peaking and net zero year



Source: IIT Bombay, Mathematical Modelling for the VIF Task Force Study – India's Energy Transition in a Carbon Constrained World. (Annexed)

Early Peaking

According to mathematical modelling by IIT B, if the NZE year remains constant at 2070, early peaking leads to a higher cost of energy transition - $ 15.5 trillion (Peaking Year 2050), $ 16.1 trillion (Peaking Year 2045) and $ 16.7 trillion (Peaking Year 2040).

Apart from net zero emission at 2070 and peaking at 2050, IIT Bombay has also modelled two other hypothetical combinations – NZE at 2065 with peaking in 2045 and NZE in 2060 with peaking in 2040 as shown in Table 22. The cost of transition goes up even further with a more compressed transition.

Table 22: Cost of energy transition for different peaking and net zero years

Cost - $ Trillion

Scenario	R95N05	R95N05	R95N05
Net-zero year	2070	2065	2060
Peaking year	2050	2045	2040
Cost of transition to net zero power sector	$15.5	$16.5	$17.2

Source: IIT Bombay, Mathematical Modelling for the VIF Task Force Study – India's Energy Transition in a Carbon Constrained World. (Annexed)

The argument that early peaking will avoid stranded assets ignores this aspect of the problem. As IIT Bombay has pointed out this leads to higher upfront capital investment in renewable and storage.

Moving towards the goal of Net Zero Emission will also change the **nature of the grid**. A power grid has to maintain a dynamic equilibrium between demand, which varies through the day as well as could see sudden disturbances, and generation. To manage this equilibrium, the grid will have to include (1) a source (such as nuclear), which can provide stable, baseload power, and (2) a portion of generation capacity that can be flexibly ramped up and down to provide balancing power. Managing equilibrium in the grid has become considerably complex with increasing penetration of variable renewable energy in the grid. In contrast with dispatchable power generated by most sources, renewable energy like wind and solar generate 'variable' energy depending upon prevalent weather conditions. To be able to meet the needs of demand at any point of time there must be sufficient operational capacity in the grid. The required generation capacity or energy storage needs in the grid therefore goes up with increasing variable renewable energy penetration entailing higher capital investments and resultant higher cost of electricity. This will also increase the need for 'flexibility'. Realisation of Net Zero Emission at minimum cost thus involves an optimum mix of renewables and nuclear determined on the basis of cost optimization besides the fact that nuclear energy in inevitable to fuel India's growth story in an NZE scenario.

The model has also brought out that early peaking leads to higher grid costs. The grid integration cost in R95N05 scenario works out to $1.4 trillion by 2070. In case of renewables, the transmission costs will go up further as large solar or wind energy projects will come up in remote locations, and particularly if HVDC (High Voltage Direct Current) lines are deployed in the future.

Changing profile of India's power sector

Changing profile of India's power sector in future will be clear from the following Table 23:

Table 23: Installed capacity and generation (10% green H2 scenario)

Installed Capacity (GW)							
		2020	2030	2040	2050	2060	2070
Scenarios	BAU	373	843	2019	4238	8504	12496
	R95N05	373	1021	3120	8959	17451	25292
	R60N10CCS30	373	996	2727	7143	11891	12950
	R50N20CCS30	373	970	2604	6565	10510	10733
	R40N35CCS25	373	960	2483	6022	9121	8917
	R05N95	373	959	2480	5422	6382	5721

Generation (TWh)							
		2020	2030	2040	2050	2060	2070
Scenarios	BAU	1329	3667	8529	16963	25171	27147
	R95N05	1329	3680	8989	18560	27300	30839
	R60N10CCS30	1329	3687	8882	17544	24991	25996
	R50N20CCS30	1329	3695	8836	17899	24669	25531
	R40N35CCS25	1329	3699	8792	17732	24361	25086
	R05N95	1328	3608	8545	16806	23102	24470

Source: IIT Bombay, Mathematical Modelling for the VIF Task Force Study – India's Energy Transition in a Carbon Constrained World. (Annexed)

The tables above underline the scale, and urgency, of the investment decision required. Taking into account most cost optimum solution of R05N95, the generation capacity will have to go upto 2480 GW in 2040, 5422 GW in 2050, 6382 GW in 2060 and 5721 GW in 2070. If we rely on renewables to provide bulk of our power requirements, the results will be more dramatic. India will need 2954 GW in 2040, 8954 GW in 2050, 1741 GW in 2060 and 25292 GW in 2070. India's current capacity is 395 GW, which is to rise to 1,000 GW in 2030 as per PM's statement at Glasgow. The corresponding increase in generation would entail heavy investment in transmission.

India cannot afford to abruptly transition from coal to renewables; it has to be phased out gradually. In judging the comparative merits of different energy sources, LCOE or the Levelised cost of electricity generation (LCOE) cannot be the only or primary criterion. This method was devised before the advent of intermittent sources (that is solar and wind, which is available only when the sun is shining or the wind is blowing, and not round the clock).[246] Tariff itself cannot be the sole matrix, where the larger question is energy self-sufficiency to sustain India's development trajectory. As carbon costs mount, the difference in tariff structure of different forms of energy sources would not be material. It has already touched $ 80 per ton in Europe.[247] India of course does not accept the concept of carbon-cost, but cannot remain entirely unaffected by international trends. Gas can be a bridging fuel for India's energy transition, though the cost of RLNG limits its use in the power sector. We have substantial gas-based power assets, which are currently stranded. We cannot afford to write them off. As the salience of Variable Renewable Energy in our power generation profile goes up, gas-based power plants can be modified to supply peaking power. IEA's estimate of 'flexibility' in India's case is 170 GW by 2040. This is based on much more modest demand and is well short of the generation required at the net-zero level. Nevertheless, this illustrates the scale of balancing power needed, which will not only absorb stranded gas assets but require continuing coal-based power plants till alternatives have been worked out.

De-carbonisation of economy requires electricity based on clean sources. While both renewables and nuclear power have low emission, the latter has unmatched capacity to provide firm power.

As mathematical modelling by IIT Bombay has shown, despite the relatively higher upfront capital cost, nuclear power provides the most cost-optimum solution. Managing the cost of transition is critical to maintaining India's development trajectory. Moving towards the goal of net zero emission also requires higher electricity generation to displace fossil fuel in additional sectors. The figures of total generation 30839 to 24470 TWh and per capita consumption 20559 kWh to 16313 kWh in different scenarios brought out by modelling also reflect aspirations for better standard of living for the people of India. It will be important to ramp up nuclear power in tandem with the phasing down of coal. The country also has to find enormous resources to cope with building additional generation and transmission assets.

Chapter 7 : Renewable Energy Scenario

India has made significant progress toward reaching its Paris Climate Change (COP21) targets and expanding renewable energy capacity exponentially. India has already reduced emissions by 28% from 2005 levels, compared to the objective of 35% by 2030 set out in its NDC (nationally determined contributions).[248] By 2050, India expects renewable energy to provide 80-85% of the country's electrical consumption. India is now ranked sixth in the world in terms of installed solar capacity. Renewable energy accounts for one-fourth of the total capacity in this area.

The Indian Government announced in 2015 that it would install 175 GW of renewable energy (excluding large hydro) by 2022. As of 31 December 2021, the total installed capacity for renewable energy in India is 100 GW (wind 40.08 GW, solar 49.34 GW and biomass 10.61 GW).[249] An additional 50 GW is under installation and 27 GW is under tendering. India has its ambition to install 450 GW of renewable energy capacity by 2030. Further enhancing this ambitious target, the Prime Minister Modi in his national statement at the COP26 Summit in Glasgow announced that India will reach its non-fossil fuel energy capacity to 500 GW by 2030.[250]

Though reaching 100 GW is commendable, the pace needs to be ramped up to reach the target of 175 GW installation by 2022. Between January and June, 2021 only 1GW of renewable energy capacity was installed on an average every month, according to data released by the Central Electricity Authority (CEA). The target for installing solar power by March 2023 is 100 GW - 40 GW rooftop solar and 60 GW ground-mounted utility scale. Out of this only 54 GW have been installed till March 31, 2022, as per MNRE's physical progress data.[251] This means that the country only has 12 months to install 45 GW if we need to achieve target in March 2023. This would entail that we install approx. 4 GW of solar energy capacity per month for a year.

In order to reach a target of 500 GW by 2030, we need to install the remaining 400 GW renewable energy capacity at the rate of approx. 3 GW per month. While there is need to accelerate the pace, the investment in clean energy has shown a downward trend.

Figure 19: New investments in clean energy in India in recent years

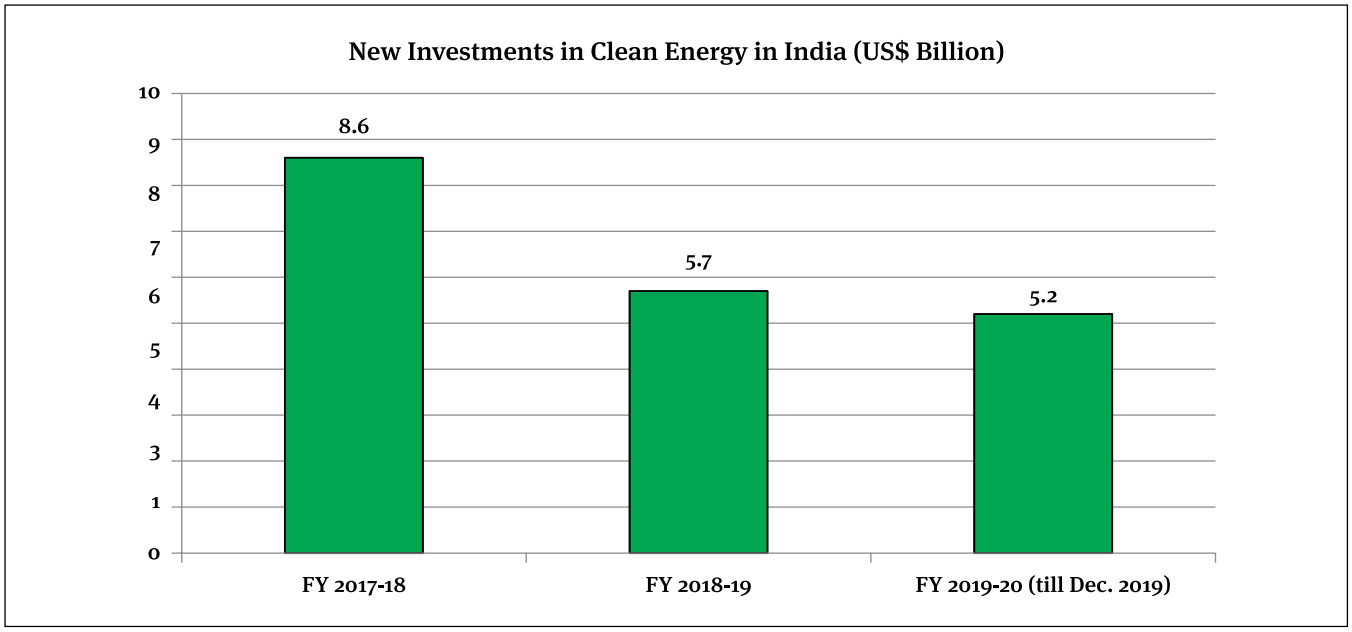


Image: VIF India.
Source: *DPIIT, Ministry of New & Renewable Energy (MNRE), Multiple News Articles.*

There is a declining trend in overall investment in the renewable sector as shown in Figure 19 above. More than US$ 42 billion has been invested in India's RE sector since 2014. New investment in clean energy in the country was to reach around US$ 15 billion in 2020.[252] Though the sector has received FDI, it is too small to compensate for drop in overall investment. While the overall investment in renewable sector in three years was US$ 19.3 billion, FDI amounted to barely US$ 335 million as the following table shows. The total FDI in this sector between April 2000 and March 2021 was US$ 10.02 billion as per IBEF. [253] FDI amounted to barely US$ 335 million as the following Table 24 shows.

Table 24: Major FDI Investments in Renewable Energy Sector

Indian Company	Foreign Collaborator	Country	FDI Equity Inflow (US$ mn)
AREVA Solar India Pvt Ltd.	AREVA Solar Inc.	USA	31.53
OSTRO Energy Pvt Ltd.	OSTRO Renewal Power Limited	Mauritius	32.21
WELSPUN Renewables Energy Pvt Ltd.	DEG-DEUTSCHE-Investitions Und-Entwicklun	Germany	32.5
RKM POWERGEN Pvt Ltd.	ENERK International Holdings Ltd.	Seychelles	32.5
BLP Energy Pvt. Ltd.	ENEL Green Power Development B.V.	Netherlands	32.61
Lalpur Wind Energy Pvt. Ltd.	ORIX Corporation	Japan	37.75
Diligent Power Pvt. Ltd.	AIRRO Singapore Pte Ltd.	Singapore	41.07
Renew Power Ventures Pvt. Ltd.	Asian Development Bank	Philippines	44.69
Avaada Energy Pvt Ltd.	Asian Development Bank	India	50

Source: IBEF. (2021). *Renewable Energy*. https://www.ibef.org/download/Renewable-Energy-July-2021.pdf

The withdrawal of FIT (Feed-in-Tariff) has impacted the wind power sector especially. The capacity addition fell from a record high of 5,500 MW in 2017-18 to 1523 MW in 2019-20. While the falling tariff makes renewable energy a success story, it has led to squeeze on profits both for operators as well as equipment suppliers like Suzlon. What has added to the uncertainty of the investors is 'tariff-shopping', where DISCOMs have cancelled existing bonafide PPAs (Power Purchase Agreements) (entered into through competitive bidding reflecting the then costs of solar panels) to take advantage of lower tariff consequent upon falling prices of solar panels. Secondly, most DISCOMs in the country are financially stressed due to the burden of uncompensated subsidies (government's promise free/subsidised power and do not reimburse the DISCOMs) resulting in late payments and often, DISCOMs resort to raising trivial disputes to postpone payments. In order to attract sufficient investment in this key sector, the investor confidence and health of the DISCOMs must be maintained Figure 20.

Figure 20: Wind power capacity additions in India in recent years

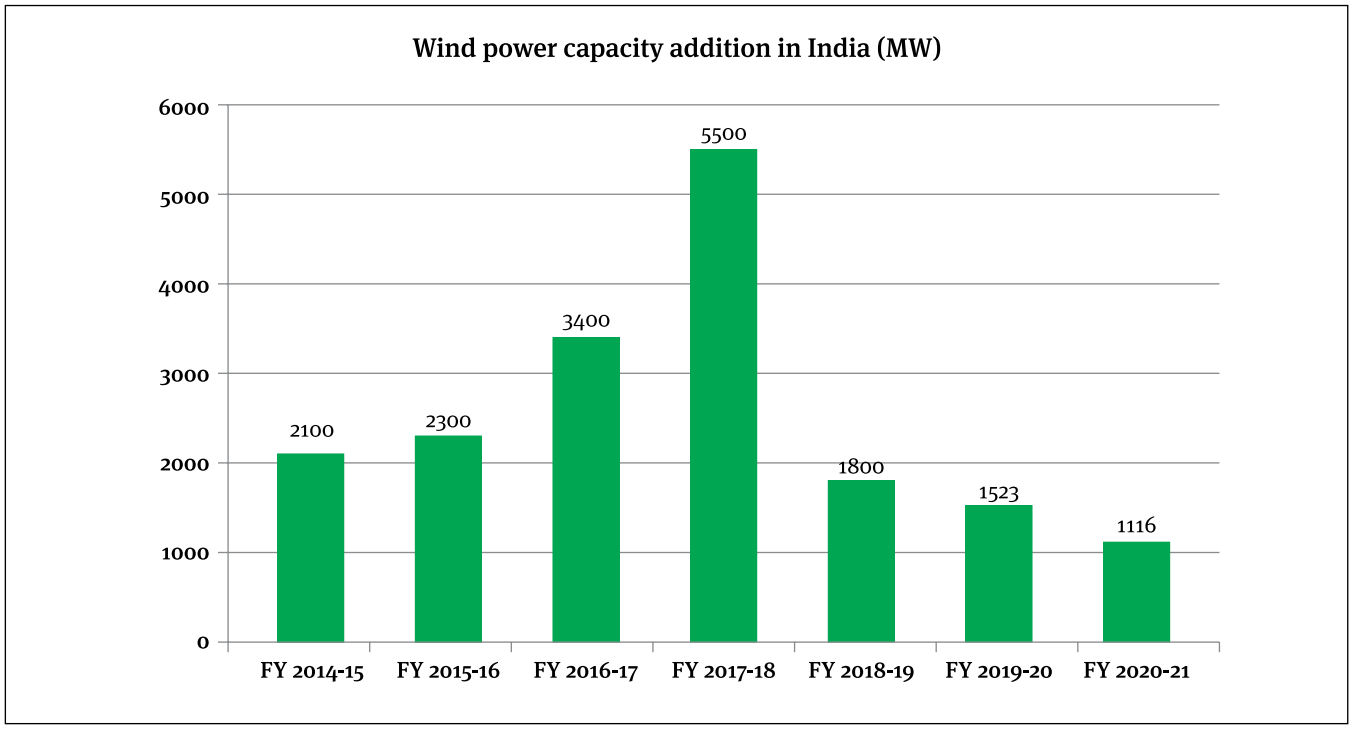


Image: VIF, India

Source: Mint. (2019). *How Wind Market Disruption Drove Suzlon to Financial Ruin*. https://www.livemint.com/market/mark-to-market/how-wind-market-disruption-drove-suzlon-to-financial-ruin-1563513801899.html

Green Energy Corridor

The Green Energy Corridor Project aims at providing grid integration for electricity produced from renewable sources, such as solar and wind, with existing power stations in the grid.

1. For evacuation of large-scale renewable energy, Green Energy Intra State Transmission System (InSTS) project was sanctioned by the Ministry in 2015-16. It is being implemented

by eight renewable-rich states of Tamil Nadu, Rajasthan, Karnataka, Andhra Pradesh, Maharashtra, Gujarat, Himachal Pradesh, and Madhya Pradesh. The project is being implemented in these states by the respective State Transmission Utilities (STUs).

Under the InSTS project, approx. 9700 ckm of transmission lines and 22600 MVA capacity of substations have been planned in eight states for evacuation of approx. 24 GW of RE projects. Out of this, 8405 ckm transmission lines and 15268 MVA of substations have been completed.[254] The purpose is to evacuate 20,000 MW of large-scale renewable power and improvement of the grid in the implementing states. The total project cost is Rs. 10141 crores. The funding mechanism consists of 40% Government of India Grant (total Rs. 4056.67 crores), 20% state equity and 40% loan from KfW, Germany (500 million EUR). The Central grant is disbursed in two instalments to the STUs: a) 70% advance on the award of contract, and b) balance 30% after successful commissioning and three months of performance testing. [255] The project is expected to be completed by 2022.

2. Recently, "The Cabinet Committee on Economic Affairs has approved Rs.12,000 cr intra-state transmission system-green energy corridor (InSTS phase-II)".[256] This plan will install around 10,750 circuit km of transmission lines and almost 27,500 Mega Volt-Amperes of substation transformation capacity. The transmission systems will be built during a five-year period, from FY22 to FY26. The Central Financial Assistance (CFA) will assist in offsetting intra-state transmission expenses, lowering electricity bills. The initiative will aid in meeting the aim of 450 GW of installed renewable energy capacity by 2030, according to the announcement. By decreasing carbon footprint, the initiative will also help to the country's long-term energy security and encourage environmentally sustainable growth. It will provide a huge number of direct and indirect job opportunities in the power and allied industries for both skilled and unskilled workers.

Increase in Tariff on solar equipment imported from China

The MNRE, Government of India announced plan a levy of 40% customs duty on the import of solar modules from April 1, 2022, as it seeks to reduce dependence on foreign supplies and boost manufacturing. The proposal, already approved by the finance ministry, also includes a 25% duty on the import of solar cells. The duty will also apply to projects that have already been bid before April 2022, but commissioned after April 2022.[257]

According to India Ratings and Research Ltd., "The increase in tariffs will increase power purchase costs for solar off-takers by Rs 900 crore annually, considering that around 10GW of solar capacity will come on stream in the next 12 months," Asmita Pant, senior analyst at India Ratings, said in a research note on March 23, 2021.[258] "This amount will keep on increasing exponentially with the commissioning of new projects, till the duty is in place or import costs and cost of local manufacturing achieve parity." "This may also affect the government's plan to achieve the targeted solar capacity of 280GW by 2030," Pant said.

Solar power: Reluctance of states to sign new PPAs

PPAS of 19 GW of renewable energy capacity tender by SECI (Solar Energy Corporation India) are yet to be signed by DISCOMs. This situation is having an adverse impact on the morale of project developers and investors and is slowing overall progress on renewable energy installation," said IEEFA energy economist and briefing note co-author Vibhuti Garg. "The missing link of PPAs affects the entire value chain. For example, without the assurance of the offtake of power for auctioned renewable energy projects, it becomes virtually impossible for developers to secure debt financing."

In 2020, we saw solar tariffs hit a record low of INR1.99/kWh," said JMK Research founder and briefing note co-author Jyoti Gulia. "Discoms are anticipating that solar module prices will decline further, leading to a reduction in future solar auction tariffs, so they are delaying signing PSAs [power supply agreements] at higher prices. According to portal PRAAPTI (Payment Ratification and Analysis in Power procurement for bringing Transparency in Invoicing of generators), the overdue outstanding of the discoms toward non-conventional or renewable energy generators is Rs. 1.23 billion as of April 2021.[259] However, On March 9, 2021, the Ministry of Finance approved the imposition of 25 per cent basic customs duty on solar cells and 40 per cent on solar modules (BCD). The BCD, which has become effective from April 1, 2022, forms part of the series of decisions taken by the Government of India (GoI) to give an impetus to domestic solar equipment manufacturers. [260]

PPA of solar with Battery storage energy system

In a recent tender, 1200MW with 50% capacity storage (for 6 hours) was awarded to Greenko Group 900(MW) and Renew Power 300 MW by Solar Energy Corporation of India (SECI) in a reverse auction for the world's largest renewable energy cum storage power purchase tender. The tender was for 1200 MW with 600 MW assured supply for 6 hours daily during peak demand hours was oversubscribed. The renewable energy generated from this tender will be capable of meeting high Peak demand.

CEA Report: Battery Energy Storage Systems

The CEA report on Optimal Generation capacity Mix for 2029-30 mentions (based on a renewable energy capacity of 496 GW against the current announcement of 450 GW) anticipates steep fall in battery prices from Rs. 7 Crore to Rs. 4.3 Crore over a period from 2021-22 to 2029-30 for a 4-hour battery system. However, there does is not appear to be cause for such optimism.[261]

Renewable energy incentives in India

Indian renewable power generation initiated in the 1990s but the deployment caught acceleration only after the formation of the Electricity Act 2003 (EA'03), National Electricity Policy 2005 and National Tariff Policy 2006. These policies were having an exceptionally influential impact on renewable power generation projects and since then they have exhibited tremendous growth every year especially after 2010.

The policy framework for the wind and solar energy projects is similar up to a certain extent due to having same form of output as electrical energy. There are also some technology-specific provisions due to the diversity of power generation systems.

Table 25 depicts the technology specific Indian policy framework for wind and solar power generation. Currently, the Indian government is providing Accelerated Depreciation benefits by allowing 40% depreciation each year, which was started in 2014 with the provision of 80% and was reduced to current level in 2017. The reduction in depreciation allowance is the indicator of the betterment of financial scenario from the perspective of RE power generation. Additional prominent policies are: Renewable Purchase Obligation (RPO), Feed-in Tariff (FIT), Power Purchase Agreement (PPA) and wheeling facility.

Table 25: Indian policy framework indicating the specific policies, their history and current status for wind and solar energy

Policy Framework	Wind	Solar
Accelerated Depreciation (AD) The Government of India allows renewable (including wind and solar) projects to depreciate a certain amount in the first year	• Announced in mid 1990s; Terminated in 2012; Reinstated in 2014[262]; last Amended 2017[263]. • Depreciation up to 80% in the first year until March 2017, from April 2017 it has been reduced to 40%.	• Announced in the mid-1990s; Reinstated in 2017. • Depreciation up to 80% in the first year till April 2017[264]; after that, it is up to 40% in the first year[265].
Generation Based Incentive (GBI) The Government of India offered GBI as an alternative to AD policy	• Announced in 2009; Terminated in 2012; Reinstated in 2013. • ₹0.5/kWh additional payment above FIT, subject to cumulative of ₹10 million/MW of installed capacity[266].	• Announced in 2009; Not active now[267]. • Active only for Rooftop PV & Small Solar Power Generation Program (RPSSGP) and Demo solar plants.
Feed-In Tariff (FIT) FIT is the rate at which the generated electricity will be sold during the purchase agreement	Announced in 2009; Revised in 2010[268]. Not Active now and the Reverse Auctions took over.	
Annual Power Purchase Cost (APPC)	• State-specific; but a petition for APPC calculation also declared time to time by Central Electricity Regulatory Commission (CERC)[269] • APPC Values: ₹3.40/kWh (2016), ₹3.48/kWh (2017), ₹3.53/kWh (2018) • No longer relevant. Now prices based on reverse auction	
Renewable Energy Certification (REC) REC is a market based tool to tackle the inequality of demand-supply. Developers have to choose any one from FIT and REC. (FIT discontinued)	Announced in 2011 by CERC; proposed to be removed by Ministry of Power[270]. Forbearance Price of one REC is ₹1000/MWh for both solar and non-solar RE sources (w.e.f. 1st July 2020)	

Renewable Purchase Obligation (RPO) RPO is the percentage target of power generation through the renewable energy sources during each year announced by state and central governments	First introduced by Maharashtra in 2004; Announced in National Tariff Policy in 2006; declared by state & central government	
Income Tax Exemption / Tax Holiday The Government of India used to allow 100% tax waiver on profits (No longer relevant)	• Announced in 2002; Expired in March 2013; Reinstated. • Firms are exempted from the payment of income tax on profits from power generation for the first 10 years of their operation [271] • Subject to Minimum Alternate Tax.	
Excise and Custom duty benefits	• Announced in 2002 • Wind turbine rotors and controllers are fully free from excise duty. Concessional custom duty exemption on certain components of wind electric generators	
Wheeling Charges Wheeling charges are the additional charges to utilize the power at other than the generation place	Inter-state : Free Intra-state: Decided by State Electricity Regulatory Commissions (SERCs) independently for each state	
Banking	• Not effective now due to the application of 2% charges • Under Hydrogen Policy renewable energy banking for 30 days is allowed	
Clean Development Mechanism (CDM) The allowance given to the project developers register their project for participating in the Certified Emission Reductions (CER)	Announced in 2005. Project developers are free to participate in Certified Emission Reduction (CER). Some states demand share in benefits.	
Viability Gap Funding (VGF) VGF is the amount of funding support given to the project developers to bridge the gap between availability and requirement of the capital investment	No VGF is available for wind or solar power generation	• Announced under Phase 2, Batch 1 of the National Solar Mission (NSM) 2009. • Capital subsidy in instalments with an upper limit of 30% of project or ₹25 million/MW, whichever is lower (The exact amount is decided through Reverse Bidding).
Interest Rate Subsidy	This central Policy does not exist for power generation of any kind, but MOP provides interest rate subsidy of 3 % for 14 years under the National Electricity Fund to power distribution utilities	
Reduced Cost Loan (Debt)	• The central government has discussed the policy but has not announced yet. • The probable interest rate of 4.5% instead of 7.83%.	
Extended Tenure Debt	This federal policy is under consideration for National Wind Energy Mission. Under the policy government may provide a loan at 12.3% for 18 years instead of 10 years.	

Cost of subsidizing renewables

The twin incentives of a) providing free transmission by way of 'socialising transmission costs' for conveying RE generated in remote locations to load centres and b) rising costs of grid stabilisation amount to very heavy subsidy. This subsidy burden will rise with increase in the share of renewables in the generation mix. According to a report by CEEW in April 2018, the transmission costs alone would be in excess of Rs. 215,000 crore (US$ 33 billion) between 2015 and 2030. They would rise further to over Rs. 3,750,000 crore (US$ 575 billion) between 2030 and 2050.[272] These costs would be still higher in case India relies primarily on renewables to reach the target of Net Zero Emission by 2070. It May also be recalled that CEEW estimate was against the target of 2^0 C, and preceded adoption of Net Zero target at Glasgow. More stringent target of limiting increase in temperature to 1.5^{0}C would vastly increase the need for electrification, and transmission costs associated with renewables.

Downplaying the actual cost of deployment of VRE could also lead to incorrect investment decisions. Comparing generation costs of renewables with those of thermal or nuclear plants is erroneous. The former carry very high systems costs including transmission cost and cost of balancing power or storage solutions. Thermal or nuclear power does not carry such costs.

The transmission cost could also become a problem in case of hydrogen. The new hydrogen policy provides free transmission and 30 day's banking. Hydrogen is a storage solution, and does not justify combining this with free transmission of electricity produced in the process. This would further increase already high transmission costs associated with VRE.

Renewable Power as Distributed Generation: KUSUM Scheme

Large states of the country i.e., Punjab, Haryana, Uttar Pradesh, Rajasthan, Maharashtra, Gujarat, Madhya Pradesh, Andhra Pradesh, Karnataka and Tamil Nadu (which constitute over 70% of the connected electrical load of the country), supply 25% to as much as 40% of their energy to the agricultural sector. It is extremely difficult for utilities to satisfactorily meet the power requirements of the subsidised / non-paying, agriculture sector.

Given the dispersed nature of farm connections, it is extremely difficult to install and read meters on pump sets. Consequently, the vast majority of the pump sets in the country are unmetered and the utilities do not have reliable statistics on the capacity of the motors, efficiency of pump-sets or even the number of active pump-sets and hence, the actual consumption of power by the agriculture sector.

The demand for agriculture is highly unpredictable – dry spells result in all pumps being switched on simultaneously, while one shower can result in a sudden load crash leading

to grid disturbances. The position gets precarious during periods of prolonged dry spells or during late Rabi (i.e. during March/April) - when agriculture demand peaks and hydro support (in the non-Himalayan hydro projects) is at its lowest. Utilities therefore find it extremely difficult to predict their power requirements and even the most well thought-out plans (for summer supplies) invariably fail.

From the above description it is clear that no utility, howsoever well equipped, can provide reliable uninterrupted power of acceptable quality to meet the requirements of residential, industrial and commercial consumers - if the highly unpredictable agriculture sector constitutes a significant proportion of its load.

A special characteristic of the agriculture sector is that the supply of power is best if supplied during day-time. This is also an essential requirement if the farmer grows irrigated dry crops. In other words, the availability of Solar Energy ideally meets the requirements (timing) of the farmer. Thus, on-farm, (pump level) Solar PV generation, coupled with energy-efficient pumps affords a unique opportunity to mitigate the problems associated with power supply to agriculture.

India is planning a huge capacity addition in solar power and is already facing issues of availability of land. Huge mega projects are planned in desert areas – but these projects also require vast investments in transmission to carry power to load centres. De-centralised generation addresses this issue.

In July 2019, the GOI has launched Pradhan Mantri Kisan Urja Suraksha evem Utthan Mahabhiyan (PM-KUSUM) Scheme for farmers and the scope of the Scheme was modified based on the learning from the first year of the implementation. The scheme consists of the following components. [273,274]

❖ **Component A: For Setting up of 10,000 MW of Decentralized Grid Connected Renewable Energy Power Plants on barren land.**

- Under this component, renewable energy based power plants (REPP) of capacity 500 kW to 2 MW will be setup by individual farmers / group of farmers / cooperatives / panchayats / Farmer Producer Organizations (FPO) / Water User associations (WUA) on barren/fallow land.
- These power plants can also be installed on cultivable land on stilts where crops can also be grown below the solar panels.
- The RE power project will be installed within 5 km radius of the sub-stations in order to avoid high cost of sub-transmission lines and to reduce transmission losses. The

power generated will be purchased by local DISCOM at pre-fixed tariff by respective State Electricity Regulatory Commission (SERC).

- If the above specified entities are not able to arrange equity required for setting up the REPP, they can opt for developing the REPP through developer(s) or even through local DISCOM, which will be considered as Renewable Power Generator (RPG) in this case.
- DISCOMs will notify sub-station wise surplus capacity which can be fed from such RE power plants to the Grid and shall invite applications from interested beneficiaries for setting up the renewable energy plants.
- DISCOM would be eligible to get Procurement Based Incentive (PBI) @ □0.40 per unit purchased or □6.6 lakh per MW of capacity installed, whichever is less, for a period of five years from the Commercial Operation Date (COD).

❖ **Component B: For Installation of 17.50 Lakh stand-alone solar agriculture pumps.**

- Under this Component, individual farmers will be supported to install standalone solar Agriculture pumps of capacity up to 7.5 HP for replacement of existing diesel Agriculture pumps / irrigation systems in off-grid areas, where grid supply is not available. Pumps of capacity higher than 7.5 HP can also be installed, however, the financial support will be limited to 7.5 HP capacity
- Individual farmers having grid connected agriculture pump will be supported to solarize pumps. Solar PV capacity up to two times of pump capacity in kW is allowed under the scheme.
- The farmer will be able to use the generated solar power to meet the irrigation needs and the excess solar power will be sold to DISCOMs.
- Central financial assistance (CFA) of 30% of the benchmark cost or the tender cost, whichever is lower, of the solar PV component will be provided. The State Government will give a subsidy of 30%; and the remaining 40% will be provided by the farmer. Bank finance may be made available for farmer's contribution, so that farmer has to initially pay only 10% of the cost and remaining up to 30% of the cost as loan.
- In North Eastern States, Sikkim, Jammu & Kashmir, Himachal Pradesh and Uttarakhand, Lakshadweep and A&N Islands, CFA of 50% of the benchmark cost or

the tender cost, whichever is lower, of the solar PV component will be provided. The State Government will give a subsidy of 30%; and the remaining 20% will be provided by the farmer. Bank finance may be made available for farmer's contribution, so that farmer has to initially pay only 10% of the cost and remaining up to 10% of the cost as loan.

❖ **Component C: For Solarization of 10 Lakh Grid Connected Agriculture Pumps.**

- Under this Component, the individual farmers having grid connected agriculture pump will be supported to solarize pumps. Solar PV capacity up to two times of pump capacity in kW is allowed under the scheme.
- The farmer will be able to use the generated solar power to meet the irrigation needs and the excess solar power will be sold to DISCOMs at pre-fixed tariff.

As part of India's Intended Nationally Determined Contributions (INDCs), the PM-KUSUM Scheme aims to ensure energy security for farmers in India while also honoring India's goal to increase the percentage of installed capacity of electric power from non-fossil fuel sources to 40% by 2030.

During the Lok Sabha Session in March 2021, The Minister of New and Renewable Energy, Shri R.K. Singh informed the parliament, "Till 28.2.2021 total 24,688 standalone solar pumps have been installed and 64 grid-connected agriculture pumps have been solarized under Component-B and Component-C of the scheme respectively. Installation of decentralized grid connected solar power plants of capacity 4859 MW sanctioned under Component-A of the scheme is at different stages of progress. Therefore, total number of beneficiaries for whom installations are completed under the scheme till 28.2.2021 is 24,752. Generation of revenue from sale of solar power is available under Component-A and Component-C. The projects under these components either are under installation or recently installed. The revenue generation can only be evaluated on completion of one year of operation. (c) With scale-up and expansion of PM-KUSUM Scheme, over 5 GW of extra solar capacity will be installed." [275]

Shri. R. K. Singh, Minister of Power delivered a statement on 11th February 2022 mentioning that India has set an ambitious target of replacing diesel with renewable energy in the agriculture sector by 2024, as part of the government's commitment to increasing the share of non-fossil fuels by 2030 and becoming a net zero emitter by 2070. "Singh emphasized that India will replace diesel with renewables in order to meet the target of zero diesel use in agriculture by 2024," the Power Ministry said in the statement.[276] The minister also emphasized the need to have a state-specific

agency dedicated to energy efficiency and conservation. He urged that the states should develop an action plan to achieve the assigned targets.[277] Hence, the states have the authority to decide the nature of electricity integration i.e. decentralized or grid-connected). Actually, use of diesel for pumping is miniscule. Diesel for tractors and other farm equipment will definitely continue for quite some time. There is very little progress in non-grid connected renewables in the country.

VRE Integration and DSM

Management of the frequency of the grid is a huge challenge. The frequency of 50 Hertz (cycles per second) is achieved when generation precisely matches demand. The tolerance levels for frequency variation are extremely low and consumers are getting more demanding even as new frequency-dependent machinery and gadgets are getting installed in the country. Hitherto, frequency management was done by thermal and hydro projects which have provision for automatically adjusting generation up to 5% to match loads.

The variable nature of renewable energy, coupled with its 'must-run status' thus poses huge challenges for maintaining grid security – particularly for a network as large as India – and has not been tried anywhere in the world.

The complexity gets progressively more serious and mitigation costs prohibitive, as the proportion of variable renewable energy (VRE) rises in the grid as the task of grid balancing gets transferred to the increasingly dwindling proportion of thermal and hydropower in the grid. Further, most of the existing thermal units cannot be backed down below 50% to 55% generation and as VRE (solar power) increases – there will be days when VRE generation would exceed the backing down capability of thermal plants which would then have to be shut down. Besides incurring huge backing down costs, the management of the grid based on VRE would then pose huge technological challenges.

Demand Side Management (DSM)

While expensive technologies will have to be employed at the generation point, fortunately, there are numerous methods to influence demand i.e. consumer behaviour – primarily, through price signals – that link pricing of power to demand-supply conditions – thereby reducing the pressure on adjusting supply. Smart meters, time-of-day tariffs etc., and a system of incentives (together with the installation of required infrastructure) will help directing demand towards slack times in the system. Centralised systems for reducing demand on certain loads – without totally affecting operations – can also be installed in consumer premises to provide relief. All this of course has cost implications which needs to be fully studied and costs estimated .

Further, the problem of meeting evening peak (and early mornig peak) , when solar generation is not available, will have to be addressed through a combination of battery, pumped storage and

other renewable energy storage technologies, supplemented by stand-alone, generating stations. (for providing this evening and early morning 'peaking power') .

Peaking power could also be supplied by gas based power plants (with some modifications where necessary). At present, India has 25 GW of gas-based power plants that are operating at low PLF of 24% due to lack of availability of domestic gas. They cannot absorb expensive imported gas. These can be used for supplying peaking power to renewables bringing down carbon footprint.

DSM optimizes the demand-supply of the electricity and smoothens the load curve and peaking stations supply energy when solar energy is unavailable. However, this is not a complete solution for meeting the fluctuations that occur when the proportion of VRE increases.

Smart Grids

VRE by its very nature is unpredictable. Over a twelve-month cycle, it is inevitable, that, here will be times when solar and wind generation will be very low for long periods. A cyclone may require windmills to be stopped and cloud cover may drastically lower solar generation for days together. Similarly a dust-storm, or fog in North India could reduce RE generation drastically. It would be necessary to have substantial capacity of stand-alone, power generation (gas, coal or nuclear) to tide over these gaps in RE generation which may last for several days.

The decentralized solar and wind energy generation, combined with a mini and micro grid, is the only way to address the uncertainty of VRE resources while also lowering transmission costs and losses, such as ROW issues that cause transmission projects to be delayed due to local opposition. These mini-micro grids, on the other hand, should be connected to the local state or distributor's network via appropriate safeguards, relays, and other means. Local entrepreneurs have begun to implement this approach in practise, but it has largely escaped the notice of policymakers and the media. This will lead to 60% drop in the cost of interstate projects. Large customers, like towns and cities, can be served by a mix of conventional and non-conventional large plants in this instance.

Nuclear is the obvious choice as it is a non GHG emitter that can deliver dispatchable power at all times and is the most ideal situation for providing this back-up power. (If India is able to rapidly scale up its nuclear power generation capacity based on assured fuel availability.)

However, the output of nuclear energy is constant and cannot be rapidly varied, unless load following reactors and SMRs are deployed. The requirement of backing down during daytime when solar is available, could then be addressed by storing the output of nuclear energy during this time through a combination of dedicated pumped storage systems or through diverting the nuclear energy during this period for desalination (for coastal plants) or for production of hydrogen. Hydrogen (production) then becomes a form of energy storage as hydrogen can then be used for transportation or by industry.

However, even with these systems in place, maintaining grid stability (i.e. grid frequency) would be challenging . The solution demands precise control over both the innumerable points of supply (generation) and demand (consumption) and can be achieved through setting up of a 'SMART grid'. (An elaborate system of *'Automation, Communication and IT systems that can monitor power flows from points of generation to points of consumption (even down to appliances level) and control the power flow or curtail the load to match generation in real time or near real time'*. The Government of India, Ministry of Power has set up the National Smart Grid Mission and is already working on finding solutions.

However, a great deal of work remains to be done to understand setting up of SMART grids with ability to handle the proportion of Variable RE envisaged for 2030 and 2050. Among the requirements would be – Flexible generation (for fossil and hydro, eventually VRE will also have to face curtailment), Ancillary Services (the term that covers a complex set of initiatives for maintaining frequency and grid integrity), special transmission systems, DSM measures, accurate (more) RE forecasting etc. Some of the technologies associated with the above are still undergoing testing and development.

Huge investments in capital infrastructure will have to be made – even estimates of which are difficult to make without exhaustive, multi-disciplinary exercises. Given the current level of bankruptcy in the Power Sector, finding the resources for this investment is a most daunting task.

- No authoritative study has been made for the investments requirements to achieve Net Zero. A study by Mckinsey has estimated the cost to be USD 275 trillion worldwide, while a study by Standard Charter, titled 'Just in Time', has estimated the overall investment for India to be USD 31 trillion.

Needless to say, all this also requires a completely new set of supporting Regulatory framework and capacity building among the Central and State agencies connected with electricity.

A combination of 'SMART' grids, SMART-RE generation (some controls would also be required to be imposed on RE generation) and DSM, will smoothen the load curve and also reduce the requirement of additional base load capacity. This will then enable a higher capacity of firm, but non-GHG emitting nuclear power, coupled with fossil plants – gas (and perhaps, even a small number of new, supercritical coal plants with higher backing down capability – say up to 40%) to ensure both grid stability and energy security.

Renewable Energy: Material Intensity and Import Dependency

The material intensities of different energy sectors, the material requirement for achieving NZE by 2050 differ from the current production. Any mineral shortfall will have to be imported or new alternative materials have to be found. The type and quantity of the materials required for

renewable power in India by 2050 under NZE scenario (production average of 2015-2019) along with the production of respective materials in India are given in the following Table 26. It can be noted that the majority of the material needs of India for solar, wind and batteries will have to be met by means of import; whereas the material deposits are in sufficient amount for the nuclear power.

Table 26: Material intensity and import status for Indian renewable power

	Material	Requirement in India	Production in India
Solar	Copper	108 MT	0.3 MT
	Indium	0.04 MT	No Production
	Lead	0.16 MT	0.15 MT
	Tin	0.22	0.02 MT
Wind	Copper	0.7 MT	0.3 MT
	Iron	7.6 MT	Sufficient production
	Nickel	0.2 MT	0.19 MT
	Zinc	0.7 MT	0.7 MT
Batteries	Lithium	0.3 MT	No production
	Cobalt	0.2 MT	0.04 MT
	Nickel	0.3 MT	0.19 MT
	Aluminium	93.4 MT	3.08 MT
	Copper	92.2 MT	0.3 MT
Nuclear	Nickel	0.004 MT	0.19 MT
	Hafnium	0.009 MT	Sufficient deposits
	Zirconium	0.004 MT	Large deposits

Source: Prof. Amit Garg, IIM Ahmedabad (INAE Webinar: Role of Nuclear Energy in Decarbonisation of Indian Energy Sector)

Land constraint on renewable production

As per CEA's projections, meeting the initial national target of 450 GW clean energy capacity would require around 280 GW solar and 140 GW wind capacities along with the nuclear power capacity of 19 GW. This would require 5669 sq. km (solar), 20000 sq. km (wind) and 47.5 sq. km (nuclear) land area.

Renewables require extensive land, which is a constraint in India as well as other countries with high population density. While there may be enough land to reach the initial target of 450 GW by 2030, there is simply not enough land for reaching the target of Net Zero Emission. It may

be recalled that according to a study by Prof. Sukhatme, India has barren, uncultivated land of 2,00,000 sq. km.[278] The land requirement will be even more in case of the higher target of 500 GW of renewables by 2030 since announced by the government.

The following Table 27 represents the land requirements in different scenario derived by VIF Team from the outcome of the mathematical modelling developed by IIT Bombay.

Table 27: Land required for projected installed capacities for solar, wind and nuclear power

Net-zero 2070	Installed capacity (GW)			Land required (Sq. km)			
Scenario	Wind	Solar	Nuclear	Wind	Solar	Nuclear	Total
R95N05	800	14680	284	114283	297040	710	412033
R60N10CCS30	800	7057	406	114283	142793	1015	258092
R50N20CCS30	800	5787	763	114283	117096	1908	233287
R40N35CCS25	800	4841	1258	114283	97954	3146	215384
R05N95	800	3036	3139	114283	61431	7851	183565

Source: IIT Bombay, Mathematical Modelling for the VIF Task Force Study – India's Energy Transition in a Carbon Constrained World.

It is clear from the above that India simply does not have enough land for production of green Hydrogen through renewable route. The above table is based on 10% Green Hydrogen demand. Chapter 13 on Hydrogen economy also covers the scenario with 25% Green Hydrogen demand. In such a case, the solar capacity required will go up from 14,680 GW to 59,160 GW according to mathematical modelling done by IIT Bombay. Therefore, the land requirement in that case will be even higher.

Chapter 8 : Solar Power: Difficulties and Options for Achieving Net Zero Emissions

The present IPCC (2021) report has reiterated the relevance of climate change studies and adoption to clean energy technologies. Most of the anthropogenic activities in the present era are fuelled by fossil fuel thus emitting a huge amount of carbon compounds. The IPCC attributes the present climate change to the fossil fuel burning including, coal, petrol, diesel, gasoline etc.[279] In order to get rid of such dirty fuels, the globe needs to opt for nuclear, solar, wind, hydrogen energy sources which are considered clean fuels. According to World Energy Outlook 2021, the energy sector has to align with climate change solutions in the center of strategy formulation.[280] This will help in attaining IEA's landmark **Net Zero Emissions by 2050 in order to** achieve the goal of stabilizing the rise in global temperature not beyond 1.5 °C. Net Zero Emissions by 2050 Scenario (NZE) is highly challenging but achievable. The approach will also help in achieving the Sustainable Development Scenario (SDS).

The Stated Policies Scenario (STEPS) which indicates current policy settings on the basis of sector-wise national assessments and globally announced policies, foresees that the energy demand will be doubled by 2050. Major fraction of this demand is due to the expansion of infrastructure in developing economies. Therefore, Announced Pledges Scenario (APS) sees a need of doubling the clean energy investments in the next decade by 2030. The APS considers that the governments will complete all climate commitments in full and on time. The World Economic Outlook suggests four points to control global temperature rise below 1.5 °C as- i). Additional push for clean electrification, ii). Focus on energy efficiency, iii). Drive to cut methane emissions from fossil fuel operations, and iv). Boost to clean energy innovation.[281]

The clean energy sources use more metals than hydrocarbon-based sources.[282] For example, an electric car uses more metals than a normal car. Also, solar and wind devices use a number of metals. The IEA report on Rare Earth Elements (REE) provides a detailed information about metals and trends of REE and their future consumption in energy sector.[283] REE are needed for permanent

magnates used in EVs and wind turbines. Usage of lithium will be more for batteries as compared to the present usage for consumer electronics. Similarly, more nickel will be used for batteries than stainless steel by 2040.

The present global share of clean energy sources including solar, wind, nuclear is 19.2% contributing as 3.2%, 5.9% and 10.1% respectively.[284] Further, solar and wind are expected to contribute towards two third of global renewable energy. Almost half of the global renewable energy rise is accounted for China alone (WER, 2021). It is expected that 60% increase in the solar and wind energy production could be achieved under NZE without any additional costs to consumers. The International Renewable Energy Agency has reported that more than 260 gigawatts (GW) of renewable energy capacity was added globally in 2020.This includes 78GW expansion of solar energy in Asia mainly China (49 GW).[285]

India has been proactive nation to accelerate clean energy actions especially in the solar and wind energy production. There is a noticeable increase in solar power capacity of India. The annual production of solar power is increased from 1.9 GW in 2015 to 9.3 GW in 2019.[286] The Production Linked Incentives (PLI) scheme which was launched in 2020 has helped in increasing the domestic production of solar photovoltaic modules and advanced chemistry cell storage batteries. Government plans to achieve 114 GW solar power by 2022 which is a bit challenging due to COVID-19 shutdown.[287] Moreover, the raw material used in the production of solar cells is not available in the country. Silica is the major raw material. `India does not have any known deposits of silica suitable for producing solar panels'. This has been accepted by GOI in the parliament in March 2021.[288] Presently, solar panel market is dominated by China as it has large capacity for silica refining and silica wafers production.

The other major concerns have been cost and efficiency of cell but these are not major hurdles. Presently, the solar energy cost is drastically reduced from Rs 2.6/kWh in 2019 and 2.36 in June 2020 to 1.99/kWh in December 2020.[289] This is a favorable factor. Also, the efficiency of energy conversion from solar radiation is enhanced due to advancement in photovoltaic technology. At present 22.8% conversion efficiency cells are available.[290, 291] It will be further improved in coming time making more efficient capture of solar radiation. Recently, it has been reported that the German researchers have achieved 44.7% conversion efficiency using new material in solar cells.[292] This will further help in reducing per unit cost of solar energy in future. Hence, the major hurdles are the raw material and electricity need to manufacture the solar devices. It also needs electricity to produce these metals and spares. It is important to note that the production of solar panel in factories needs more electricity than they produce on installation.

Other factors impacting solar energy production negatively, include- i). Carbon-dust deposition on panels: The atmosphere in Indian region is full of mineral dust. In urban areas, the dust is mixed with the carbon particles emitted by automobiles, industries and other combustion sources. It is reported that around 3.6 kgC/ha per year carbon rich dust is deposited through sedimentation

in Delhi.[293] The deposition of blackish dust may affect conversion efficiency significantly.[294] and ii). Reduction in incoming solar radiation: The carbon rich dust creates haze affecting the intensity of incoming solar light further reducing the efficiency of cell. Moreover, the cloud cover also affects incoming radiation and so the charging of batteries will be another problem especially during monsoon season. This may be overcome by using solar-wind hybrid source.

In a nutshell, we are heavily dependent on imports for all necessary raw material needed in generating solar energy. Therefore, we have four options- i). continue import to meet the clean energy targets and earn relief and economic share under different conventions on this account. It means that the continuous import of solar energy material from a few selected countries which are part of global policy formulation will give huge and long-term business to the country like India which will develop cordial relations. This will be like going alongside and winning the faith of the elite countries. Considering the volume of business for long duration, we may be given the status of the extremely favored nation. Another aspect of mutual favor is that the clean energy credits in India may also be shared as CDM type mechanisms. Since, this will be benefiting to those supplying countries too, India may be provided all types of support to grow through different global programs. This is certainly not an option for Self-reliant India. The other options include- ii). use solar-wind hybrid model which also has almost similar consequences as first option, iii). start finding out new metals, materials and methods for solar energy generation based on the available ores in India during the transition which will take a longer time but will be making us self-reliant. In order to implement Paris agreement, the clean energy targets would require six times more minerals in 2040 than at present. We need to increase in house mineral processing many fold. iv). to work for hydrogen energy and v). to increase our capacity in nuclear energy for general electricity supply as well as for electrolysis for hydrogen production. This will help by diversifying our dependence on the available sources in energy sector. Therefore, we need to exercise on options iii), iv) and v) for making self-reliant India in energy sector by 2050.

Supply Chain Issues in Solar Energy Sector

In fact, choosing clean energy option means shifting from fuel rich technology to mineral rich technology e.g. an electric car uses six times more metals than a normal car. Similarly, manufacturing of solar and wind devices involves a number of metals. According to estimates, presently, 0.7Mt of metals are used in solar power which is expected to rise to 3.3 Mt in NZE scenario.[295] It means that the solar and wind energy sources will have severe import dependency in future suggesting a need of monitoring of supply chain.

The major concerns of supply chain are- i). raw material and ii). electricity needed to manufacture the solar devices. One MW solar power requires around 3000 solar modules.[296] India's target is to enhance 25-35 GW of renewable energy capacity per year, it may have demand of millions of solar modules indicating a very big challenge in supply chain for future.[297]

The solar photo voltaic equipment and battery modules need a number of minerals and metals such as silicon , selenium, indium, tellurium, molybdenum, gallium, tin, germanium silver and titanium dioxide, iron cadmium, copper, lithium, and lead.[298]

It is important to mention that mineral processing and supply of most of key minerals are restricted to a few countries. Presently, we rely on import of these modules primarily from China (80%).[299] Silica is the major raw material. `India does not have any known deposits of silica suitable for producing solar panels'. This has been accepted by GOI in the parliament in March 2021.

Table 28 gives major suppliers of some of the major metals needed in solar cell manufacturing:

Table 28: Major metals required for solar energy in countries where they are available in abundance

General	Around 90% of REE is done by the Chinese companies.[i]
	Around 80% solar panel modules are imported from China.
Silica (SiO_2)	At present, no company is making silicon wafers in India.[ii] Solar panel needs wafers of crystalline silica of 99.99999% purity which are achieved by purifying the metallurgical grade silica (MGS). Quartz is the source of MGS which is achieved by removing oxygen from the quartz by heating in an electric arc furnace. On exposure to hydrochloric acid and copper, trichlorosilane gas is produced which is treated with hydrogen resulting in silane gas. Then molten silicon is manufactured from this silane gas followed by its doping with phosphorous and boron to make a semiconductor. This material is cut into wafers and is used in solar cells.
Lead (Pb)	95% of the lead is extracted from three minerals i.e. galena (PbS) cerussite (PbCO3) and anglesite (PbSO4). Australia, China, Peru, Mexico and United States are the top Lead reserve countries. In spite of 2nd rank, China was the top Lead producer in 2020. India has only around 3% share in total global lead deposits,[iii] mostly mines located in Rajasthan, Andhra Pradesh, Jharkhand, Madhya Pradesh.
Titanium (Ti)	China, South Africa, Australia and Canada are the top producers of TiO2. India imports Titanium from Korea, China, Germany and Japan although rich in titanium minerals.
Tellurium (Tl)	Tellurium is used for making thin film in solar cell manufacturing. When it is alloyed with cadmium, it forms a compound having high electrical conductivity and such a thin film can absorb sunlight effectively for electricity conversion. The primary producers of tellurium are Sweden, Japan, Russia, China, the United States, and Peru.
Selenium (Se)	Selenium is mostly imported from Japan, Canada, United States and Belgium.
Nickel (Ni)	50-70% of nickel processing is done by the Chinese companies.

Sources:
- [i] IEA. (2021). The Role of Minerals in Clean Energy Transitions. https://iea.blob.core.windows.net/assets/24d5dfbb-a77a-4647-abcc-667867207f74/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf.
- [ii] EB2B. (2021). Coal India Might Start Fabricating Solar Wafers In The Country. https://www.electronicsb2b.com/headlines/coal-india-might-start-fabricating-solar-wafers-in-the-country/
- [iii] Statica.com. (2021). Lead Reserves Worldwide as Of 2021, By Country. https://www.statista.com/statistics/273652/global-lead-reserves-by-selected-countries/.

Similarly, most of other metals are also imported. This means that the supply chains can be affected by any kind of instability including changes in regulations, trade policy or political turbulences in the mining and processing countries. Considering these facts, India needs to build a strong supply chain involving domestic and global experienced players. We need to start finding out new metals, materials and methods for solar energy generation based on the available raw material in India which may take time but will be building a self-reliant India. We need to increase in house mineral processing as well.

Due to the present Russia-Ukraine war, the supply chain of REE and other metals may be affected which may have long term consequences on global renewable energy targets. It is foreseen that Indian 2030 targets for battery driven vehicles may also be delayed due to this war crisis. Recent anticipation of Tesla company which is the lead manufacturer of EV, that Russia Ukraine war would affect Tesla electric car company negatively[300] also supports this possibility of short supply of EVs worldwide in near future.

Disposal Practice and Waste Management Regulation of Solar Panels

Generally, the photovoltaic (PV) panels have a life time of 25-30 years. The discarded material can either be used for landfill or recycled. Obviously, sending discarded PVs to landfills is remarkably cheaper than its recycling. Globally, the solar PV waste is estimated to touch around 78 million tonnes by 2050.[301] There will be 35 thousand tonnes of solar panel waste in India by 2030.[302] It could reach 7.5 million tonnes by 2050[303] placing India among top five photovoltaic (PV) scrap creators. At present, India does not have a solar waste management policy. The PV waste is guided by the e-Waste Management Rules, 2016 which does not give any directions how the solar waste can be handled.[304] The solar waste generated by the used solar panels is sold as scrap in India. Therefore, in order to regulate a quantum of PV wastes generated from the discarded panels or from the manufacturing units in near future, a firm policy is needed immediately.

There are two types of photovoltaic panels- i). Silicon based and ii). Thin-film based. Table 29 below gives material-wise contents of two types of PVs:

Table 29: Material-wise solar panel contents

Material	Silicon based PVs	Thin-film based PVs
Glass	76%	89%
Plastic	10%	4%
Aluminium	10%	6%
Silicon	5%	-
Other metals (Copper and Tin etc.	1%	1%

Source: GreenMatch. (2022.) The Opportunities of Solar Panel Recycling. https://www.greenmatch.co.uk/blog/2017/10/the-opportunities-of-solar-panel-recycling.

Recycling of Silicon Based Solar Panels

First of all, aluminium and glass parts are disassembled. 100% of aluminium is reused for remoulding the cell frames while around 95% of the glass is reused. Then the remaining waste is heated at 500°C. This allows encapsulating plastic to evaporate leaving the silicon wafers which are further processed. The present technology ensures the reuse of evaporated plastic **as a heat source** for further thermal processing. Silicon wafers are etched away using acid. If there are any broken wafers, these are melted for the production of new silicon panels. Thus, in the recycling process, 85% of silicon material is reused.

Recycling of Thin-Film Based Solar Panels

The thin-film based panels are first shredded into 4-5 mm size pieces. Thereafter, with the help of rotating screw, solid and liquid materials are separated. The rotating screw allows spinning the solid parts inside a tube, while the liquid drops into a vessel. The liquid is then sent to a precipitation and dewatering unit to ensure purity. Further, it is taken to a metal processing unit where metals are separated. Around **95% of the metals are reused**. The solid is generally contaminated with interlayer materials. Since, these interlayer materials are lighter; these can be removed by vibrating the surface. After rinsing the solid material, pure glass is obtained. Around **90% of the glass is reused in the production of new panels.**

Since, PV waste contains toxic metals which are harmful to the environment and human health, its landfill utilization must be banned. It is recommended that more and more recycling units must be established for the safe disposal and reuse of the waste.

Chapter 9 : Hydropower

Introduction

Hydropower is an important source of low-cost, clean, and renewable electricity. Besides, it also provides balancing power for other variable renewable energy sources such as solar and wind. Solar and wind power primarily produces electricity when the sun is shining or the wind is blowing. Hydropower can reliably compensate for when the sun is not shining or the wind is not blowing because it can be ramped up very quickly and at very low-cost. Hydropower therefore has an important role to play in facilitating the transition towards clean and renewable energy. In light of this, this chapter discusses the current status of hydropower development in India. It observes that faster deployment of hydropower is essential for India's clean energy transition. The chapter also explores the current status of hydropower development in Bhutan and Nepal. Owing to their increased deployment of hydropower, both countries have become important sources of low-cost, clean, and renewable electricity. Besides, India, Bhutan, and Nepal has a combined hydropower potential of 265.51 GW –145.32 GW in India, 36.90 GW in Bhutan, and 83.29 GW in Nepal. Against this potential, the three countries have a combined installed hydropower capacity of 54.973 GW –51.36 GW in India, 2.335 GW in Bhutan, and 1.278 GW in Nepal. This leaves a huge untapped potential and cooperation in the hydropower sector that can be mutually beneficial for all three countries. Finally, the chapter discusses the potential implications of climate change, glacier melting in particular, on hydropower generation in India. It observes that India must undertake detailed analysis of the degree of dependency of its rivers on Himalayan glaciers and their vulnerability to climate change. All the while, it must continue to develop hydropower judiciously at sites that offers the greatest potential for electricity generation.

Global hydropower scenario

According to the Renewable Energy Policy Network for the 21st Century's (REN21) *Renewables 2021 Global Status Report*, global hydropower installed capacity reached 1,330 GW and it generated an estimated 4,370 terawatt hours (TWh) of electricity in 2020.[305, 306] This is around 16.8% of the world's total electricity generation, the third largest source of electricity after coal and natural gas. It is also

approximately equivalent to the United States' entire annual electricity consumption for that year. Besides, hydropower accounted for 60% of all renewable electricity.

China remains the world leader in respect of total hydropower installed capacity with over 370 GW or 27.81% of total global hydropower installed capacity in 2020. Brazil (109 GW), the United States (102 GW), Canada (82 GW) and India (50 GW) make up the rest of the top five. While the share of renewable energy in the global electricity mix reached its highest ever at 29% in 2020, hydropower's share within the sector remained stable at around 16.8% despite the 70% growth in global hydropower's total capacity over the last 20 years. That has prompted the International Energy Agency (IEA) to refer to it as "the forgotten giant of low-carbon electricity."[307] Hydropower however is increasingly seen as the perfect complement to fast emerging variable energy sources such as solar and wind power. When the sun does not shine and the wind does not blow, it can reliably supply homes and businesses with clean electricity. Investing in sustainable hydropower will therefore help electricity grids to expand renewable supply in a stable and reliable way, without the need to fall back on fossil fuels to avoid blackouts.

India's hydropower scenario

While hydropower continues to be the largest source of electricity among all renewable energy sources in India, its share in the country's total installed electricity capacity has witnessed a sharp decline. In 1947, hydropower accounted for 37.30% of India's total installed electricity capacity.[308] That increased to 50.61% in 1963. But it has declined ever since and reached just 12.98% as of 28 February 2022. A Lok Sabha Standing Committee on Energy report that was published in 2019 outlined the following reasons for hydropower's decline in India:[309]

a) **Land acquisition**: Acquisition of land for dam, power house, switch yard, etc. has often encountered procedural delays, unavailability/mismatch of land record, court cases, and unreasonable demands by land owners.

b) **Environment**: Clearances for hydropower projects are required from three different wings of the Ministry of Environment and Forest (MoEF) - environmental clearance from the Expert Appraisal Committee (EAC), forest clearance from the Forest Advisory Committee (FAC) and wildlife clearances from the National Board of Wildlife (NBWL). This makes the process of acquiring clearances cumbersome and time consuming.

c) **Rehabilitation and resettlement**: Hydropower projects can lead to huge population displacement. Their rehabilitation and resettlement can be expensive and time consuming and often lead to court cases.

d) **Law and order problems**: Protests by the local people who demanded employment and extra compensation often created law and order problems. That delayed the completion of hydropower projects.

e) **Culture/religion**: Religious sentiments attached with rivers and cultural importance of rivers often hampered hydropower construction.

f) **Technical/geological**: Hydropower projects, especially in the Himalayan region, are susceptible to geological surprises especially during underground tunneling. Besides, natural calamities like landslides, hill slope collapses, road blocks, flood, cloud bursts, etc. often delayed the construction of hydropower projects.

g) **Difficult terrain and poor accessibility**: Hydropower project sites are often located in inaccessible and remote locations. The absence of approach roads for transporting large and heavy equipment to the project sites often cause delay in construction. In fact, the construction of transmission lines through forests, mountain ranges and river crossings to transfer electricity to load centers prove to be more challenging than building hydropower stations at times.

h) **Finance:** While hydropower is a low-cost source of power with low operational costs, it is capital intensive and requires a great deal of investment upfront. Uncertainty over the final costs and completion time of the projects often affected the financing of hydropower projects.

To address these challenges, India has instituted a number of policy measures including the *National Rehabilitation and Resettlement Policy 2007* that provided for benefits (land, house, monetary compensation, skills training, preference for jobs etc.) and compensation to people displaced by land acquisition purchases or any other involuntary displacement.[310] The policy also established the post of Ombudsman to address grievances that may arise from the process of rehabilitation and resettlement. Meanwhile, the *Hydro Power Policy 2008* sets out a broad policy framework for accelerating the pace of hydropower development in India such as inducing private investment in hydropower development, harnessing India's full hydropower potential, improving resettlement and rehabilitation, and facilitating financial viability of hydropower projects.[311] Furthermore, the *Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement Act, 2013* sets out procedures for land acquisition that is "humane, participative, informed and transparent."[312] Norms for compensation, rehabilitation and resettlement of affected persons, and Social Impact Assessment (SIA) of large development projects were also prescribed. In addition, India has also approved the following measures on 8 March 2019 to hasten the deployment of hydropower in the country:[313]

a) Recognizing large hydropower projects as renewable energy source;

b) Compulsory hydropower purchase obligation for power distribution companies;

c) Tariff rationalization to bring down the costs of hydropower tariff;

d) Budgetary support for flood moderation/storage hydro electric projects; and

e) Budgetary support to costs of enabling infrastructure such as roads and bridges.

The aforementioned policy measures could facilitate the rapid deployment of hydropower in India. In fact, 36 hydropower projects with a combined installed electricity capacity of 12.66 GW are under construction in the country as of 28 January 2022. They are expected to be completed between 2022 and 2026. Furthermore, India plan to increase its total installed hydropower capacity to 70 GW by 2030.[314] Achieving this goal is not beyond the realm of possibility given that India has an estimated hydropower potential of 145.32 GW.[315] This potential is located in the following river basins:

a) **Brahmaputra:** 65.4 GW (45% of India's total potential);

b) **Indus:** 33.02 GW (22.72%);

c) **Ganga:** 20.25 GW (13.93%);

d) **East flowing rivers:** 13.77 GW (9.47%);

e) **Central Indian rivers:** 3.86 GW (2.66%); and

f) **West flowing rivers:** 8.99 GW (6.19%).

Among states, Arunachal Pradesh, located in the Brahmaputra River basin, has an estimated hydropower potential of 50.06 GW or 34.45% of India's total potential.[316] Against this potential, the state has an installed hydropower capacity of 0.54 GW as of 28 February 2022. That is just 1.08% of its total estimated potential. As such, there is a clamor for the construction of more hydropower projects in the state as it is widely seen as the key to unlocking its economic potential especially in its border regions.[317] Besides, hydropower projects in Arunachal Pradesh could also help offset the potential hydrological and strategic implications of Chinese dams on the Yarlung Tsangpo River.

The Brahmaputra River originated as the Yarlung Tsangpo in southwest Tibet. It flows 3,848 kilometers through the Tibetan Plateau in China, India, and Bangladesh where it merges with the Ganges and later the Meghna before it empties into the Bay of Bengal. The river is viewed by China as a major source of renewable electricity and it plans to build as much as 28 hydropower projects on it.[318] Five of them are known to have been either completed or planned for construction. Construction of the first hydropower project, the 0.51 GW Zangmu Hydropower Station, began in 2009 in Gyaca County in Shannan Prefecture and was completed in 2015. This dam was hailed as ushering in "a hydropower era for Tibet's rivers."[319] Construction of a second hydropower project, the 0.36 GW Jiacha Hydropower Station, soon followed in 2015 on the same stretch of the river in the same county and was completed in 2020.[320] The remaining three hydropower projects - Zhongda, Jiexu and Langzhen - are believed to be under various stages of planning, engineering, and construction. There are concerns that these hydropower projects may withhold water during the dry seasons and reduce the flow of the Brahmaputra River in India. Conversely, they may release excess water during the wet season and trigger floods downstream in Arunachal Pradesh

and Assam. China's hydropower projects on the Yarlung Tsangpo River could also facilitate the development of more infrastructures including border villages and roads close to, and even inside, India and significantly enhance China's strategic position along the contested Sino-Indian border region.

The potential hydrological and strategic implications of Chinese hydropower projects on the Yarlung Tsangpo River are not lost on India. Back in 2010 when China was building the Zangmu Hydropower Station, Jairam Ramesh, India's then minister of environment, noted that India too needs to be "more aggressive in pushing ahead hydro projects (on the Brahmaputra)" as that would put the country "in better negotiating position (with China)."[321] More recently, a statement from the Jal Shakti Ministry that was released on 20 January 2021 observed that "Any attempt to divert water of Brahmaputra River shall act as an encroachment on the entitled rights of lower riparian states like India, Bangladesh and adversely affect the availability of water in the Brahmaputra basin during the lean season."[322] India has long expressed its interest in instituting legally binding water sharing/management treaty with China to address these issues. But China has refused its proposal steadfastly. A key reason for this is its desire to exercise a degree of hydro-hegemony over rivers that originated from within its border. In fact, China views transboundary rivers as "sovereign resources" that should be exploited in an unrestricted manner.[323] Such attitude has led the country to view legally binding multilateral and bilateral water sharing treaties that are the bedrock of effective transboundary river co-operation as detrimental to its national interests and sovereignty. Southeast Asia offers a case in point. Despite repeated invitations by the Mekong River Commission (MRC), China has refused to join it as a full member. The MRC is an inter-governmental agency of the four countries of the lower Mekong river basin namely Cambodia, Laos, Thailand and Vietnam. China felt that joining the MRC will restrict its ability to act unilaterally on its portion of the Mekong River. Thus, despite repeated objections by the MRC, the country has constructed 11 hydropower projects on its portion of the Mekong River between 1993 and 2018.[324] And they have increasingly threatened the flow of water downstream in Southeast Asia. In the face of this challenge, the only recourse for India is to also increase the deployment of hydropower projects on rivers like the Brahmaputra. That would enable the country to establish its riparian rights over the river, offset the potential hydrological implications of Chinese dams on the Yarlung Tsangpo, and consolidate its position along the disputed Sino-Indian border more effectively.

Electricity imports from Bhutan and Nepal

Besides expanding its hydropower capacity, India should also continue to explore ways to increase the import of low-cost, clean, and renewable electricity from its neighbours. Bhutan and Nepal in particular have abundant hydropower potential, are surplus electricity producers, and willing sellers too. Importing electricity from these countries could help India augment its clean and renewable energy capacity. It would also generate substantial revenues for Bhutan and Nepal.

The case of Bhutan

Hydropower in Bhutan is a "key strategic national resource." It is also among the country's "five economic jewels" alongside agriculture, tourism, cottage and small industries, and mining. As of 2021, the country has an installed hydropower capacity of 2.33 GW.[325] Its total hydropower potential on the other hand is estimated at 36.9 GW. Bhutan's current installed hydropower capacity therefore is just 6.32% of its total estimated potential. The hydropower sector contributed significantly to the Bhutanese economy and it accounted for 19.45% of domestic revenue, 34.15% of total export earnings, and 8% of GDP in 2016.[326] More recently, its Ministry of Economic Affairs estimated that in 2020, hydropower accounted for 57% of Bhutan's total export earnings and 63.24% of its total export earnings from India, its largest trading partner.[327] Resources mobilized through exploitation of hydropower therefore are critical for future growth and diversification of the Bhutanese economy.

Hydropower cooperation between India and Bhutan was considered to be "the most visible symbol of the mutually beneficial bilateral cooperation."[328] On 23 March 1974, just six years after India and Bhutan established diplomatic relations, the two countries signed the "Agreement Between the Government of India and the Royal Government of Bhutan Regarding the Chukha Hydro-Electric Project." Under this agreement, India agreed to fund the construction of the 0.33 GW Chukha Hydropower Project, Bhutan's first major hydropower project, with 60% grant and 40% loan at an interest rate of 5% payable over a period of 15 years after the commissioning of the project.[329] India also agreed to purchase all surplus power from the project. The project was completed in 1988 at a total cost of Rs. 246 crores. India subsequently funded the construction of the 0.06 GW Kurichhu Hydropower Project (commissioned in 2001) and the **1.02 GW Tala** Hydropower Project **(commissioned in 2006)** and the 0.72 **GW Mangdechhu** Hydropower Project **(commissioned in 2019).** And on 28 July 2006, India and Bhutan signed a comprehensive agreement to further enhance cooperation in the hydropower sector. An additional protocol to the agreement was signed in 2009 under which India agreed to assist Bhutan in developing a minimum of 10,000 MW of hydropower by 2020.[330] As such, **t**hree hydropower projects are currently under various stages of construction – the **1.2 GW Punatsangchhu-I** Hydropower Project **(likely to be commissioned in 2024), the 1.02 GW Punatsangchhu-II** Hydropower Project **(likely to be commissioned in 2022) and the** 0.6 GW Kholongchhu Hydropower Project (likely to be commissioned in 2024). Furthermore, Detailed Project Report (DPR) has been cleared and implementation agreement has also been signed between the two countries for the construction of the 0.18 GW Bunakha Hydropower Project**, the** 0.57 GW Wangchhu Hydropower Project**, the** 0.77 GW Chamkharchhu-I (Digala) Hydropower Project**, and the 2.58 GW** Sankosh Hydropower Project**. Furthermore, DPR** has been prepared and cleared **for the construction of the 0.54 GW Amochu** Hydropower Project **although it is unclear if an implementation agreement has also been signed. Finally,** DPR has either been prepared or under preparation for the construction of the 2.64 GW Kuri Gongri Hydropower Project.

Currently, electricity generated from hydropower projects at Tala, Chukha, Kurichu and Mangdechu is exported to India through 400kV, 220kV and 132kV transmission lines. And as of 2016, electricity export from Bhutan amounted to 1.54 GW.[331] With more hydropower projects likely to be commissioned in the coming years, the volume of Bhutan's electricity export to India will also increase. As per the inter-governmental agreement that was signed in 2006, India agreed to buy a minimum of 10 GW by 2020. This was subsequently enhanced to 10 GW. While the current volume of Bhutan's electricity export to India might not seem much, there is tremendous prospect for future growth. And it will be a win-win situation for both countries. Besides augmenting India's clean and renewable energy capacity, electricity export will continue to generate substantial revenue for Bhutan. Bhutan already has the highest per capita income among countries of the South Asian Association for Regional Cooperation (SAARC). Thus, electricity export will continue to play a vital role in further improving the country's economy and the living standards of its people in the years ahead.

The case of Nepal

Nepal has a hydropower potential of 83.29 GW of which 42.13 GW is considered to be economically viable.[332] Against this potential, the country has an installed hydropower capacity of 1.27 GW in 2020.[333] This is 1.53% of its total estimated hydropower potential and 3.03% of its potential deemed to be economically viable. According to a plan outlined on 8 May 2018, Nepal aimed to increase its hydropower capacity to 15 GW by 2028. Realizing this goal will require massive investment including from India with which it has a long history of cooperation in areas such as water sharing, irrigation, flood control, hydropower and cross-border electricity trade. Cooperation between India and Nepal in the aforementioned areas are underpinned by a number of bilateral agreements such as the Kosi Agreement (signed on 25 April 1954 and amended on 19 December 1966), the Gandak Agreement (signed on 4 December 1959 and amended on 30 April 1964), and the Mahakali Treaty (signed on 12 February 1996). Consequently, India helped Nepal build the 0.024 GW Trishuli Hydroelectric Project (commissioned in 1967), the 0.001 GW Hydropower Project (commissioned in the 1969), the 0.015 GW Gandak Hydropower Project (commissioned in 1979), and the 0.014 GW Devighat Hydropower Project (commissioned in 1984).

Besides, a number of India-funded hydropower projects are at various stages of planning for a long time. It included the 3 GW Sapta Koshi High Dam Multipurpose Project, the 4.8 GW Pancheshwar Multipurpose Project, the 900 MW/0.9 GW Arun III Hydropower Project, the 0.67 GW Lower Arun Hydropower Project, and the 0.90 GW Upper Karnali Hydropower Project. Some observers have noted that since the commissioning of the Devighat Hydropower Project in 1984, cooperation between India and Nepal have slowed significantly owing to factors such as political instability, local opposition, failure to receive clearances, etc. As such, the construction of hydropower plants financed by Indian entities "has met with little success."[334] The slow pace of hydropower development in turn has contributed to Nepal's long-running electricity shortages with load

shedding averaging up to 16 hours a day during 2008-2016.[335] According to the World Bank, that has reduced the country's Gross Domestic Product (GDP) by more than 6% during the period.[336] Nepal finally ended residential load shedding since early 2017 and industrial load shedding since early 2018. Imported electricity from India played a critical role in this. In fact imported electricity from India still accounted for 31.83% of the Nepal Electricity Authority's (NEA) "total available energy" in 2021.[337] Import of Indian electricity is facilitated by cross-border transmission lines such as the Muzaffarpur-Dhalkebar 400KV line, Kataiya (India)-Kusaha (Nepal) 132 kV line, and Raxaul (India)-Parwanipur (Nepal) 132 kV line. More such lines are under various stages of planning and construction.

Following the operationalisation of the 0.45 GW Upper Tamakoshi Hydropower Project on 5 July 2021, Nepal became an electricity surplus country, with an installed electricity capacity of 2 GW against a domestic requirement of around 1.5 GW by the year's end.[338] As such, it has been aiming to export its surplus electricity and has reportedly secured India's permission to sell 0.03 GW - 0.02 GW from the Trishuli Hydropower Project and 0.01 GW from the Devighat Hydropower Project - on the Indian Energy Exchange (IEX).[339] Nepal has also sought India's permission to sell 0.58 GW of electricity generated from the Upper Tamakoshi Hydropower Project, the 0.045 GW Upper Bhotekoshi Hydropower Project (commissioned in 2001), and the 0.069 GW Marsyangdi Hydropower Project (commissioned in 1989). It is only logical that India buys more of Nepal's surplus electricity owing to increased demand for low-cost, clean, and renewable electricity in the country. Furthermore, to ensure its sustainability, India should also invest more in Nepal's hydropower sector. Besides being mutually beneficial, it will also further strengthen their overall relationship going forward.

Conclusion

India's clean energy transition will necessitate the deployment of all renewable energy sources including hydropower. However, concerns remain about climate change adversely affecting its hydropower generation. The second installment of the Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6) that was released on 28 February 2022 warned of devastating consequences on hydropower production in the Indus, the Ganges, and the Brahmaputra rivers due to the melting of Himalayan glaciers. The report projected Himalayan glaciers to melt by 49 ± 7% under its medium-emissions scenarios and by 64 ± 5% under its high-emissions scenarios by the end of 2100.[340] This assessment is consistent with other previous findings. The Kathmandu-based International Centre for Integrated Mountain Development (ICIMOD) observed in a landmark report that was released in 2019 that even if the Paris Agreement's goal of limiting global warming to 1.5°C by the end of 2100 is achieved, the Himalayan region will still experience more than 2°C of warming.[341] As a result, at least 36% of the region's glaciers will melt. However, if emissions are not reduced, temperature could rise by 5°C and 66% of the glaciers will melt. Another study by the Columbia University in the United States showed that on average, the glacier surfaces in the

Himalayas have sunk by 22 centimeters (8.7 inches) a year from 1975 to 2000.[342] But that doubled to 43 centimeters (17 inches) a year from 2000 to 2016. Accelerated melting of Himalayan glaciers is likely to increase the flow of water in the Indus, the Ganges and the Brahmaputra rivers and they may reach their "peak water" by 2050 through to 2060. After that, the flow of water will decline as most of the glaciers will have melted away. However, the Indus, the Ganges, and the Brahmaputra rivers have varying degrees of dependency on Himalayan glaciers. As such, their accelerated melting is likely to have varying degrees of impacts on hydropower generation across these river basins. India must therefore undertake detailed analysis of the degree of dependency of its rivers on Himalayan glaciers and their vulnerability to climate change. All the while, India must continue to develop hydropower judiciously at sites that offers the greatest potential for electricity generation and strengthen its cooperation with Bhutan and Nepal over the import of low-cost, clean, and renewable electricity.

Chapter 10 : India's Energy Security and The Role of Nuclear Power

"The Biden Administration maintains the United States' decades-long commitment to advancing nuclear energy as a solution to the climate crisis at home and abroad."

— John Kerry, US Presidential Envoy for Climate Change[343]

Nuclear power accounted for 10.2% of global electricity generation in 2020.[344] There was a slight decrease in the share of nuclear power by 0.2% as compared to the previous year. This was not unusual, as the pandemic had drastically affected the level of economic activities the world over. The sector had seen a slow down since the Fukushima incident of 2011. However, climate pressure is bringing about a renaissance for this sector. Japanese Prime Minister Kishida has re-affirmed the importance of nuclear power for his country. The Biden Administration has announced support for existing nuclear power plants and funding for R&D for advanced reactors. Similar announcements have been made by UK and France. The trend is likely to be accentuated by the hike in fossil fuel prices. This has gained further momentum after the Ukraine crisis, as the focus has increasingly shifted from climate concerns to energy security.

Nuclear power combines twin advantages of low emission with stable, dense, base-load power, which is unmatched by any other energy source. These will ensure a role for nuclear power beyond the exigencies of the current geopolitical situation. The inclusion of nuclear power in the energy mix can help lower the cost of reaching the target of Net-Zero Emission than an approach based only on renewables. As Bill Gates said in his book How to Avoid A Climate Disaster, 'No other clean energy source comes even close to what nuclear already provides today.'[345] However, the sector is not without its problems. High up-front capital costs and disposal of nuclear waste are two such problems. This chapter examines the issue of cost; the disposal of nuclear waste is covered in the following chapter. It also analyses the relative advantage of nuclear power over renewables, which are intermittent. Nuclear power also has an advantage over coal in terms of providing emission-free energy. The Glasgow Summit on Climate Change has adopted a decision on 'phasing-down' of coal. Coal provides 71% of India's power generation. To avoid disruption in supply, and ensure affordable power tariffs, this has to be in tandem with ramping up of the nuclear power. Nuclear

power can also be deployed to produce hydrogen, supply process heat for industries, and run desalination plants.

Most of the major economies have a much higher share of nuclear power in their generation mix than India. This includes US (20%), EU (20%), Russia (20%), and Japan (5%). Under the Fifth Basic Energy Plan, Japan plans to ramp up nuclear power to account for 20-22% of the country's power generation by 2030.[346] This will be double the share of nuclear power in India's generation mix by that date. The contribution of nuclear power to China's generation mix stands at 4.7%. China plans to increase it to 10% in the future. In contrast, nuclear power accounts for 1.8% of India's generation mix. Even though India seeks to expand the nuclear power capacity to 22,480 MW by 2031, it will still be only 3% of capacity and 5% of the generation mix.

The relatively small size of the nuclear sector in India is a result of twin constraints. For a long period, this sector has suffered from international sanctions. Though the country has received an NSG exemption, there are policy constraints. Under the Atomic Energy Act, this sector is not open to majority private equity holding or foreign equity. This places it at a disadvantage vis-à-vis renewables. In most developed countries, both private participation and foreign participation are allowed. In the case of the Barakah nuclear power plant, the South Korean consortium has been allowed equity participation. Similarly, the UK has allowed a consortium led by French company EDF. At one stage, the consortium also included a Chinese company. The incentives given to the nuclear sector by other countries are detailed in the following chapter. The concept of carbon cost in the EU provides an arbitrage, which provides a competitive advantage to the nuclear sector over fossil fuel tariffs. In the US, emission credits are given by the states. India does not have a carbon tax. Though renewables are given a series of incentives, these are not provided to nuclear power even though it is an emission-free source of energy.

Cost and Emission

While nuclear power plants indeed have high, upfront capital costs, they have a much higher Plant Load Factor (PLF) of around 80-85 % as compared to solar 20-22%, and wind 35%. Therefore, a cost comparison based on capacity alone would be misleading. A 1000 MW solar power plant would generate only around 1/4th of electricity as compared to a nuclear power plant. In the case of wind power, though PLF is higher than solar, it is available only 4 months a year in India. The capital cost of a nuclear power plant for a given annual electricity generation is thus in the same range as solar, wind or hydro. However, the interest during construction in case of nuclear is higher due to higher gestation period. Battery storage in case of solar or wind increases the cost both for additional generation and storage, and still cannot cope with inter-seasonal variation in the case of wind power, or a minimum of 12 hours gap in the case of solar power. There is no grid-scale storage solution available. Both nuclear power and renewables have lower fuel costs as compared to thermal power plants. Renewables however entail a much higher systems related costs as compared to nuclear power plants.

The cost comparison between nuclear and renewables should be based not simply on generation cost at the plant level, but final cost to the consumer. In the case of wind and solar, there are very high systems costs. These are not captured in any calculation of the Levelised Cost of Energy (LCOE). The **systems costs** include the cost related to higher investment in peaking capacity which could be high when penetration of variable renewable energy is high, the cost of **balancing power** when the sun is not shining, or the wind is not blowing and **stranded power** when operable capacity has to back down as a result of excess power in the grid. The size of the grid and share among different types of energy sources need to be carefully optimized to arrive at the minimum cost to consumer while assuring energy security and meeting of emission targets. As most of the larger renewable projects will come up in remote locations requiring dedicated transmission lines working at low utilization factor, this involves very high **transmission costs**. Nuclear power is one of the densest sources of energy that can be located near the consumption centers leading to a reduction in transmission costs.

In terms of operating costs of existing nuclear power plants, they are significantly lower than the all fossil-fuel competitors, with a low risk of inflationary pressure on tariff as plants are expected to operate for almost 60 years or longer.[347] When the share of renewables exceeds a nominal proportion, the system costs increase and exceed the generation costs from these sources.[348] VRE demand higher backup, grid connection, and reinforcement costs. [349] While it is true that low-carbon technologies, predominantly VRE are expected to deliver increasing shares of decarbonization, nuclear power can complement and integrate the large share of renewable generation by ensuring cost effective energy supply, energy security and dispatchability.[350] Fuel costs form a relatively small share of the cost of the nuclear power plants. Given the steep hike in the price of fossil fuels (gas and coal) in the past year, this makes nuclear power more attractive. The advantage of nuclear over coal-based power plants in terms of fuel costs would be clear from the following comparison in the following Table 30:

Table 30: Comparison of fuel cost of nuclear and coal-based power plants running on imported fuel

a. 1,000 MW Nuclear Power Plant (Light Water Reactor)	USD 4,40,79,000 per annum (Rs. 335 crore per annum)
b. 1,000 MW Coal Based Power Plant (sub-critical and supercritical plants)	USD 98,10,00,000 per annum (Rs. 7455.6 crore per annum)

Note:

(a) A 1,000 MW LWR would need about 25 tonnes of such fuel per year at 82% PLF. Price: USD 17,63,158 per Tonnes (Rs. 13,40,00,000 per Tonnes). Considering this, the fuel cost for a nuclear power plant would work out to USD 4,40,79,000 per annum (Rs. 335 crore per annum) (at 1 USD = Rs. 76).

(b) Need: 3,000 tonnes / MW per annum. Price: 327 USD per Tonnes.[351]

Thus the annual import of such coal for a 1,000 MW capacity would work out to Rs. 7455.6 crore (at 1 USD = Rs. 76, almost 98 times that of nuclear fuel import cost).

Nuclear power also offers lower systems costs, which gives it an advantage over renewables. Since the plant load factor of renewables is much lower than that of thermal or nuclear power

plants, 'a significantly higher capacity is needed to produce the same amount of electricity.'[352] An OECD study on 'The Cost of Decarbonisation' has found that 'as the VRE penetration increases, vast excess capacity, thus investment, is needed to meet the same demand'.[353] Thus, as distinct from plant-level costs, the advantage shifts decisively in favor of nuclear when considering systems costs. The irony is that 'deploying VREs does not automatically translate into carbon emission reductions. For instance, when nuclear power is substituted by a mix of VREs and a gas-fired generation that produces electricity when VREs are not available, overall carbon emissions will increase.'[354] In the Indian context, balancing power for renewables is supplied by coal instead of gas. This would further exacerbate the problem.

As chapter 5 on the Power sector has brought out, the tariff for nuclear power compares favorably with wind and solar taking into account storage cost. The average tariff for a nuclear power plant in India in 2019 was Rs. 3.43/kWh. The corresponding tariff for solar with storage was Rs. 4.30/kWhr. Wind tariff tends to be higher than solar in India. Storage cost for renewables has to be taken into account to ensure an equitable comparison between a stable (nuclear) and otherwise an intermittent source (solar or wind) of electricity. Even this does not give a true measure of the cost of renewables, since battery storage offered along with the solar power project was limited to 9 hours, while nuclear power provides round the year electricity.

A recent UN study has established that nuclear power has the lowest emission costs considering the entire cycle from mining to plant construction and electricity production as shown in Table 31 below:

Table 31: Emission costs of nuclear power compared to wind and solar power

	Nuclear	Solar PV	Wind
Emission	5.11-6.4	8.0-83	7.8-16
(g CO_2 eq/kWh)			

Source: UNECE. (2021). Life Cycle Assessment of Electricity Generation Options. https://unece.org/sites/default/files/2021-10/LCA-2.pdf

The energy sector is the largest contributor to greenhouse gas (GHG) emissions, accounting for approximately three-quarters of global emissions.[355] Driven by national economic developmental strategies, the global energy demand is bound to rise in the near future leading to a corresponding increase in emissions if left unchecked. The UNFCCC NDC Synthesis Report prior to the recent Glasgow Climate Conference declared that despite recent trends in the reduction of GHG emissions, countries need to double their climate mitigation efforts to avert the change in global temperature to beyond 1.5°C.[356]

While contributing 10% of the total world generation, NPPs have saved 1.5-2 billion tonnes of GHGs on a yearly basis since 1990.[357] Estimated global energy emissions between

the 1970s and 2018 would have been 20% and 6% higher in the absence of nuclear power.[358] According to the Nuclear Energy Institute, the United States of America avoided more than 476 million\metric tonnes of CO_2 emissions in 2019 due to nuclear power generation.[359] France is one of the EU's best performers in terms of per capita emissions that have seen a continuous downward curve in emission rates. This is mainly attributed to the country's extensive nuclear capacity (70% of total capacity), which ensures a steady generation of CO_2-free power.

Must-run status and the need for long term tariff policy

Nuclear power plants involve heavy capital expenditure, which makes the investment decision difficult. Providing incentives for long-term, high-capital investment in deregulated markets driven by short-term price signals presents a challenge in securing a diversified and reliable electricity supply system.[360]

An OECD study points out, that capital-intensive, low-carbon technologies require long-term price stability.[361] Politicians have been willing to accord such stability in the form of guaranteed feed-in tariffs (FITs) to renewables, in particular, wind and solar photovoltaics. With two-thirds or more of total lifetime costs spent before the day of commissioning a nuclear power plant (NPP), investors have very little financial flexibility to react to changes in the price environment.[362] In India, feed-in tariffs were offered to renewables, though it has since been discontinued. Renewables, however, continue to be given other incentives such as 'must-run' status, free inter-state transmission, and renewable purchase obligations (RPO) or renewable energy certificate (REC). Nuclear power, however, is not provided these incentives, though it is a stable base-load power (which renewables cannot provide being intermittent) with lower emissions.

The must-run status accorded to renewables is a major incentive, which gives them preference over fossil fuels. Nuclear power has an even smaller emission profile than renewables. Nuclear reactors cannot be rapidly ramped up and down. On both counts, nuclear power deserves 'must-run' status on par with renewables. This combined with the high capital expenditure associated with nuclear power in the initial phase makes it necessary that nuclear power plants have a 'must-run' status, which is accorded to renewables. Merit Order Dispatch cannot be applied to the nuclear power sector. The heavy CAPEX requires long-term price stability. This is an essential feature of government pricing policy in the UK under Contract for Difference (CfD).

Systems costs

The systems costs of renewables have been discussed in the previous chapters on Variable Renewable Energy and the Future of Grid. As the share of renewables in the grid increases to move towards a low emission economy, these costs rise 'disproportionately'. Renewables being intermittent, require a stand-by capacity to provide balancing power when the sun is not shining

or the wind is not blowing. This remains idle or is operated at low capacity when the renewables are available. This redundancy adds to the inefficiency and cost of the system. As the systems move towards a lower emission scenario, this cost increases disproportionately The renewables also have lower plant load factor and require higher capacity addition to achieve the same generation. These studies have established that the inclusion of nuclear power is necessary to optimize the cost of moving towards more stringent emission norms.

A recent study by McKinsey has found that the major portion of the delivered cost of electricity in case the world relies upon renewables only to achieve the Net Zero Emissions target would be grid cost. This is despite the fall in operating costs on account of the greater use of renewables.

The OECD Report

The OECD report titled 'The Cost of Decarbonization: Systems Costs with High Share of Nuclear and Renewables' states that the costs of achieving deeper decarbonization goals increase over-proportionally with their share in the system when decarbonization is done by means of VRE as compared to when done by nuclear.[363]

The OECD study cites a mathematical model by MIT on the average price of electricity as a function of pathways and emission intensity targets. The model used a case study of two US States – Texas and New England. Their conclusion was:

(i) 'The average cost of electricity increases as the carbon constraint becomes more stringent, but this increase depends strongly on the technology path followed.'

(ii) 'The structure of the optimal generation mix varies significantly depending on the power system considered and changes drastically as the decarbonization target becomes more binding., and'

(iii) 'the share of nuclear energy in the optimal mix increases as the carbon constraint becomes more stringent.'[364]

The OECD study brought out dramatic differences in costs and changes in the optimal generation mix as the carbon intensity of the power system is progressively reduced. If nuclear is allowed in the generation mix, the cost of reducing carbon intensity increases 'almost linearly.' However, the 'generation costs increase over-proportionately if only VRE are allowed'. In the latter case, the costs increase by 2 – 2.7 fold to achieve the same carbon intensity.'[365] According to OECD/MIT study, as against around 100 GW capacity where nuclear power is included in the generation mix, renewable with battery solution will require nearly 600 GW of capacity to reach 1 g/kWh of emission target.[366] If transmission costs are factored in, the costs of the renewable-only route will increase further.

The MIT Report

The MIT 2018 report on the "Future of Nuclear Power in a Carbon-Constrained World" which was also corroborated by the findings of the OECD report brings out that in the absence of nuclear power, the cost of achieving deep decarbonization targets increases significantly.[367] Their mathematical model shows that while various combinations of low and zero-carbon technologies can be deployed to mitigate carbonization, nuclear technology can make a substantial contribution toward deep decarbonization.

The MIT study has conducted two case studies in New England, USA, and the Tianjin-Beijing-Tangshan (T-B-T) region of China. In each case it has considered three scenarios (a) no nuclear allowed, (b) nuclear is allowed at nominal overnight capital cost ($5,500 per kWe for New England and $ 2,800 per kWe for T-B-T), and (c)nuclear is allowed with improved overnight capital cost ($4,100 per kWe for New England and $2,100 per kWe for T-B-T). The report's finding is:

> 'The cost of escalation seen in the no-nuclear scenarios with aggressive carbon constraints is mostly due to the additional build-out and cost of energy storage, which becomes necessary in scenarios that rely exclusively on variable renewable energy technologies.'[368]

The MIT model has shown that average generation cost increases without nuclear power in the generation mix. Conversely, the inclusion of nuclear power reduces the cost of achieving an emission target. This effect is most pronounced at carbon emission targets below 50 gCO_2/kWh (i.e., at 10 gCO_2/kWh and 1 gCO_2/kWh). **For achieving an emission target of 1 g-co2/kw,** the **inclusion of nuclear power reduces the cost to almost half the level without nuclear power** (with a lower overnight capital cost of nuclear technology ($4100/kWe in 2050). Interestingly, the **benefit of including nuclear in the generation mix to optimize costs is more pronounced for developing countries (China)** with a lower capital cost of construction of nuclear power plants. The mathematical model in the MIT study also brought out that the share of nuclear power in the generation-mix increases with lower emission targets.

The MIT report notes that the current world average of carbon-intensity of the power sector is about 500 gms of CO_2 equivalent per kWhr (g/kWh). For India, the corresponding figure is 700 gms of CO_2 equivalent per kWhr; India has pledged to bring it down to the current world level by 2030.

Land Foot-print

Meeting the demands of energy transition and the aim to reach net-zero targets require the expansion of low-carbon generating facilities. In such scenarios, direct land-use effects and the addition of infrastructure will have a direct bearing on emissions and cost. The challenge in India in reference to land availability for large power projects is to do with the acquisition of land. 15% of land conflict in India is attributed to power projects.[369] It, therefore, becomes empirical to assess

the land use requirements of low carbon generating sources of electricity to compare their viability and subsequent effects on costs and the environment.

For India, a life cycle land use assessment of nuclear, solar, and wind power concludes that nuclear has a significantly lower requirement in terms of land transformation. Nuclear power requires 6% of the total land area of Solar PV and 1/5th of that for wind power per GWh of electricity generated.[370] These elements also factor in the costs of generation. Moreover, the value deflation because of intermittency and land usage impacts of renewables coupled with increasing fossil fuel generation to meet post-pandemic demands has led to the highest increase in electricity prices, even in developed economies.[371] Thus an optimal nuclear – renewable energy mix is vital to offset the increment in generation costs due to the intermittent nature of renewables.

The French government company RTE in its report has mentioned 'Renewable energy development raises concerns about the use of land and the limitation of other uses.'[372] A study by the Nuclear Energy Institute has found that a nuclear facility requires 1.3 square miles of land per 1000 MWh of installed capacity. In contrast, a wind farm would need 260 to 360 square miles and solar PV between 45 to 75 square miles. (USA figures).[373] A study by Stanford-MIT experts has shown that in case Diablo Canyon Nuclear Power Plant in the US is closed down, a solar PV plant would require 90,000 acres of land in place of 900 acres for the existing nuclear power plant.

The land requirement for alternative pathways for nuclear and renewables required for India to reach the target of Net-Zero Emission by 2070 has been discussed in chapter 7 on renewables. Nuclear power will have the smallest land foot-print.

Diablo-Canyon Power Plant

A team of experts from Stanford and MIT has recommended extending the life of the Diablo-Canyon power plant in California, which the State has decided to close down. The extension would help 'reduce California's carbon emissions by an average of 7 Mt CO2 a year, and financial savings of $ 15-16 billion'. 'Operating Diablo-canyon facility as a poly-generation facility – with coordinated and varying production of electricity, desalination plant, and clean hydrogen –would provide multiple services to California'. 'Diablo Canyon hydrogen could cost up to 50% less than hydrogen produced from solar and wind power with a small fraction of the land footprint.'

Regardless of the fate of the Diablo Canyon Power Plant, the study holds important lessons for India.

Source: An Assessment of the Diablo Canyon Nuclear Plant for Zero-Carbon Electricity, Desalination and Hydrogen Production.

Competitiveness of tariff of Nuclear Power plants (NPPs) in India and other countries promoting nuclear as a carbon-free option

The finances of nuclear power generation take into account several cost heads – capital costs (cost of site preparation, construction, manufacturing, and financing of NPPs), plant operating costs (cost of fuel, maintenance costs, decommissioning funds, and waste management), and external costs that factor into tariffs.[374] The tariffs of NPPs vary across countries that adapt to nuclear power as a carbon-free resource in the energy mix owing to disparities in investment and financing capabilities, state of technology, and policy measures such as feed-in tariffs, regulated assets, carbon credits, etc.

The average tariff of nuclear power plant in India in 2019 was Rs. 3.43 per KWhr (USD 45.13/MWh). In the United States of America, the total cost per MWh is currently USD 27.03 for multiple unit plants and USD 39.64 for single-unit plants.[375] France had suggested a €42-48/MWh (USD 44.95-51.38/MWh) 'price corridor' for nuclear power set by the Energy Regulation Commission to allow French consumers to benefit from less expensive electricity by sharing nuclear power production with all consumers and not only EDF (France's historic electricity supplier).[376] In the UK for Hinkley Point C under the CfD the initial strike price is set at £89.50/MWh (USD 111.85/MWh) if the planned new nuclear power plant at Sizewell goes ahead. If Sizewell C does not go ahead on or before the Reactor One Start Date, then the Strike Price shall be increased with effect from the Reactor One Start Date by £3 MWh (USD 3.75/MWh) to £92.50 MWh (USD 115.60/MWh).[377] It may be mentioned that the operating cost of nuclear power is lower in the US as it's reactor fleet is old. If new reactors are built, the cost will go up. It would be more appropriate therefore to compare the Indian nuclear tariff with the tariff in France or UK.

Contribution of Nuclear Power to Employment and Economy in India

In terms of economic sustainability, investment in nuclear power is found to generate a larger economic impact in comparison with the other sources of generation. According to a recent IMF study, spending on nuclear energy can crowd in investment stimulating parts of the economy, "leading to the employment of both high and lower-skilled resources" more than other low-emission sources.

Nuclear power is now recognized as an essential component of industrialization in macroeconomic growth pathways, owing to its positive effects on electricity generation and price stability. For example, the United Arab Emirates identifies the role of the deployment of nuclear power projects for industrialization as a key to achieving economic diversification away from oil/gas extraction. The following section explains the contribution of nuclear power to employment and the economy in India.

Economy

- NPCIL is a profit-making, dividend-paying company with its instruments rated AAA, the highest credit rating.
- Nuclear power plants have so far generated about 755 Billion Units avoiding over 650 million tons of CO_2 emissions. Nuclear power generation has kept pace with the growth of total electricity generation, with the share of nuclear power remaining around 3% of the total generation since its inception. It is likely to increase with the completion of under construction, sanctioned, and planned nuclear power projects.
- The value of assets transferred to NPCIL at the time of its formation was Rs. 1313 crore. The total assets have grown manifold and by March 31, 2021, it stood at Rs. 1,14,152 crore. The Net Worth of the company has also grown manifold to Rs. 42,951 crore as of March 31, 2021. The profit before tax (PBT) of NPCIL has been steadily increasing, indicating the sound performance of the company.
- Since its inception, NPCIL has paid tax and dividends to the tune of about Rs 11785 crore and Rs 13174 crore respectively as of March 2021, thus positively contributing to the country's economy. Nuclear power tariffs have also remained comparable to those from contemporary units of other baseload electricity generating stations located in the region.
- NPCIL's contribution is likely to grow as the demand for electricity and the need for de-carbonization of the energy sector in view of the growing concern about the impact of climate change grows. NPCIL will continue to play its role in the transition to net-zero and in strengthening the economy of the nation.

Business Opportunities

- Setting up nuclear power plants requires huge supplies and services from the industry. This opens up a plethora of opportunities for businesses in the relevant sectors. As a result, the large business entities having received large orders have enhanced their manufacturing capabilities to the exacting standards thereby enhancing the product quality.
- The emphasis on the 'Make-In-India' initiative has also led more domestic business partners to participate in the sector. It will help strengthen India's credentials as a major nuclear manufacturing powerhouse.

Employment Potential

- With the expansion of the nuclear power program over years, employment opportunities, both direct and indirect, across the spectrum have increased. A significant number of people from relatively remote and backward areas, which otherwise have lesser avenues beyond their traditional means, could be benefitted from the installation of nuclear power plants.

- Large employment is generated with the contractors/ vendors and from business opportunities that emerged consequent to the increase in economic activity at the nuclear power project sites.
- Typically for a twin unit Nuclear Power Project (NPP), around 200 NPCIL employees are deputed to manage project activities and around 5000-8000 persons/year are employed through different contracts at the site for a period of 5-6 years during construction/ commissioning phase and an equal number are likely to be employed on related industrial activities in the public domain.
- In addition, employment also gets generated by businesses that emerge to meet the demand for various goods and services arising out of operating nuclear power stations and the resultant increase in economic activity in the areas around the site.
- About 1000 persons get direct employment in a twin unit operating station and equal numbers through different contracts to provide support services to the operating station and residential colonies during the operational life of around 60 Years.

Knowledge Management

- Nuclear Power being a high-end technology requires the development of people to the required standards. Thus, training and research always played a vital role in the development of the nuclear power program. The knowledge base was not only retained but also expanded in the country.
- Besides educational and research institutions, the expertise is shared with the industry for enabling them to develop products of required exacting standards. NPCIL's Directorate of Technology Development facilitates the development of indigenous vendors, particularly for Nuclear Specific Equipment. The equipment is designed based on the highest safety requirement, stringent quality control, and material specifications.
- NPCIL has a large pool of engineers and scientists with the requisite qualification and experience to carry out quality jobs in various domains, and the same is expanding.

Factors affecting the economic viability of NPPs, Financing Mechanisms, Access to clean energy finance

In liberalized electricity markets, the economic competitiveness of nuclear power is challenged as utilities compete to meet the given demand by supplying power at the lowest cost.[378] In the nascent phase, the upfront capital costs of the construction of NPPs are high. Moreover, the following characteristics with specific regard to nuclear power make financing particularly challenging:

1. The high capital cost and technical complexity of NPPs, present relatively high risks during construction (delays and cost overruns) and operation (equipment failures and unplanned outages), and management.
2. The relatively long period required to recoup investments or repay loans for NPP construction increases the risk from electricity market uncertainties.

3. The public perception of the nature of nuclear projects, gives rise to additional political and regulatory risks.
4. The need for clear solutions and financing schemes for nuclear waste recycle, radioactive waste management and decommissioning, which only governments can formulate.
5. The need for NPPs to operate at high capacity factors, preferably under baseload conditions. (OECD, 2009. The Financing of Nuclear Power Plants).[379]
6. An exhaustive, lengthy, and expensive permitting and licensing regime.[380]

High fixed to variable cost ratios are a challenge in markets where pricing and demand are uncertain. This is true of all low-carbon generating sources as opposed to fuel-based sources where the fuel itself is the principal cost.[381] Additionally, NPPs face new operational requirements to balance the intermittency of Variable Renewable Energy (VRE) technologies.[382]

Keeping in mind the low-carbon nature of nuclear power, the following strategies may be adopted (are adopted in a few countries where nuclear power is accepted as a low carbon source in the energy mix) to make it economically viable and to mitigate and better distribute risk among stakeholders:

(1) Increasing standardization in design and reducing the size of NPPs. Standardized designs can help reduce construction uncertainties and the time required to build new reactors, thereby attempting to reduce capital costs.

(2) Small modular reactors (SMRs) might be suitable for off-site construction. Also, given their relatively simpler design structure and passive safety measures, they are expected to have lower operational and maintenance costs.[383]

(3) Reviewing electricity market regulation to ensure that it provides a level playing field for long-term investments such as nuclear power that contribute to energy diversity and security (Government Initiative).[384]

(4) Modernization of existing NPPs facilitating life span extension.[385]

Policy support available in India to renewables may be extended to the nuclear sector

The growth in nuclear power can be facilitated with the extension of policy support that is currently available to renewables, which are as follows:

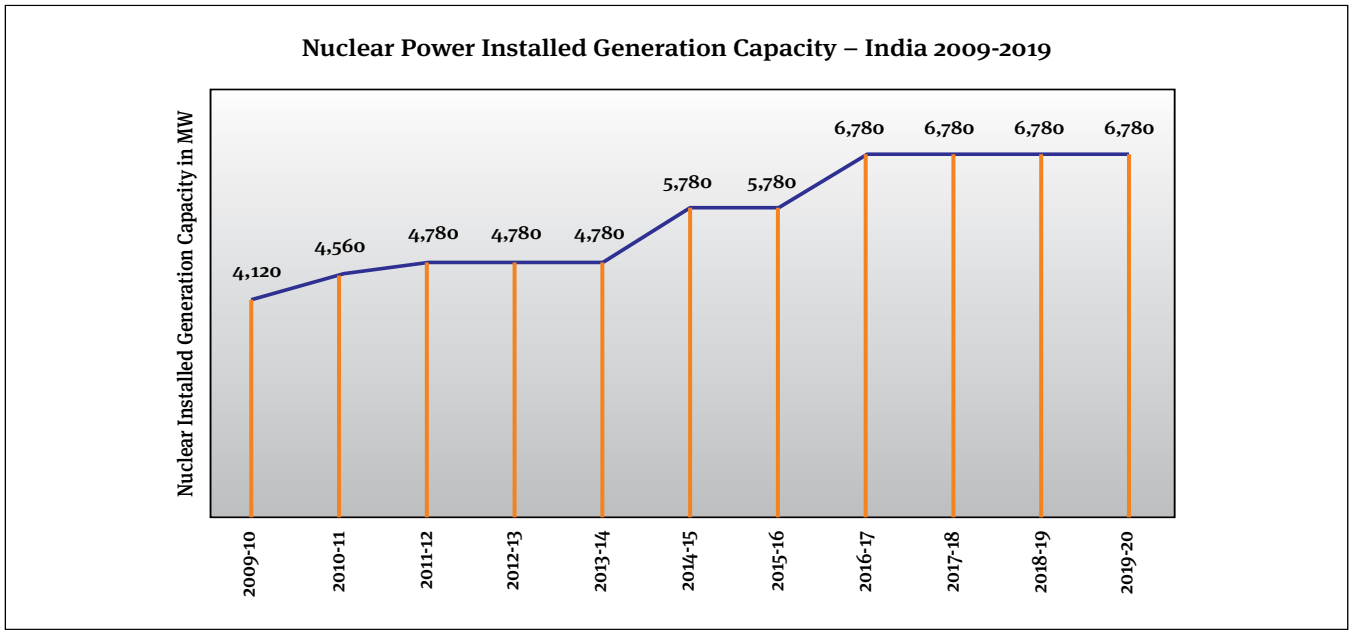
1. Nuclear power should be declared to be a clean energy and made eligible for all existing policies and benefits that solar/renewable energy has.
2. The existence of Renewable Purchase Obligation (RPO) targets and Renewable Energy Certificates (RECs) provides support to the renewable energy sector. RPOs may be converted into clean energy purchase obligations to include the nuclear power sector and facilitate it to meet its renewed targets.

3. Accelerated Depreciation may be extended to nuclear power investment. In the US, the tax code allows for accelerated depreciation of some form of nuclear power investment, by allowing assets used in the construction of NPPs to be depreciated over 15 years instead of 20.[386]
4. Comparable incentives may be provided to the nuclear power sector in line with how renewable sources are exempted from interstate transmission charges and transmission losses for a period of 25 years from the date of signing of the Power Purchase Agreement.
5. To provide a level playing field the nuclear power sectors should be given the 'must run' status like the renewables receives in India. NPPs run on a continuous basis and without the must-run status, there will be a steep increase in tariffs to overcome high capital costs.[387]
6. Borrowing for nuclear power projects in India is at commercial rates. However, if finances are procured from the National Clean Energy and Environment Fund, a soft loan that solar energy in particular receives, the tariffs would come down drastically.[388]

Changes necessary in government policy to retain nuclear power as an option to meet future energy needs of the country and to support grid stability

India has now proposed its nuclear power capacity to increase to 22,480 MW by 2031, a significant increase from the previous aim of 6,780 MW.[389] Moreover, India has surpassed its target of atomic-power generation in the first quarter of FY 2021, exceeding the target of 10164 million units (MUs) with an actual generation of 11256 MUs.[390] There has been a steady increase in the installed capacity from 2009-to 2017 as indicated in the graph below (Figure 21).

Figure 21: Nuclear Power Installed Generation Capacity – India 2009-2019.



Source: UNFCCC. (2021). India – Third Biennial Update Report to the UNFCCC. https://unfccc.int/sites/default/files/resource/INDIA_%20BUR-3_20.02.2021_High.pdf

If increased targets are to be met along with noteworthy achievements of atomic-power generation, they must be coupled with valid policy measures to retain the level of growth of nuclear power in keeping with the goal to reduce emissions and meet future energy needs. The target for generation by the nuclear sector itself will have to be ramped up substantially. According to mathematical modelling by IIT Bombay, R05N95 scenario with predominant share of nuclear power will be the most cost-optimum solution to attain net zero emission stage. This will require ramping up nuclear capacity to 3139 GW by 2070.

Financing

Increasing the share of nuclear power to meet renewed targets requires a considerable share of resources. Nuclear Power Plants are funded with a debt-equity ratio of 70:30, with the equity funded via budgetary support and internal generation of reserves and debt-funded via bonds and commercial borrowings, both short and long term from banks or the external sector on a limited scale.

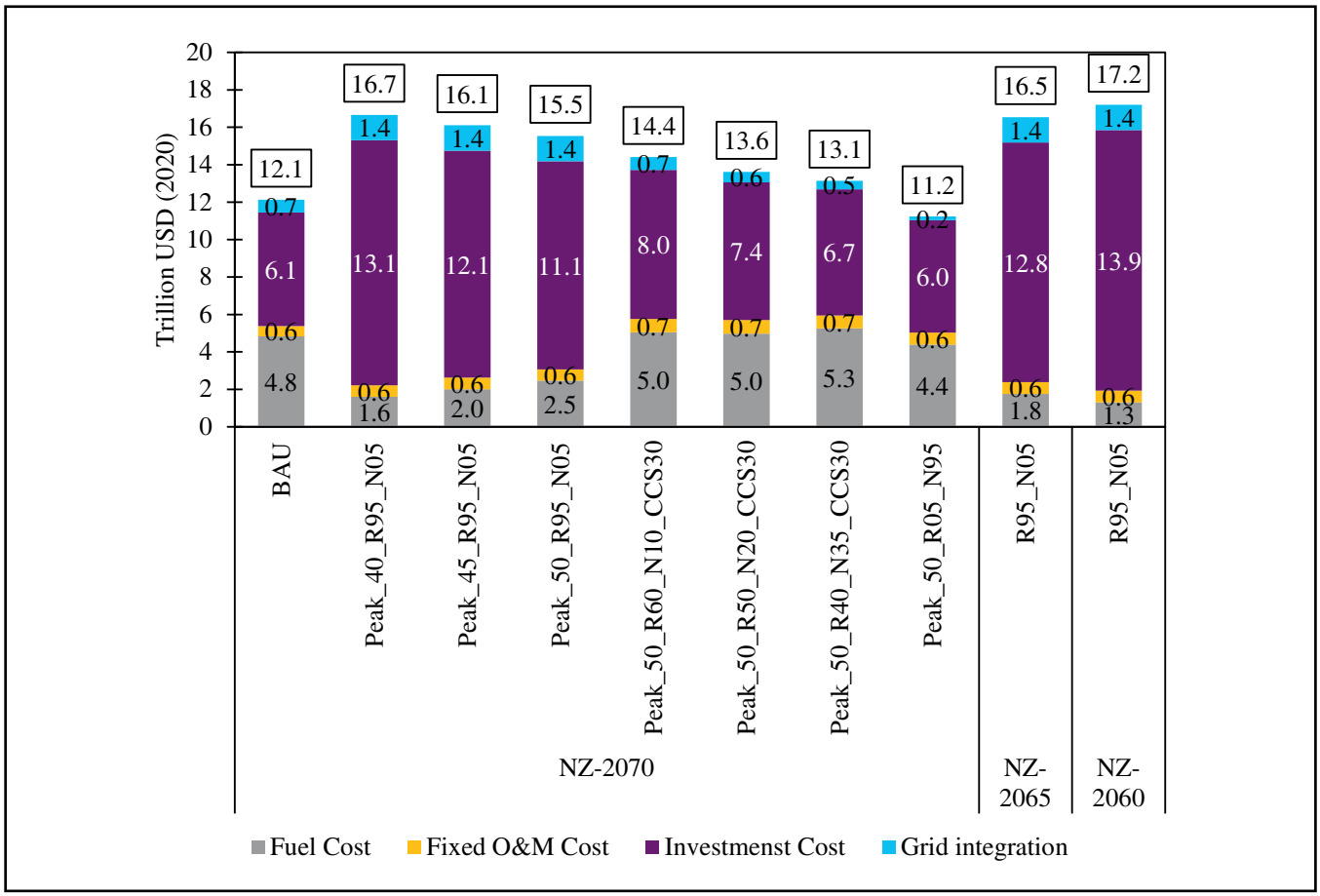
It is estimated that an amount of 220,000 crores will be required to complete ongoing projects over the next 10 years. In keeping with the debt-equity ratio, this would amount to Rs. 150,000 as debt and Rs. 66,000 as equity.[391] With the added proposition of the Indian Government to increase nuclear power capacity to 22,480 MW by 2031, this estimate is likely to increase.

In terms of its financial position, for the FY 2019-2020 the total assets of the NPCIL amounted to around Rs. 102,221 crores. Total liabilities amounted to Rs. 61,545 crores and net worth were reported as Rs. 39,900 crores.[392] It is therefore clear that the NPCIL's internal accruals are not remotely sufficient to meet the financing requirements. This requires a series of measures on the government's part in terms of policy initiatives. NPCIL on its part should continue initiatives to maximise internal resources through cost- optimisation and the time control in project implementation activities.[393]

Net Zero Emission and the role of Nuclear Power

According to the mathematical modelling done by IIT Bombay, a generation-mix with a predominant share of nuclear power (R05N95) is the most cost-optimum solution to transition to the net zero emission stage with a total cost of $11.2 trillion. The renewable heavy scenario (R95N05) will entail the highest cost at $15.5 trillion (Figure 22).

Figure 22: Net zero in 2070 with 10% green H2 demand— Cost of power sector transition under different scenarios



Source: IIT Bombay, Mathematical Modelling for the VIF Task Force Study – India's Energy Transition in a Carbon Constrained World. (Annexed)

The investment required in nuclear power from 2020 till 2070 is $5 trillion out of $11.2 trillion in the R05N95 scenario. This amounts to 45% of the total cost of transition. In terms of capacity, India will need a minimum of 284 GW nuclear power in R95N05 scenario and maximum of 3139 GW in R05N95 scenario in 2070.

The rapid increase in nuclear power in India's energy mix is demanded by a transition to a low carbon economy. Resources for ramping up the nuclear program at this scale and speed cannot be generated internally by the NPCIL. They also go beyond Rs 3000 crores per annum for 10 years announced by the government. Since there are limitations for nuclear sector to attract equity from the stock market, there is a need for the government to step in. Recognizing pre-existing technology self-reliance and significantly lower capital cost of a made-in-India nuclear power plant, a domestic consortium consisting of BARC, a power utility and a manufacturing Industry should develop a domestic nuclear power plant as a product for marketing it in India and abroad. Once such a competitive domestic product has been developed, one may consider opening this

sector for progressive private investments thereby supplementing Government investment. It is interesting to note that UK and UAE have also opened the sector to FDI, even though the latter is rich in terms of capital resources as well as hydro-carbon fuel. Participation of foreign companies on a BOT basis also ensures price discipline and risk-sharing on the part of the foreign vendor. Perhaps the biggest incentive to nuclear power in these countries is recognition of carbon cost, which gives nuclear power, like renewables, an advantage in terms of tariff over power generation based on fossil fuels.

The US and UK models are different from the structure of the nuclear power sector in India. Perhaps, the French case offers greater similarities. Like NPCIL in India, nuclear power generation is in the hands of a government-owned company. EDF, which has a monopoly in nuclear power generation has 86% government ownership. It will be instructive to recall the recommendation of RTE, a French government transmission company, which recently submitted its report to the French government:

> 'New reactors represent extremely capital-intensive investments, and the experiences of recent years show that it will not be possible to develop them without robust government support, whether in the form of contracts for difference or direct public investment. They can be economically attractive as long as financing terms are consistent with those available to other low-carbon technologies.'[394]

The incentives given to the nuclear power sector are covered in detail in the following chapter. Nuclear power can also be used for the production of hydrogen needed for sectors like steel production, where emissions are hard to abate. This is covered in chapter 13. Development of SMRs and advanced reactors could bring about a major revolution in the use of nuclear power. SMRs being small in size, reduce land requirements and can be deployed in brown-field sites in place of coal-based power plants which may be closed down. Their modular construction will also reduce the cost and time involved in commissioning new nuclear power plants. More details can be seen in the write-up on the subject in the following pages.

Small Modular Reactors (SMR) – An additional strategy to supplement nuclear power in India

Factors such as high cost and delays in construction in the new projects leading to cost escalations have affected the growth of nuclear power worldwide. SMR technology holds the promise of bringing down upfront total capital costs (leveraging economy of mass production rather that of larger size), as well as providing flexible generation needed to provide balancing power to renewables, which will have an increasing share in the future grid. "Small Modular Reactors (SMRs) are nuclear power plants that [are] smaller in size (300 MWe or less) than current generation baseload plants (1,000 MWe or higher). These smaller, compact designs are factory-fabricated reactors that can be transported by truck or rail to a nuclear power site."[395]

The output is scalable by putting a number of smaller units to get larger capacity. Synergistic deployment of such factory manufactured made-in-India SMRs along with medium size 700 MWe PHWRs that have been standardized and are being deployed in fleet mode appears to be an optimum strategy for rapid scale up of nuclear power capacity in India.

Advantages of SMRs:

- Small size – offers siting flexibility in locations unable to accommodate larger nuclear plants.
- Modularity – offers flexibility for incremental power additions.
- Smaller size and the prediction of shorter delivery times reduces upfront investment needs for SMRs compared to larger reactors. The result is a lower financial risk for potential customers and investors, which could make SMRs a more affordable option.
- Enhanced safety and security – SMRs are designed with more passive safety features.
- Lower power levels – hence smaller level of decay heat making safety management simpler and cheaper. The release of hazardous radiation elements to the environment following an accident will be much reduced.
- SMRs that provide only a few megawatts, could bring electricity to remote, rural native communities or small islands (where fossil-based generators e.g. Diesel are more prevalent) or military bases.
- SMR flexibility capabilities- enhanced load-following and non-electric applications could bring system-cost benefits and new market opportunities, thus facilitating access to nuclear energy in regions and sectors where the use of large nuclear power plants is more limited. SMRs will use a tiny fraction of land compared to wind and solar. Small reactors can power retired fossil sites, can integrate with renewables, and be used for heat, desalination, and other applications such as hydrogen generation.[396]

Disadvantages of SMRs:

- Cost-effectiveness in terms of lower capital cost requires certain optimum numbers to be mass-produced/deployed. Cost per MWe would be much higher as compared to a large reactor till there are enough orders to reach optimum production rate. Sustaining the right level of order book could also be a serious challenge.
- Being a new design as well a new mode of reactor supply arrangement, the licensing process would need to be retailored and this can take time and entail high cost
- Public acceptance particularly since siting criteria would need adjustments.[397]

SMRs as part of India's Energy-mix:

Nuclear capacity addition in India is required to be very large considering the need to bridge what could be the largest differential between the current level of energy use and the level we need to realize for fueling the growth in our economy in a net zero world. To bridge this gap in a manageable way, we do need large capacity reactors to be deployed. Made in India 700 MWe PHWR is the right work horse in this context and the strategy to deploy multiple fleets of such reactors is the right one in Indian context. However, a large number of existing thermal power plant are expected to be retired in coming years. Some of the sites vacated by retiring coal plants could be leveraged to locate SMRs by designing them to suit such sites. A consortium between a project developer like NTPC, BARC (as reactor designer) and a manufacturing industry could develop such a product and market it within the country and abroad. Experience has shown that manufacturing nuclear reactors in India (for that matter all high tech. equipment) is a much cheaper proposition (cost may be roughly half) than getting them imported from abroad. Further India has proven experience of design, development and manufacture of such products that have demonstrated world class performance.

Following points need to be noted in this context:

- India has indigenously built an 83MWth (30MWe) small nuclear reactor for ARIHANT. It can be categorized under the SMR category with far higher level of complexity.
- The DAE and Indian industry already possess the know-how for building SMRs. Further development of AHWR a 300 MWe reactor system with minimum impact in public domain even in worst case accidents was developed in DAE. This attribute can be integrated in made in India SMR (unit size say ~ 100 MWe) that is factory assembled and rail transportable. A prototype would need to be designed and built. Following this, deployment of such systems can be done in 3-4 years as against 9-10 years taken by large capacity new builds.
- Since it is indigenous, and with a country already constructing nuclear power plants, with all infrastructure for component manufacturing, regulatory framework, and operational experience of large reactors in place, the cost can be much lower than the large reactors.
- This SMR can be used for non-power applications too such as desalination, hydrogen/ methanol production, Pulp & paper manufacture, etc. High temp gas-cooled Reactor (HTGR) is also being developed by BARC which can be useful for direct Hydrogen production without going through electricity generation.
- SMR being flexible (load following feature) can be useful in hybrid composition with renewable providing dispatchable power on one side and cogenerating hydrogen on the other. Acceptability of nuclear as baseload alone may not win the support of policymakers.

The only SMRs currently in commercial operation are KLT 40 S of Russia with 35 MWe capacity since December 2019 and High Temperature Reactor HTR PM of China with 100 MWe capacity since December 2021. NuScale Power has developed an SMR of 45 MWe capacity, which has received design approval from the US NRC in August 2020. In October 2020, the US Department of Energy (DOE) awarded funding to Terra Power for the development of the NATRIUM reactor, as part of the Advanced Reactor Demonstration Program. Early movers include CAREM of Argentina with 25 MWe capacity, which is under construction.[398] India can join the group of countries developing SMR technology. This would however require funding to DAE for R&D of this technology and a prototype. In US, UK, and France, this is being provided by Government.

Development of high temperature reactors (presently underway at BARC) along with technologies for thermo-chemical splitting of water (presently underway at BARC and ICT, Bombay) also need to be accelerated. Such a development would enable direct splitting of water without having to go through generation of electricity for electrolysis of water. Apart from gain in energy efficiency thereby making hydrogen production cheaper as compared to electrolysis route, this should considerably reduce the demand on electricity generation capacity needs in the country which otherwise could become as high as 80% of the total energy consumption.

Several countries have also undertaken research on the development of HTGRs. These include US, UK, Germany and Japan. However, &D on HTGR ntries have undertaken reserach .China has already commissioned a twin 100 MWe High Temperature Gas Cooled Reactor-Pebble Bed Modules (HTR-PM) driving a single 210 MWe turbine to demonstrate this technology. We need to accelerate both the high temperature reactor technology as well as technology to take laboratory scale development of thermochemical splitting of water to commercial scale. In absence of such a development, one would be forced to resort to electrolysis of water on a large scale leading to higher costs as well as a much larger investments in the electricity system in the country. In the interim however large scale dependence on electrolysers seems inevitable. Considering the scale and importance of hydrogen economy in the net zero target to be reached by 2070, it is essential that heavy R&D investments are made in this crucial area with a mission mode approach.

There will be a continued requirement for bigger reactors for meeting large-scale energy demand. SMRs can complement the large reactors where the demand is smaller, and can be located in existing brown-field sites of thermal power plants, which are being retired. In addition, the proposed mode of SMR implementation would open a different mode of deployment of nuclear power which would build industry capability in nuclear business enabling a more rapid capacity deployment going forward.

Russian SMR

Rosatom has developed KLT-40 S reactor with 35 MW capacity, which is in commercial operation. With 2 units of KLT-40 S reactor, it has a thermal capacity of 300 MW. It is providing heating to Pevek, a major Arctic port in Russia's north-east since 2019.

Rosatom has since come with RITM - 200 series which offers both floating solution (100 MW electrical capacity) and land based solution (110 MW electrical capacity). This is however, at a concept design stage. The land-based version has 2 RITM reactors of 55 MWe capacity each. Their thermal capacity is 380 MW (2x190 MW). It has a design life of 60 years. Plant area is 15 acres (0.06 square kms) with a construction period of 3-4 years. Modular design allows for more units to be added later. It includes both active and passive systems. Apart from electricity generation, the reactors can be used for supplying industrial heat, desalination and hydrogen production.

NATRIUM

Future grid will have high salience of variable renewable energy. This will increase demand for balancing power or flexible generation to provide back-up electricity when the sun is not shining or the wind is not blowing. Terra Power, a start-up floated by Bill Gates has come up with a novel solution. Together with GE Hitashi Nuclear Energy, it has developed a 345 MWe sodium fast reactor and gigawatt-hour scale, molten salt energy storage. 'The storage can boost output to 500 MWe of power for more than five and half hours when needed. This innovative combination creates an integrated energy solution that provides clean, firm generation for electricity grids that have a growing mix of renewables.'[399] In October 2020, the US Department of Energy (DOE) awarded Terra Power funding, as part of the Advanced Reactor Demonstration Program.

In contrast to a conventional light water reactor, where nuclear fission is used to heat water under pressure, Natrium reactor uses molten sodium metal as a coolant. 'Because sodium has a much higher boiling temperature than water, the coolant would not have to be pressurized, reducing the plant's complexity and cost. The sodium would transfer its heat to molten salt, which could then flow directly to a steam generator or to a storage tank, to be held to generate steam and electricity later.'[400] The molten salt storage tank could be used to ramp up and down the energy output, while the reactor continues to run steadily. The reactor is to be built in Wyoming. 'TerraPower hopes to market a Natrium plant for less than $ 1 billion'.[401]

High Temperature Gas Cooled Reactors

High Temperature Gas Cooled Reactors (HTGR) will have a role are expected to provide most cost-optimum solution for production of green hydrogen through thermos-chemical splitting of water. A number of countries including US, UK, France and Japan have announced R&D program for development of HTGR. China is the first country to develop and connect HTR-PM reactor to the grid.

China National Nuclear Corporation (CNNC) announced on 20th Dec 2021, connection of the world's first High Temperature gas cooled Reactor (Pebble bed Modular) (HTR-PM) to the grid. It is also the first fourth generation (GEN IV) NPP and also the world's first demonstration project to commercialize high-temperature gas-cooled nuclear power reactor technology. With this, China has become one of the few countries mastering the GEN IV technology.[402]

The plant features two small 250MWt reactors that drive a single 210 MWe turbine. It is owned by a consortium led by China Huaneng (47.5%), with China National Nuclear Corporation subsidiary China Nuclear Engineering Corporation (32.5%) and Tsinghua University's Institute of Nuclear and New Energy Technology (20%), which is the research and development leader. Chinergy, a joint venture of Tsinghua and CNEC, is the main contractor for the nuclear island.[403]

HTR- PM are SMRs with Generation IV Safety eliminating off-site emergency response through a Meltdown-Proof Reactor. They are supplement to large reactors, especially to replace coal-fired power plant in population dense region, co-generation of electricity (steam up to 560°C) and hydrogen with a huge market potential. [404]

The HTR-PM follows on from China's HTR-10, a 10 MWt high-temperature gas-cooled experimental reactor at Tsinghua University's Institute of Nuclear & New Energy Technology, which started up in 2000 and reached full power in 2003. A further 18 such HTR-PM units are proposed for the Shidaowan site. Beyond the HTR-PM, China proposes a scaled-up version - HTR-PM600 - with one turbine rated at 650 MWe driven by six reactor modules. Feasibility studies on HTR-PM600 deployment are under way for 4 provinces. [405]

IAEA Report – Nuclear Energy for a Net Zero World: Country Statements:

Emissions reductions pathways comprise of two key elements to achieve decarbonization – widespread leveraging of low carbon energy resources which inevitably results in enhanced electrification of economies and development and deployment of low carbon energy carriers to hard to abate sectors of industry and transport. Nuclear power fits the criteria by being attributed as the power source with the lowest level of GHG emissions, round the clock availability, minimum land footprint, operational feasibility and versatility to decarbonize hard to abate activities.[406]

The following section provides excerpts from country statements published in a 2021 report by the IAEA titled Nuclear Energy for a Net Zero World, indicating the importance of nuclear power in the energy mix vis a vis its decarbonization merits.

"Nuclear energy is also an important part of Canada's non-emitting energy mix.

It is clear that in order to achieve Canada's ambitious climate targets by 2050, we must incorporate the use of all available sources of non-emitting energy and technology. That is why Canada, with a full spectrum of nuclear capabilities, innovative technology and expertise in low carbon and sustainable solutions, is ready to work w like-minded countries on the road to a just and clean transition that incorporates a diverse energy mix including nuclear energy."

Jean-François Tremblay, Deputy Minister of Natural Resources, Canada.

"As a clean, low-carbon and efficient base-load energy source, nuclear power plays an important role in the achievement of the UN 2030 Agenda for Sustainable Development. It is also an important option for China to secure the energy supply, optimize the energy mix, and achieve the goals of peak carbon emissions and carbon neutrality."

ZHANG Kejian, Chairman, China Atomic Energy Authority.

"In Finland, nuclear power is an integral and growing part of our energy mix. Our national goal is to become climate neutral — net zero — by 2035, a task where we clearly need all available clean energy technologies."

Riku Huttunen, Director-General, Energy,
Ministry of Economic Affairs and Employment, Finland

"Nuclear power is a proven technology for decarbonization. To realize carbon neutrality, it is important to pursue every option, including nuclear power. Therefore, in addition to the further safety improvement of light- water reactors, it is necessary to proceed with R&D for nuclear power innovation by advanced technologies."

KAJIYAMA Hiroshi, Minister of Economy, Trade and Industry, Japan

"Nuclear power is the major source of low-carbon electricity generation in our country. Its share in the electricity generation mix is more than 20%. Greenhouse gas emissions from nuclear power plants (NPPs), throughout the entire life cycle, are close to those from wind power. NPPs in Russia prevent more than 100 million tonnes of carbon dioxide equivalent emissions annually — a reduction of approximately 7% of total emissions in Russia."

Ruslan Edelgeriev, Special Presidential Representative on Climate Issues and Adviser to the President, Russia

"Nuclear power continues to be an important source of reliable clean electricity, supplying around 17% of the electricity generated in the UK in 2019. It is an energy-dense technology which provides large volumes of power from a very small land area and can reduce system costs at low levels of emissions. But, with the existing nuclear fleet largely retiring over the next decade, we are taking steps to maintain nuclear's important place in our energy mix."

Greg Hands, Minister of State for Energy, Clean Growth and Climate Change, The United Kingdom

Source: IAEA. (2021) *Nuclear Energy for a Net Zero World*. https://www.iaea.org/sites/default/files/21/10/2101495e_bro_net_zero_world_web_v3_reduced_size.pdf

Recent statements by state heads in support of nuclear power

French president Macron said that to keep energy costs at a "reasonable" level and reduce dependence on imports, France must continue to save energy and invest in domestic carbon-free energy production.

"This is why, to guarantee France's energy independence, to guarantee our country's electricity supply and achieve our objectives, in particular carbon neutrality in 2050, we are going, for the first time in decades, to relaunch the construction of nuclear reactors in our country and continue to develop renewable energies."

"These investments will allow us to live up to our commitments. As we close COP26 in Glasgow, this is a strong message from France," he added.[407]

Japan's Prime Minister Fumio Kishida recently announced that the country would use nuclear reactors to help reduce its own and other countries' dependence on Russian energy.

He said Japan would address the "vulnerability of our own energy self-sufficiency" by broadening where it buys energy from, promoting renewables and using nuclear power to diversify its sources of generation. [408]

Chapter 11 : Nuclear Power: Incentives Given by Other Countries

Climate change promises to bring a nuclear renaissance. Countries are attempting to increase the share of non-fossil fuel based generation in an effort to achieve their climate goals. Prior to the pandemic, electricity generated from nuclear sources has increased for seven consecutive years and covers 10% of the total global generation.[409] It can provide both - stable, base-load power and emission-free energy. Policy support to the nuclear sector is therefore essential to augment energy security while lowering the economy's carbon footprint. The following incentives and policy support are available to the nuclear sector in countries where nuclear is accepted as a clean energy source:

United States of America

Though the country has the highest private sector participation in generation of nuclear power, the government is comprehensively involved in regulation, funding and setting energy security goals that are inclusive of nuclear energy.

i. Energy Policy Act, 2005

The Energy Policy Act of 2005 is slated to have made compelling changes in the funding policies of nuclear energy in the United States. It aimed at providing tax breaks to both producers and consumers. The following were the significant inducements provided for nuclear energy:

1. Production tax credit (PTC) of 1.8 ¢/kWh for the initial 6000 Mwe in the first 8 years of operation of new nuclear capacity for plants that are in service before 31st December 2020 and with the PTC maximum value of USD 6 billion for the 8-year period. This has been extended to include reactors entering into service after the said date in 2018. However, PTCs can only be claimed after the generation begins and inflation is adjusted for.

2. Federal risk insurance amounting to USD 2 billion to cover regulatory delays in full power operation of the first 6 advanced new NPPs.

3. Rationalized tax decommissioning funds.
4. Federal loan guarantees for advanced nuclear technologies covering up to 80% of project cost.
5. Extension of 20 years of the Price Anderson Nuclear Industries Indemnity Act that aims to compensate the non-military nuclear industry against liability claims in which a no-fault type insurance system is created to industry fund the first USD 15 billion. [410]

ii. The Consolidated Appropriations Act, 2018

The Consolidated Appropriations Act of 2018 includes over USD 1.2 billion support for the DOE Nuclear Energy programs and USD 992 million for the Nuclear Regulatory Commission. The bill also allows reactors entering service after December 2020 to qualify for tax credits and enables the US Secretary of Energy to allocate credits for up to 6000 MW(e) of new nuclear capacity which enters service after 1 January 2021.[411]

iii. The American Job's Plan, 2021

President Biden's recent climate action plan promises to leverage the carbon-pollution free energy provided by existing sources like nuclear and hydropower, while ensuring those facilities meet robust and rigorous standards, for worker, public and environmental safety and justice.[412] The administration's focus will be on managing nuclear energy cost, safety and waste-disposal challenges. The climate plan also lists "reclaiming" domestic uranium mining as a goal.[413] The existing Advanced Research Projects Agency–Energy (ARPA-E) will be boosted with an ARPA-C agency for climate technology goals in particular. Within the ARPA-C initiative are "affordable, game-changing technologies to help America achieve our 100% clean energy target", that include small modular reactors at "half the construction cost of today's reactors".[414]

iv. US Infrastructure Act, 2021

The Infrastructure Investment and Jobs Act, signed into law in November 2021, consists of a number of provisions for nuclear infrastructure. In an effort to promote nuclear as a clean energy source and prevent the premature retirement of existing NPP's, the following provisions have been laid out:

USD 6 Billion Civil Nuclear Credit Program: The credit program is established to preserve the existing nuclear fleet and prevent the premature shut downs of NPPs that would otherwise retire and are certified as safe to continue to run. Plant owners/operators need to apply for the credit program with a need based justification. The program also supports plants that support domestically produced fuel. The 6-billion-dollar program is likely to start within four months of November 2021 and anticipates to preserve significant amounts of clean electricity and high paying jobs. [415]

The Act also provides about USD 21.5 billion in funding for clean energy demonstrations and research hubs focused on the next generation technologies needed to help achieve the USA's goal of reaching net-zero by 2050. The vast majority of this is earmarked for clean hydrogen (USD8 billion) and carbon capture, direct air capture and industrial emission reduction (more than USD10 billion), with USD2.5 billion earmarked for advanced nuclear through the DOE's Advanced Reactor Demonstration Program (ADRP).[416]

v. Zero Emissions Credit

Recognizing that NPPs should be offered incentives to continue operation because they provide the benefits of clean electricity and a stable base load power, the US has implemented a Zero Emissions Credit (ZEC) to ensure the value of generation without emissions is factored into decisions about the future of the NPP. Most state programs involving ZECs state that load-serving entities (i.e., utilities) are obligated to buy from nuclear generators. ZEC prices are largely based on an established social cost of carbon, intended to reflect the environmental costs of carbon emissions, with some adjustment allowed for changes in market trends or power costs. Programs in Illinois, New York, New Jersey, and Ohio show ZEC prices ranging from $10.00 per megawatt hour (MWh) to $17.50/MWh.[417]

A report by the Brattle Group in 2016 on ZECs revealed that, 'the retention of existing nuclear generating plants, even at a modest premium, represents a cost-effective method to avoid CO2emissions and enable compliance with any future climate policy ... at reasonable cost. Sustaining nuclear viability in the interim will reduce near-term emissions, and is a reasonable and cost-effective insurance policy in the longer term.'[418]

France

France has one of the highest shares of nuclear energy with more that 70% of its electricity being generated from it. The role of nuclear power was central to the law that established the guidelines for energy policy and security in 2005. France established the Nuclear Power Council in 2008 underlining the importance of nuclear technologies to France in terms of economic strength, notably power supply. It is chaired by the President and includes the prime minister as well as the cabinet secretaries in charge of energy, foreign affairs, economy, industry, foreign trade, research and finance[419]. The energy policy revised in 2018, recognizes that nuclear energy will be the backbone of the French Energy Strategy with a 50% share in the energy mix in 2035.[420] Nuclear power has been one of the core points of President Macron's re-industrialization plan for 2030. USD 9.2 billion has been allocated towards the development of clean energy technologies which includes the building of small modular reactors for nuclear power.[421] This is in keeping with RTE's (France's electricity transmission operator) report revealing that the cheapest way for France to reach its net-zero targets by 2050 would be through the construction of 14 new reactors, including SMRs.[422]

The key player in the nuclear sector is EDF, which owns and operates all the nuclear power plants in France. The French government has 83 percent share in the company. Under European Commission guideline, it is obliged to sell part of its output to other suppliers, who may be its competitors. This is a part of the origin of the ARENH system of supply of electricity at regulated price. The acronym ARENH stands for 'Accès Régulé à l'Electricité Nucléaire Historique' (Access to regulated nuclear electricity). This came into being in December 2010 under the European Commission law **NOME - Nouvelle Organisation du Marché de l'Electricité (New Organisation for Electricity Market)** with the following objectives: (i). To allow consumers to benefit from the competitiveness of the incumbent nuclear fleet and (ii). To allow competition to develop on the supply market.

The French tariff for nuclear sector consists of two parts. EDF has to sell 100 TWhr or 25 % of its output (estimated annual output being around 400TWhr), at regulated price (ARENH) of Euro 42 per MWhr. It is however, free to sell the balance 75 % of its output at market price. This arrangement is expected to remain in place till 2025 when it will come up for review. The regulated price is established taking into account different elements of cost:

> "Regulated tariffs are established by adding the price of regulated access to incumbent nuclear electricity (known by the acronym "ARENH"), the cost of the electricity supply complement which includes the capacity guarantee, transmission costs and marketing costs, as well as a normal rate of return on investment. This method aims to ensure that these tariffs can be "challenged" by alternative suppliers (other than EDF) , i.e. they are able to offer consumers market products at prices equal to or lower than the regulated sale tariff."

The system provides for long term price stability with a price fixed for 15 years period. This is fixed taking into account capacity cost, marketing cost and a certain return on investment. This represents a cost-plus system, where not only EDF's costs are taken care of, but a normal rate of return on investment is assured. This is a major incentive for the nuclear sector.

The EDF however has complained that the ARENH mechanism amounts to a double jeopardy:

> 'EDF CEO Jean-Bernard Lévy described the ARENH mechanism in 2019 as a real danger and EDF's biggest handicap. For them, the mechanism is an option to their disadvantage. That is, if the market price exceeds the ARENH price then everyone wants ARENH and EDF will sell its product at the ARENH price. However, if the market price is below the ARENH price (which was the case between 2015 and 2017) then nobody asks for ARENH and EDF must sell its production on the market at a price lower than ARENH. According to them, they have the choice between losing or losing.'[423]

There is however the other side of the coin. 73 alternate suppliers (other than EDF) anticipating high prices on the wholesale markets, had requested upto 147 MWh of electricity supply at ARENH prices during 2020. Applying proportionate reduction in order to remain within the ceiling of 100 TWhr, each supplier was allotted 100/147 = 68% of its demand.

> 'But then came the pandemic, the demand shock and the resulting fall in wholesale prices. Suppliers who thought they had escaped the market mechanisms found themselves obliged to buy electricity at a price of 42€, which they could not sell in full to their customers. They will therefore have to dispose of the surplus on the wholesale markets, the evil entity which now has average prices of around €20.'[424]

Two of the suppliers tried to invoke Force Majeure clause to escape their contractual obligation. This was turned down by the French regulatory authority CRE. This brings out the other dimension of the regulated price mechanism, which ARENH represents:

> 'The regulated access price amplifies the losses that suppliers incur because it is an option until they subscribe to it, but it is an obligation to withdraw megawatt-hours once subscribed.'[425]

The ARENH mechanism affects only part of the EDF balance-sheet. It has the flexibility to sell the bulk of its produce in the open market. While ARENH price governs 100 TWhr or 25 % of EDF output, it can sell the balance 75 % at the wholesale electricity price. According to recent trends, the latter are higher than the ARENH price and continue to maintain an upward trend. While ARENH price remains fixed at Euro 42 per MWhr, the French wholesale electricity price reached Euro 172 per MWhr in October 2021 according to Statista. [426]

This was more than four time the ARENH price. By the end of the year, the wholesale electricity prices went up higher. According to EDF website, the electricity wholesale price, which was Euro 50 per MWhr at the beginning of the year, reached Euro 222 per MWhr by 8th December 2021. [427]The higher price in the wholesale market should provide EDF higher revenue and profits even if the ARENH price mechanism may not have worked in its favour at times .

There has been subsequent increase in the volume of electricity to be sold by EDF at regulated prices. The French Economy Minister Bruno Le Maire announced recently a plan under which EDF will sell 'an additional 20 terawatt-hours of electricity at reduced prices to its competitors, on top of 100 terawatt-hours it already had agreed to deliver to them under a mechanism known as ARENH'[428] The measure is aimed at providing a cushion to the consumers by limiting increase in electricity price to 4%. The EDF said that the new measure 'could wipe €7.7 billion, equivalent to $8.82 billion, off its earnings this year. The precise effect will depend on market power prices'. There was a 15 percent drop in EDF's valuation.

While the above measure increases the volume of electricity sold by EDF in the regulated market from 25 to 31 percent, it can still sell the bulk of its produce (70%) in the open market, where the wholesale electricity prices are four times higher. 'The trouble for EDF, analysts said, is that it has sold forward most of the power it expects to generate this year. As a result, it will have to buy power at high market prices to sell to rival suppliers at a lower, government-mandated price of €46.20 a megawatt-hour'. [429]

Are the high electricity prices in the wholesale market a temporary phenomenon? What if these prices drop? The whole sale prices in European market are a function of two factors – high gas price and carbon price. As the EDF site mentions:

> 'The strong increase in the price of electricity is explained by considerable (strong) hike in prices of gas and carbon price (which has influence on the cost of production of power plants based on fossil fuel). The rise in commodity prices can be explained in part by the strength of global economic revival.' [430]

Even if the gas price moderates, the mounting climate concerns will ensure that upward trajectory of carbon price in Europe will continue. The carbon prices in EU have gone up from 50 Euro per ton to more than 80 Euro per ton now. This has given EDF a built-in premium for emission free electricity. Renewable electricity in Europe depends upon gas to provide balancing power. This is not only subject to commodity price fluctuations, but also attracts carbon price pushing up the cost of renewable electricity.

RTE, the French government grid company has published its report on French energy options in making a transition to low carbon economy. It has debated 6 different generation-mix consisting of renewables, nuclear and other energy sources. One of the key recommendations of the report titled Energy Pathways to 2050 is:

> 'The study concludes with a fair degree of confidence that the scenarios that include a nuclear fleet of at least 40 GW (N2 and N03) may, over the long term, result in lower costs for society than one based on 100% renewables and large energy farms'.[431]

Domestically, French government might continue to pressurize EDF to sell more electricity at regulated prices in order to protect French consumers from the sharp rise in electricity prices. However, as long as EDF has flexibility to sell bulk of its produce at wholesale electricity prices, and the latter remain high, or it can export, it will have a cushion. As a report of RTE, the French Transmission company put it:

> 'In an interconnected power system and with neighbouring countries relying heavily or mostly on fossil fuels, France does not run the risk of incurring stranded costs by developing or maintaining its low- carbon generation fleet. Electricity exports are profitable from an economic standpoint, as the prices on the European market usually depend on fossil fuel prices and the carbon price on the EU-ETS market.' [432]

France, along with a group of central and eastern states have advocated for nuclear power to be included in Green Taxonomy at EU level. This should ensure cheaper financing for nuclear power plants, which have high upfront capital costs. This will further increase safeguards for the nuclear sector.

In India, nuclear sector has no such cushion in terms of carbon price or allowance for producing emission-free electricity. The government may therefore consider some mechanism to compensate nuclear power for providing emission free electricity. The Nuclear sector's case is particularly strong, because it provides, stable baseload power, unlike the renewables, which are emission free but intermittent and have to be backed by a stable base-load electricity source.'

Japan

Japan's 5th Basic Energy Plan presents nuclear power as "an important source contributing to the stability of the long term energy supply and demand structure" with an objective to increase the share of nuclear power to 20-22% in its energy mix by 2030.[433] The draft energy policy released in 2021 retains the importance given to nuclear energy to support its decarbonization objectives. Following the Fukushima incident, Japan has incorporated several laws to continue to keep nuclear in the energy mix while addressing the safety concerns. Two prominent ones being – 1. the Reactor Regulation Act. The purpose is to ensure that the uses of nuclear source material, nuclear fuel material and reactors are limited to peaceful uses in accordance with the spirit of the Atomic Energy Basic Act, and also to provide necessary regulations on refining activities, fabricating and enrichment activities, interim storage activities, reprocessing activities and waste disposal activities, as well as on the installment and operation of reactors in order to prevent radioactive substances from being released at unsafe levels from nuclear facilities or installations, as a result of either a severe accident or a large scale natural disaster and 2. Designated Waste Final Disposal Act to prescribes the implementation of disposal procedures, a funding mechanism for disposal costs, and a systematic site selection process. Besides, Japan also has an Act on Special Measures Concerning Promotion of the Development of Nuclear Power Site Regions to promotes the development of regions where nuclear power plants are located by providing financial and other assistance, and protection against the spread of nuclear accidents.[434]

United Kingdom

i. Contract for Difference – UK's key mechanism for supporting low carbon electricity generation:

Nuclear Power Plants (NPPs) while having low long term running costs, require high upfront capital expenditure. Successful financing of NPPs therefore require efficient funding mechanisms while providing long term price stability. To address revenue uncertainty, stakeholders have attempted to develop approaches to risk sharing of NPPs that provide additional assurance to potential lenders and reduce capital costs.[435] One such mechanism adopted in the UK is the Contract for Difference (CfD) as part of the implementation of the Energy Market Reform (EMR) in which low carbon generation projects are able to apply and compete for support.[436]

In essence, a CfD is an agreement between two entities, wherein one entity agrees to pay the other the difference between the actual value of commodity in question – the current market price, and the value at the pre-agreed level when the CfD was established – the strike price. CfDs have been commonly known to provide a price support mechanism to promote investment in sustainable production methodologies. The predictability of the revenue streams inculcates a sense of security and encourages stakeholders to invest in new technologies, which might initially be avoided if only dependent on market price mechanisms. Under the CfD, the entities

share the risk that electricity price will not be sufficient to repay the capital expenditure over an agreed period.

In the UK, developers of low carbon projects enter into a private law contract with the Low Carbon Contracts Company, owned by the Department of Business Energy and Industrial Strategy of the Government of UK for a period of 15 years. The main objective of the strike price is to delineate a maximum price, presented on a price per MWh basis, that the Government is willing to offer the developer for different low carbon technologies.[437] The following factors are considered while determining the strike price:

a. Technology specific factors such as capital, financing and operating costs and building limitations.

b. Estimated wholesale electricity prices determined on market mechanisms and discounts which producers face while signing the Power Purchase Agreements (PPAs).

c. Policy considerations in line with meeting the carbon budgets, reducing emissions, cost reductions and deployment scalability.

Strike prices for different low carbon technologies vary with respect to their Levelized cost, relative to which strike prices could be set at a lower or higher rates. The following factors govern the rates at which strike prices are set:

a. Costs unaccounted for in standard Levelized costs in which instance the CfD payments will be made after accounting for the transmission losses of the generators.

b. Discounted prices when power is sold via PPAs.

c. Remainder of project life revenues post the expiration of the CfD. As CfDs are allotted for a period of 15 years, the strike price needs to be increased above Levelized cost which is the operating life cost of the project.

d. Cost assumptions that differ across low carbon technologies. Each low carbon technology will have different cost estimates and CfDs are different for different technologies.[438]

The methodology to set a strike price uses the generation costs to model a supply curve for each technology in each delivery year. The supply curve depicts the estimated capacity in MW that could be build at different strike prices.

After CfDs are allotted via auctions, if wholesale prices rise above an agreed 'strike price', payments from the generator will be returned to consumers. If they fall below this price, the generator will receive a top-up payment. Customers pay nothing until the power plant is operational.

The Hinkley Point C CfD provides a Strike Price for the developer of £92.50/MWh (2012 prices), reducing to £89.50/MWh (2012 prices) if EDF take a FID on their proposed Sizewell C project, for a 35-year term from the date of commissioning.[439] The average-weighted strike price for wind and solar producers currently stands at GBP151/MWh as of July 2021.[440]

An initial assessment by the WNA on the CfD for Hinkley Point C stated that as CfDs are available to a range of low carbon technologies, given the context of the UKs deregulated electricity market, there is little risk that the Hinkley Point C will 'crowd out' other renewables, giving the players of the low carbon electricity market a 'level playing field.'[441]

ii. Regulated Asset Based Model

In 2018, the UK introduced the Regulated Asset Based (RAB) Model as an alternative to the CfDs. The RAB is long-term tariff system that is formulated to encourage investment. The RAB allows for the government to provide a plant owner with regulated rates that can be adjusted to guarantee costs are covered.[442] This model allows the regulator to collect an authorized return on the asset's value that includes operating costs and profit. The regulator levys a charge on the consumers reflected in the electricity bills that goes towards the construction of new power plants.[443]

In 2021, the UK government announced a new legislation called the Nuclear Energy (Financing) bill which would allow the RAB model to be used for nuclear energy financing.[444] The government rationalizes that in the long run the RAB model will lead to an overall reduction in or recouped electricity prices as the money made available by way of the levy will help finance capital costs and avoid taking out loans for upfront construction.[445] The UK government estimates that this will lead to net savings of 30 billion pounds of consumers per electricity project.[446]

European Union

EU Taxonomy

The European Taxonomy is a classification list of sustainable economic activities, including climate-friendly energy sources established in an effort to meet the EU's climate and energy targets for 2030. It operates as a transparency tool for investors and creates a common language that can be utilized for investment decisions in environmentally positive and sustainable ventures.[447] The Taxonomy Regulation lays out criteria to deem an activity to be environmentally sustainable whilst meeting the following objectives:

- Climate change mitigation
- Climate change adaption
- The sustainable use and mitigation of water and marine resources
- Transition to a circular economy
- Pollution prevention and control
- The protection and restoration of biodiversity and ecosystems.[448]

In 2020, the European Commission launched an in-depth analysis on the decision to include or exclude nuclear energy from the taxonomy. As an initiative, the Joint Research Centre of the Commission drafted a technical report on the 'do no harm' aspect of nuclear power. Reviewed by Group of Experts on radiation protection and waste management and the Scientific Committee on Health, Environmental and Emerging Risks, the report was key to informing the EU in this decision.[449]

Early December 2021 saw the EU pass the first part of the investment rules for climate friendly investments under the EU taxonomy to come into effect from January 2022. The rules help to green label activities that fit under the purview of the Taxonomy Regulation set the environmental criteria for investments in renewable energy, shipping and car manufacturing. With the rules in place the EU aims to float investment towards carbon friendly projects and avoid unsubstantiated environmental claims of the investors.[450]

In December 2021, the European Commission also decided to include nuclear and natural gas as a part of the EU Taxonomy paving the way to allow investments in NPP's for at least two decades and natural gas for at least a decade.[451] The decision was taken after the group of pro-nuclear European countries, led by France, and pro-gas governments in southern and eastern Europe, demanded the taxonomy should not punish energy sources that provide a bulk of their power generation.[452] The draft text of the Taxonomy Related Complementary Delegated Act promotes three distinct nuclear related activities for inclusion in the taxonomy: demonstration units for advanced nuclear technologies, the construction of NPP's using best available technologies and electricity generation from existing nuclear installations.[453] The draft text recognizes that "evidence on the potential substantial contribution of nuclear energy to climate mitigation objectives was extensive and clear".[454] The proposed act outlines that individual nuclear projects must meet the following criteria to be considered taxonomy compliant:

1. New nuclear construction projects must be based on "best available technology" and fully comply with the European Nuclear Safety Directive and respect the technical parameters of International Atomic Energy Agency standards and the Western European Nuclear Regulatory Association.

2. Waste and decommissioning funds must be in place and there must be operational facilities for the disposal of low and intermediate-level waste streams, with a plan in place for a high-level waste disposal facility to be operational by 2050 and new projects must use accident tolerant fuel. Notification and reporting requirements to the European Commission are also set, and lifecycle greenhouse gas emissions must be below the threshold of 100g CO2e/kWh.[455]

Chapter 12 : Nuclear Safety, Waste Management and Decommissioning of NPP's in India

Nuclear safety, waste management and decommissioning of nuclear power plants are important aspects of nuclear power plant lifecycle and are given due consideration in the design of nuclear power plant. The Atomic Energy Regulatory Board (AERB) has laid down strict guidelines, which are strictly followed by NPCIL in design and operation of the nuclear power plants. NPCIL has to obtain environmental clearance from the Ministry of Environment and Forests and submit regular compliance reports.

Safety

- Safety is accorded utmost importance in all aspects of nuclear power plants encompassing siting, design, construction, commissioning, operation till eventual decommissioning.
- Ever since its inception, NPCIL has had an impeccable safety record. There has not been any accident or incident of release of radioactivity in the public domain beyond stipulated limits. Indian nuclear power reactors have registered over 560 reactor-years of safe operation so far.
- Safety reviews of Indian NPPs post Fukushima accident also reconfirmed inherent strengths in design having sufficient margins, operating practices and safety regulation of Indian NPPs to withstand extreme natural events. Additional strengthening measures for safely handling extreme events exceeding the design basis of the NPPs are also implemented.
- The data collected from various Environmental Survey Laboratories (ESL) of each site before the start of reactor operation and thereafter from various environmental matrices have shown that the increase in radiation level around nuclear power plants has been negligible and within the variations in the natural background in the region.
- The radiation dose from NPCIL's nuclear power plants has been found to be a negligible fraction of the limit stipulated by AERB.

- We are continuously bathed in radiation from natural sources like the sun, space, rocks, soil and even the food we eat. The radiation dose, a measure of effect of radiation, from natural background varies from place to place depending on the location, soil etc. The average background is 2400 micro-Sievert per year (Units of Radiation). The radiation dose at boundary of nuclear power plants (over natural background) is found to be 1 to 26 micro-Sievert per year, which is an insignificant fraction of the natural background and within the variations in natural background.[456]

Nuclear Waste Management

- India follows a closed fuel cycle policy where the spent (used) fuel is not treated as waste but is reprocessed to obtain fuel for the next stage of the nuclear power programme. Moreover, during reprocessing many valuable radionuclides likes cesium-137, strontium-90, ruthenium-106 with important radiopharmaceutical applications are recovered which has led to the concept of viewing nuclear waste as wealth. Reprocessing and recovering the useful material thus minimizes the waste generation.

- The wastes generated at the nuclear power stations during their operation are of low and intermediate radioactivity level. These constitute filters, resins, washes of laboratories, exhaust air from active areas etc.

- These wastes are appropriately treated, concentrated and subjected to volume reduction. The concentrates are immobilized in inert materials like cement, bitumen, polymers etc. and stored in specially constructed structures located at the site under monitoring.[457]

- The treated liquids and gases are diluted and discharged under continuous monitoring, ensuring that the discharges are well within the limits set by the AERB.

- The radioactivity level of the stored wastes reduces with time and by the end of the plant life, falls to very low levels.

- With reprocessing and recycle strategy, only less than two to three percent of the spent fuel becomes waste and the rest is recycled. [458] This waste is immobilized in glass matrices by process of vitrification, sealed safely in double walled containers and stored in specially designed facilities under constant monitoring.

Decommissioning of NPPs

- The Indian fleet is comparatively young. The world over, there are proposals to extend the life of nuclear power plants beyond 40 years. PHWRs which constitute the main stay of Indian nuclear power programme have relatively lighter and thinner components that are

exposed to high neutron field. Decommissioning of PHWRs in principle is thus easier than LWRs which have heavy pressure vessels exposed to high neutron field. In this context it is worthwhile to recall that India has gained significant experience with rehabilitation and repair of nuclear power plants including en-masse replacement of coolant tubes/channels. This experience should come in handy during decommissioning.

- The eventual decommissioning of the nuclear power plants will be carried out in accordance with the safety guides of the AERB on decommissioning. Technical competence exists within the country.

Chernobyl and Fukushima incidents have shaped public perceptions of nuclear power as inherently risky. While the lessons learnt need to be incorporated in reactor design and operations, this cannot be a reason to shun nuclear energy, which provides a pathway to low carbon future. The Japanese Prime Minister Kishida has said that 'it is crucial that we start nuclear power plants.' The US has the largest number of nuclear power plants. The Wall Street Journal in a recent article mentioned:

> 'All the nuclear waste produced in the U.S. since the 1950s adds up to about 85,000 tons of material. Compare that with the tens of billions of tons of carbon dioxide that would have been produced had that electricity come from fossil fuels. The U.S. Department of Energy estimates that the nation's total nuclear waste would cover a single football field, 10 yards high. By contrast, carbon dioxide, a colorless, odorless gas, is typically released into the atmosphere, affecting the climate of the entire globe.'[459]

In this context it should be pointed out that U.S. pursues an open fuel cycle policy in contrast to India which pursues closed fuel cycle wherein the spent fuel is reprocessed and recycled leaving only a small fraction to be treated as waste.

Chapter 13 : Hydrogen Economy

The burning of hydrogen produces water; there is no CO_2 emission. This makes hydrogen an ideal fuel for a carbon-constrained world. Hydrogen is not only an energy carrier but also provides a storage solution for electricity produced by renewables. This can be transported to deliver energy to users and/or burned to regenerate electricity when the sun is not shining and the wind is not blowing. However, this two-stage conversion or round-tripping involves energy loss. According to an estimate, the final energy output is only 30 percent of the input. There are several factors that determine the efficiency of conversion from electricity to hydrogen and from hydrogen to electricity and there is potential to significantly improve these efficiencies. A number of countries have been experimenting with different variants. The electricity required for electrolysis to break water molecules into hydrogen and oxygen can also be supplied by nuclear power.

Apart from electrolysis which requires electricity to produce hydrogen from water, one can split water directly without using electricity using thermo-chemical processes. A number of these technologies are under development including in India. (For example, sulpher-iodine cycle under development at BARC and copper-chlorine cycle under development at ICT Bombay). It has been estimated that these technologies would significantly reduce the cost of hydrogen production in comparison with electrolysis particularly since the step of electricity production is eliminated. High temperature required for the purpose can be produced both through concentrated solar thermal technology and high temperature nuclear reactors. Both these technologies need development but are well within our reach. High temperature nuclear reactors are a part of development programme at BARC. There is a need to accelerate these developments in mission mode. Till such time the development reaches a mature level, it would be necessary to use electrolysis for production of hydrogen. Here again technology for high temperature steam electrolysis which is expected to deliver much higher efficiencies should be the preferred choice.

Hydrogen is the most abundant chemical element in the universe, but producing it in its pure form for a range of industrial processes is energy-intensive, with a significant carbon footprint. 'Almost 95% of current hydrogen demand is met by utilizing carbon-intensive production processes such as steam methane reforming. This is unsustainable in light of the global clean energy transition'.[460]

The use of nuclear energy for producing hydrogen either directly or through electrolysis can help reduce the carbon footprint in a significant way.

There are three forms of hydrogen depending upon the process used. Grey hydrogen is the term ordinarily used for hydrogen production from fossil fuels (coal/oil/gas). This is cheapest in terms of cost but has a high carbon footprint. Blue Hydrogen is produced from fossil fuel but is combined with CCUS (Carbon-capture, Use, and Storage) technology to reduce carbon emissions. Green hydrogen is produced using green energy (solar or wind) for electrolysis to produce hydrogen. This eliminates carbon use from the production process to produce clean fuel. However, it is the most expensive at present.

India has chosen the Green Hydrogen route. However, most other countries are experimenting with a variety of other options. The reintroduced Hydrogen policy of the GOI defines Green Hydrogen/ Green Ammonia as **'Green Hydrogen/Green Ammonia produced by way of electrolysis of water using renewable energy'**. This is somewhat restricted definition, and excludes not only Blue hydrogen, but also production of Green hydrogen using nuclear power. It is important to recognise that in addition to technologies at the upstream of green hydrogen value chain, one would need a number of technologies at the downstream end for using hydrogen in several individual demand segments. These technologies while their adaptation would take time, are independent of the colour of hydrogen. Thus, it makes sense to start using available cost-effective hydrogen at the energy demand end and switch over to green hydrogen when its costs become competitive.

It is also important to recognise that hydrogen economy would be a sizeable part of the energy economy, being an important fuel to meet the needs of industry and transportation sectors in the clean energy transition. Depending on the mode of production of hydrogen (through electrolysis or directly as discussed above) the share of electricity in the overall energy economy would get determined. Another factor that would determine the preferred mode of production of hydrogen relates to issues concerning hydrogen storage and transportation. While this is also an area of considerable technology development, till such time the related issues are resolved in a commercially credible way, it may be necessary to set up captive plants to produce hydrogen for inhouse use. While these plants could be based on electrolysis or direct conversion through thermochemical route, factors like delivered cost electricity or hydrogen in comparison to cost of solar thermal plant or nuclear reactor of the requisite capacity may also become relevant. It is inconceivable that the renewable energy alone would be able to meet the energy needs to produce the required amounts of electricity and hydrogen. Nuclear energy would be inevitable for the purpose and needs to expand rapidly through development of PHWRs, SMRs as well as high temperature reactors (HTRs).

British Prime Minister Johnson's 10 Point Action Plan includes '5 GW of **low carbon** hydrogen production capacity by 2030.' [461]The US is exploring different processes including fossil fuel, renewables, and nuclear for the production of Hydrogen.[462]

Cost

According to a report by the US Congressional Research Service, green hydrogen is two and a half times more expensive than grey hydrogen:

> 'BNEF estimates the current cost of producing renewable hydrogen in 2018 dollars at about $2.50 to $4.50 per kg (or approximately $18.60 to $33.50 per million BTUs). This compares to BNEF's estimate of fossil fuel-derived hydrogen of $1.00 to $1.75 per kg (equating to approximately $7.40 to $13 per million BTUs).'[463]

Relatively higher cost of hydrogen as compared to natural gas presents a challenge to commercial-scale use of hydrogen as a fuel. The CRS report further states:

> 'By comparison, the per BTU price of hydrogen is much higher than the per BTU price of natural gas (currently below $2 per million in several markets). This cost difference presents a long-term challenge to the use of hydrogen as a substitute for natural gas.'[464]

Currently, gas prices have spiked in Europe and elsewhere. This may change the cost comparison between hydrogen and natural gas. An IAEA 'study found that as gas prices increase, the optimal mix of technologies for producing low-carbon hydrogen shifts in favor of nuclear and renewable energy and away from natural gas with or without carbon capture and storage.'[465] The study is based on current gas prices in UK and EU, where 'the spot prices have spiked to $35 and $40 per million British thermal units (BTU).' The shift in cost calculus happens at a lower threshold of $ 10-15 per million BTU.[466] Its conclusions may not necessarily hold for other markets. The Henry Hub prices in the US market are $ 3.91 per million BTU. While gas prices in the spot market have shown considerable volatility, nuclear energy offers a more stable price outlook, particularly in price-sensitive markets like India.

The EU is also exploring various options; cost consideration is a factor in its choice. An official Communication (Policy proposal) from the European Commission to the European Parliament lists the cost and emissions from different sources of Hydrogen:

> 'Green' or 'Renewable' hydrogen is 'produced by electrolysis of water with renewable electricity, at a cost range of about €2.5-5.5/kg. No GHG is emitted during the process.'

> 'Grey hydrogen is produced from natural gas by steam-methane reforming at a cost around €1.5/kg, depending on the price of gas and carbon emissions. This production process results in emissions of about 9.3 kg CO2 per kg of hydrogen.'

> 'Blue hydrogen uses the same production processes as grey hydrogen, but the CO2 is captured and stored permanently. Its production costs around €2/kg, making it more expensive than grey hydrogen but cheaper than green hydrogen.'[467]

The energy choices will be different in the case of India and China, which have abundant coal but are deficient in gas. 'The vast majority of hydrogen production from coal currently takes place in

China using coal gasification, mainly to produce ammonia. China is exploring the role of hydrogen in its economy, and using coal is currently the cheapest way of producing it, with costs amounting to RMB 0.6–0.7/m3 (about USD 1/kgH2). CHN Energy, China's largest power company, is also the world's largest hydrogen production company.'[468] The IEA report suggests that 'In China and India, with their established coal mining infrastructure and the lack of availability of cheap domestic natural gas, coal-based hydrogen equipped with CCUS is likely to be at least in the medium term the cheapest option for clean hydrogen production.' [469]

The US Department of Energy has announced 'the Earthshots initiative, which aims to cut the cost of green hydrogen by over 80% to $1 per 1 kg in 1 decade, or the "1 1 1" plan. Manufacturing components, storage, transportation, handling, safety, and other issues associated with hydrogen are all secondary concerns if cost-parity with fossil fuels can be reached.'[470] At this stage, this is a futuristic target.

India's National Hydrogen Energy Mission

The government of India is committed to lowering emissions with a view to achieving a clean environment. As far back as 2006, it had come out with a National Hydrogen Energy Mission 2006. This considered the entire range of processes for Hydrogen production:

- Steam reforming
- Electrolysis
- Partial oxidation of heavy hydrocarbons
- Gasification or partial oxidation of coal
- Production from biomass
- Hydrogen Production from Bio-organic Wastes
- High-temperature thermochemical splitting of water
- Low-temperature water splitting
- Postproduction cleaning processes
- Carbon dioxide sequestration
- Synthetic fluid fuel.

The above included Grey Hydrogen (Coal based), Blue Hydrogen (Fossil fuel with CCUS), and Green Hydrogen (Renewables and Nuclear Power). Since then the focus has narrowed down to Green Hydrogen. The Finance Minister in her budget speech of 2021-22 mentioned that the Government will promote the use of Hydrogen:

> 'The Government of India will facilitate demand creation in identified segments. Possible areas include suitable mandates for use of green hydrogen in the industry such as fertilizer, steel, petrochemicals, etc.'[471]

Writing in Hindustan Times, the NITI Ayog CEO Sri Amitabh Kant mentioned:

> 'While many nations are pursuing a twin pathway towards supporting both blue and green hydrogen, India is setting up an exclusively green and zero-carbon green hydrogen mission.'[472]

While the change in approach may be justified by greater urgency for reducing carbon emissions, a developing country like India cannot overlook the costs involved. Besides, at an early stage of technology development, it will be prudent to adopt a flexible approach involving use of cheaper hydrogen at the demand end to facilitate adoption of hydrogen even as technologies for green hydrogen evolve and mature. Exclusive dependence on renewables electricity is predicated upon its availability in required amounts, cost of renewable electricity integration and cost-effective storage solutions. At this stage, this appears difficult. Further, battery technology, CCUS as well as hydrogen production processes are not mature technologies. Renewables require large space and entail high transmission costs if they are located in remote areas. Germany and Japan are also considering sourcing hydrogen from abroad. If emission-free electricity is the criterion, the role of nuclear power in hydrogen production has to be borne in mind. It will be instructive to have a look at the approaches taken by other countries for hydrogen production.

Hydrogen Strategy of Different Countries

United Kingdom

British PM Johnson's 10 Point plan or Green Industrial Revolution includes plans 'to develop 5 GW of **low carbon** hydrogen production capacity by 2030'. The Plan envisages 'Hubs, where renewable energy, CCUS, and hydrogen congregate, will put our industrial 'SuperPlaces' at the forefront of technological development'. 'Producing low carbon hydrogen at scale will be made possible by carbon capture and storage infrastructure.' It will also use off-shore wind and renewables. The UK is exploring 'the use of hydrogen for heating, replacing fossil fuels like natural gas with hydrogen and hydrogen blends.' The UK also plans to use nuclear power for hydrogen production. The British government is 'committing up to £170 million for a research and development program on Advanced Modular Reactors. These reactors could operate at over 800°C and the high-grade heat could unlock efficient production of hydrogen and synthetic fuels.'[473]

European Union

The EU is 'predominantly focusing on the development of renewable hydrogen.' 'However, the EU also envisages a temporary use of other forms of low-carbon hydrogen to decarbonize existing fossil-based hydrogen production.' [474] The European Commission's 'hydrogen strategy has been designed using a phased approach and with the goal to increase the hydrogen share from less than 2% today up to 13-14% by 2050.'[475]

In addition, EU member states have their national hydrogen strategies. Germany, France, Italy, and Spain adopted a hydrogen strategy in 2020. They committed around Euro 11.5 billion to hydrogen from 2021 to 2026 in the framework of Next Generation EU.[476]

France

As the gas prices soared making Europe's electricity crisis worse, President Macron announced that 'The number one objective is to have innovative small-scale nuclear reactors in France by 2030'.[477]

Germany

In support of its new hydrogen strategy, Berlin will invest €9 billion in green hydrogen projects. Out of this, '€7bn will be invested in its own national market and €2bn have been designated for hydrogen projects in Ukraine and North Africa (Morocco). The aim is to forge partnerships as the future green hydrogen production might be more cost-efficient outside of Europe.' 'The German Government has already accepted in its new hydrogen strategy that it will not be able to produce sufficient electricity for its green hydrogen economy as it does not have the space to expand its RES-based electricity due to its high population density.[478]

US

The US Infrastructure Investments and Jobs Act foresees the creation of at least four "regional clean hydrogen hubs". They will produce hydrogen from renewables, fossil fuels, and nuclear. 'Furthermore, the legislation uses a highly debated definition of clean hydrogen, according to which a kilogram of hydrogen produced with CO_2 emissions of up to two kilograms is defined gas as 'clean'. [479] That's roughly a fifth of the typical amount of CO_2 released when hydrogen is made now, using natural gas.[480]

China

'China currently is the world's largest hydrogen producer but not of green hydrogen, as most production is based on coal'. Under 14th Five Year Plan, it 'aims to increase the share of renewables-based hydrogen to 50% of total hydrogen production by 2030'.[481] China, like the US, plans to use CCS technologies to de-carbonize hydrogen production. This means that it is also considering the use of fossil fuels for hydrogen production to bring down costs.

Japan

Hydrogen production is part of Japan's 'Green Growth Strategy' published in 2020. Japan plans to ramp up hydrogen consumption from 3,00,000 tons per annum currently to 6 million tons by 2030. Domestic production consisting of 3,00,000 tons will be renewable hydrogen. 'The remaining demand will be met by imports of natural gas-based and renewables-based hydrogen'.[482]

ROK

ROK started in 2006 'a 12-year national program to develop and demonstrate the technologies required for the future nuclear H2 system'. The hydrogen produced using nuclear energy will be

used in the steel industry, which accounts for 11 % of the country's energy consumption. It will also be used for methanol production. 'A two-step approach has been decided which foresees in the first step the deployment of an advanced HTGR (AHTGR) with a moderate coolant outlet temperature of 850°C to be connected to a steam–methane reforming system with the syngas used in iron ore reduction or methanol production. The final step will be the more challenging VHTR with a coolant outlet temperature of 950°C'. [483]

The Middle East

'In the November COP26 summit, the UAE revealed aims for a 25 percent share of the global low-carbon hydrogen market by 2030 through its 'hydrogen leadership roadmap'. 'Saudi Arabia is already investing heavily in hydrogen projects'. 'This comes as part of the national transport and logistics strategy to boost annual non-oil revenues from the sector to $12 billion by 2030. 'Oman hopes to establish a hydrogen-centric economy by 2040, with 30 GW of green and blue hydrogen.' 'The $30 billion plants will be powered by 25 gigawatts of wind and solar energy, aiming for an eventual hydrogen output of 1.8 million tonnes per year.' [484] With vast tracts of desert land and considerable gas reserves, Middle Eastern countries have a natural advantage in producing Grey or Blue Hydrogen.

India

India has announced that it will pursue the Green Hydrogen route based on the production of hydrogen from renewables using the electrolysis process. The Government has announced incentives for hydrogen production. 'A 15,000-crore Production Linked Incentive (PLI) scheme for electrolyzer production is part of India's ambitious quest for green hydrogen. The government's main aim is to reduce the cost of green hydrogen to $1/kg and establish a green hydrogen capacity of five million metric tonnes per year (MMTPA) in India by 2030.'[485]

In the private sector, Reliance Industries Limited has ambitious plans. Shri Mukesh Ambani, CEO of Reliance recently announced that the green Energy Giga Complex will have an electrolyzer factory for green hydrogen production, and a fuel cell factory. Ambani hopes that India can bring down hydrogen costs massively in the future. Reliance Industries Limited hopes to become a net-zero emissions company by 2035, and a ₹75,000 crore investment in green energy is a large part of the plan. He added that 'Efforts are on globally to make green hydrogen the most affordable fuel option by bringing down its cost to initially under $2 per kg.' He expressed hope that India will be 'the first country globally to achieve $1 per 1 kilogram in 1 decade – the 1-1-1 target for green hydrogen.' [486]

A Financial Express article mentioned that, 'The proton exchange membrane accounts for about 25% of total electrolyzer costs. DuPont holds the exclusive IP on membrane technology. Developing alternative membranes should be prioritized to lower costs of manufacture in India.' It suggested that the Indian 'Industry should also collaborate with DRDO, BARC and CSIR laboratories, which have been developing electrolyzer and fuel cell technologies.' [487]

Hydrogen produced using nuclear power

An IAEA report says:

> 'Nuclear power reactors can be coupled with a hydrogen production plant to efficiently produce both energy and hydrogen as a cogeneration system. For hydrogen production, the cogeneration system is fitted with components for either electrolysis or thermochemical processes. Electrolysis is the process of inducing water molecules to split using a direct electric current, producing both hydrogen and oxygen. Water electrolysis operates at relatively low temperatures of around 80°C to 120°C, while steam electrolysis operates at much higher temperatures and is, therefore, more efficient.' [488]

The IAEA report titled 'Hydrogen Production Using Nuclear Energy' brings out the advantage of high-temperature steam electrolysis:

> 'A principal variant of electrolysis considered promising for the future is high-temperature steam electrolysis (HTSE). Unlike low-temperature water electrolysis, the total energy demand of electrolysis in the vapour phase is reduced by the heat of vaporization, which can be provided much more inexpensively by thermal rather than electric energy. Decreasing electricity input can be seen with increasing temperature and is about 35% lower compared to conventional electrolysis in the high-temperature range of 800–1000°C. Also, the efficiency of electrical generation at this high-temperature level is significantly better.'[489]

The report adds:

> 'Thermochemical processes can produce hydrogen by inducing chemical reactions with specific compounds at high temperatures to split water molecules. Advanced nuclear reactors capable of operating at very high temperatures can also be used to produce heat for these processes'.[490]

One of the processes for producing hydrogen using nuclear power is the Sulphur-iodine cycle. The IAEA report mentions 'In all studies that systematically examined thermochemical cycles, those of the sulfur family — sulfur–iodine, hybrid sulfur, sulfur–bromine hybrid — have been identified as the potentially most promising candidates with higher efficiency and a lower degree of complexity (in terms of a number of reactions and separations)'.[491] This can be combined with Japan's HTTR reactor design and China's HTR-PM 600 and HTR-10 designs.

Nuclear power can not only produce emission-free hydrogen but requires much less land. It can be located close to industry centers for supplying hydrogen and electricity on large scale. This would require providing funds to DAE for R&D in high-temperature reactors. Its commercial-scale application will be subject to the same cost consideration as that in the case of renewables.

The mathematical modelling done by IIT Bombay for the VIF study has brought out that relying mainly on renewable for production of green hydrogen through electrolysis of water will have very high land footprint. In a R95N05 scenario, with 10% of electricity delivered as Hydrogen, the land

requirement will be 4,12,033 square kms. This will exceed total surplus land available as per Prof. Sukhatme study.

IIT Bombay has modelled two other variants of R95N05 scenario of 10% and 25% of energy delivered as green Hydrogen. The variant of 10% green hydrogen was discussed at the end of Chapter 7. The installed capacity and corresponding land capacities for the 25% green Hydrogen variant are as given in Table 32.

Table 32: Land required for projected installed capacities for solar, wind and nuclear power

Net-zero 2070	Installed capacity (GW)			Land required (Sq. km)			
Scenario	Wind	Solar	Nuclear	Wind	Solar	Nuclear	Total
R95N05	800	59160	862	114283	1197061	2156	1313500
R60N10CCS30	800	19561	863	114283	395803	2158	512245
R50N20CCS30	800	7157	962	114283	144817	2406	261506
R40N35CCS25	800	5564	1590	114283	112584	3977	230843
R05N95	800	2219	3917	114283	44900	9796	168979

Source: IIT Bombay, Mathematical Modelling for the VIF Task Force Study – India's Energy Transition in a Carbon Constrained World.

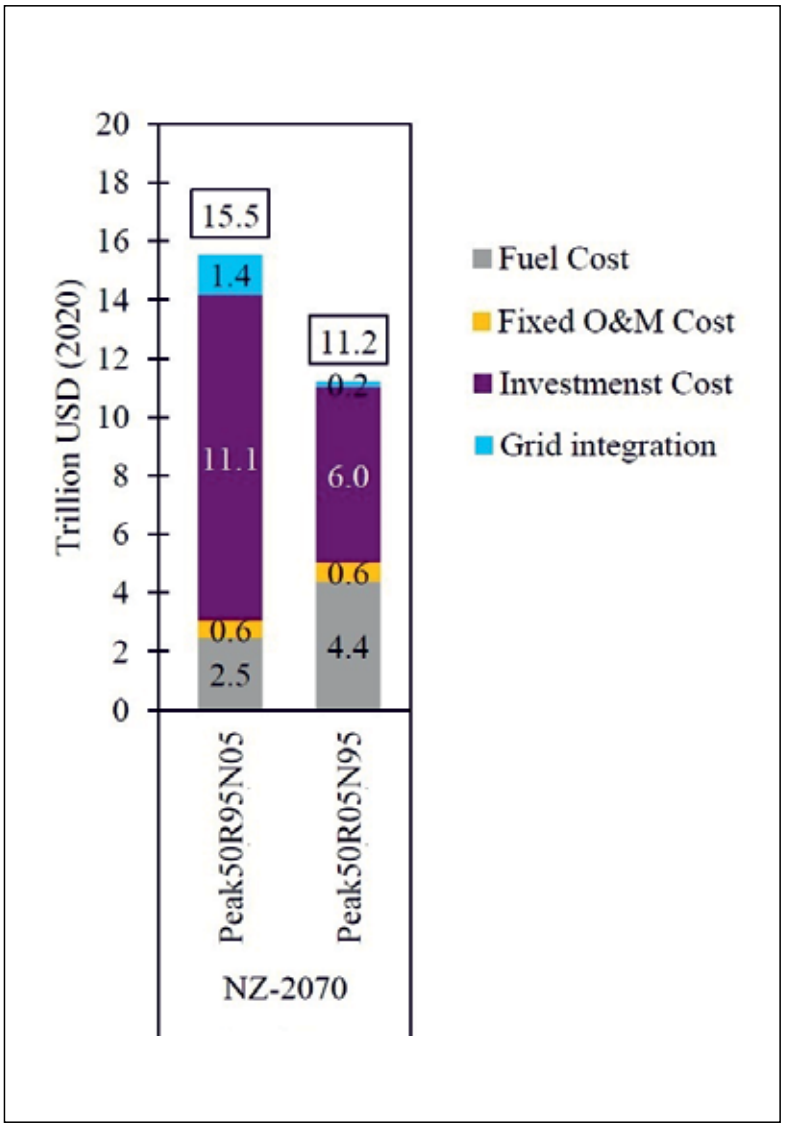
The above table shows that land required in case of 25% Hydrogen demand to be met in a high renewable scenario (R05N95) using renewable energy for electrolysis of water will be 1313500 square kms. India simply does not have surplus land available on this scale. India's success in fostering a Hydrogen economy would require expanding the scope of Hydrogen policy to include nuclear power for the production of green Hydrogen. In case of high nuclear scenario (R05N95), the land requirement will be much more modest at 168979 square kms.

Green H_2 production using electricity solely from renewables will significantly increase the SPV installed capacity due to the low efficiency of the electrolyser, losses involved in the two-stage conversion, and losses involved in the transportation and storage of H_2. There are three other possible alternatives — (a) Ramp up the capacity for wind as it is available throughout the day, (b) use electricity from nuclear and other clean resources to produce H_2, and (c) use high temperature from nuclear reactors for the thermo-chemical splitting of water. Wind-power has even larger land foot-print than solar power. Therefore, only practical options are the last two – use of nuclear power or thermos-chemical splitting of water using high temperature reactors.

Cost of Transition

Dependence upon renewable energy for production of green hydrogen will also increase the cost of transition to net zero. In case of 10% hydrogen demand, this will be $ 15.5 trillion using the renewable high (R95N05) scenario as against $11.2 trillion for nuclear high scenario (R05N95) (Figure 23).

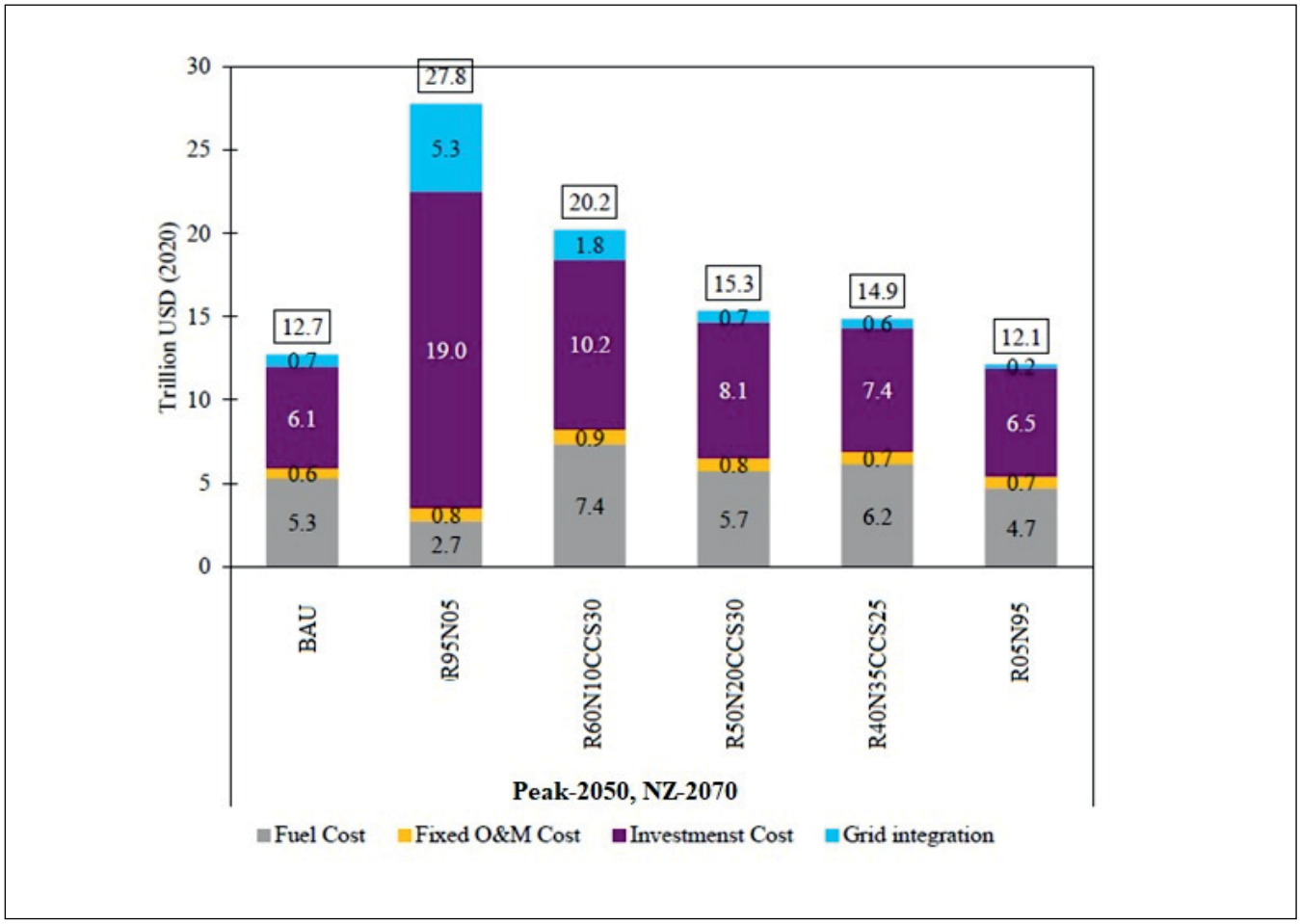
Figure 23: Net zero in 2070 with 10% green H2 demand— Cost of power sector transition under different scenarios



Source: IIT Bombay Mathematical Modelling for the VIF Task Force Study – India's Energy Transition in a Carbon Constrained World. (Annexed)

In case of 25% hydrogen demand, the cost of transition to net zero will be an astronomical $ 27.8 trillion using renewable route (R95N05) as against $12.1 trillion using nuclear route (R05N95). In case of R95N05 scenario, in the absence of sufficient baseload capacity, additional solar PV capacity is required to supply the peak evening demand via storage. This will eventually drive the system cost very high, as seen in Figure 24 below. With an increase in baseload nuclear and CCS capacity, the requirement for solar PV to supply the peak demand reduces, thereby decreasing the overall cost of transition.

Figure 24: Net zero in 2070 with 25% green H2 demand— Cost of power sector transition `under different scenarios

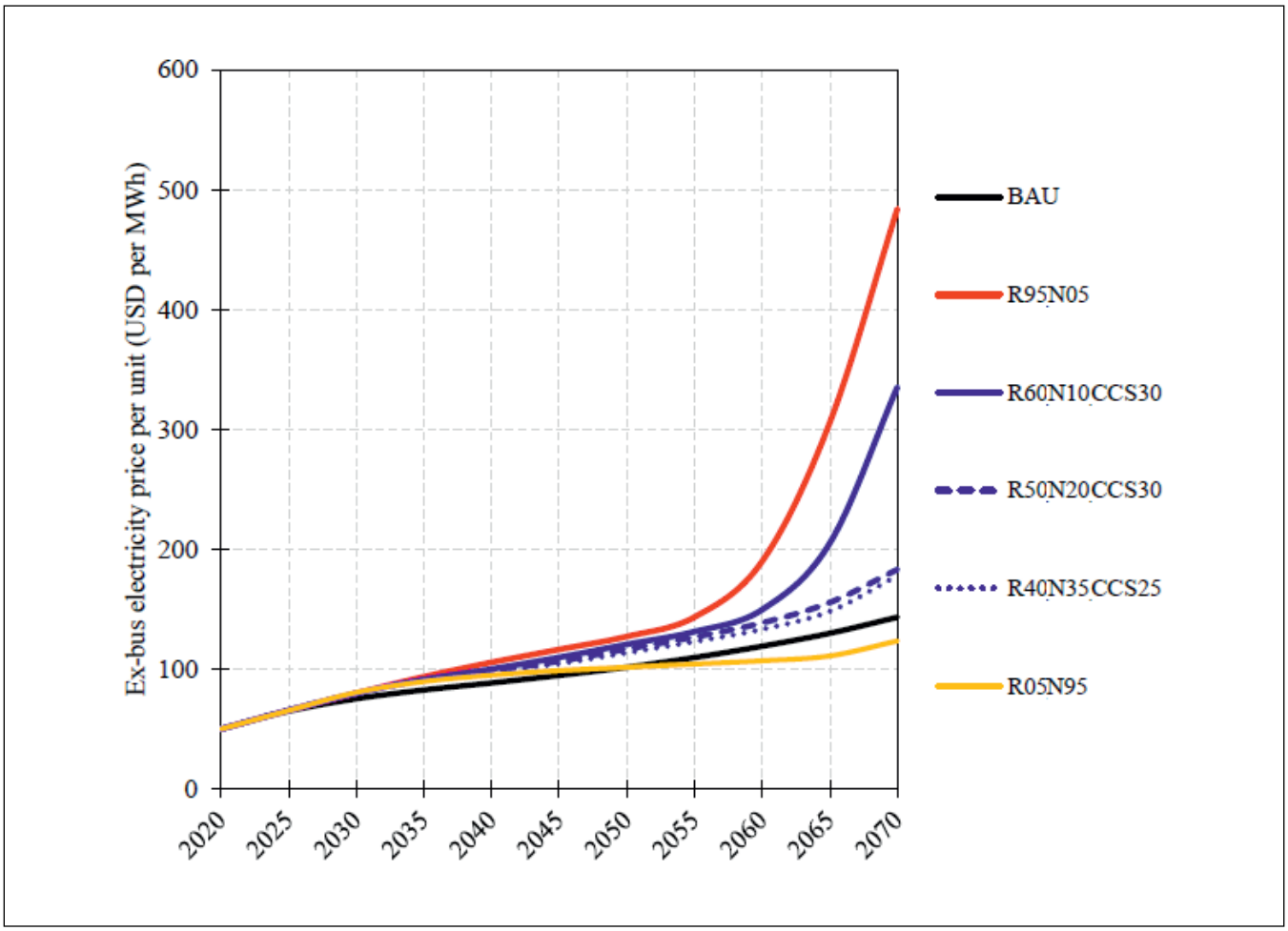


Source: IIT Bombay Mathematical Modelling for the VIF Task Force Study – India's Energy Transition in a Carbon Constrained World. (Annexed)

Huge investment in renewable high route will also impact grid cost of electricity in 2070. This will be $ 164 per MWh in case of renewable high (R95N05) scenario. It will be $ 103 per MWh in case of nuclear high (R05N95) scenario. Perhaps the most dramatic will be increase in grid cost of electricity. This will be nearly $484 per MWh in renewable high (R05N95) scenario. It will be little

over $123 per MWh in case of nuclear high scenario. The following graph (Figure 25)illustrates the grid cost for different scenarios with 25% hydrogen demand.

Figure 25: Net zero in 2070 with 25% green H_2 demand - Grid cost of electricity under different scenarios



Source: IIT Bombay Mathematical Modelling for the VIF Task Force Study – India's Energy Transition in a Carbon Constrained World. (Annexed)

Chapter 14 : Natural Gas – A Bridging Fuel

Energy Landscape of India

Energy transition to a low carbon future is a complex task. At present, India's generation mix is heavily dominated by coal which accounts for 71 % of India's generation-mix. The government is increasing the share of renewables in the grid. Currently, they account for barely 9-10 percent of India's electricity generation. This ratio will change only gradually. As renewables have low PLF, high systems costs and require large land area, there are limits to the extent renewables can assume the burden of coal. Eventually, nuclear capacity will have to be ramped up. This will take time. In the meantime, gas will be required to provide a bridge towards a low carbon future for India.

India's per capita energy consumption is 23.2 Gigajoules per capita, which is very low compared to world's 71.4 Gigajoules per capita and of Asia pacific is 59.6 Gigajoules per capita. On a per capita basis, India's energy use and emissions are less than half the world average, as are other key indicators such as vehicle ownership, steel and cement output.

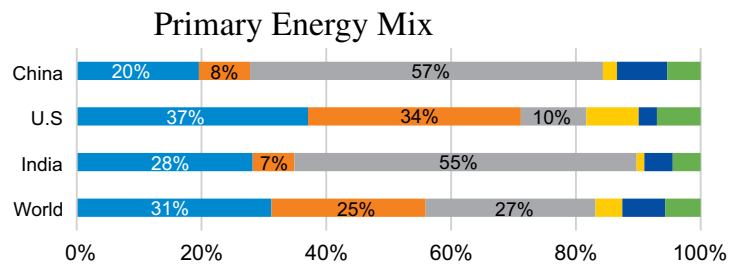
India has so far contributed relatively little to the world's cumulative greenhouse gas emissions, but with growing energy consumption in coming decade, there shall be a relative increase in emission as well. Cleaner forms of energy sources shall play a pivotal role in defining nation's pathways of energy transition.

Ukraine War and Gas Supply

There has been a sharp increase in gas prices following the outbreak of the Ukraine war. The Asian LNG prices have climbed from $ 27.51 per MMBtu to $ 34.84 per MMBtu. The Henry Hub prices have $ 4.78 per MMBTU to $ 6.60 per MMBTU. The Indian consumer has been partly shielded by the existence of long-term contracts. But the need for a diversified source of gas remains. High gas prices have resulted in higher Urea prices which have nearly tripled in one year. High volatility affects demand, but climate change concerns underline the long-term need for gas as a bridging fuel. There has been an increasing number of extreme weather events.

Figure 26 shows the Primary Energy Mix of India and the world.

Figure 26: Primary Energy Mix



	World	India	U.S	China
Oil	31%	28%	37%	20%
Natural Gas	25%	7%	34%	8%
Coal	27%	55%	10%	57%
Nuclear energy	4%	1%	8%	2%
Hydro electric	7%	5%	3%	8%
Renew- ables	6%	4%	7%	5%

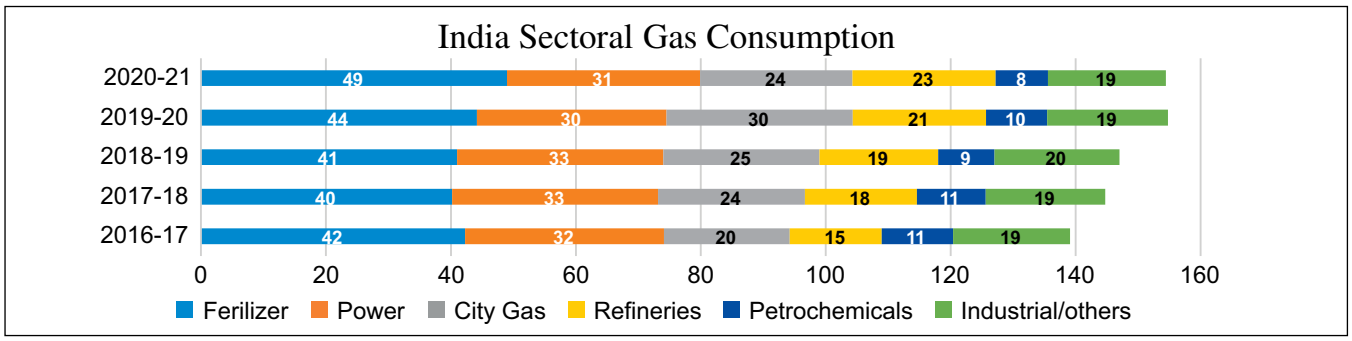
Source: BP. (2021). *BP Statistical Review 2021*. https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2021-full-report.pdf

Natural Gas Fueling the Clean Energy Transition

Share of natural gas in India's energy mix is of ~6.7% as against ~24.7% global average. Efforts are being made to increase natural gas production while also creating import infrastructure to meet the growing domestic demand. Increasing the share of gas from 6.7% to 15% means a significant jump to approximately 600 MMSCMD of gas market from current level of 148 MMSCMD assuming an increase of 1.6 times in country's primary energy basket reaching from present around 800 mtoe to 1300 mtoe by 2030. It is estimated by 2030 domestic gas production is expected to be around 150 to 200 MMSCMD, while the balance is expected to be met through imports.[492]

The gas consumption pattern in India is given below in Figure 27.

Figure 27: India Sectoral Gas Consumption.



Figures are represented in MMSCMD
Source: PPAC

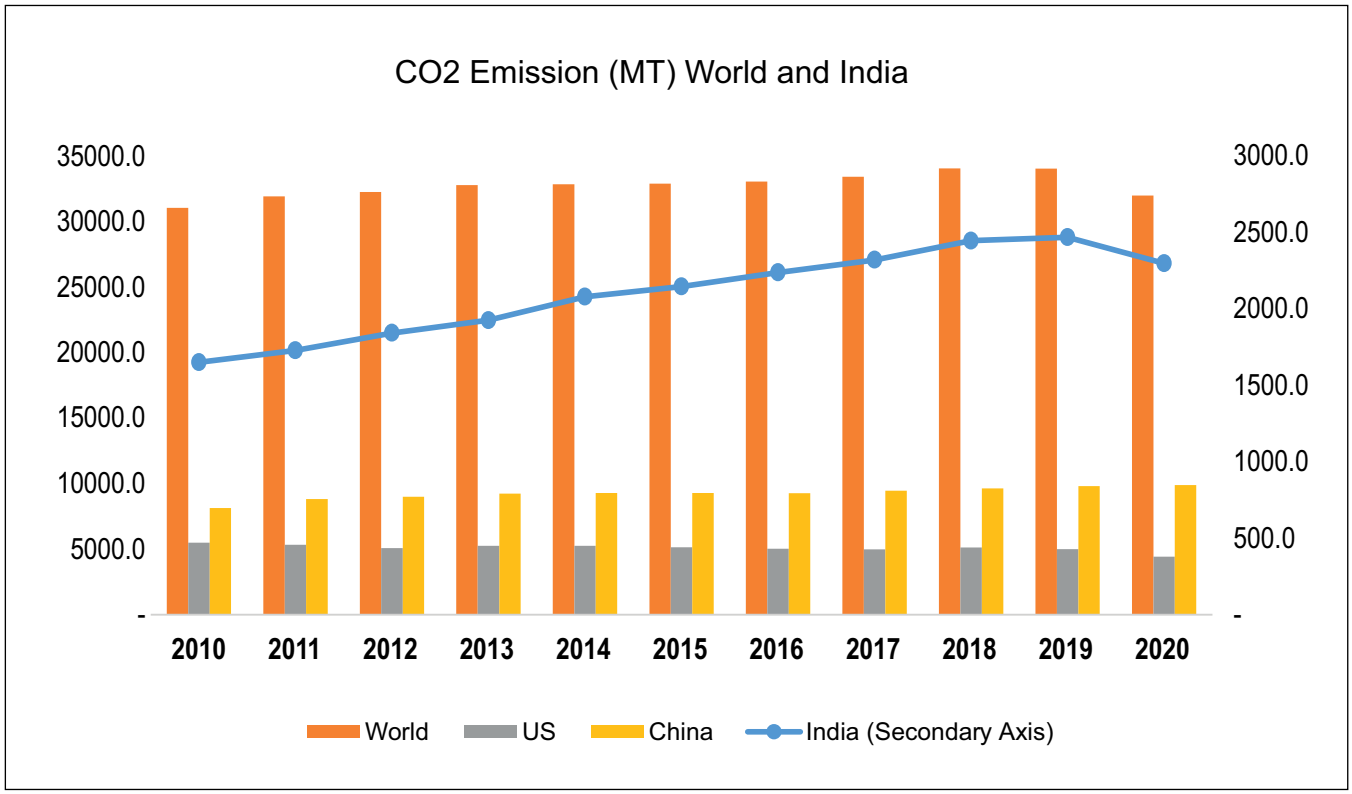
From the consumption pattern shown above it is observed that the yearly average of growth of gas market is 4% in last 5 years. Out of total 154 MMSCMD, 45% of the gas comes from domestic sources while rest 54% is imported LNG and majority of growth has come from CGD and refinery segment during last 5 years.[493] Pricing and affordability are the key challenges for India as anchor consumers - Power and Fertilizer, and emerging sectors such as CGD are price-sensitive

Hon'ble Prime Minister Shri Narendra Modi has clearly envisaged a cleaner, greener and more inclusive future for India by placing "accelerating our efforts to move towards gas-based economy" at top of the seven elements of India's energy sector vision.

Natural Gas, Emission and its role Decarbonization

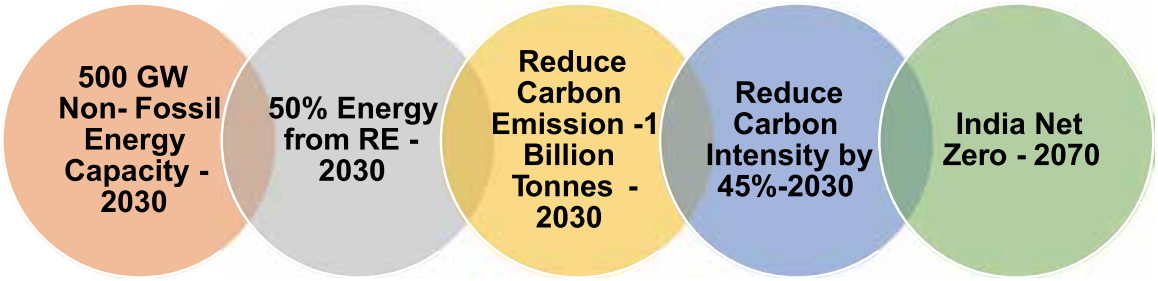
Natural gas is the least carbon intensive fossil fuel; unlike other carbon-based fuels, natural gas has a high hydrogen/carbon ratio and therefore emits less carbon dioxide for a given quantity of energy consumed. Natural gas is a cleaner burning fuel than coal or oil. When burned, it releases up to 50 percent less carbon dioxide (CO_2) than coal and 20-30 percent less than oil. Use of Natural gas can help to meet CO_2-reduction goals as well as reduce unhealthy emissions such as NOX, SOX and particulates.[494] Figure 28 shows the CO2 emission trend of the world and India.

Figure 28: CO2 Emission Trend



Source: BP. (2021). *BP Statistical Review 2021*. https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2021-full-report.pdf

Figure 29: India COP26 Pledges



According to the Sixth Assessment Report (AR6) by the Intergovernmental Panel on Climate Change released in 2021 the world can emit approximately 400 billion tonnes more of carbon dioxide before hitting the 1.5°C limit.[495] The world currently emits about 40 GtCO2 annually; the 1.5°C budget is likely to be exhausted in 11.5 years at 50 per cent likelihood and nine years at 67 per cent likelihood.

Natural Gas plays an important role in short to midterm, using unabated natural gas (fossil gas without CCS), and in the longer term as abated (gas with) CCS gas and other low-carbon gases and technologies scale up. Investments done so far in unabated natural gas supply chain lays the groundwork for a zero-carbon future because the infrastructure can be repurposed.

The main drivers of natural gas use under decarbonization are as follows:

- Clean Energy Access: PNG penetration in urban areas can help in replacing LPG and making the latter available to rural area, thus leading to clean energy access.
- Hydrogen: natural gas as a feedstock has potential to cater to new market for producing hydrogen (blue hydrogen) through steam methane reforming (SMR).

Gas Networks Supporting Energy Transition

National Gas Grid (NGG) is conceptualized under the vision of 'One Nation, One Gas Grid' to integrate all-natural gas pipelines into a nationwide gas grid and increase the availability of natural gas across the country.

The majority of existing Natural Gas Pipelines were transporting gas towards West, North, and Central India while there was no provision for connectivity to North-East with various sources from other parts of India. There are also few isolated networks in the southern region. Hence the concept of NGG has been put forward to ensure equitable distribution of natural gas across the width and breadth of the country, which will remove regional imbalance within the country with regard to access to natural gas and provide clean and green fuel throughout the country. Further, the NGG is envisaged to connect gas sources to major demand centers and ensure the availability of gas to

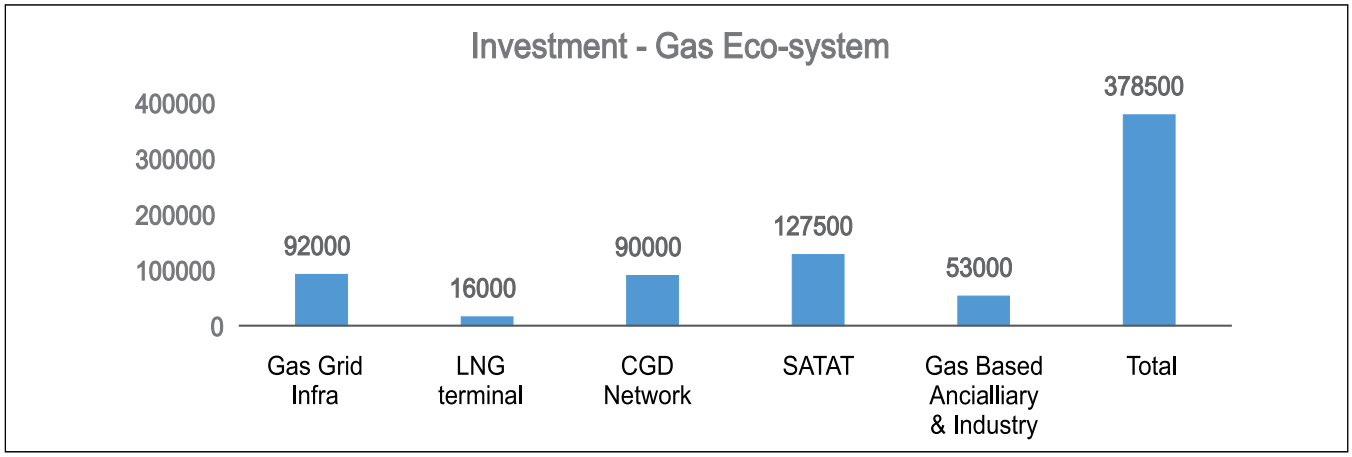
consumers in various sectors and the development of City Gas Distribution Networks in various cities for the supply of CNG and PNG.

In the Union Budget 2014-15, the implementation of an additional 15,000 km of New Natural Gas pipeline infrastructure was announced for the establishment under the National Gas Grid (NGG) of India. The majority of these pipelines have already been authorized by MoP&NG/PNGRB and work at these pipelines is at various stages of execution as per the approved work plan. The national gas grid (NGG) is expected to expand from the present 18,700 km to 34,500 km in next few years.

Figure 30 shows the investment in the Gas eco-system in India.

Figure 30: Investment in the Gas Eco-system in India

All figures are in Rs. Crores.



Source: Collated from inputs of press releases and MoPNG and PIB

CGD has been identified by India as an important mechanism to combat pollution while offering affordable energy to masses. It is expected that with already awarded GAs in the 8th, 9th and 10th round, while 11th round is also announced 86% of India's area and 96% of its population spread over 600 district & in 28 states/UTs would have to CGD network. PNG is helping to divert LPG for rural areas which are still dependent on biomass, wood etc. The 11th city gas distribution (CGD) authorization round has been launched to expand CGD network particularly in Chhattisgarh, Madhya Pradesh, and Vidharba. The developing hydrocarbon infrastructure can also serve as backbone for low carbon energy transition especially for the developing countries.

Additionally, one crucial component of the proposed NGHM is the creation of Hydrogen Hubs which will require establishing a robust hydrogen supply chain from production to demand centers- the creation of new infrastructure and repurposing existing Natural Gas infrastructure to suit the proposed dimensions of NGHM. All these contours of NGHM pose opportunities for India and foreign organizations.

Fast and reliable response to intermittency and supports grid balancing

Gas has lower capital costs compared with coal generation making it more cost effective at small scale. The ability of gas-powered turbines to ramp up and ramp down quickly makes natural gas the ideal partner for intermittent renewable sources.

The Ministry of Power, under the draft National Electricity Policy 2021, has focused on the generation of power from renewable energy sources and also refers to gas-based generation for long-term requirement of balancing capacity where gas-based power can contribute significantly for peaking or balancing power.

The Standing Committee on Energy has also reiterated and highlighted the key role gas-based plants can play specially to meet the peaking demand and balancing the grid.

Gas based power can also be bundled with solar power to provide guaranteed peaking support during evening peak hours especially when solar availability drops coal-based plants take time to ramp up.

Sustainable Alternative Towards Affordable Transportation (SATAT)

The 'SATAT' scheme on CBG was launched which envisages targeting production of 15 MMT of CBG (Compressed Bio Gas) from 5000 plants by 2023. The Government of India has taken various enabling steps to ensure the success of the SATAT scheme.

Recommendations

Non-inclusion of Natural Gas under GST

Non-inclusion of Natural Gas under GST is impeding the growth of Natural Gas in the energy basket of the country.

For the companies producing and trading in Natural Gas, the blockage of GST-ITC (Input Tax Credit) on input, input services and capital goods is resulting in increase in the cost of the Natural Gas to end consumer thereby creating inflationary pressures on the economy.

Companies using Natural Gas as an input/ fuel for their industrial processes are not able to claim any input tax credit of VAT paid on procurement of Natural Gas. The other fuels such as coal, naphtha, fuel oil covered under GST are in advantageous position as compared to Natural Gas.

Higher burden of state VAT, coupled with loss of GST-ITC leads consumers to opt for other fuels which are under GST is nullifying government's efforts to push the Indian economy to cleaner and environment friendly ecosystem.

Non-inclusion of Natural Gas under GST is also acting as a barrier in setting up of Gas Trading Hub/ Exchange. There has to be uniform taxation on Natural Gas for free trade of Natural Gas and this can only be achieved by bringing Natural Gas under the ambit of GST.

Stranded Gas Based Power Plants

More than half of India's gas-based power generation capacity is not being used due to lack of gas. The non-availability of domestic gas and high cost of imported supply (LNG) has "stranded" gas-based power plants. These could be used to supplement renewables, by supplying balancing power or peaking power.

As India moves towards a larger portfolio of renewable power, there will be proportionately larger requirement of 'balancing power' to ensure uninterrupted supply of electricity when the wind or solar power is not available. This can be supplied by stranded gas assets thus minimizing cost for building new capacities. According to an estimate by IEA, the requirement of flexible generation would be of 'over 170 GW in India (from 40 GW) by mid-century.'[496] This size of the capacity needed for 'balancing' is sufficient to absorb both existing thermal as well as gas based assets. Gas-based power plants because of their relatively lower capital cost, and capacity for quick ramp-up are ideal for supplying peaking power. This involves evolving a policy for peaking power. This also entails a review of the "merit order dispatch" schedule, which gives preference to power plants with lowest running cost without accounting for externalities in terms of higher emission or systems cost.

Conclusion

Climate change is an existential crisis and demands urgent action. It requires a change in source and uses of energy to reduce carbon footprint. The energy transition of this magnitude in the course of a few decades has never been attempted in the past. It requires recognition of the historical responsibility of the developed countries. They have not only distanced themselves from the principle of special but differential responsibilities, their record of providing financial assistance is also patchy. However, this is not a reason to postpone action on our part. India, like all other developing countries, is already affected by changing weather patterns and natural disasters.

The severity of the electricity price hike in Europe, and the coal crisis first in China and now in India, points to the complexity of the problem. It shows that there is no one solution that fits all situations. The renewables are an intermittent source of power, and cannot provide stable base-load power. They also need a backup by gas or coal or other flexible generation modality going forward to provide electricity, when the sun is not shining or the wind is not blowing. This is at the root of the ongoing problem in the UK and some of the European countries, which have witnessed a five-fold increase in electricity prices. Though China and India have similar energy profiles with coal providing the bulk of the electricity consumption, the Chinese per capita emission (9.4 tonnes per annum) is more than four times higher than the Indian level (2.2 tonnes per annum). Having secured a larger share of the global carbon budget, the energy transition will involve less pain for her than India's case, where premature capping will mean lost development opportunity.

Peak emission levels are different for different economies. This means that developed countries and China have not only cornered 80 percent of the global carbon budget, they will continue to appropriate a greater share of the remaining carbon space also. This will perpetuate discrimination and accentuate the disadvantages for the developing countries as the world approaches net zero. The debate in Europe to impose Border Trade Adjustment Tax to avoid 'carbon leakage' ignores this fact. Widely differing peaking levels will leave in place existing asymmetries. China is more than twice the size of the EU in terms of population, and will have nearly double the per capita emission by 2030 (China 9.8 MT and EU 5.3 MT) Though Indian population size is roughly the same as China, its per capita emission will be near 1/4th the Chinese level. China also runs a massive trade surplus with both the EU and the US.

India must ensure that energy transition does not result in foreclosing her development options. Europe's electricity crisis has underlined the cost of increasing penetration of renewables in the grid. Being intermittent, they need to be supplemented by flexible sources of generating power. Combined with the volatile price of imported gas, it has resulted in a steep increase in electricity prices. Currently, the renewables' penetration in the grid ranges from 40-50 percent in the case of the UK and Germany. The problem will be much worse if this level goes up. These costs are difficult for developed economies to meet. In India's case, they will be unbearable.

IEA reports have suggested a 90 percent share of renewables in the grid at the Net Zero Emission stage in 2050, with electricity providing 50 percent of the energy basket. The IEA reports – Net Zero Emission 2050 as well as the more recent World Energy Outlook 2021, have hinted at the magnitude of the problem for Europe and the US as well as India. But it has shied away from estimating the cost to the economy. In India's case, the report says that 170 GW of flexibility will be required by 2050. This will make electricity prohibitively costly. Successful de-carbonization of the economy requires keeping electricity prices low. As MIT report has suggested, the only way to do so is by including nuclear power in the energy mix.

Recommendations

1. India has accepted the goal of clean energy and is well on track in achieving her Intended Nationally Determined Contributions (INDC). The Prime Minister has announced at the Glasgow Conference ramping up the share of non-fossil fuels to 500 GW by 2030.
2. As part of its INDCs, India had made a commitment at the Paris conference of seeking an 'additional carbon sink' of 2.5 to 3 billion tonnes of CO_2 equivalent by 2030. India achieved 39 million tonnes between 2015 and 2017 and 42 million tonnes between 2017 and 2019 (Total 81 million tonnes). India to step up the pace to achieve the minimum target of 2.5 billion tonnes.
3. Accelerating adaptive capacity – Community-Based Adaptation forms an important part of the ongoing climate programs in the country in rural, urban and peri-urban spaces, and can become an important part of domestic climate action. Scaling adaptive capacity across population groups can lead to better climate outcomes and palliate disaster risks. These include climate-resilient interventions in the field of agriculture, water resources, energy, and infrastructure. State governments are implementing adaptive action in various sectors by mainstreaming it with Sustainable Development Goals and with climate-resilient local-level planning.
4. Large-scale government programs, such as MNREGA, National Rural Livelihoods Mission, etc., have become important vehicles of enhancing adaptation works, resulting in climate-positive co-benefits. These measures addressing climate vulnerability need to be mainstreamed and highlighted as part of India's development policy frameworks.
5. Mitigation action – Key mitigation action points for the country span the areas of enhancing energy efficiency, increasing the forest carbon stock, knowledge dissemination, and R&D including technological needs aggregation, policies for electric and efficient vehicles in the field of transportation, and diversification of energy sources.

6. **India has to bring down the carbon footprints of its economy while moving up the development ladder. De-carbonisation of the economy will require increased electrification of sectors currently dependent upon fossil fuel. This will necessarily imply higher consumption of electricity per head. At present, India's per capita consumption is amongst the lowest in the world. This will have to be ramped up to 20559 kWh (R95N05), 17331 kWh (R60N10CCS30), 17021 kWh (R50N20CCS30), 16724 kWh (R40N35CCS25), 16313 kWh (R05N95) per capita by 2070, depending upon the scenario chosen, to cater to a low carbon economy which includes e-mobility, hydrogen production and supplying energy and process heat to industry. The emission levels of the developed and the developing countries should move towards a convergence.**
7. Renewables, particularly solar will have to assume a larger share of India's energy requirements. This has to be done in a fully transparent and balanced manner bringing out the cost of the system, including balancing cost and transmission charges, which have to be factored into the tariff structure of the renewables.
8. Renewable power could be deployed as part of distributed generation (preferably in agriculture segment) to minimize the requirement for transmission infrastructure and help reduce the cost. Free/Unmetered power to agriculture constitutes 20 to 40 % of the power consumption of most major states. Apart from revenue loss to the DISCOMs, this has led to profligacy in the use of electricity and groundwater resources leading to lowering of the water table in some States with long-term consequences. The farmers could be given solar panels at subsidized rates/free to reduce the pressure on the grid.[497]
9. Nuclear as a source of non-fossil, stable base-load power has to be a significant part of India's energy matrix along with renewables. Major economies like the US, UK, China, Japan, and France have already declared nuclear power as part of their pathway towards a low carbon economy.
10. There is a positive convergence between the growth of renewables and nuclear power. Renewables are an intermittent source of energy and need a source of backup power when the sun is not shining and the wind is not blowing. Availability of appropriate share of nuclear capacity in the grid enables dispatchable power while at the same time keeps the investments needed for peak power capacity under check. To avoid increasing import dependence and lower carbon-foot-print even as one approaches net zero, the share of nuclear power has to be increased correspondingly.
11. **As the MIT study has pointed out, without the contribution of nuclear power, 'the cost of achieving deep decarbonization targets increases significantly.' An increase in the share of nuclear power is necessary not only to meet India's additional power requirements but also optimize costs without which the goal of increasing the share of electricity in the energy mix will remain elusive. According to mathematical modelling done by IIT Bombay, India's energy transition to Net Zero Emission stage by 2070 would cost $ 11.2 trillion in a nuclear**

dominated scenario (R05N95), while the cost in case of a renewable dominated scenario (R95N05) would be 28% more at $ 15.5 trillion.

12. **Early peaking leads to higher upfront capital investment in renewable resources and storage. It will also require an additional investment of USD 1.2 trillion to shift the peaking year from 2050 to 2040. However, it leads to a lower stranded coal capacity in 2070.**
13. India should evolve a clean energy policy and identify nuclear energy as an integral element of that policy. Nuclear should be declared to be a clean energy and made eligible for all existing policies and benefits that solar/renewable energy has. Thus nuclear power should be given 'must-run status' on par with the renewables.
14. Merit Order Dispatch cannot be applied to the nuclear sector as heavy CAPEX requires stable prices.
15. Nuclear power's contribution to grid stability should be factored in the pricing mechanism. Similarly, pricing should factor in the large investment needed to install additional capacity to provide balancing power for renewables, which are intermittent.[498]
16. The nuclear sector should be allowed a level playing field vis-a-vis renewables and provided support on the lines of Renewable Purchase Obligations. Renewable purchase obligation may be converted into clean energy purchase obligation.
17. The nuclear power sector should be exempted from GST on inter-state transfer of goods for project execution. This facility may also be extended to the equipment supplied by vendors.
18. India needs to achieve a balanced energy basket to ensure energy security, and minimize volatility in electricity prices on account of commodity price fluctuations or weather conditions.
19. Major economies are retaining coal in the generation mix in the short to medium terms, while China is building new coal based power plants. India should explore options for minimizing emissions, such as super-critical technology with higher efficiency and CCUS.
20. As part of its de-carbonization strategy, India needs gas as a bridging fuel. Gas remains a substantial part of the energy mix of developed economies including the US and EU. Though this adds to the import bill, the alternative of development loss cannot be ignored. The energy transition and investment required for this purpose will take time, while there will be strong pressure to cap and phase out coal-based generation. To minimize the impact of international price fluctuations, long-term, stable contracts for the purchase of LNG as well as piped gas from neighboring should be encouraged. Gas can also supply peaking power to renewable power plants. Most of the stranded gas-based power plants are based in renewable-rich states.
21. To avoid creating new dependencies, we must build up domestic manufacturing capacity, especially for the renewable sector which is going to witness major expansion.
22. The Government and private sector have to invest in R&D in Green Technologies. India's R&D expenditure has consistently lagged behind international levels. The government should extend funding for R&D for development of SMR reactors, HTGR as well as load following reactors, which can provide flexible generation.

23. As a dense source of energy, nuclear power can play a role in producing hydrogen through electrolysis as well as through thermochemical splitting of water using high temperature reactors, supplying to long distance heavy vehicle transportation and process heat to industry. To this end, there is need to widen the scope of the new hydrogen policy, which limits production of green hydrogen to use of renewable energy for electrolysis of water. We need not foreclose our options at this stage when the technologies have not matured. The policy should include production of green hydrogen using nuclear power as well as a range of intermediate solutions including blue hydrogen.

24. Similarly concentrated solar is an important source for hydrogen production through thermo-chemical water splitting route apart from its importance in terms of cheap energy storage for 24/7 electricity generation and should be encouraged.

25. **The land requirement to be taken into account in making energy mix choices for reaching NZE by 2070. This in case of the renewable heavy scenario (R95N05) would be 4,12,033 square kms exceeding the total surplus land of 2,00,000 square kms available in India. This can be substantially reduced to 1,83,565 square kms in case of nuclear heavy scenario (R05N95). The land requirement will go up even further to 13,13,500 square kms if the share of hydrogen in total demand is increased from 10% as in the case above, to 25% and green hydrogen is produced using renewables only excluding nuclear power.**

26. Hydro-power can play a role in providing storage solutions and meeting peaking power requirements. This is inherently limited by land and population pressures. Building up and import of hydro-power from Nepal and Bhutan is a long-term solution. This will be a win-win situation for the countries.

27. The developed countries should be held to their promise of providing financial assistance to developing countries to make the transition to a low-cost economy. The goal of $ 100 billion per annum assistance is part of the Paris Conference pledge. As noted by the UN Secretary-General, developed countries fell short of reaching even this target. Of the amount provided, 2/3rd consists of credit. This pre-dates the current Net Zero Emission and peaking power concepts, which will result in more stringent emission norms and a shorter transition period. The finance to be provided by the developed countries should match higher ambition for climate action. As mentioned by PM Modi at the Glasgow Conference, climate financing to the tune of approximately US $1 trillion by 2030 would be required by India.

28. Since India will have to largely depend upon internal sources for Energy transition, it is imperative that the health of DISCOMs has to be restored to minimize government's fiscal burden. Major investment decisions to create new generation assets and strengthening of grid require long lead time to implement. There is a need for deciding the targets for 10-15 years, and a stable policy framework for the medium term. Ramping up of nuclear Power should take place in tandem with phasing out of coal. The government needs to bring out a policy paper to initiate debate and achieve consensus of all the stake-holders.

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Annexure

Report of IIT Bombay on Mathematical Modelling for the VIF Task Force report on India's Energy Transition in a Carbon-Constrained World

Subhadip Bhattacharya, Sarvesh Chaudhari and Venkatasailanathan Ramadesigan
Department of Energy Science and Engineering, IIT Bombay, Mumbai

Background

In line with global trends, India has continuously revised its renewable energy targets since the introduction of the Jawaharlal Nehru National Solar Mission (JNNSM) in 2010. In 2015, India founded the International Solar Alliance (ISA) alongside France to revise the then-existing target of 20 GW of grid-interactive solar energy by 2022 to five times at 100 GW [1]. Not just solar but also another 60 GW of wind power and 15 GW of other renewable energy sources like small hydropower and biomass are in contention. These policy targets aligned with India's Intended Nationally Determined Contributions (INDCs), achieving 40% of its total installed capacity from renewable sources by 2030. In 2018 the Ministry of Power (MoP) released the National Electricity Plan (NEP'18), aiming at 275 GW of renewable energy contributing to 44% of the installed capacity and 24.4% by generation in 2027 [2]. In September 2019, India set a 450 GW renewable energy target beyond 2022, although no specific timeline was announced. In the recently concluded COP-26 summit at Glasgow in November 2021, India set a timeline for installing 500 GW of non-fossil fuel capacity by 2030. Along with this target, India set four other targets — (a) India to meet 50% of its energy requirements from renewable energy by 2030, (b) India would reduce the total projected carbon emissions by one billion tonnes from now till 2030, (c) By 2030, India would reduce the carbon intensity of its economy by more than 45 %, (d) India would achieve the target of net zero by 2070 [3]. Since then, GOI has announced updated NDCs on 3rd August, where the country will achieve about 50% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2050.

In its sixth assessment report, the IPCC stated that to limit the mean global temperature rise to 1.5°C and 2°C, the available GHG emissions budget from 2020 to 2100 is 500 $GtCO_2$ and 1150 $GtCO_2$,

respectively [4]. There is a need for a more equitable and fair division of remaining carbon space. As of 2020, China, the US, and India are the most significant GHG-emitting countries [5]. The latest UNECE report, considering the life cycle emission of different electricity generation technologies, reveals that nuclear and not renewable energy sources (RES) have the lowest CO_2 emission factor, as shown in Table 1. Moreover, RES suffer from their uncertainty of output and seasonal variability. High penetration of RES would also require adequate storage to act as a balancing resource during its unavailability. Without storage and dedicated transmission corridors, there could be a significant curtailment and wastage of RES. There are also challenges in maintaining grid frequency within the specified limits in a low inertia power grid with high renewable penetration. Most of the previous studies pertaining to India have exclusively focussed on the role of RES, thereby neglecting the role of nuclear in most of the analyses and policy discourse. All these factors entail looking back at the current strategy for advancing the renewable-only deployment pathway to combat climate change.

Table 1 Life cycle CO2 emission of different generating technologies [6]

Technology	Coal	Gas	Hydro	Solar PV	Onshore Wind	Nuclear
Emission (g CO_2 eq./kWh)	751-1095	403-513	6-147	8-83	7.8-16	5.1-6.4

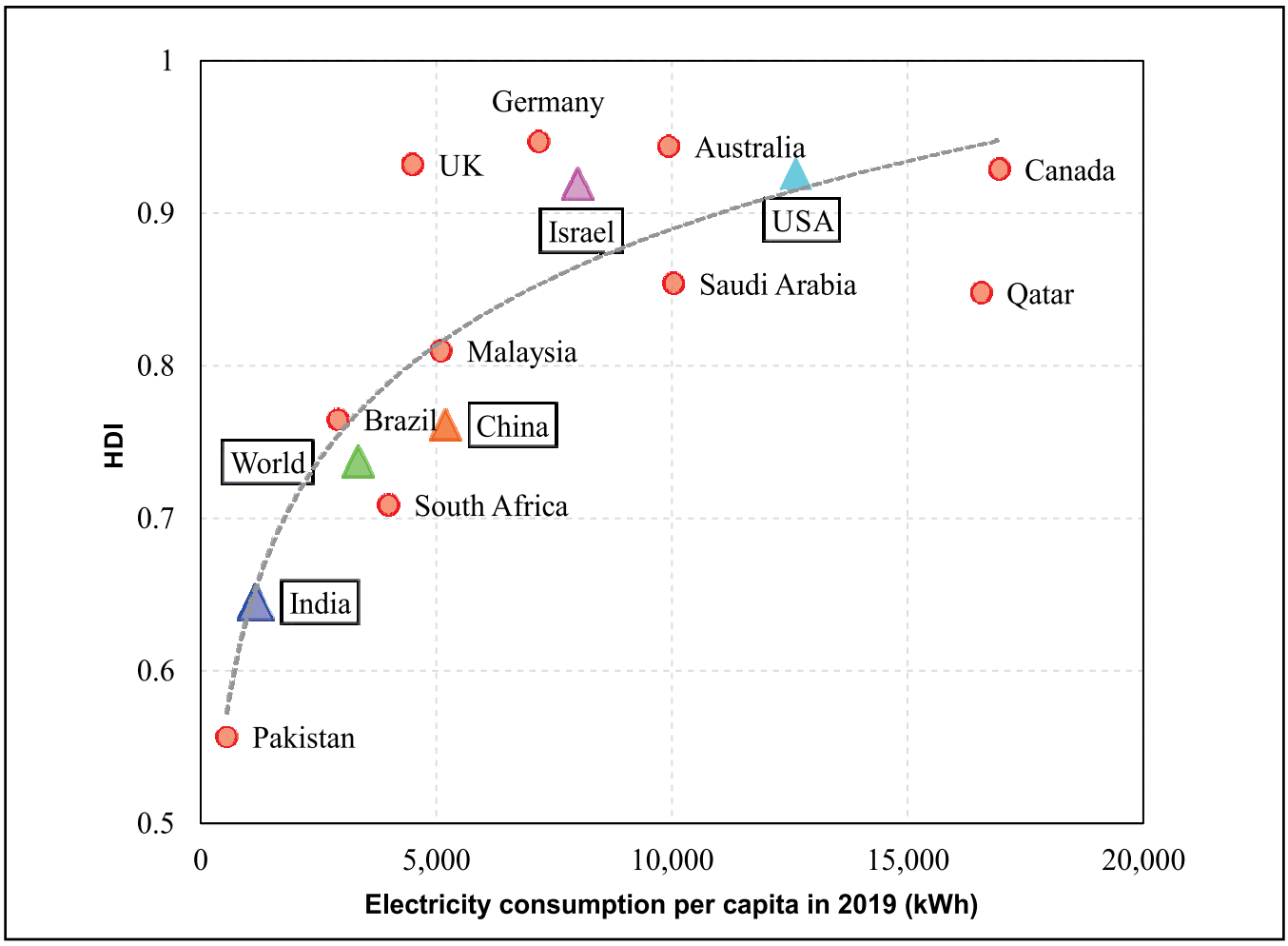
Vivekananda International Foundation Task Force requested IIT Bombay (IITB) to assist it with mathematical modelling for a study on 'India's Energy Transition in a Carbon-Constrained World.' The present report is in pursuance of this request. IITB was asked to examine five scenarios in addition to BAU: R95N05, R60N10CCS30, R50N20CCS30, R40N35CC25, and R05N95 (R- Renewable, N - Nuclear, CCS Carbon, Capture, and Storage). Apart from net zero-emissions (NZE) in 2070 with peaking at 2050, IIT Bombay also examined two other scenarios – NZE in 2065 with peaking in 2045 and NZE in 2060 with peaking in 2040. All scenarios generate green H_2 from the electricity output from both renewable and nuclear. Green H_2 would mainly be used in hard-to-abate sectors, e.g., refineries, fertilisers, and steel industries, for methanol production, as a vehicular fuel, and H_2-based fuel cells for electricity generation. Two demand scenarios for green H_2 demand have been studied: 10% and 25% of the final energy demand.

India's power sector accounts for 45% of the country's total emissions. Hence, reaching the net zero emissions target would involve going beyond the power sector. The mathematical modelling by IITB is based on converting 75% of energy to electricity which is a much more ambitious target than assumed by other Think Tanks (for instance, the IEA report assumes only converting 50% of the energy basket to electricity by 2050). While applying emission constraints, we cannot ignore the severe resource constraints and development aspirations of a developing country like India. Therefore, instead of making an apriori assumption, the model examines the cost implications of different scenarios ranging from renewable high to nuclear high. The results are based on mathematical modelling of the given scenarios using data and studies published by NITI Aayog and CEA. IITB has also consulted a diverse range of sources for this study comprising reports from the CEA, UNECE, IRENA, and IEA

Electricity demand

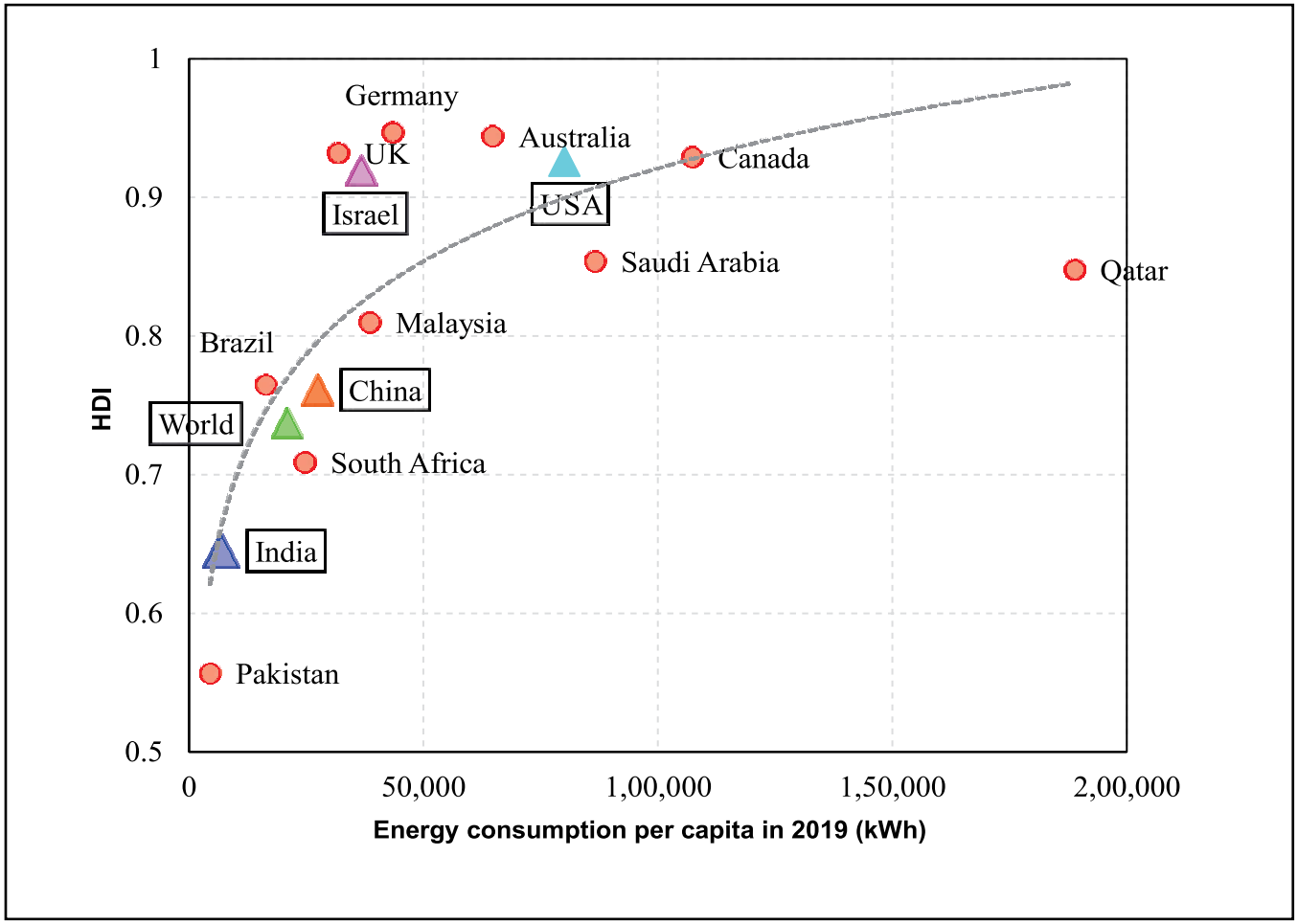
Several existing pieces of literature were referred to analyse India's electricity demand in 2070. The electricity demand would be driven by the electrification of end-use sectors like transport, residential cooking and cooling demand, better living standards, urbanisation, and infrastructure growth. Figure 1 shows the HDI vs per-capita electricity consumption of major countries worldwide. A strong positive correlation between living standards (HDI) and electricity consumption is observed at a lower level of HDI (less than 0.8) and per-capita electricity consumption (6000 kWh per capita). No such correlation can be observed beyond an HDI of 0.8. Most European countries' per-capita electricity consumption lies between 5000 to 6500 kWh. India's per-capita electricity consumption in 2020 from the supply side (including losses) is 1181 kWh [7], excluding demand from captive power. Considering the past trend, China's per-capita electricity consumption in 2001 is comparable to India's present per-capita electricity consumption.

Figure 1 : HDI vs per-capita electricity consumption (2019).



A similar trend is observed while comparing the HDI with the per-capita energy consumption of different countries, as shown in Figure 2. A positive correlation is observed between an HDI of 0.8 and per-capita primary energy consumption of 25,000 kWh. India's per-capita energy consumption is around 7000 kWh, one-third of the world average. In most developed countries, space heating is achieved through non-electrical means (gas etc.). Hence, per-capita electricity consumption in these countries would be significantly higher if heating by equivalent electricity is accounted for in the energy mix. However, cooling is almost totally based on electricity.

Figure 2: HDI vs per-capita energy consumption (2019).



In its 2020 energy outlook, BP projected India's electricity demand to grow by 4 to 4.6% per annum by 2050. India's share of the world's final energy demand will be 13% [8]. Table 2 summarises the IEA's latest world and India outlook reports. In the net zero scenario, the share of electricity in final demand rises to 47%. Table 3 summarises the studies analysing India's electricity demand growth before the COP-26 announcement. None of these studies has evaluated a net zero energy sector for India. Table 4 summarises a few latest studies predicting India's future electricity demand considering India's net zero targets of 2070. Studies post-Glasgow summit project higher future electricity demand as most end-use sectors become electrified.

The trend of electricity consumption in the past is no index of demand in the future. Achieving a net zero emission target would require bringing new sectors like transport, housing, and electricity under electrification. This will require an increase in demand for electricity, and its share in the energy basket, to rise beyond the previous CAGR of electricity consumption. Electricity is around 20% of energy consumption. Its share in the energy basket will also go up.

Table 2 : IEA World Energy Outlook 2020 and India Energy Outlook 2020 summary

World [9]	Scenario	2050 demand (EJ)			CAGR (%) (2019-2050)
2019 world primary energy supply: 613 EJ	Stated Policy scenario	744			0.6
	Announced Pledges scenario	675			0.3
	Sustainable Development scenario	578			-0.2
	Net zero scenario	543			-0.4
2019 world electricity generation: 26959 TWh (97 EJ ≅ 16%)	**Scenario**	**2050 generation (TWh)**	**2050 generation (EJ)**	**Percentage of overall energy demand (%)**	**CAGR (%) (2019-2050)**
	Stated Policy scenario	46703	168	23	1.8
	Announced Pledges scenario	54716	197	29	2.3
	Sustainable Development scenario	57950	209	36	2.5
	Net zero scenario	71164	256	47	3.18
India [10]	**Scenario**	**2040 demand (EJ)**			**CAGR (%) (2019-2040)**
2019 India's primary energy demand: 39 EJ	Stated Policy scenario	66			2.5
	Sustainable Development scenario	48			1
	India Vision scenario	64			2.4
2019 India's electricity demand: 1207 TWh (4.35 EJ ≅ 11%)	**Scenario**	**2040 demand (TWh)**	**2040 demand (EJ)**	**Percentage of overall energy demand (%)**	**CAGR (%) (2019-2040)**
	Stated Policy scenario	3146	11.3	17	4.7
	Sustainable Development scenario	2980	10.7	22	4.4
	India Vision scenario	3433	12.4	19	5.1

Table 3 Summary of electricity demand for India pre-Glasgow summit without considering any net zero year

Year of publication	Author/Institute	End year	Electricity demand	Ref.
2006	Grover et al.	2052	5305 kWh/capita	[11]
2015	Shukla et al.	2050	7000 TWh or 4667 kWh/capita	[12]
2017	NITI Aayog	2040	3439 TWh, i.e., 2924 kWh/capita	[13]
2018	Parikh et al.	2050	8656 TWh or 5770 kWh/capita	[14]
2019	CEA	2037	For three scenarios of GDP growth • Pessimistic (6.5%): 3067 TWh, i.e., 2044 kWh/capita • BAU (7.3%): 3517 TWh, i.e., 2344 kWh/ capita • Optimistic (8%): 3878 TWh, i.e., 2585 kWh/ capita	[15]
2020	NREL	2047	4190 TWh, i.e., 2793 kWh/capita	[16]
2020	Dasgupta et al.	2050	For three scenarios of GDP growth • Pessimistic (6%): 3367 kWh/capita • BAU (6.7%): 4079 kWh/ capita • Optimistic (10%): 8321 kWh/capita	[17]
2020	TERI	2050	6000 TWh or 4000 kWh/capita	[18]
2021	RMI	2050	11000 TWh, i.e., 6586 kWh/capita	[19]
2021	Barbar et al.	2050	5250 TWh, i.e., 3144 kWh/capita	[20]
2021	CEEW	2050	8000 TWh or 5333 kWh/capita	[21]

What distinguishes the pre-Glasgow from post-Glasgow studies is that the Glasgow outcome has resulted in more stringent emissions standards. Many of the pre-Glasgow projections were not based on net zero emissions. A revised target with more stringent emission standards is bound to increase the demand for electricity per capita as well as in overall terms. The varying timeframe also impacts electricity demand at the final stage. Extreme weather conditions and higher living standards will also drive up the demand for electricity.

Table 4 Summary of electricity demand for India post-Glasgow summit based on studies assuming net zero by 2070

Year of publication	Author/Institute	End year	Electricity demand	Ref.
2021	CEEW	2100	24000 TWh or 16000 kWh/capita	[22]
2022	Bhattacharyya et al.	2070	14867 kWh/capita	[23]

In 2020, the share of electricity in the final energy demand was around 14%. The energy demand in the BAU scenario reaches 33,000 TWh with about 50% electrification in 2070. The maximum possible electrification of the entire energy sector is about 75% —nearly 100% electrification of most of the sectors (residential, commercial, agricultural, transport and misc.) except for some industrial demand (heating and reducing agent) which cannot be directly replaced by electricity. With this 75% electrification, the final energy demand reduces to 25,000 TWh, with an efficiency gain of 24% from the BAU demand of 33.000 TWh. Therefore, the electricity demand was estimated to be around 18,900 TWh in 2070. Past trend of final energy consumption (Ref. IEA): energy consumption increased at a rate of 3.4% between 2010-19.

- From IESS analysis, final energy consumption in 2020 = 6292 TWh
- BAU scenario energy consumption in 2070 = $6292\times(1+0.034)^{50}$ = 33482 TWh

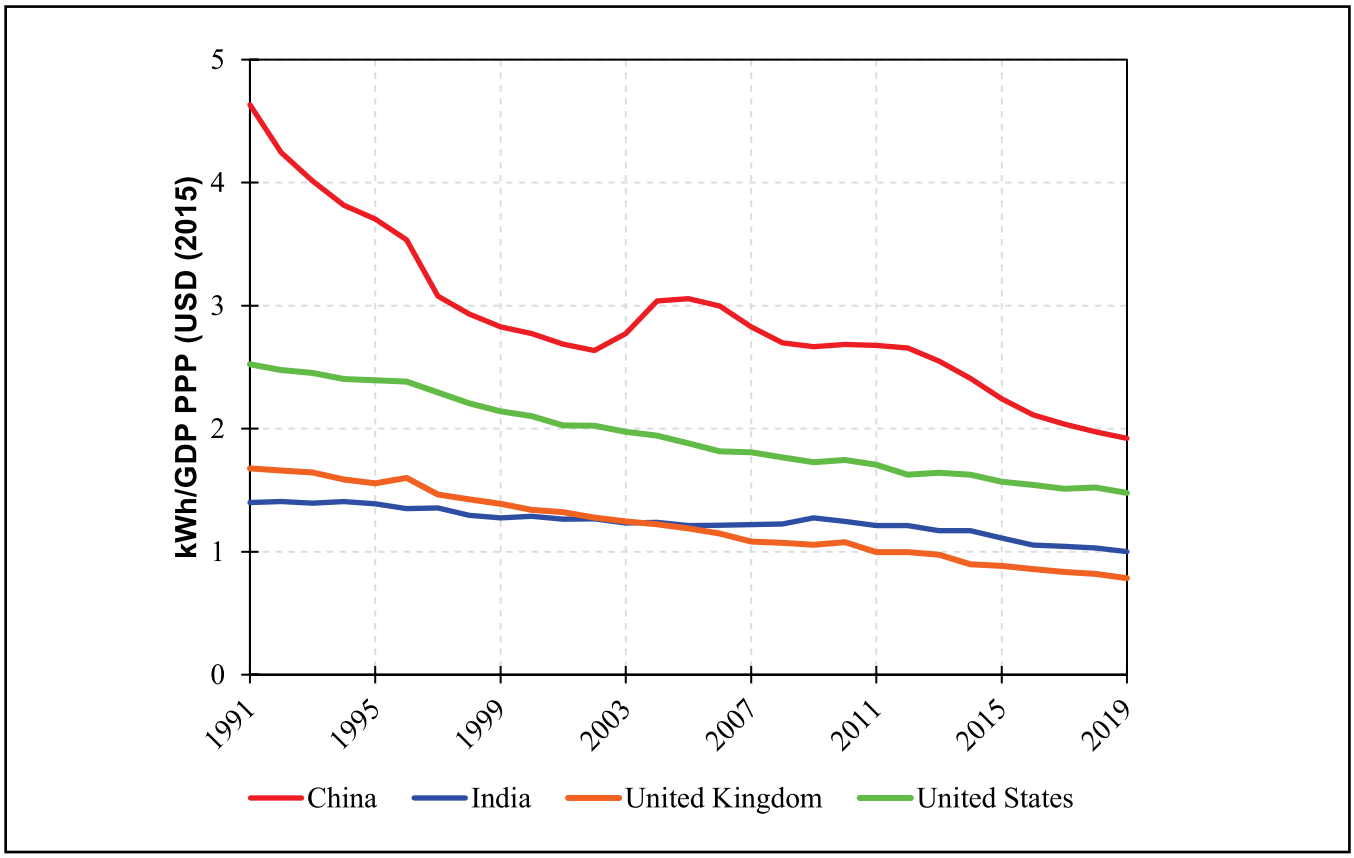
India's energy intensity of GDP has declined at an average CAGR of 2.56% between 2011 and 2020 (Ref. EIA), as shown in Figure 3. This decline is a result of multiple factors such as:

1. Increase in service sector GDP, which consumes relatively lower energy than manufacturing industries per unit GDP output.

2. Improvements in the energy efficiency of appliances: In the residential sector, the penetration of efficient LEDs has increased significantly. In the industrial sector, the PAT scheme has pushed to reduce specific energy consumption in energy-intensive industries such as cement, steel, and refineries. Other programmes, such as the street lighting programme, green building programme, and Ag DSM programme, contribute to energy savings. In 2018-19, 28 mtoe (around 5% of India's total final energy consumption) energy savings took place as an effect of all these schemes (Ref. BEE).

3. A slight improvement in the share of electricity in the final energy use. From 11% in 2012, it grew to 14% in 2020. This is a slight change in 10 years; however, as the electrification increases in transport, agriculture and industries, the energy intensity is expected to decrease further.

Figure 3 Energy intensity of GDP



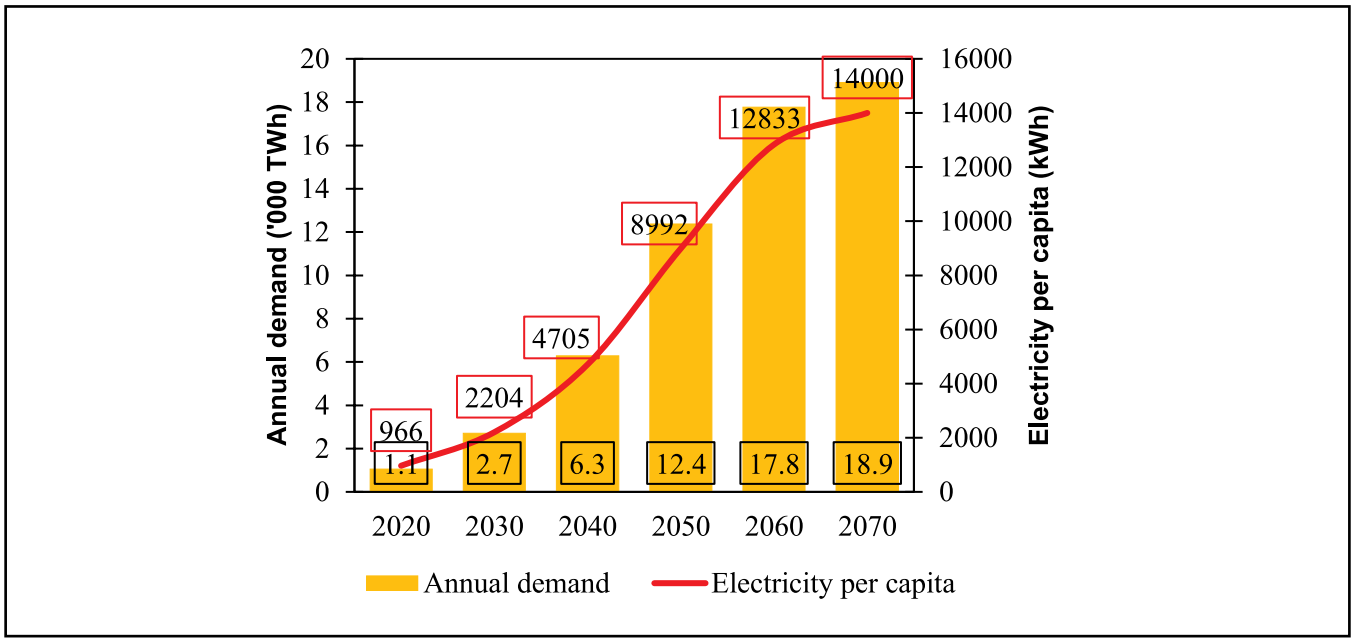
Source: EIA

The share of service sector industries in the country's GDP is likely to saturate in the long term. The potential for reduction in SEC of industries will also gradually decline. These two phenomena would slow down the energy intensity reduction. However, it is expected that very high electrification of all the demand sectors in future would be necessary to achieve net zero GHG emissions. Thus, the later years would see a rapid change in the fuel mix. Electric appliances tend to be more energy-efficient than their conventional counterparts. For example, an electric pump is more efficient than a diesel-based pump. Analysis of the IESS2047 model shows that an electric car consumes almost five times less energy than a diesel-based car to cater to the same passenger-km demand. An electric two-wheeler is also six times more energy-efficient than a conventional two-wheeler. An electric bus is two and a half times as efficient as a diesel-based bus. Electric/induction cookstoves have efficiency in the range of 80%-85%, whereas LPG cookstoves have 55% efficiency.

In this study, electricity from captive power plants is not considered. The end-use electricity demand (not considering electricity demand for green H_2) growth considered is shown in Figure 4. The AT&C losses are assumed to decrease from the present value of 21% to 10% in 2070. India's population is expected to peak by 2050 and gradually decline to 1.5 billion in 2070 [24]. The per-

capita electricity demand would reach 14000 kWh by 2070. The overall CAGR of electricity demand is 5.7% between 2020 to 2070.

Figure 4 Electricity demand growth, including AT&C losses.



Modelling framework

An integrated energy system optimisation model, TIMES, developed by the Energy Technology System Analysis Program (ETSAP) of the IEA, has been used in this study [25]. It is a technology explicit bottom-up modelling framework, the source code written in GAMS. Taking the input of present resource stock known as the reference energy system, current and future technology description, and projected demand, it determines the optimum future system portfolio at minimum cost, subject to several techno-economic and policy-related constraints, which is depicted in Figure 5. The techno-economic input parameters have been separately provided in Appendix A: Techno-economic parameters.

Model's objective function

The model's objective function is to minimise the net present value (NPV), which is the discounted sum of investment and operational costs over the modelling time horizon. This study does not consider transmission constraints. The overall optimisation framework is based on the following decisions — (a) which is the cheapest generator to be built to meet the load demand at every hour of the planning horizon and (b) which are the cheapest units to commit in each hour complying the operational constraints (c) how much power should each unit generate.

$$\boldsymbol{min.\ NPV} = min. \sum_{n=1}^{N} \frac{C_{INV_n}}{(1+d)^n} + \sum_{n=1}^{N} \frac{C_{OM_n}}{(1+d)^n} \pm \sum_{n=1}^{N} \frac{C_{IMP(+)/EXP(-)}}{(1+d)^n} \quad (1)$$

where,

$$C_{INV_n} = \sum_{g=1}^{NG} \sum_{l=1}^{n} c_{l,g}^{inv} IG_{l,g} \quad (2)$$

$$C_{OM_n} = \sum_{t=1}^{T} \left(\sum_{g=1}^{NG} \left(c_n^{fom} IC_{n,t,g} + c_n^{vom} P_{n,t,g} + c_g^{su} S^U_{type_{n,t,g}} + c_g^{sd} S^D_{n,t,g} \right) \right) \quad (3)$$

Therefore, the overall objective function,

$$\begin{aligned} &\boldsymbol{min.\ NPV} \\ &= min. \sum_{n=1}^{N} \frac{\sum_{g=1}^{NG} \sum_{l=1}^{n} c_{l,g}^{inv} IG_{l,g}}{(1+d)^n} \\ &+ \sum_{n=1}^{N} \frac{\sum_{t=1}^{T} \left(\sum_{g=1}^{NG} \left(c_n^{fom} IC_{n,t,g} + c_n^{vom} P_{n,t,g} + c_g^{su} S^U_{type_{n,t,g}} + c_g^{sd} S^D_{n,t,g} \right) \right)}{(1+d)^n} \\ &\pm \sum_{n=1}^{N} \frac{C_{IMP+/EXP(-)}}{(1+d)^n} \end{aligned} \quad (4)$$

Subject to

1. ***Power balance constraints:*** Total generation must balance the sum of the load demand, auxiliary energy consumption and transmission and distribution losses,

$$\sum_{g=1}^{NG} P_{n,t,g} = L_{n,t} + P_{n,t}^{aux} + P_{n,t}^{loss} \qquad \forall n, t\ \forall g \in TH \quad (5)$$

2. ***Generation limits:*** The power output from the generating unit must be within the maximum continuous rating (MCR) of the generator and the MSG level,

$$P_{n,t,g} \geq u_{n,t,g} P_g^{min} \qquad \forall n, t\ \forall g \in TH \quad (6)$$

$$P_{n,t,g} \leq u_{n,t,g} P_g^{max} \qquad \forall n, t\ \forall g \in TH \quad (7)$$

3. ***Start-up and shut-down constraints:*** A generating unit cannot start up and shut down at the same time,

$$u_{n,t,g} = u_{y,t-1,g} + S^U_{type_{n,t,g}} - S^D_{n,t,g} \qquad \forall n, t\ \forall g \in TH \quad (8)$$

4. ***Ramp rates:*** The rate of change of power output from the generator must be within the ramping limits,

$$P_{n,t,g} - P_{n-1,t,g} \leq u_{n,t-1,g} R_g^U + S_{type_{n,t,g}}^U P_g^{SU} \qquad \forall n, t\ \forall g \in TH \tag{9}$$

$$P_{n,t-1,g} - P_{n,t,g} \leq u_{n,t-1,g} R_g^D + S_{n,t,g}^D P_g^{max} \qquad \forall n, t\ \forall g \in TH \tag{10}$$

5. ***Minimum up and downtime:*** Once the generating unit has come online, it must run for a minimum period; and once it is off, it must remain off for a minimum time

$$u_{n,t,g} \geq \sum_{\tau=t-t_g^{up}}^{t} S_{type_{n,t,g}}^U \qquad \forall n, t\ \forall g \in TH \tag{11}$$

$$\sum_{l=1}^{n} IG_{l,g} - u_{n,t,g} \geq \sum_{\tau=t-t_g^{down}}^{t} S_{n,t,g}^D \qquad \forall n, t\ \forall g \in TH \tag{12}$$

6. ***Total units committed:*** The number of units committed at a particular instance should be less than the number of generator units built

$$u_{n,t,g} \leq \sum_{l=1}^{n} IG_{l,g} \qquad \forall n, t\ \forall g \in TH \tag{13}$$

7. ***Renewable energy sources output*:** The power output from a renewable energy generator is limited by the number of units installed and the capacity utilisation factor (CUF)

$$P_{n,t,g} \leq \left(\sum_{l=1}^{n} IG_{l,g} \right) P_g^{max} CUF_{n,t,g} \qquad \forall n, t\ \forall g \in RES \tag{14}$$

A discount rate '*d*' of 9% is used in this study, which is equal to the normative post-tax weighted average cost of capital (WACC) based on the normative debt-equity ratio of 70:30 as specified in CERC tariff regulations.

Model's planning horizon

A planning horizon spanning 50 years from 2020 to 2070 is considered in this study, with 2020 as the base or the reference year. Figure 6 gives the schematic of the temporal resolution used for analysis. The entire model horizon is segregated into ten equal periods of five years each. The base year 2020 and the end year of each interval is a "*milestone year*," i.e., 2025, 2030. 2035, ..., and 2070 when a new technology can be introduced or retired from the system. Each year comprises twelve seasons representing each month — January, February, March, ..., and December to capture the seasonal variability in load demand. Each season of a particular year is decomposed into one day — D01, D02, ..., and D12. Each day has 24 hours corresponding to the hourly load profile. Therefore,

Figure 5 Overall modelling framework (corresponding numbers denote the sequence of steps to be followed)

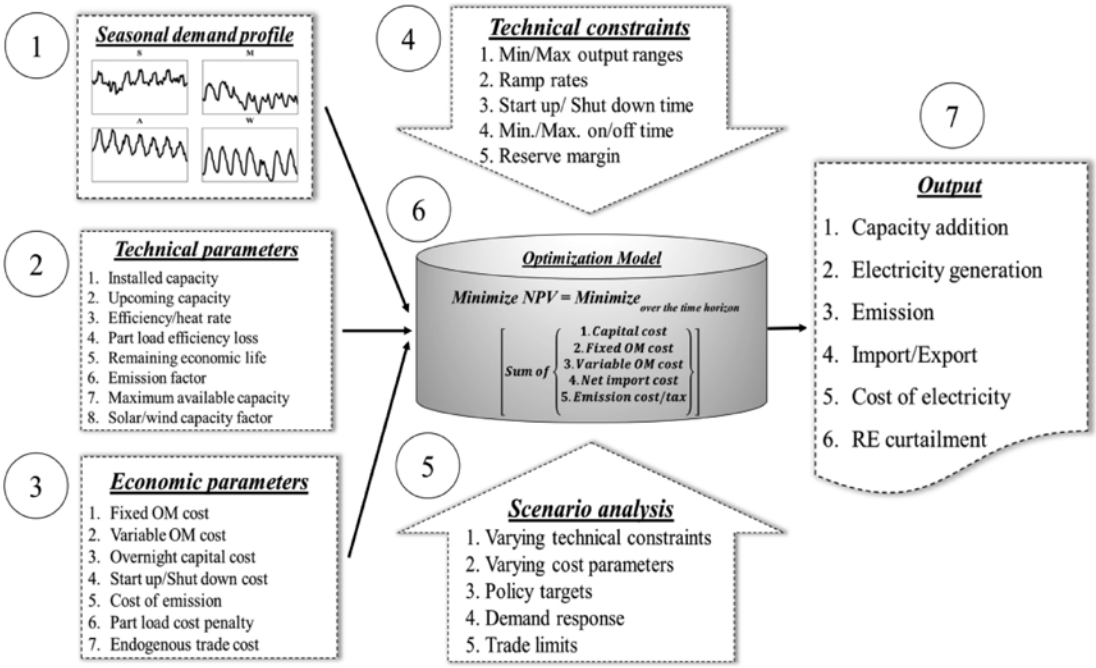
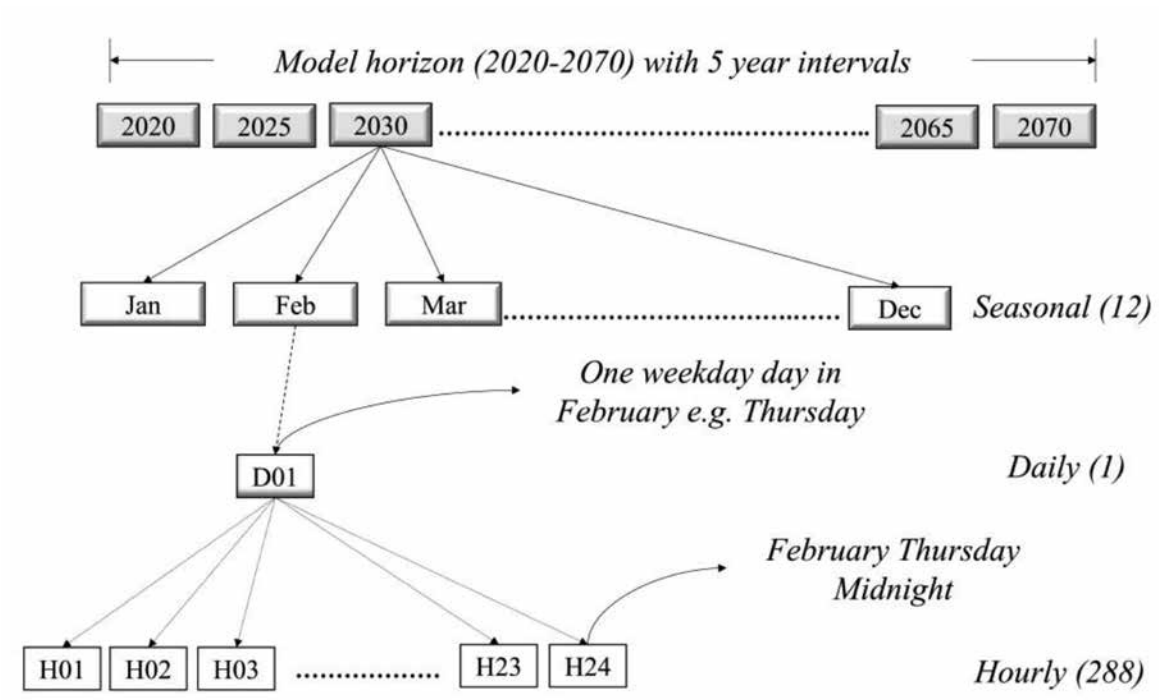


Figure 6 The temporal resolution of the model.



each year has 12×24 = 288 time slices. Thus, the model solves for 288×11 = 3168 time slices for a particular case run.

Scenarios

All scenarios generate green H_2 from the electricity output from renewable and nuclear. The demand for green H_2 starts emerging beyond 2022. Green H_2 would mainly be used in refineries, fertiliser, and steel industries, for methanol production, as vehicular fuel and H_2-based fuel cells for electricity generation. Two demand scenarios for green H_2 demand have been studied:

(a) The demand for green H_2 is considered to be 10% of the final energy demand of 25,000 TWh, i.e., 2,500 TWh in 2070. Considering a calorific value of 142 PJ/MT, the green H_2 demand reaches 64 MT in this scenario. Therefore, out of the end-use energy demand of 25,000 TWh, 18,900 TWh is directly electrified. Out of the remaining 6,100 TWh, 2,500 TWh is supplied by green H_2. The remaining 3,600 TWh is considered hard to abate.

(b) The remaining 3,600 TWh must also be supplied by green H2, taking its share to about 26% of the final energy demand. Therefore, the final demand for green H2 reaches 6,100 TWh. This increases the green H2 demand to 164 MT, 2.5 times the previous value of 64 MT. Therefore, out of the end-use energy demand of 25,000 TWh, 18,900 TWh is directly electrified.

(c) Ten scenarios are used in this study with different penetration of renewables and nuclear, as shown in Table 5. All scenarios expect the BAU to have CO_2 emission constraints to achieve net zero at the desired year. Scenarios 2 to 6 have different technological mixes, but all constrain CO_2 emissions to zero by 2070. Additionally, scenarios 7 and 8 impose additional CO_2 emission constraints to achieve net zero by 2070 but with different peaking years. Further, two scenarios with an early net zero have been analysed in scenarios 9 and 10.

All scenarios have a constraint on the maximum installed capacity of wind, biomass, and hydro. The wind has been further categorised into offshore and onshore. The maximum potential for onshore wind has been limited to 730 GW and that of offshore wind to 70 GW, thereby effectively limiting wind resources to 800 GW of maximum potential. Biomass has been capped at 25 GW of maximum potential. Similarly, hydro has been categorised into small and large and capped at 160 GW maximum potential.

Table 5 Scenario description with 75% electrification and 10% supplied by green H_2

Sl. No.	Net zero year	Peaking year	Scenario	Description
1	–	–	BAU	Business as usual scenario with 5% electricity from nuclear in 2070
2	2070	2050	R95_N05	95% electricity from renewable energy resources and 5% from nuclear in 2070
3			R60_N10_CCS30	60% electricity from renewable energy resources, 10% from nuclear and 30% from coal and gas CCS in 2070
4			R50_N20_CCS30	50% electricity from renewable energy resources, 20% from nuclear and 30% from coal and gas CCS in 2070
5			R40_N35_CCS25	40% electricity from renewable energy resources, 35% from nuclear and 25% from coal and gas CCS in 2070
6			R05_N95	5% electricity from renewable energy resources and 95% from nuclear in 2070
7	2070	2045	R95_N05	95% electricity from renewable energy resources and 5% from nuclear in 2070, with early peaking in 2045
8		2040	R95_N05	95% electricity from renewable energy resources and 5% from nuclear in 2070, with early peaking in 2040
9	2065	2045	R95_N05	95% electricity from renewable energy resources and 5% from nuclear in 2070, with an early net zero in 2065
10	2060	2040	R95_N05	95% electricity from renewable energy resources and 5% from nuclear in 2070, with an early net zero in 2060

Results

1. 10% green H_2 demand

(a) Net zero in 2070 with a peak in 2050

Table 6 summarises the results from various scenarios peaking in 2050 and net zero in 2070. Figure 7 and Figure 8 depict the installed capacity and the generation from different technologies during

the transition to net zero. Figure 9 depicts the cost of transition to net zero for the power sector. The installed capacity, generation, decadal capacity built rate and cost estimates have been separately provided in Appendix B: Installed capacity, generation, capacity built rate and cost.

Table 6 Summary of results from scenario analysis (1 USD ≈ 74 INR)

Scenarios	BAU	Net zero 2070				
		R95_N05	R60_N10_CCS30	R50_N20_CCS30	R40_N35_CCS25	R05_N95
Net zero year	–	2070				
Peaking year	–	2050				
Generation in 2070 (TWh)	27147	30839	25996	25531	25086	24470
Per-capita electricity consumption (kWh)	18098	20559	17331	17021	16724	16313
VRE penetration by generation in 2070 (%)	54	92	57	47	37	4
Maximum solar capacity (GW)	6985	14680	7057	5787	4841	3036
Maximum wind capacity (GW)	800					
Maximum coal capacity (GW)	1874	975	961	958	942	940
Stranded coal capacity in 2070 (GW)	–	484	452	451	437	438
Maximum nuclear capacity (GW)	215	284	406	763	1258	3139
CCS capacity (GW)	–	–	1269	1178	944	–
Maximum storage capacity (TWh)	3798	10621	3894	2925	2073	1438
Maximum H_2 electrolyser capacity (GW)	381 GW (to produce 64 Mt of green H_2)					
Cost of transition to net zero power sector (Trillion USD)	12.1	15.5	14.4	13.6	13.1	11.2
Investment in new technology (Trillion USD)	6.1	11.1	8	7.4	6.7	6
Electricity (ex-bus + grid integration) cost in 2020 (USD per MWh)	50					
Electricity (ex-bus + grid integration) cost in 2070 (USD per MWh)	122	164	155	140	131	103
Peak annual CO_2 emission (Gt) (peaking year)	13.2 (2060)	6.8 (2050)				

Figure 7 Net zero in 2070 with 10% green H2 demand — Installed capacity under different scenarios

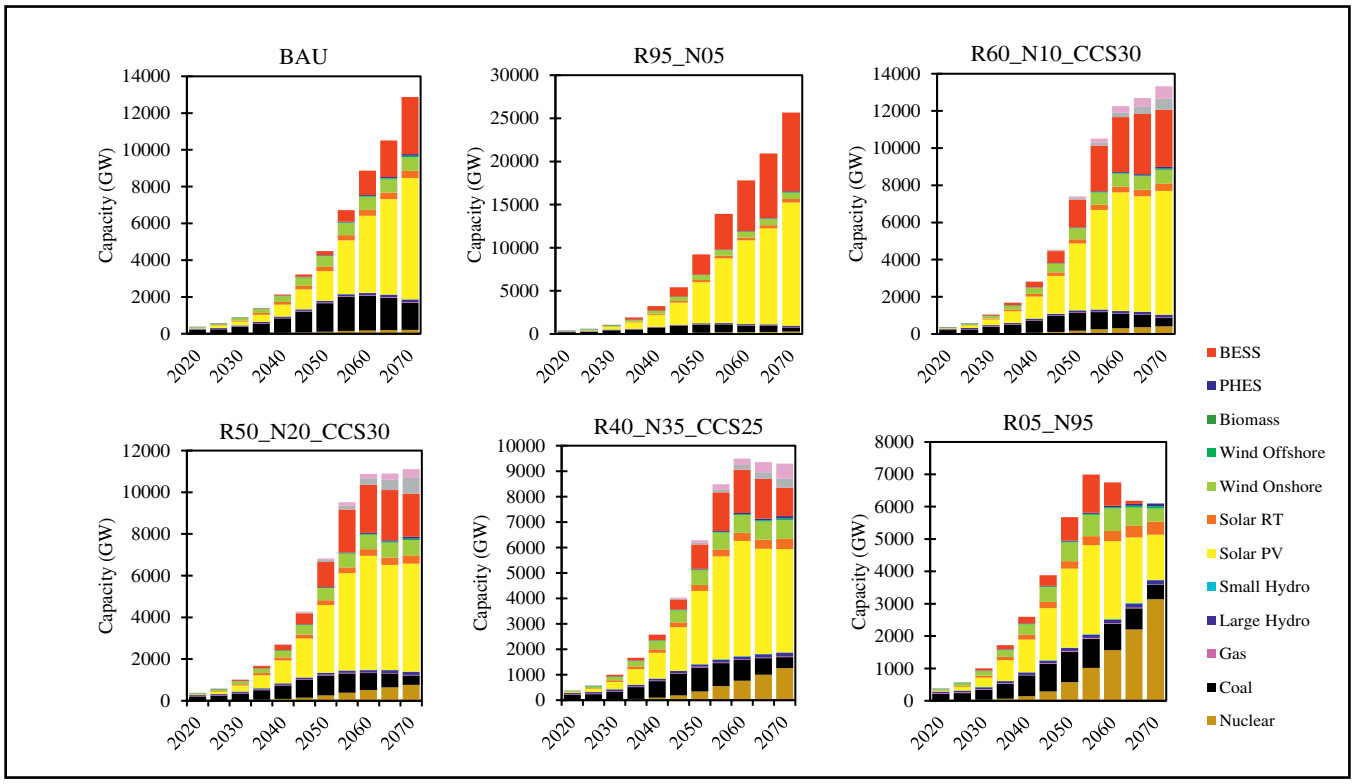


Figure 8 Net zero in 2070 with 10% green H2 demand — Generation under different scenarios.

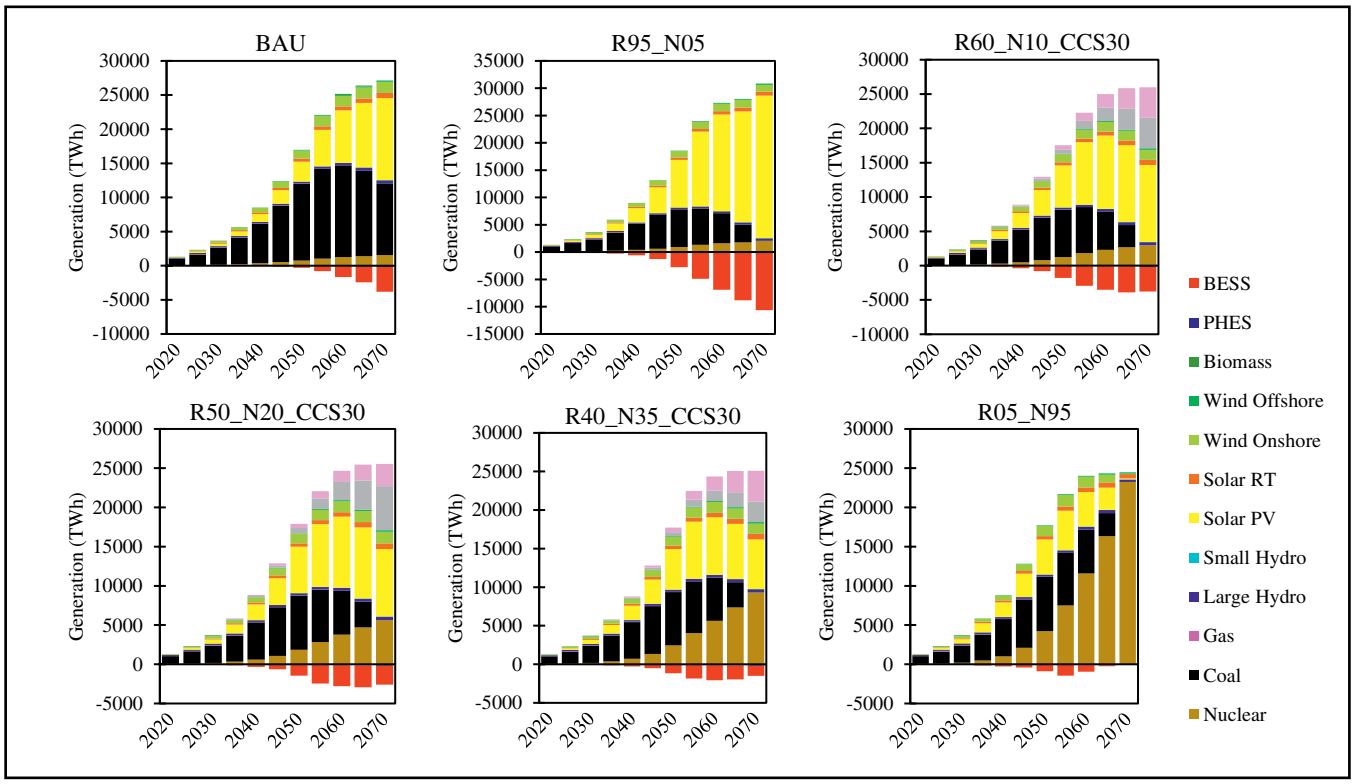
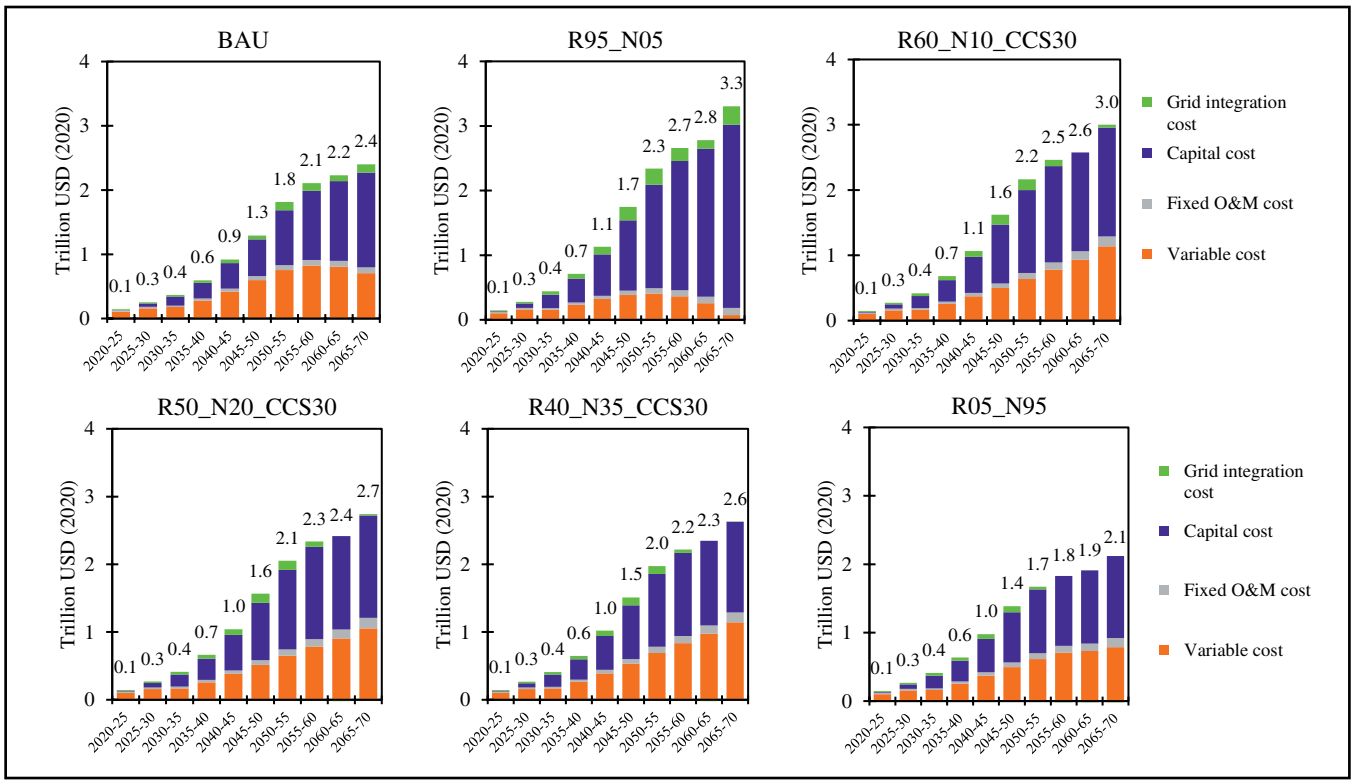


Figure 9 Net zero in 2070 with 10% green H2 demand — Cost of power sector transition.



(b) Early peaking

Table 7 summarises the results from scenarios involving an early peaking with a net zero in 2070. Figure 10 depicts the installed capacity and generation under early peaking scenarios. Early peaking leads to higher upfront capital investment in renewable resources and storage, as shown in Figure 11.

Table 7 Summary of results for early peaking (1 USD ≈ 74 INR)

Scenario	R95_N05	R95_N05	R95_N05
Net zero year	2070		
Peaking year	2050	2045	2040
Generation in 2070 (TWh)	30839	30839	30839
Per-capita electricity consumption (kWh per capita)	20559	20559	20559
VRE penetration by generation in 2070 (%)	92	92	92
Maximum solar capacity (GW)	14680	14680	14680

Scenario	R95_N05	R95_N05	R95_N05
Maximum wind capacity (GW)	800		
Maximum coal capacity (GW)	975	819	618
Stranded coal capacity in at net zero year (GW)	484	255	66
Maximum nuclear capacity (GW)	284	284	284
Maximum storage capacity (TWh)	10621	10621	10621
Maximum H2 electrolyser capacity (GW)	381 GW (to produce 64 Mt of green H2)		
Cost of transition to net zero power sector (Trillion USD)	15.5	16.1	16.7
Electricity (ex-bus + grid integration) cost in 2020 (USD per MWh)	50		
Electricity (ex-bus + grid integration) cost in 2070 (USD per MWh)	164	163	162
Peak annual CO2 emission (Gt) (peaking year)	6.8 (2050)	5.8 (2045)	4.5 (2040)

Figure 10 Net zero in 2070 with early peaking (a) Installed capacity (b) Generation

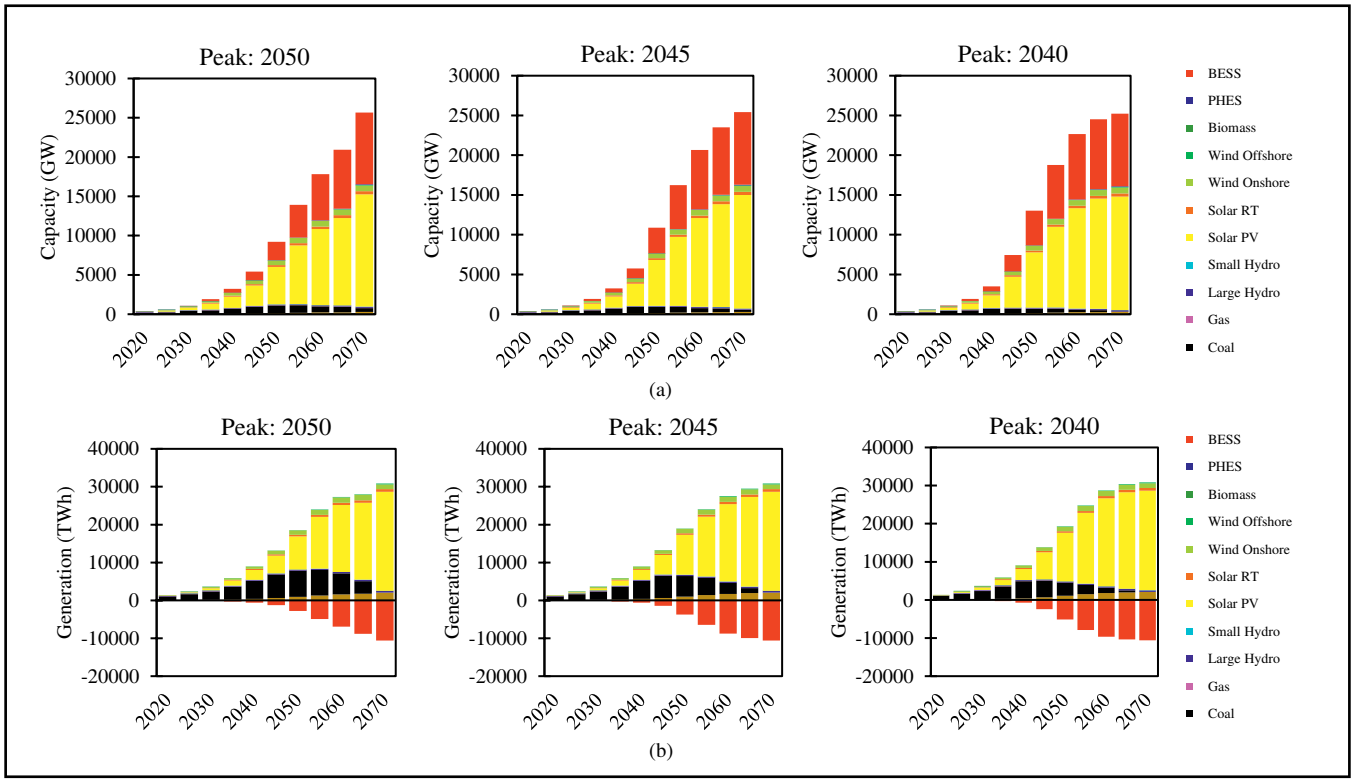
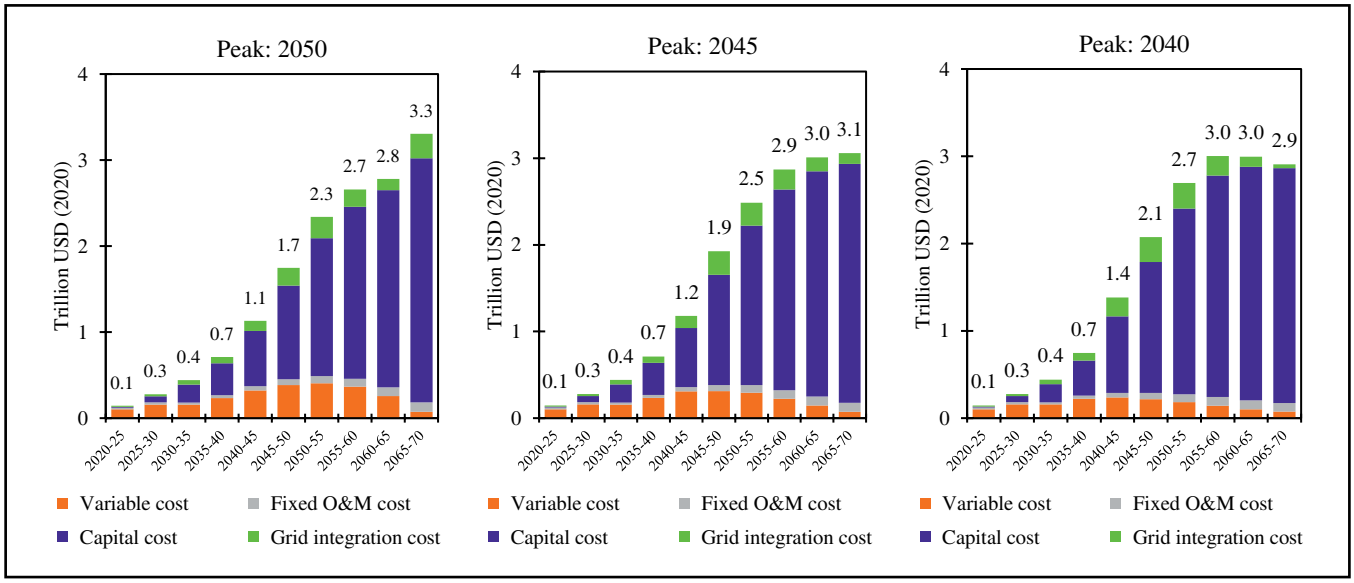


Figure 11 Net zero in 2070 with early peaking — Cost of power sector transition



(c) Early net zero

Table 8 summarises the results from scenarios involving early peaking and net zero years. Figure 12 depicts the installed capacity oand generation under early peaking scenarios. Early peaking leads to higher upfront capital investment in renewable resources and storage, as shown in Figure 13.

Table 8 Summary of results of alternate net zero years (1 USD ≈ 74 INR)

Scenario	R95_N05	R95_N05	R95_N05
Net zero year	2070	2065	2060
Peaking year	2050	2045	2040
Generation in 2070 (TWh)	30839	30839	30852
Per-capita electricity consumption (kWh per capita)	20559	20559	20568
VRE penetration by generation in 2070 (%)	92	92	92
Maximum solar capacity (GW)	14680	14817	14788
Maximum wind capacity (GW)	800		
Maximum coal capacity (GW)	975	773	592
Stranded coal capacity in at net zero year (GW)	484	205	1
Maximum nuclear capacity (GW)	284	284	284

Scenario	R95_N05	R95_N05	R95_N05
Maximum storage capacity (TWh)	10621	10621	10640
Maximum H_2 electrolyser capacity (GW)	381 GW (to produce 64 Mt of green H_2)		
Cost of transition to net zero power sector (Trillion USD)	15.5	16.5	17.2
Electricity (ex-bus + grid integration) cost in 2020 (USD per MWh)	50		
Electricity (ex-bus + grid integration) cost in 2070 (USD per MWh)	164	163	161
Maximum electricity (ex-bus + grid integration) cost (USD per MWh)	164 (2070)	165 (2065)	172 (2055)
Peak annual CO_2 emission (Gt) (peaking year)	6.8 (2050)	5.5 (2045)	4.3 (2040)

Figure 12 Net zero before 2070 with early peaking (a) Installed capacity (b) Generation.

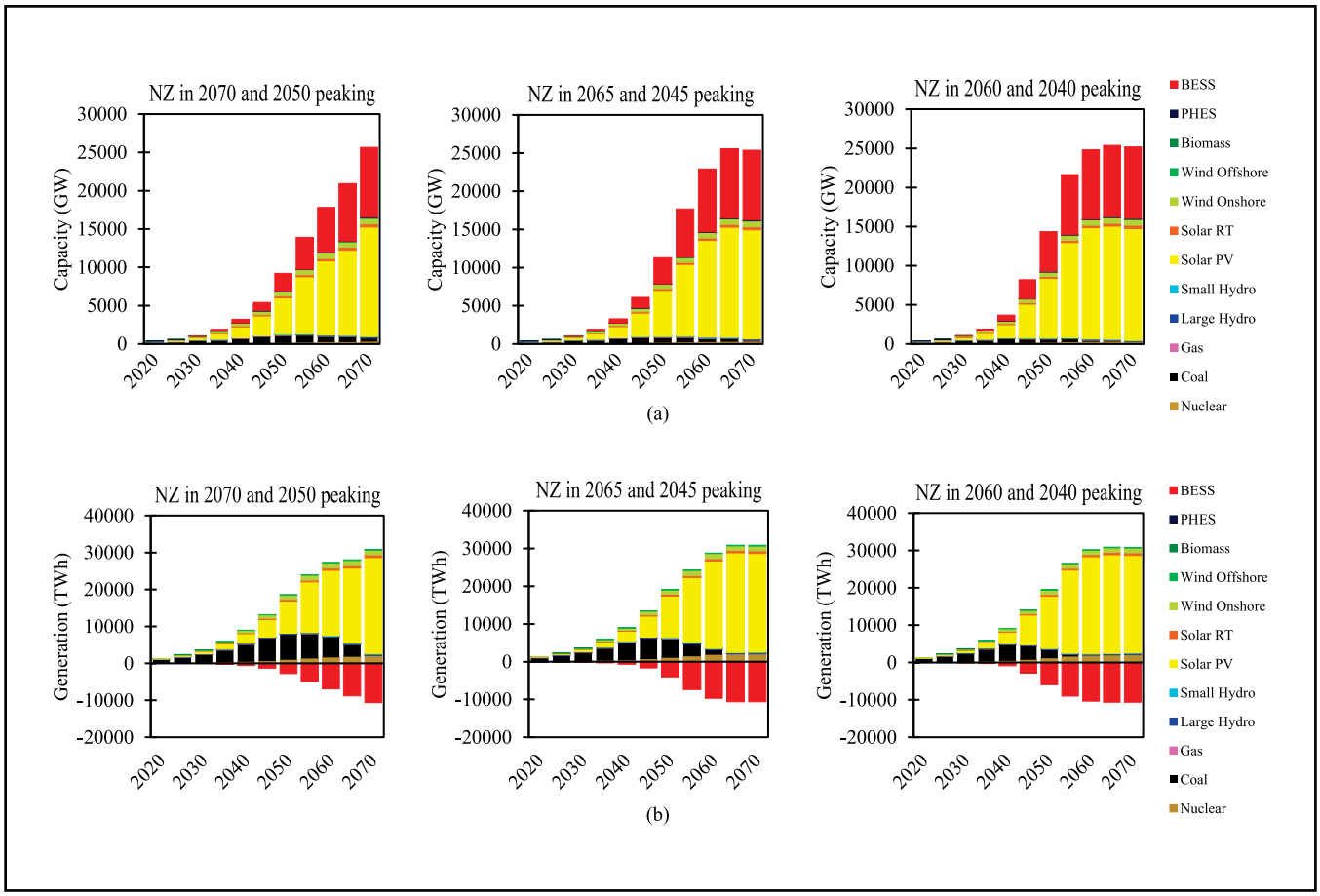
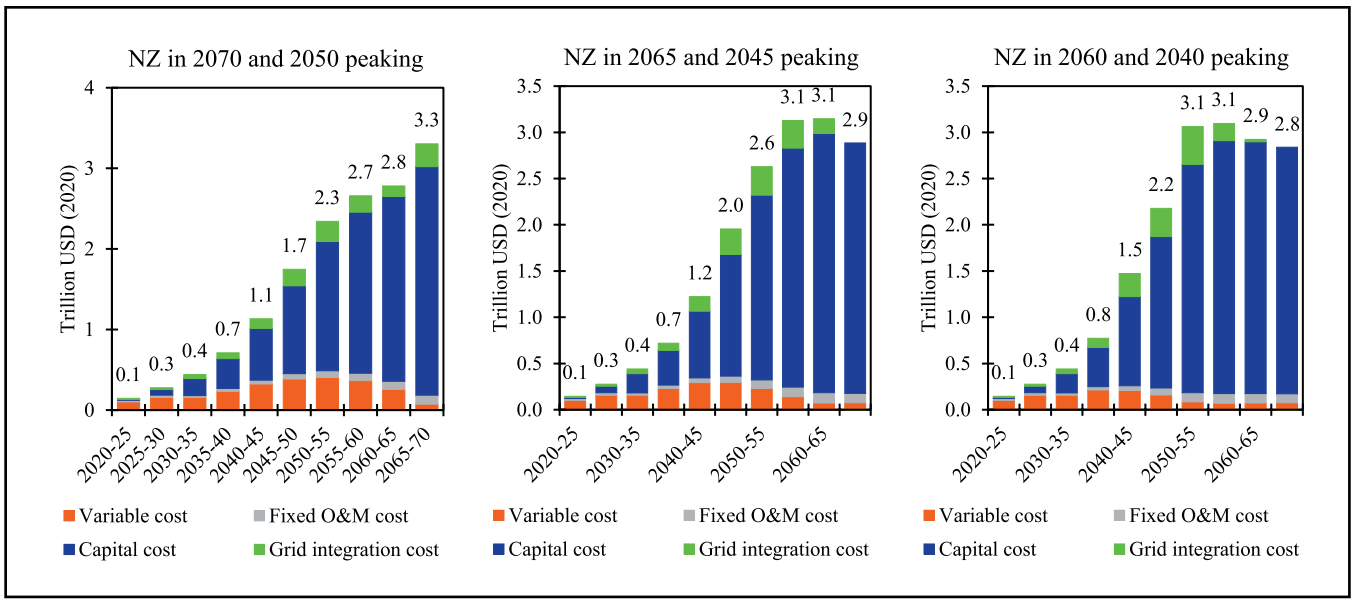


Figure 13 Net zero before 2070 with early peaking — Cost of power sector transition.



2. 25% green H_2 demand

Net zero in 2070 with a peak in 2050

Table 9 summarises the results from the various scenarios peaking in 2050 and net zero in 2070. Figure 14 and Figure 15 depict the installed capacity and the generation from different technologies during the transition to net zero. Figure 16 depicts the cost of transition to net zero for the power sector.

Table 9 Summary of results from scenario analysis (1 USD ≈ 74 INR)

Scenarios	BAU	Net zero 2070				
		R95_N05	R60_N10_CCS30	R50_N20_CCS30	R40_N35_CCS25	R05_N95
Net zero year	—	2070				
Peaking year	—	2070				
Generation in 2070 (TWh)	33264	116758	63481	31986	31438	30547
Per-capita electricity consumption (kWh)	22176	77839	42321	21324	20959	20635
VRE penetration by generation in 2070 (%)	45	94	59	47	39	4
Maximum solar capacity (GW)	7252	59160	19561	7157	5564	2219
Maximum wind capacity (GW)	800					
Maximum coal capacity (GW)	1982	975	961	960	946	935

Scenarios	BAU	Net zero 2070				
		R95_N05	R60_N10_CCS30	R50_N20_CCS30	R40_N35_CCS25	R05_N95
Stranded coal capacity in 2070 (GW)	–	467	453	452	440	431
Maximum nuclear capacity (GW)	904	862	863	962	1590	3917
CCS capacity (GW)	–	–	2569	1492	1190	–
Maximum storage capacity (TWh)	3764	10538	4222	3698	2608	1367
Maximum H_2 electrolyser capacity (GW)	928 GW (to produce 164 Mt of green H2					
Cost of transition to net zero power sector (Trillion USD)	12.7	27.7	20.2	15.3	14.9	12.1
Investment in new technology (Trillion USD)	4.7	19	10.2	8.1	7.4	6.5
Ex-bus electricity cost in 2020 (USD per MWh)	50					
Ex-bus electricity cost in 2070 (USD per MWh)	143	484	335	183	178	123
Peak annual CO_2 emission (Gt) (peaking year)	12.2 (2060)	6.8 (2050)				

Figure 14 Net zero in 2070 with 25% green H2 demand— Installed capacity under different scenarios

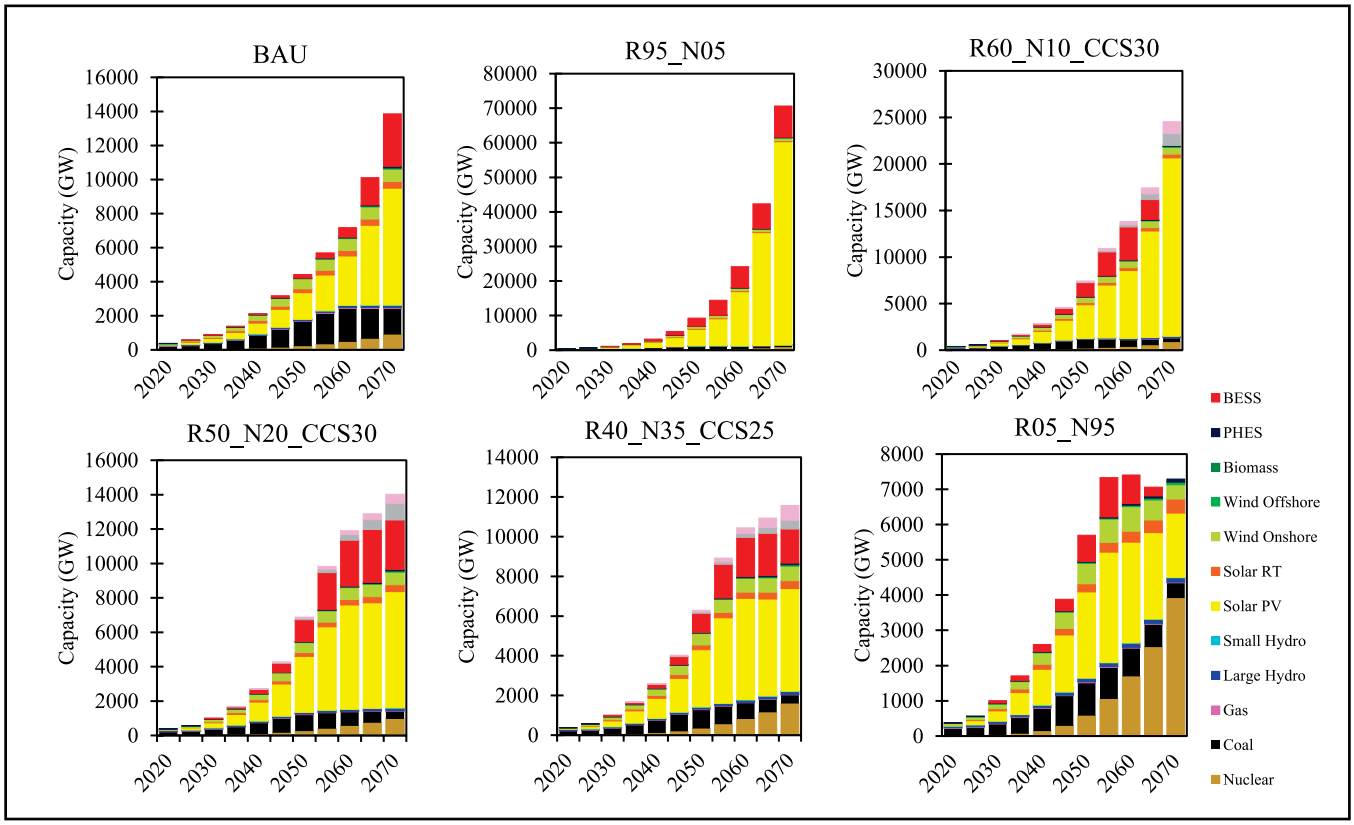


Figure 15 Net zero in 2070 with 25% green H2 demand— Generation under different scenarios

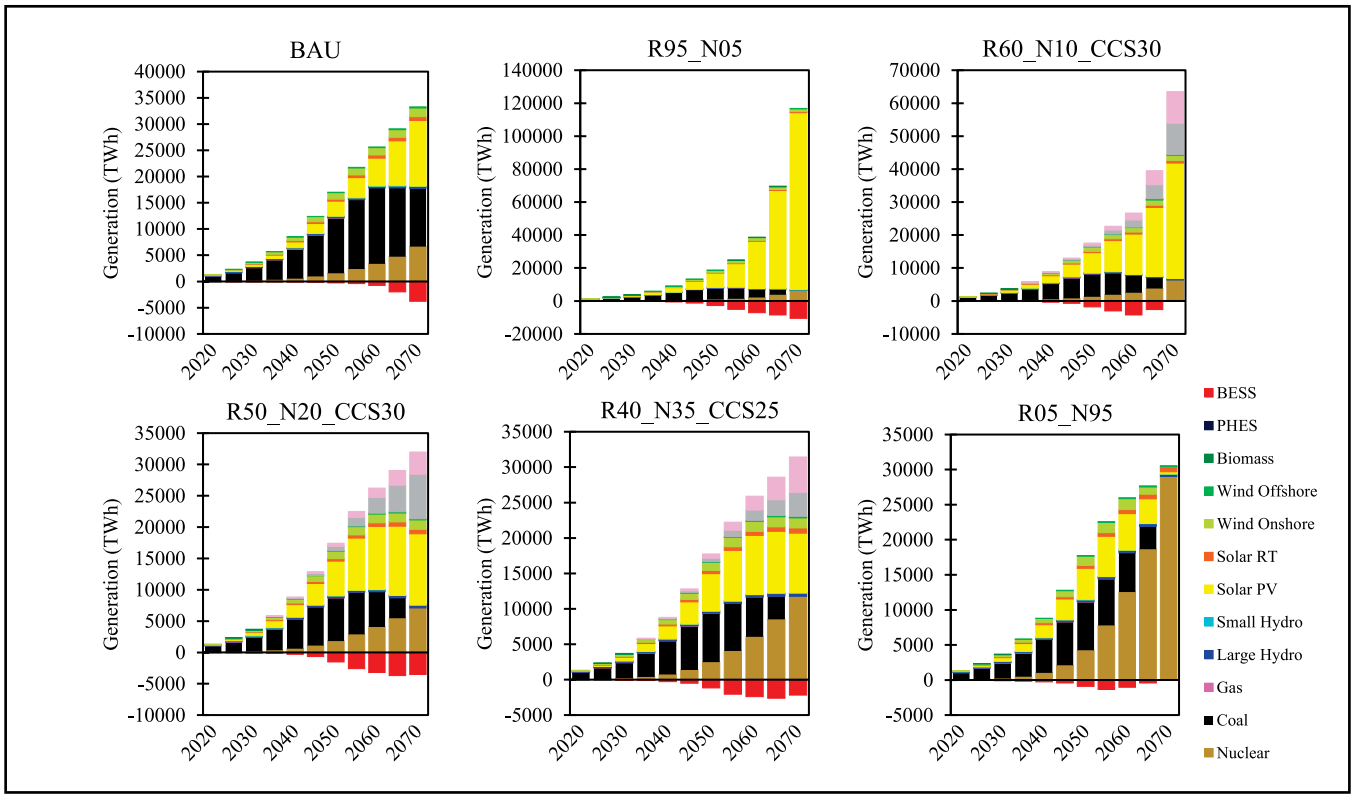
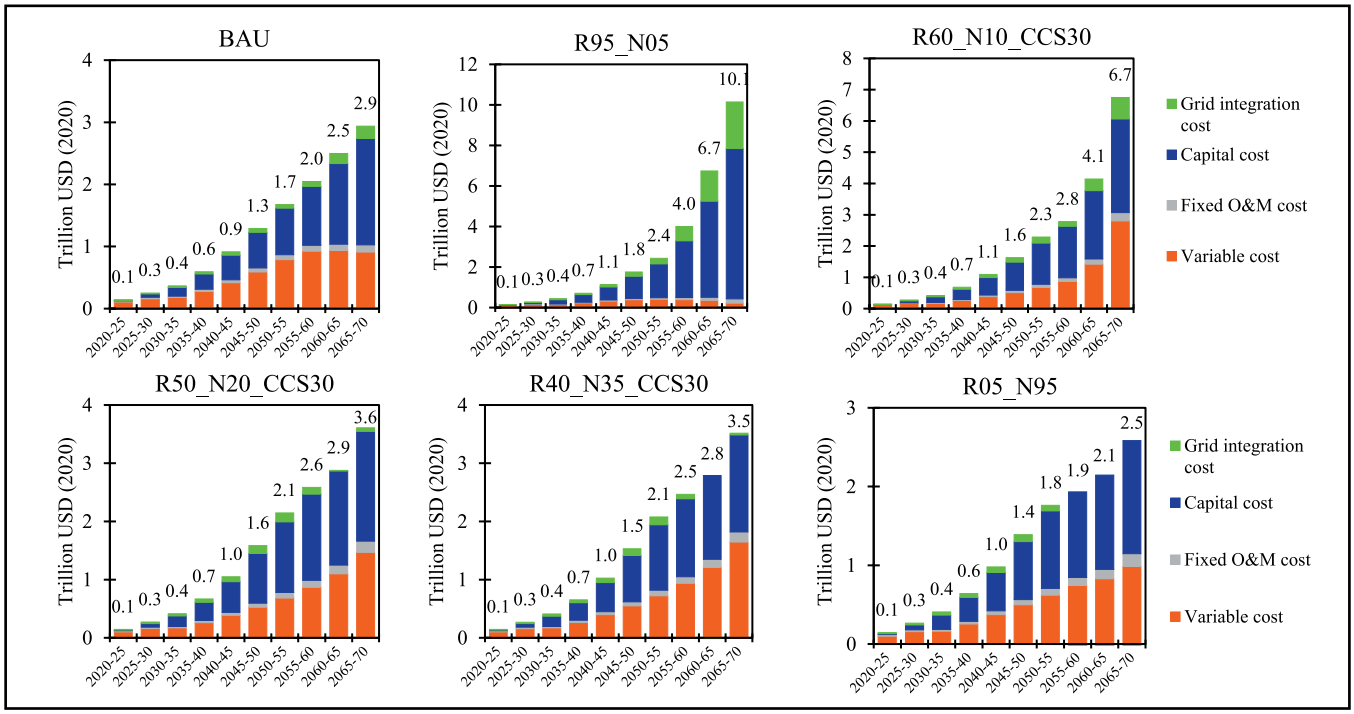


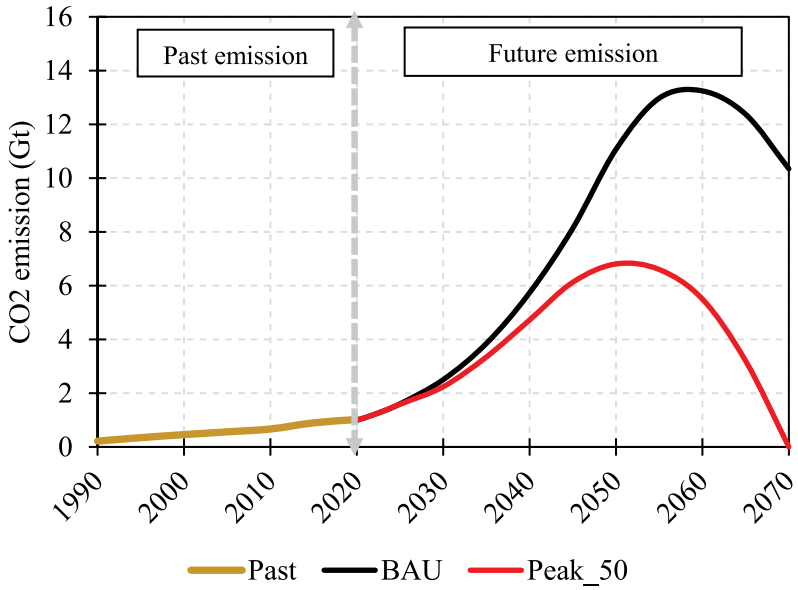
Figure 16 Net zero in 2070 with 25% green H2 demand— Cost of power sector transition



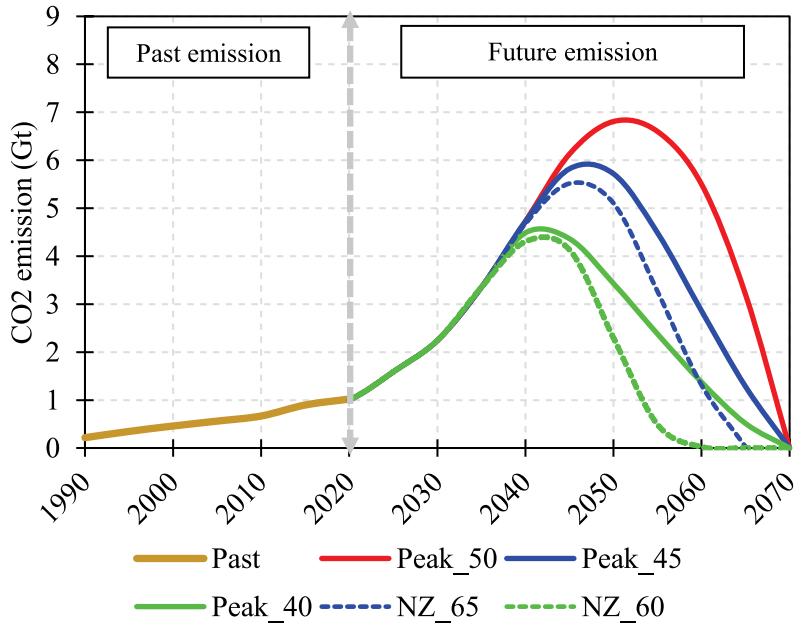
CO_2 emissions

Figure 17 shows the future CO_2 emission trajectories under different scenarios. In the BAU scenario, peak emissions occur between 2055-60. Alternately, three scenarios, namely Peak_50, Peak_45, Peak_40, NZ_65, and NZ_60, are explored with different peaking and net zero years.

Figure 17 CO2 emission trajectory— (a) BAU (black) and peak in 2050 with net zero in 2070 (red) (b) Scenarios with different peaking and net zero year.



(a)



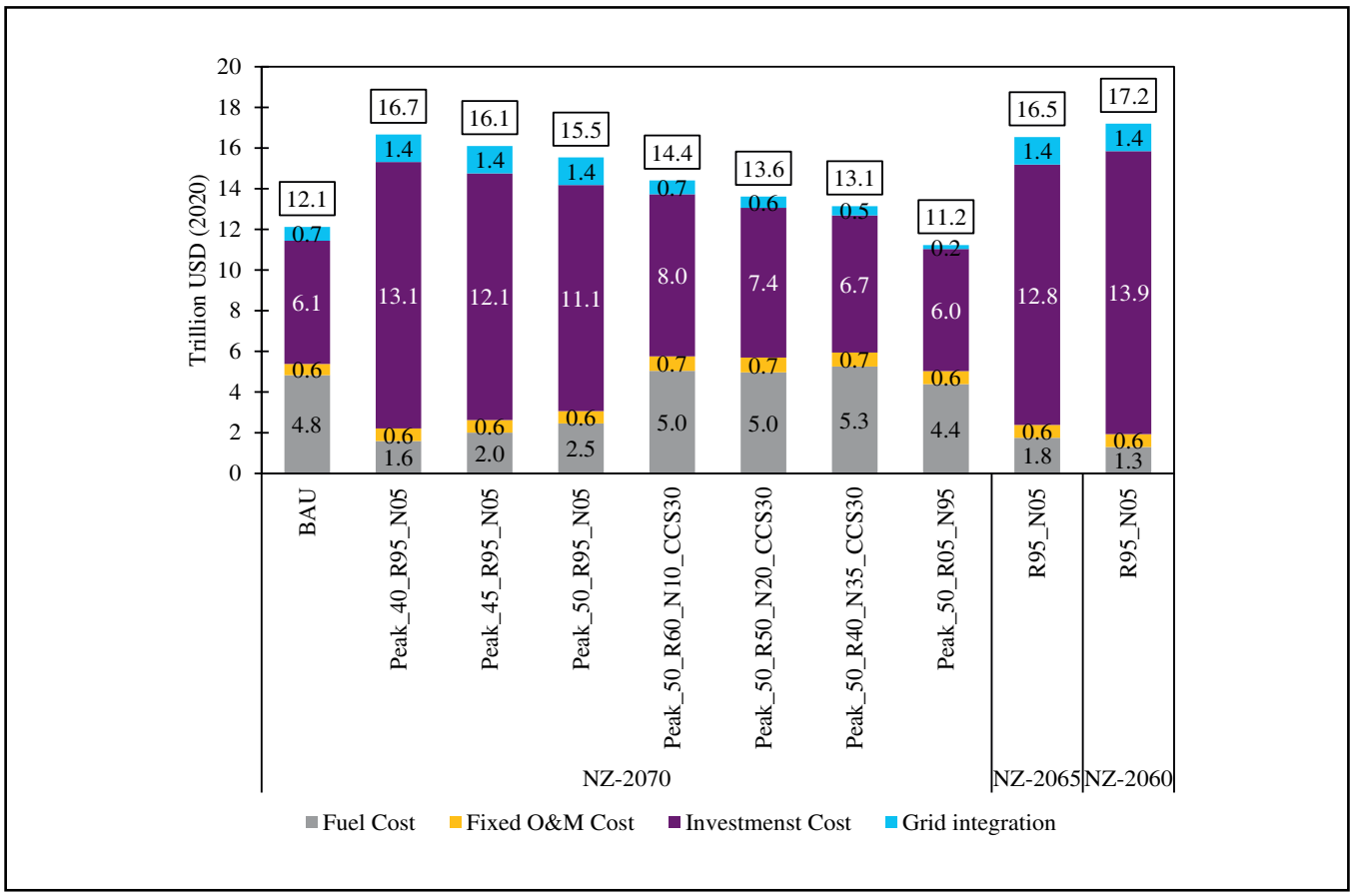
(b)

Cost of transition

1. 10% green H_2 demand

Figure 18 shows the cost of power sector transition under different scenarios. It ranges from 11.2 trillion USD for a nuclear-dominated scenario (Peak_50_R05_N95) to 15.5 trillion USD for a renewable-dominated scenario (Peak_50_R95_N05). Compared to a nuclear-dominated scenario, a high renewable scenario requires twice the investment in new technologies, mainly solar PV and storage. Early peaking increases the upfront capital cost, as shown in Figure 11. Early peaking raises the total system transition cost by about 1.2 trillion USD, as seen in the Peak_40_R95_N05 scenario. An early net zero plan for India, by 2065 or 2060, further increases the system transition cost by 1.7 trillion USD, as seen in Figure 13. Grid integration cost refers to the additional cost of inter-state power transmission required to evacuate power from renewable-rich sites. The cost of transmission is not a modelling parameter (input to the model). It has been taken exogenously as INR 65 lakhs per MW of renewable capacity as supplied by PGCIL to VIF to arrive at the final cost of transition [26].

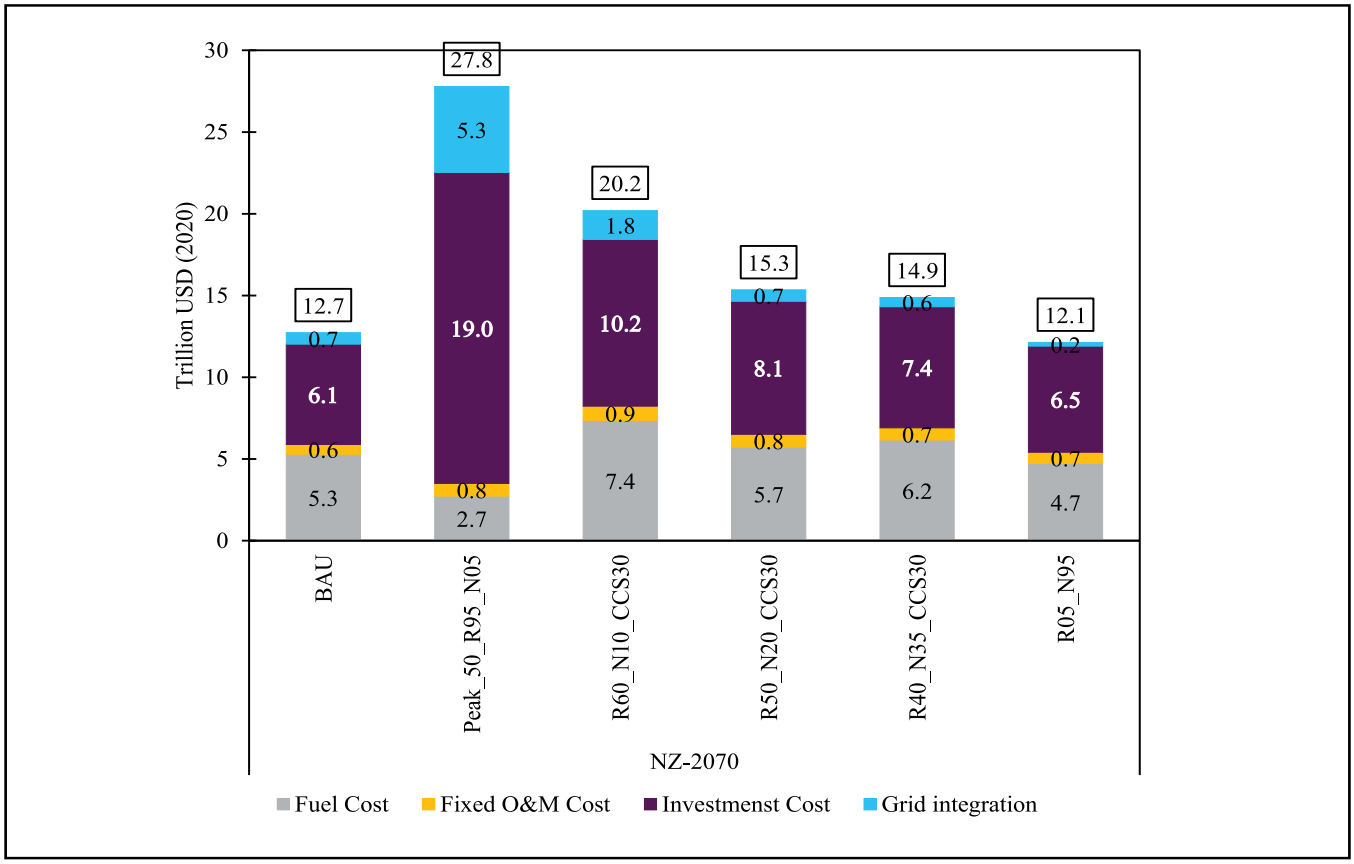
Figure 18 Net zero in 2070 with 10% green H2 demand— Cost of power sector transition under different scenarios.



2. 25% green H2 demand

An increase in green H2 demand increases the installed capacity of solar PV since the wind has been capped at a maximum of 800 GW. All the scenarios achieve peak emissions in 2050. Most solar PV output would be utilised to generate green H2. Therefore, in the case of a high renewable scenario (R95_N05) and the absence of sufficient baseload capacity, the model would oversize the system by building high solar PV capacity to supply the evening peak load demand via storage. This would eventually drive the system cost, as seen in Figure 19. With an increase in baseload nuclear and CCS capacity, the requirement for solar PV to supply the peak demand reduces, thereby decreasing the overall cost of transition.

Figure 19 Net zero in 2070 with 25% green H2 demand— Cost of power sector transition under different scenarios.



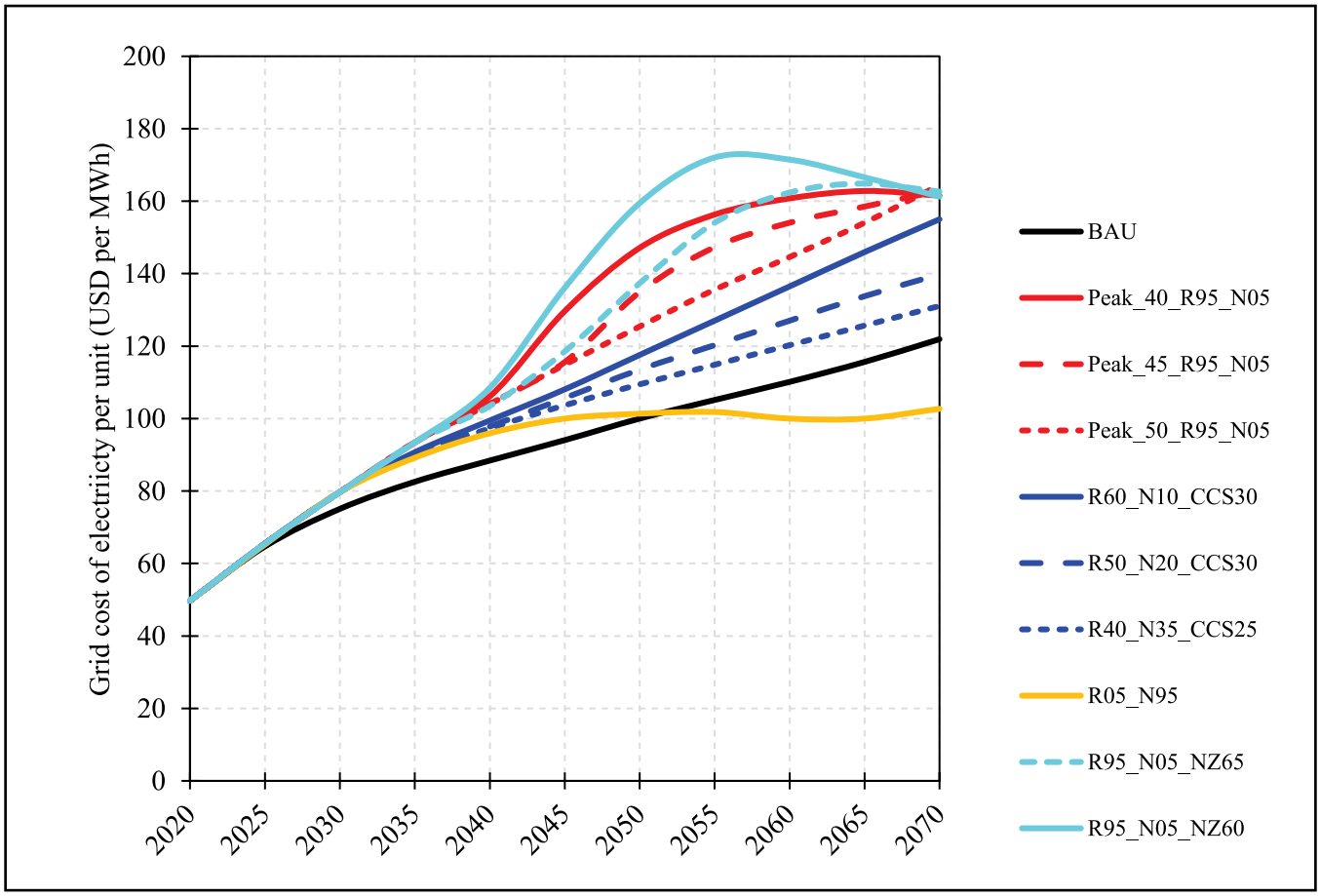
Grid cost of electricity

1. 10% green H_2 demand

Figure 20 shows the annual average grid cost of electricity under different scenarios. The current average cost of electricity (ex-bus cost + grid integration) is about 50 USD/MWh, which would

increase more than three times to about 160 USD/MWh for the NZ target in 2070 in the scenario where renewables have a dominant share in the generation-mix (R95N05). However, an early peaking (say 2040 or 2045) would initially increase the same cost to stabilise at about 160 USD/MWh. However, a high nuclear scenario (R05_N95) would stabilise the cost much earlier to about two times the current cost at 100 USD/MWh.

Figure 20 Net zero in 2070 with 10% green H2 demand— Grid cost of electricity under different scenarios.

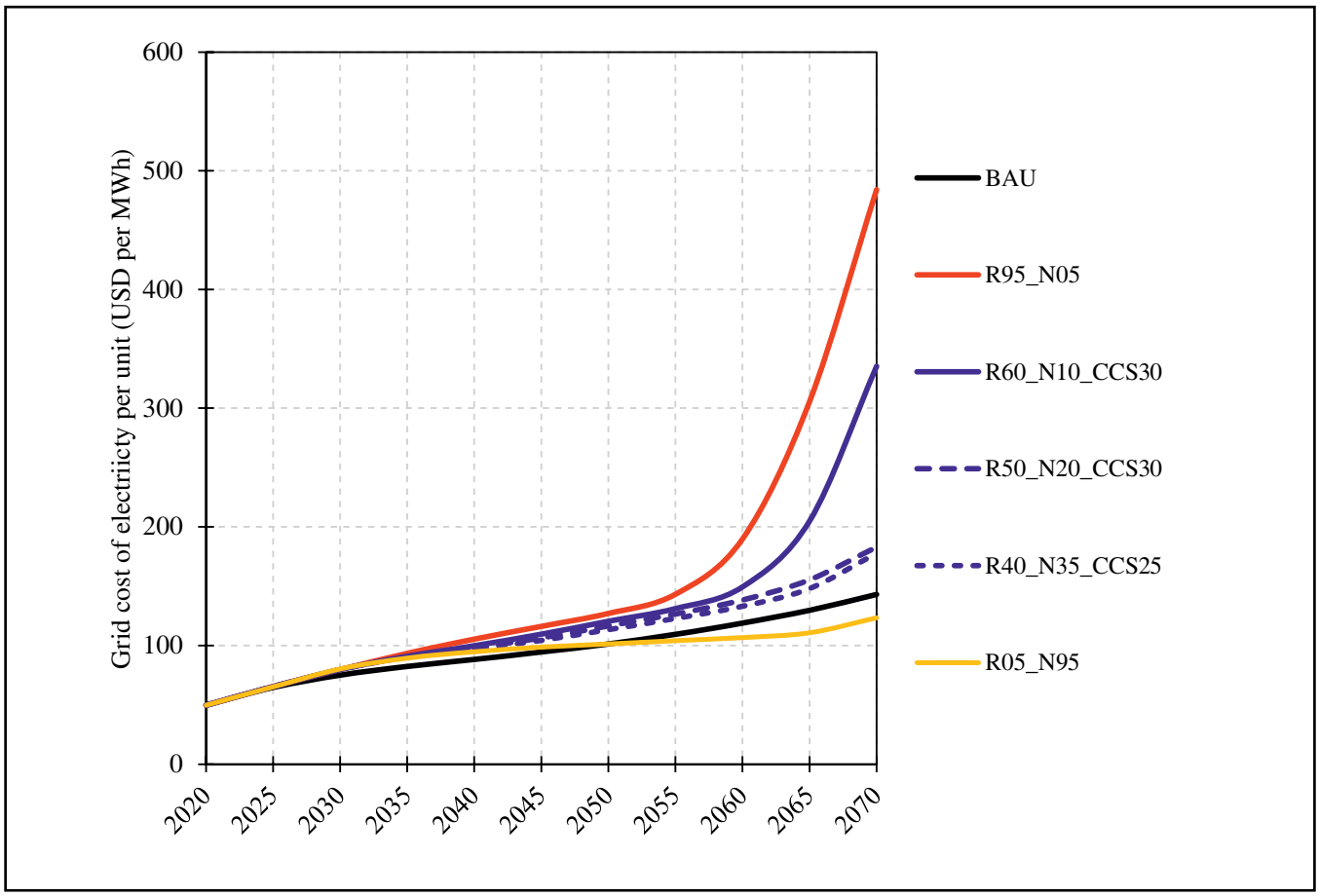


2. 25% green H2 demand

Figure 21 shows the annual average grid cost of electricity under different scenarios. In the case of low dispatchable base load capacity (R95_N05, R60_N10_CCS30), supplying the peak demand would require significant storage capacity to supply the peak demand. Since biomass, hydro and wind resources are constrained by their maximum potential, the model builds significant solar PV capacity to charge the batteries, thereby oversizing the system. As more dispatchable baseload capacity (nuclear and CCS) are added (R50_N20_CCS30, R40_N35_CCS25), the dependence on storage to supply the peak demand reduces, which in turn is now provided by nuclear and CCS. In

conclusion, green H_2 generation solely from solar and wind would require an excessive capacity deployment of these resources, which would be diverted for H_2 generation, leaving very little for direct consumption as electricity. Under high-RES penetration, energy from storage is required to supply the peak demand, which does not coincide with the peak RES generation. It will thus unnecessarily oversize the system to supply energy to the storage, and an increase in storage would result in high losses during the charge-discharge cycle.

Figure 21 Net zero in 2070 with 25% green H2 demand— Grid cost of electricity under different scenarios.



Conclusions

1. Driven by its high aspirational need, India is set to witness sustained high growth in the next half a century. This high growth would directly impact its energy demand. Estimates from this study point to five times increase in energy demand in 2070 from 2020 under a business-as-usual scenario. The share of electricity in the final energy demand increases from about 14% to 75%. However, according to commitments in COP26, India aims at net zero emissions by 2070, gradually reducing its dependence on fossil fuels. Decarbonising the economy through

either renewable or nuclear energy is a possible solution. A high level of electrification coupled with an increase in end-use efficiency would lower overall energy demand to about four times the current value in 2070. The per-capita electricity consumption is estimated to increase by eighteen times the current value.

2. Solely supplying this large amount of green electricity from RES would require a high deployment of solar, wind, hydro, and biomass resources. For example, annual solar PV deployment from now till 2070 under a renewable-dominated scenario (R95_N05) is as high as 300 GW. Unlike conventional fossil fuel resources, most of these renewable resources have the maximum technical potential based on land availability and capacity factor at a particular location.
3. Increasing the share of baseload capacity like nuclear and CCS reduces the dependence on intermittent solar PV and storage. Increasing the share of nuclear from 5% to 95% in the generation mix leads to an increase in nuclear capacity from 284 GW to 3139 GW. This simultaneously reduces solar PV capacity from 14689 GW to 3036 GW.
4. Among the scenarios studied in this report, the transition to the Net Zero Emissions stage in 2070 a nuclear-dominated scenario would cost USD 11.2 trillion, while a renewable-dominated scenario would cost 28% higher at USD 15.5 trillion. Two-thirds of the transition cost would be incurred in the last two decades, i.e., between 2050-70. This is due to the higher demand being met either solely by RES and storage or capital-intensive nuclear. An early transition to net zero emissions, i.e., 2060 or 2065, or an early peaking, i.e., 2040 or 2045, would result in an additional front-loaded investment of at least 11%.
5. Green H_2 production using electricity solely from renewables would significantly increase the solar PV installed capacity in a renewable-dominated scenario due to the low efficiency of the electrolyser, losses involved in the two-stage conversion, and losses involved in the transportation and storage of H_2. It is also because renewables, such as solar PV-driven storage systems, must meet peak demand. Targeting a high share of green H_2 would necessitate additional clean dispatchable baseload capacity like nuclear and CCS to supply the peak demand requirement. Therefore, replacing direct green electricity with green H_2 as an energy carrier may not be cost-effective in the current form of a two-stage conversion process. The thermochemical splitting of water using the heat from nuclear reactors may be a possible solution instead of a two-stage conversion process. The use of green H_2 as it stands today should only be limited to sectors that are hard to abate and where direct electricity cannot be used unless the green H_2 supply chain's technological parameters are improved by further R&D.
6. Early peaking leads to higher upfront capital investment in renewable resources and storage. It will also require an additional investment of USD 1.2 trillion to shift the peaking year from 2050 to 2040. However, it leads to a lower stranded coal capacity in 2070.
7. Reliance on a renewable-heavy approach increases land requirements. Exclusive reliance on renewables to produce green hydrogen will particularly exacerbate this problem.

Appendix A: Techno-economic parameters

Table 10 Cost and technical parameters of different technologies

Technologies	[i]Capital cost (Million USD/MW)		Annual fixed O&M cost (% of capital cost)	Variable cost (USD/MWh)	Variable cost (USD/MWh)	Life (years)	Nor-mative PLF	[Ref], Page no.
	2020	2070		2020	2070			
Coal	1.12	1.12	2.5	29.59	101.72s	30	0.85	[27], 38
Gas	0.64	0.64	3.6	58.38	157.13	30	0.60	[27], 49
Nuclear	1.79[ii]	2.42[iii]	3.7	33.78	55.56	50	0.85	[27], 150, 152
LHP	1.61	1.61	3.5	–	–	50	0.35	[28], 38
SHP	1.09	1.09	3	–	–	50	0.23	[28], 38
Solar RT	0.58	0.21	0.88	–	–	25	0.19	[27], 113
Solar PV	0.60	0.40	0.88	–	–	25	0.21	[28], 38
Wind onshore	0.89	0.78	1	–	–	25	0.26	[27], 79
Wind offshore	3.11	1.47	3	–	–	25	0.35	[27], 97
Biomass	0.77	0.77	2	71.47	245.66	25	0.80	[28], 38
Base Coal + CCS (MEA)	2.06	2.06	4	44.59	153.28	30	0.85	[27], [29], 10
Base Gas + CCS (MEA)	1.27	1.27	4	73.38	208.69	30	0.85	[27], [29], 10
BESS (4 hours)	0.95	0.57	2	–	–	10	0.17	[28], 38
PHES (6 hours)	0.81	0.81	2	–	–	50	0.25	[27], 135
Green H2 electrolyser	0.97	0.21	1.5	20.3	3.38	20		[30]

i 1 USD = INR 74
ii Corresponding to 80% PHWR and 20% LWR
iii Corresponding to 20% PHWR and 80% LWR

Appendix B: Installed capacity, generation, capacity built rate and cost

Table 11 Installed capacity (10% green H2 scenario)

Installed capacity (GW)							
		2020	2030	2040	2050	2060	2070
Scenarios	BAU	373	843	2019	4238	8504	12496
	R95N05	373	1021	3120	8959	17451	25292
	R60N10CCS30	373	996	2727	7143	11891	12950
	R50N20CCS30	373	970	2604	6565	10510	10733
	R40N35CCS25	373	960	2483	6022	9121	8917
	R05N95	373	959	2480	5422	6382	5721

Table 12 Generation (10% green H_2 scenario)

Generation (TWh)							
		2020	2030	2040	2050	2060	2070
Scenarios	BAU	1329	3667	8529	16963	25171	27147
	R95N05	1329	3680	8989	18560	27300	30839
	R60N10CCS30	1329	3687	8882	17544	24991	25996
	R50N20CCS30	1329	3695	8836	17899	24669	25531
	R40N35CCS25	1329	3699	8792	17732	24361	25086
	R05N95	1328	3608	8545	16806	23102	24470

Table 13 Capacity addition required in each decade over and above the capacity as of March 2020 (10% green H_2 scenario)

	Installed capacity (GW)						
	Scenarios	2020-30	2030-40	2040-50	2050-60	2060-70	Annual average
Solar (GW)	R95N05	316	1225	3530	5712	6632	348
	R50N20CCS30	316	895	2334	2885	1160	152
	R05N95	316	815	1615	645	170	71
Wind (GW)	R95N05	108	217	325	279	357	26
	R50N20CCS30	108	217	325	279	357	26
	R05N95	108	217	325	279	36	19.3
Nuclear (GW)	R95N05	18	34	74	91	61	5.6
	R50N20CCS30	21	59	168	261	246	15.1
	R05N95	26	108	435	993	1571	63
Coal (GW)	R95N05	211	285	486	17	0	20
	R50N20CCS30	134	362	451	0	0	19
	R05N95	120	372	435	2	0	18.6
CCS (GW)	R95N05	0	0	0	0	0	0
	R50N20CCS30	0	37	128	355	694	24.3
	R05N95	0	0	0	0	0	0

Table 14 Decadal investment (10% green H_2 scenario)

Cost (Trillion USD 2020)							
		2020-30	2030-40	2040-50	2050-60	2060-70	Total
Scenarios	BAU	0.40	0.96	2.21	3.92	4.63	12.1
	R95N05	0.42	1.15	2.88	5.00	6.09	15.5
	R60N10CCS30	0.42	1.10	2.69	4.63	5.57	14.4
	R50N20CCS30	0.41	1.08	2.61	4.39	5.12	13.6
	R40N35CCS25	0.41	1.06	2.53	4.19	4.95	13.1
	R05N95	0.41	1.05	2.36	3.48	3.93	11.2

Appendix C: Nomenclature

$c_{l,g}^{inv}$	Investment cost in new generation type g (USD/MW)
$IG_{l,g}$	Additional capacity installed of generation type g (MW)
c_n^{fom}	Fixed O&M cost in year n (USD/MWh)
$IC_{n,t,g}$	Existing installed capacity in year n, hour t and generation type g
c_n^{vom}	Variable cost in year n (USD/MWh)
$P_{n,t,g}$	Energy supplied in year n at time t by generator type g (MWh)
c_g^{su}	Start-up cost of generator type g (USD)
d	Discount rate
$C_{IMP(+)/EXP(-)}$	Total cost of energy import or revenue from energy export
$L_{n,t}$	Load demand in year n and hour t
$P_{n,t}^{aux}$	Auxiliary energy consumption in year n and hour t
$P_{n,t}^{loss}$	Transmission and distribution losses in year n and hour t
$u_{n,t,g}$	Number of committed units of generator type gin year n and hour t
P_g^{max}	Maximum continuous rating of generator type g
P_g^{min}	Minimum stable generation level of generator type g
$S_{type_{n,t,g}}^{U}$	Number of start-up of type (hot, warm, cold) in year n and hour t of generator type g
$S_{n,t,g}^{D}$	Number of shut-downs in year n and hour t of generator type g
R_g^U	Ramp-up rate (MW/h)
P_g^{SU}	Maximum output of generator type g when started (MW)
R_g^D	Ramp-down rate (MW/h)
$CUF_{n,t,g}$	Capacity Utilisation Factor of renewable energy generator of type g in year n and hour t
g	Index of generator types
$g \in TH$	Set of thermal generators
$g \in RES$	Set of renewable energy generators
t	Index for hour
n	Index for year

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VIVEKANANDA INTERNATIONAL FOUNDATION
3, San Martin Marg, Chanakyapuri, New Delhi - 110021
Tel: 011-24121764, 24106698 • Fax: 011-66173415
E-mail: info@vifindia.org, Website: www.vifindia.org
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