INDIA:
TRANSFORMING TO A NET-ZERO EMISSIONS ENERGY SYSTEM

Scenarios *Sketch*

www.shell.in/Indiasketch
www.teriin.org

The Energy and Resources Institute

CONTENTS

Click on the **contents titles** (left) to navigate to each page. A navigation toolbar (below-left) is also situated at the base of every page. The left and right arrows take you forward and backwards one page at a time and the central menu button takes you back to this contents page.

Previous page Contents Next page

Dr. Vibha Dhawan
Director General
The Energy and Resources Institute (TERI)

Mr Nitin Prasad
Chairman
Shell Companies in India

FOREWORD

Energy is at the heart of economic development and perhaps no country is more challenged by that association than India as it strives to create a better life for its population of almost 1.4 billion people. But how can India accomplish this and make progress towards reaching a net-zero emissions economy by 2050 in support of broader well-being?

In the 50 years since its creation, the Shell Scenarios team has sought to make a constructive contribution to public debate on a wide range of issues – including economic development and associated energy pathways. In India, The Energy and Resources Institute (TERI) and Shell have maintained a strong and active collaboration over the years to jointly examine these questions and explore a range of options for enhancing India's energy security and enabling energy transitions in a smooth and just manner. Most recently we have worked together to create this scenario sketch to explore the ongoing development of the Indian economy and the energy transition, taking into consideration the government's goals of significant economic growth, universal electricity access and clean cooking for all. Each of these goals requires significant industrial capacity to achieve and, unless carefully managed, has the potential to increase greenhouse gas emissions. This sketch illustrates a technically possible, but highly challenging pathway to steering the domestic energy system towards net-zero emissions by 2050, while achieving India's economic development ambitions.

Today, greenhouse gas emissions have become central to any discussion on energy

> ...it is an opportune time for India to re-evaluate its energy strategy and examine the choices, opportunities and risks across the energy sector.

system choices and technological progress has brought to the fore an increasing number of fuel and technology alternatives that can be adopted at a commercial scale. Furthermore, the pressing need of eliminating dependence on fossil fuels is now recognised globally. There is an increased emphasis on innovative policies to avoid even greater dependency on fossil fuels in the future and ensure long-term sustainability.

Against this setting, it is an opportune time for India to re-evaluate its energy strategy and examine the choices, opportunities and risks across the energy sector. In this sketch, TERI and Shell have evaluated India's current options and limits across each of the energy sectors and sub-sectors and assessed the technology and policy options that can help the country accelerate towards the goal of net-zero emissions by 2050.

In this collaboration we have developed a **Net-Zero Emissions (NZE)** scenario[1], the principle focus of this publication, to examine whether adequate opportunities exist to fully decarbonise the energy sector; we also highlight the areas where India's energy sector does not have enough choices for full decarbonisation by 2050. From a second scenario, **Towards Net-Zero (TNZ)**, we highlight barriers to change that might emerge.

Energy efficiency, electrification and a switch towards decarbonised fuels are the three main pillars of India's energy strategy, with the need for a transformative move towards renewable electricity, hydrogen and bioenergy as key fuels. This analysis indicates that the industrial and heavy transport sectors are likely to face limits in achieving full decarbonisation, primarily due to technological constraints which leave residual emissions in the system. This necessitates the need for carbon removal options to achieve net-zero emissions, including both technical and natural solutions.

This report is a comprehensive assessment of a net-zero emissions strategy for India's energy system.[2] We offer it in the hope that the findings from this study encourage further deliberations on energy sub-sectors that could benefit policymakers and planners in charting India's sustainable energy transition.

The Energy and Resources Institute

INTRODUCTION

Over the last 50 years, India's economic transformation has been remarkable. Until the COVID-19 pandemic struck in early 2020, the country's economic story was defined by strong growth, an increasingly dynamic business environment, rising productivity and a well-documented boom in the tech industry. By 2019, India had become the fifth largest economy in the world, overtaking the UK and France.

In 2016, Shell, TERI and the Council on Energy, Environment and Water (CEEW) collaborated to produce *Energizing India: Towards a Resilient and Equitable Energy System*. In that report the collaborating partners explored the energy choices available to India's society and economy at a time of considerable uncertainty – and opportunity – in the global energy system. The report highlighted the opportunities and challenges in developing a robust but flexible set of strategies for meeting India's future energy needs, against the backdrop of making the energy system more resilient, driving India's economic growth and making energy access more equitable across all sections of society. This sketch can be seen as an extension of the scenarios presented in the Energizing India report, but with a focus on achieving a net-zero emissions energy system by 2050.

The 2016 report notes the national plan of the day to increase domestic coal production to 1,000 megatonnes (Mt) a year by 2021, but the country is now charting a course to a different future. Thanks to renewable energy being deployed rapidly across India, coal use is already being disrupted. Production in 2019 was 756 Mt, a slight fall from 2018 and only 12% higher than 2015, despite an 18% increase in power generation.

It is not just power generation where the outlook has changed. The Energizing India analysis concluded that through to 2050 transport will continue to rely on oil products for most of its needs, but today many commentators would not come to such a conclusion. An electric vehicle landscape is rapidly emerging globally, not just for passenger cars but for buses, delivery

vehicles, municipal trucks and potentially for some longer distance road haulage. For example, in the UK the government has every expectation that there will be no need for further sales of internal combustion engine passenger vehicles after 2030, and General Motors has announced its intention to stop producing internal combustion engine cars and trucks by 2035.

Today the government of India is focusing on maintaining strong growth to achieve its aim of being a $5 trillion economy by 2025 and addressing the continuing inequality gap across the country. Its goals include increasing the manufacturing share of GDP to 25% by 2025, providing housing for all by 2022, doubling the income of farmers by 2024 and making substantial progress on universal access to healthcare by 2030.

Around the world, the transition of economies from agriculture to technology-based societies has typically seen energy growth by a factor of 10 or more. Eventual primary energy demand depends on local circumstances such as climate, social norms, industrial structures and whether compact or sprawling models of urban development have predominated.

Historical evidence – combined with future possibilities for improvements in structural and end-use energy efficiency and with detailed studies from developing economies – suggest that about 100 gigajoules (GJ) per capita per year of primary energy is needed for people to experience a decent, modern quality of life.[3] Consumption in India in 2019 was 25 GJ per person.

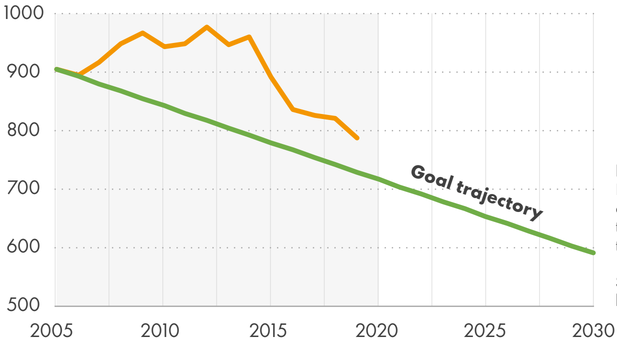
As has been the case for all countries, fossil fuels have enabled the energy demand required for industrialisation and in turn contributed to rising carbon dioxide (CO_2) emissions. India's per capita CO_2 emissions – at 1.8 tonnes per person in 2015[4] – are around a ninth of those in the USA and around a third of the global average of 4.8 tonnes per person. However, overall, India is now the planet's third-largest emitter of CO_2, behind China and the USA. Some costs of the country's dynamic growth are increasingly visible, namely major congestion in urban centres and declining air quality.

In the early years of this century the international community was not focused on net-zero emissions. Instead, the emphasis was on substantial mitigation through efficiency, a reduction in coal use and the further

Figure 1: India is delivering on its first Paris Agreement NDC

Reduce carbon emissions intensity of GDP by 33-35% by 2030 from 2005 level

Fuel combustion CO_2 per GDP, grammes CO_2 per $ (constant US 2010)

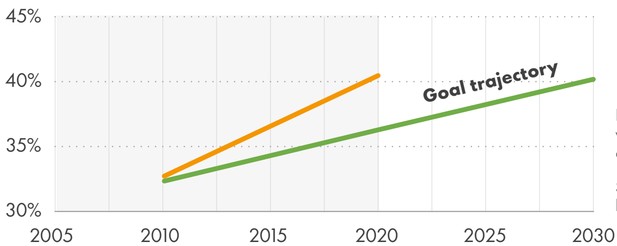


Note: Although the Nationally Determined Contribution (NDC) goal covers all emissions, we present here the progress for the energy system, the major component of the total.

Source: TERI and Shell analysis based on historical IEA data and the World Bank data

40% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030

Percent non-fossil fuel based generation capacity

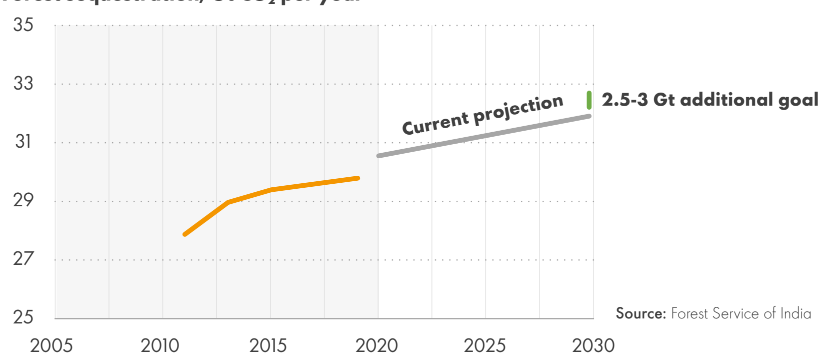


Note: Non-fossil generation includes variable renewables, hydro, nuclear and biomass.

Source: TERI and Shell analysis based on historical IEA data

To create an additional carbon sink of 2.5-3 billion tonnes CO_2 through forest and tree cover by 2030

Forest sequestration, Gt CO_2 per year



Source: Forest Service of India

development of biofuels. More recently, significant reductions in the cost of developing wind and solar power projects, the rollout of electric vehicles by most automobile manufacturers and the development of hydrogen projects has offered the opportunity to both discuss the need for a net-zero emissions society globally and envisage a clear, but still highly challenging, pathway to achieving it.

The government of India has already developed ambitious goals to manage emissions. In its first Nationally Determined Contribution (NDC) under the Paris Agreement,[5] the country has pledged a 33-35% reduction in the emissions intensity of its economy by 2030, compared to 2005 levels. It also aims for 40% of its installed electricity capacity to be renewable and nuclear by 2030. In recent years, India has made progress in its transition to a lower-carbon energy system through a marked slowdown in the rate of construction of new coal-fired power stations and the emergence of a viable and large-scale solar photovoltaic (PV) sector.

Although India is delivering on its NDC (Figure 1), absolute emissions continue to rise and the current development trajectory could see greenhouse gas emissions more than double by 2050 (TERI baseline case), (Figure 2).[6] A more focused policy intervention is required to steer the economy of India towards a much lower and ultimately net-zero emissions outcome.

In parallel, the international focus has shifted towards meeting the stretch goal of the Paris Agreement to limit the global average temperature increase to 1.5°C above pre-industrial levels this century. This follows the 2018 publication of the Intergovernmental Panel on Climate Change's (IPCC) Special Report on 1.5°C[7] that set out the increase in climate impacts and risks between a 1.5°C and 2°C temperature rise. Building on the progress India has made so far, this sketch sets out what it would take for India to achieve a net-zero emissions energy system by 2050, what it would take for society as a whole – government, business, consumers and citizens – to make progress towards that goal and what India's energy system would look like in 2050.

> A more focused policy intervention is required to steer the economy of India towards a much lower and ultimately net-zero emissions outcome.

This pathway requires building widespread support to transform the diverse economic activities across India, from its remote farming communities to its rapidly expanding industrial sector. And it requires an emphasis on local benefits for India's people, industrial competitiveness and protection of the environment. Collaboration between participants within sectors – such as iron ore smelting and cement production – will also be essential, with pioneers needed in government, business and civil society.

Recognising growing demand and financial opportunities, many companies, organisations and entrepreneurs in India are already developing lower environmental impact industrial processes and lower-carbon mobility options. But there are also limits to what society can achieve without the policy frameworks needed to align, guide and motivate all those trying to contribute.

The broad objective of this report was to evaluate India's current options and limits across each of the energy sectors. **A Net-Zero Emissions (NZE)** scenario was designed to assess whether adequate solutions exist to fully decarbonise the sector and/or examine the level to which each of the sectors could theoretically move to net-zero emissions by 2050. The **NZE** scenario is ambitious and assumes that all social, infrastructural and behavioural barriers can be overcome if the required technologies are available. A second scenario, **Towards Net-Zero (TNZ)**, highlights the barriers to change that might emerge.[8]

THE COVID-19 IMPACT

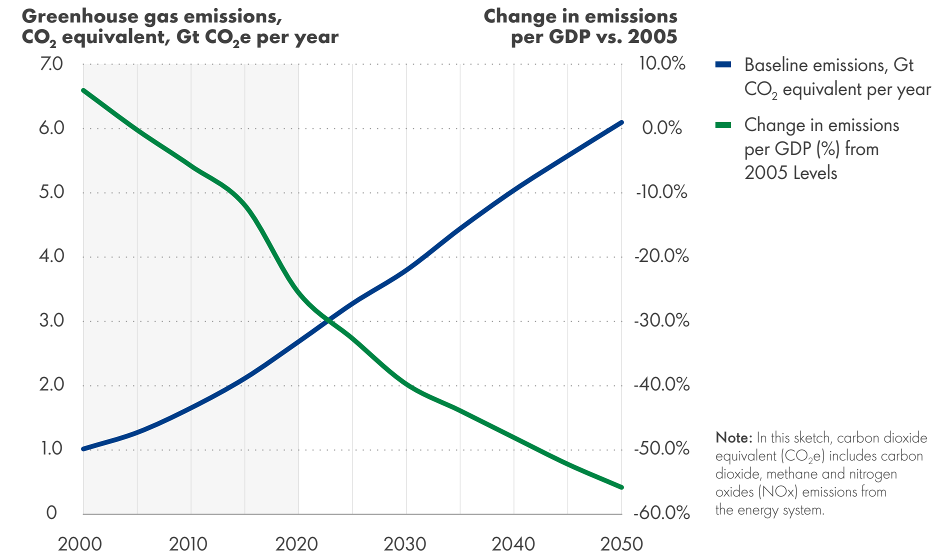
It is important to recognise that this analysis incorporates pre-COVID-19 data and as such does not include the effects of the pandemic. Like so many countries, India's economy has been impacted, along with its energy system. While the near-term future remains uncertain, the underlying trends outlined in this sketch remain in place and the pathway towards net-zero emissions continues to be possible. The COVID-19 pandemic has generated significant turning points with shifts across almost all societies and economies. It has exposed tensions and weaknesses in the global systems but it has also shifted policy and behaviour in ways that could accelerate change in the future.[9]

The way in which countries emerge from the pandemic could shape the course of the energy system. One initial response to the crises of 2020 is to repair the economy – a focus on wealth first. Other underlying societal and environmental pressures receive less attention initially until their relative neglect provokes backlash reactions. Then, moving quickly, but starting later than required to meet the goals of the Paris Agreement, society achieves an energy system with net-zero emissions – a fast but late transition.

Alternatively, governments and societies may decide to focus on their own security, with a new emphasis on nationalism threatening to unravel the post-World War 2 geopolitical order. The normal course of equipment and infrastructure replacement and the deployment of cleaner technologies bring progress and eventually net-zero emissions, but the world overshoots the timeline and does not achieve the goals of the Paris agreement – a slow transition.

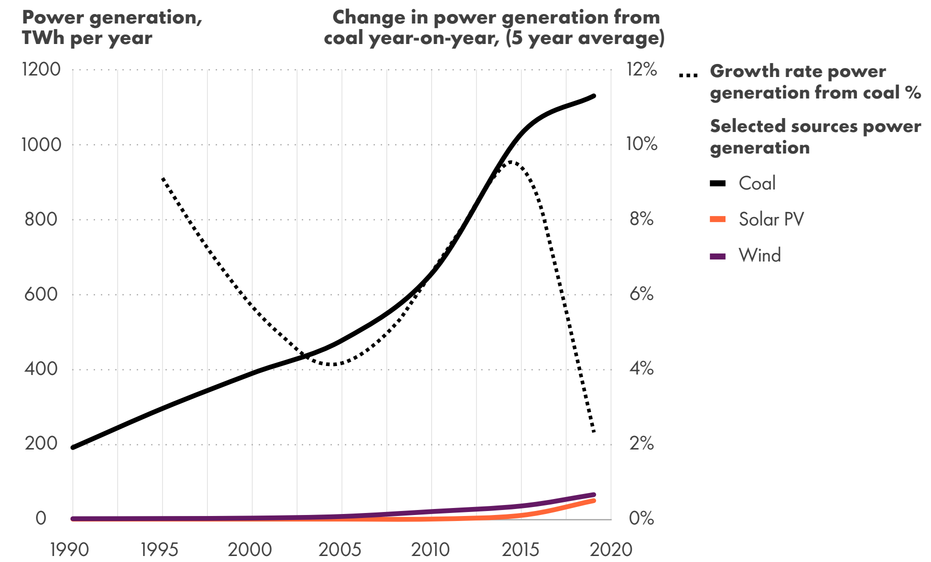
Another possibility is that the response to the crises of 2020 could be a renewed focus on the broader issue of societal well-being – a health first approach. Lessons learned from shared best practices, alignments of diverse interests and institutional improvements help create a pathway to the welfare of people and society and the health of the environment, including meeting the goals of the Paris Agreement – accelerated decarbonisation now.

Figure 2: India has a booming and vibrant economy, but potential for high emissions remains



Source: TERI analysis

Figure 3: The transition of power generation is making progress



Source: TERI and Shell analysis based on historical IEA data

SECTION ONE
ENERGY SYSTEM CHANGE

SEIZING THE OPPORTUNITY

The transition challenge that India faces is quite different to most other countries in that a substantial portion of the potential future emitting infrastructure has yet to be built or deployed, but it almost certainly will if current investment trends do not shift. For example, motor vehicle numbers in India are around a tenth that of many European countries on a per capita basis and will certainly increase. The pathway for India is to rapidly adopt a range of new energy and mobility technologies before it has committed to a high-emitting energy system.

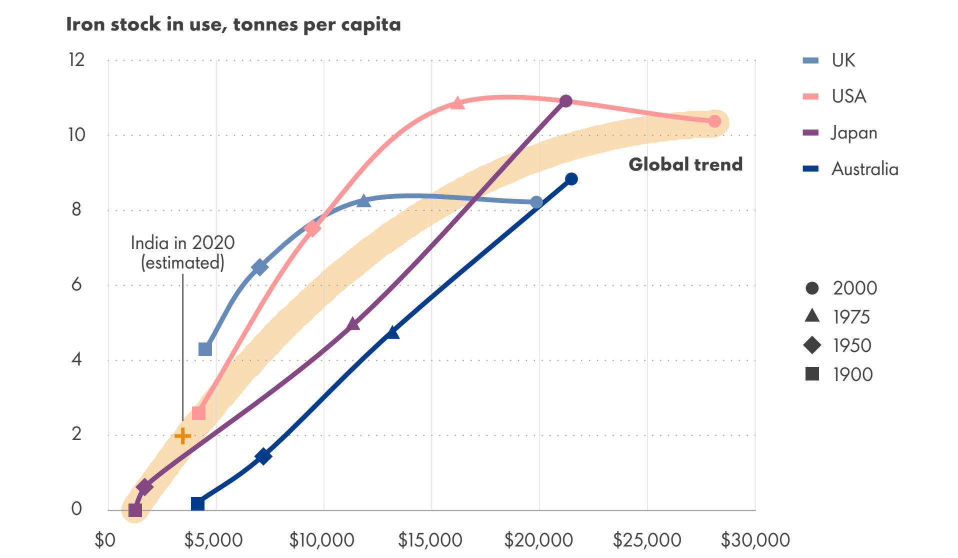
There is a further central opportunity to mitigate future emissions. India's development trajectory will likely feature a broader balance between industrial and service sectors earlier in its development compared with other countries. Taking advantage of the efficiencies offered through electrification, renewable energy and digitalisation, the country could reach a given level of GDP per capita with a much lower energy consumption than developed economies. This will be crucial if India is to succeed in managing its emissions. There are also potential wide-ranging economic benefits on offer. New sources of growth and competitive advantage that India could derive from cleaner technologies and renewable resources also offer commercial opportunities for businesses across the country, while weening India off its demand for oil, 80% of which is imported.

THE CHALLENGES AHEAD

India is at a pivotal point in its development. Energy use remains low and the use of materials such as iron is still modest compared to developed economies. There is clear evidence that India is adopting recent technologies as it develops. For example, the LED lighting market has grown in tandem with access to electricity in India. There is a trend towards first-time LED use in low-income households as electricity becomes available, which helps to manage both access to electricity and emissions. However, there are challenges ahead.

Today there are about 3 billion tonnes of steel in use within the country, in buildings, cars, appliances, pipelines and industrial plants (Figure 4). But as India aspires to be a developed economy, that number will likely rise to around 15 billion tonnes.[10] Every other country has built its steel infrastructure with coal as the energy source, but if India does the same that could add another 24 billion tonnes of CO_2 to the atmosphere globally, based on production emissions of about 2 tonnes of CO_2 per tonne of iron. This is 6% of the IPCC 1.5°C carbon budget globally[11] and would create a significant emissions spike, even considering efficiency improvements in smelting and optimised recycling. It will also add to the local environmental stresses that people in India feel each and every day. And that is just one aspect of India's national development pathway.

Figure 4: Demand for materials puts pressure on emissions; steel use in India could quintuple over time



Iron stock data are based on medium lifetime assumptions, except for Japan, where lower lifetime estimates were applied.

Source: Muller et. al., Patterns of Iron Use in Societal Evolution, Environmental Science & Technology, Vol. 45, No. 1, 2011, pp.182-188.

> Today there are about 3 billion tonnes of steel in use within the country, in buildings, cars, appliances, pipelines and industrial plants.

The challenges related to development in India need to be recognised to reach the goal of net-zero emissions. India is a country that is rapidly developing and industrialising, a process that is inherently emissions-intensive if it follows the path previously taken by all leading economies. The **NZE** scenario addresses these issues through the technologies, practices and behaviours it analyses. Below we look in more detail at actions required to:

- accelerate the mass deployment of clean technologies and energies;
- support energy-efficient and low-carbon choices; and
- remove unavoidable emissions.

PART 1: ACCELERATE CLEAN TECHNOLOGIES

To reach a net-zero emissions energy system by 2050, India needs to deploy cleaner energy technologies on a mass scale.

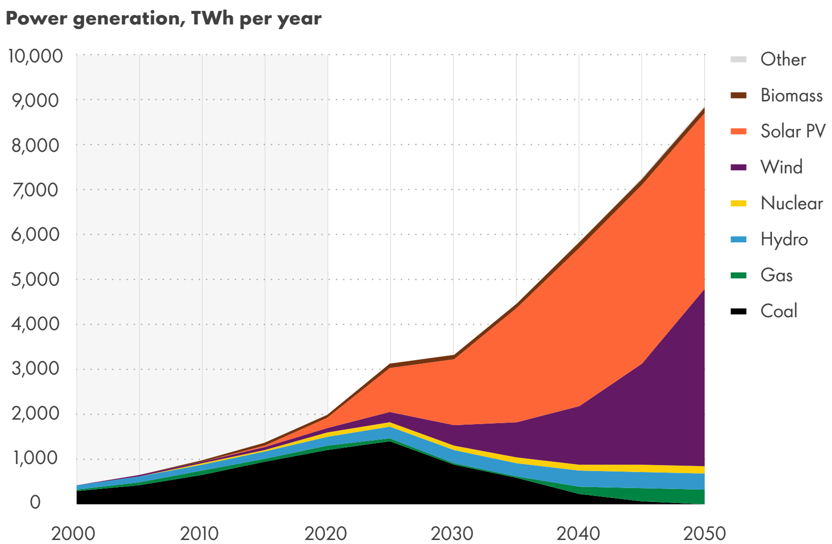
It requires more widespread and faster deployment and adoption of large-scale solar, wind and hydro power – replacing coal – to power greater electrification across the country, both in rural and urban areas. In tandem, it requires the development of new fuels, such as liquid biofuels and biogas, to help drive the decarbonisation of the agricultural and transport sectors. And, over time, India requires hydrogen produced from electrolysis to manage carbon emissions from hard-to-abate sectors such as heavy industry and heavy commercial vehicles.

The role of electricity

The electrification of energy services is a major lever for the transformation of the energy system and reduction of emissions, particularly as the electricity system shifts to zero-carbon generation through solar and wind power.

Opportunities for electrification exist in every sector of the economy, with most making use of available or near-term technologies.

Figure 5: Power generation grows, dominated by wind and solar mid-century



Source: TERI analysis

In the agricultural sector, a complete phase-out of diesel pumps is needed to support the net-zero transition, replaced by solar and electric pumps. The current momentum in using solar pumps for irrigation in agriculture needs to continue so that by 2050 most water can be pumped without generating emissions.

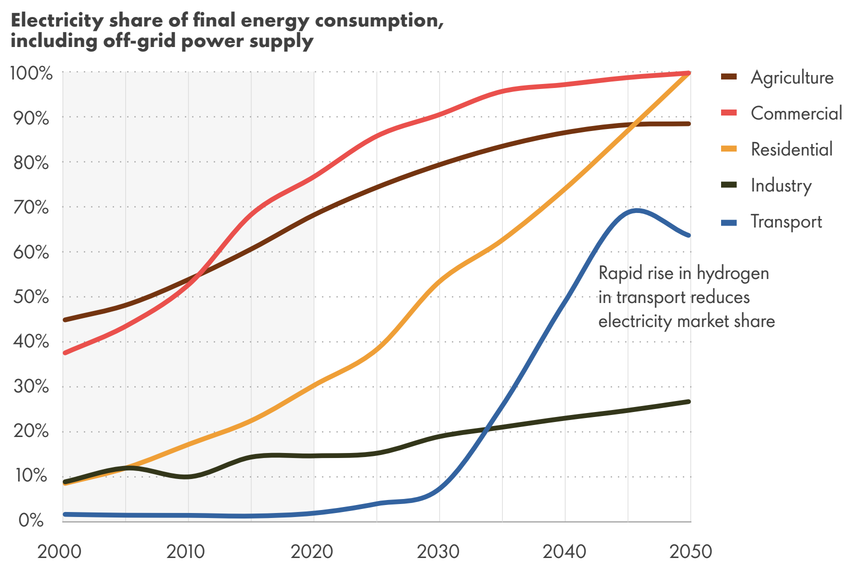
Electric tractors are a potential alternative for decarbonising land preparation activity. Electric tractors, though not fully commercialised, are gaining in popularity in India but are mostly lower-powered models which are currently best suited to battery technology. By mid-century, at least 30% of agricultural tilling should be by electric tractors and the rest by tractors running on biofuel-blended diesel.

The transport sector should adopt the highest possible levels of electrification in all vehicle segments to decarbonise, with rapid progress needed. All two and three-wheeler vehicles should be completely electric by 2030 and the sale of larger passenger vehicles should be restricted to electric only by 2030.

Bus fleets should also be largely electric by 2050, but with support from bio-compressed natural gas – a carbon-neutral fuel – for that fraction of the fleet serving long-distance routes. Railways (both passenger and freight) should also be completely electrified to support the transition to net-zero emissions. Many heavy commercial vehicles should also be electrified, although this may be constrained by payload capacity, in which case hydrogen-powered fuel cell electric vehicles could provide a solution.

In the commercial sector, cooking in hotels and restaurants is the major source of direct emissions. However, commercial establishments are more amenable to policy and regulatory interventions, making it possible to make a complete transition to electric cooking by 2050.

Figure 6: Opportunities to electrify exist in every sector



Source: TERI analysis

> All two and three-wheeler vehicles should be completely electric by 2030 and the sale of larger passenger vehicles should be restricted to electric only by 2030.

Dependence on kerosene and biomass for lighting and cooking in the residential sector has decreased rapidly in recent years through increased electrification and awareness of the health impacts from burning biomass indoors. Cooking fuels have shifted to liquefied petroleum gas and piped natural gas, but the **NZE** scenario requires a complete shift to electric cooking in both urban and rural areas to achieve its goal.

There is also opportunity for electrification in industry, such as the use of electric-arc furnaces for steel recycling, but heavy industry processes such as cement manufacture will still require high-temperature combustion of fuels.

In the **NZE** scenario, nearly 90% of the generation mix comes from renewables by 2050, but this depends on regional grid connectivity and the development and deployment of grid-scale electricity storage for managing solar intermittency. A further feature of the scenario is the sheer scale of electricity infrastructure development: in the space of 30 years the power system grows by a factor of more than four. Similar growth has been the case over the last 20 years, although from a much smaller base.

A hydrogen economy emerges

Although electricity becomes a growing and important energy carrier in India, electrification of all energy services remains elusive. This is not purely an issue in India but a global one. Some industrial processes and various forms of heavy transport need very high temperatures or very high energy-density fuels, which cannot be delivered by electricity technologies in the near term. For a rapidly developing industrial economy like India, this is a crucial factor.

Hydrogen emerges as the solution in the **NZE** scenario. It can be burned directly in furnaces, used to reduce iron ore and offers an alternative to battery-electric systems for heavy transport when used in a fuel cell electric vehicle. Green hydrogen can be produced by electrolysis using renewable energy. While the technologies to deliver a green hydrogen economy exist, scaled deployment into a viable operating network is yet to take place anywhere in the world.

The hydrogen economy begins to operate in the early 2030s, putting India at the forefront of emerging hydrogen industrial technologies.

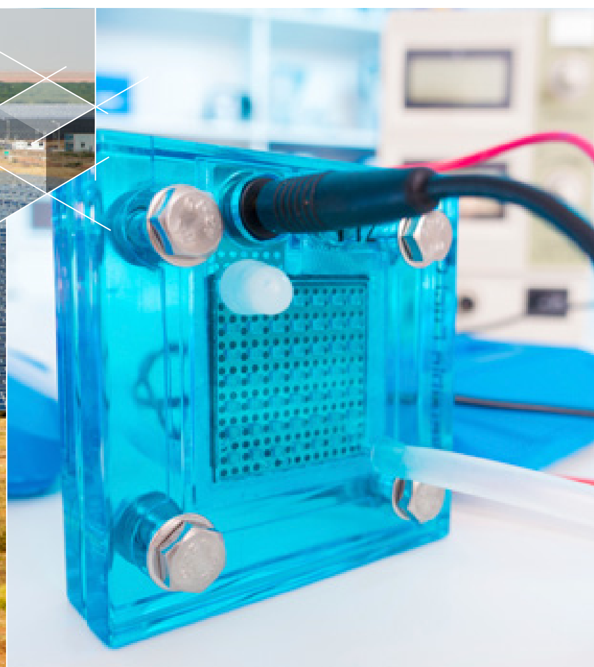
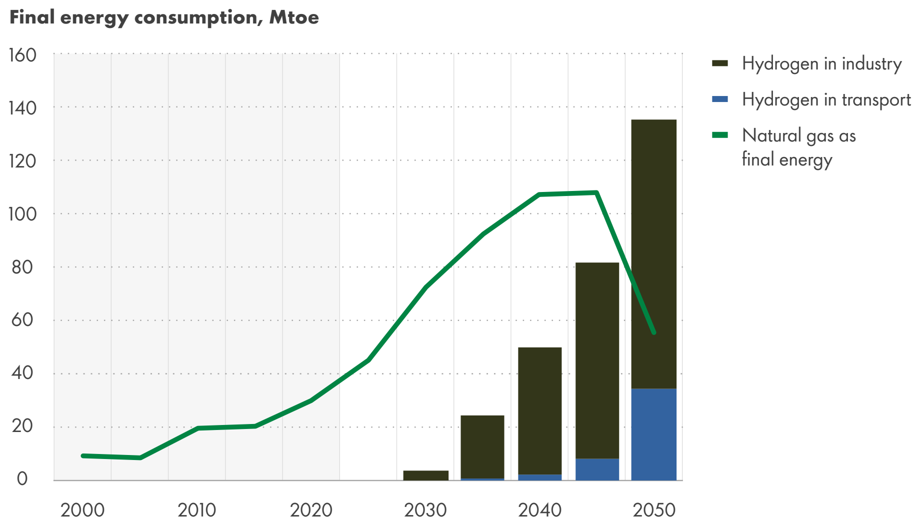


Figure 7: Hydrogen plays a key role in decarbonising industry and transport sectors



Source: TERI Analysis

Businesses will need to take their decisions on hydrogen before the mid-2020s to allow sufficient time for the planning, development and construction of facilities operating with hydrogen in the 2030s. India could become the country to build the first commercial-scale hydrogen-based industries, such as for iron ore smelting, using the early work done on piloting in the EU.

Hydrogen in the transport sector begins to emerge at scale between 2040 and 2045, although the first trucks appear in the mid-2030s. By 2050 some 3 million hydrogen-fuelled trucks are on the road and hydrogen as a final energy carrier exceeds the use of natural gas.

The development of hydrogen as an energy carrier highlights the need for sector-based cooperation within the overall transformation. Those companies developing energy services need assurance that hydrogen supply will be available, and those companies producing hydrogen need to know there will be demand for their product. Coalitions between different parts of the business community, supported by government, can give impetus to sectoral change and in some cases, like hydrogen, are essential to its development.

Transforming biomass use

Across India today, traditional biomass is a major form of energy. Cheap and readily available, it is used for both commercial activities and in many homes, where it makes up more than two-thirds of residential energy use, mainly in rural areas. Using it in the home results in poor indoor air quality and can lead to various health issues.[12]

The **NZE** scenario envisages a transformation in biomass use with much greater cultivation of biomass for liquid fuels, biogas and direct combustion for industrial purposes. Biomass use in homes is replaced by electricity, delivering significant health benefits.

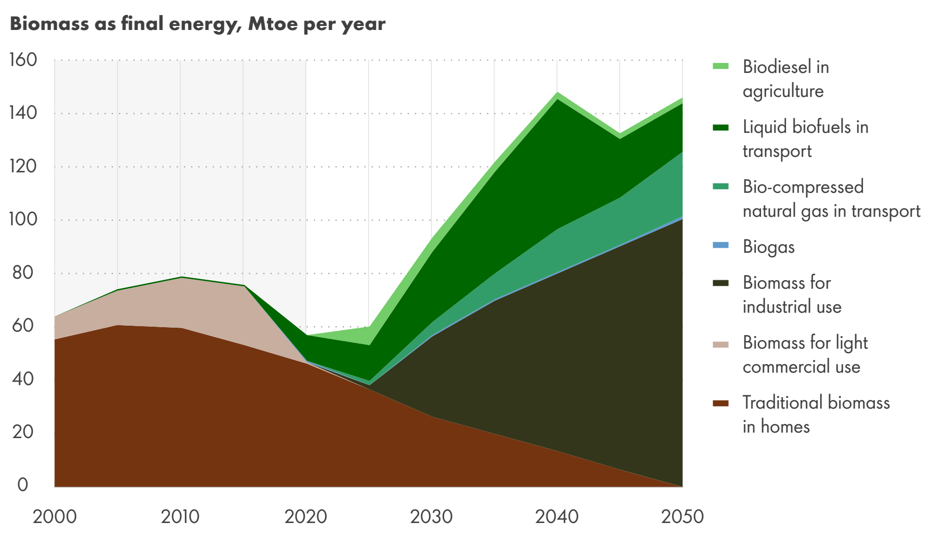
> "Biofuel use declines across India as 2050 approaches, due to the shift to electricity and hydrogen in transport."

In the years leading up to 2020, commercial biomass is primarily used for combustion by small enterprises, but this progressively declines as local clean air regulations push businesses towards electricity, LPG and CNG. As larger industries seek to decarbonise, commercial biomass emerges again as an important fuel for some process industries that use cleaner and more efficient combustion technologies.

Up to 2050, the only practical route for decarbonisation of aviation is to make use of sustainable aviation fuels sourced from biomass. While hydrogen could transform the sector in the second half of the century, that will not be possible in the medium term. Transport via inland waterways and coastal shipping could benefit from biodiesel, but electricity and hydrogen fuel cells may also play a role in reducing emissions.

In the **NZE** scenario, liquid biofuel use peaks around 2040, reaching a level close to that of petroleum in transport in 2005-10. Biofuel use declines across India as 2050 approaches, due to the shift to electricity and hydrogen in transport. Unused production capacity provides the country with an opportunity to export biofuels across the region.

Figure 8: Bioenergy is transformed, primarily fuelling transport and industry by mid-century



Source: TERI analysis

PART 2: SUPPORT ENERGY EFFICIENCY AND LOW-CARBON CHOICES

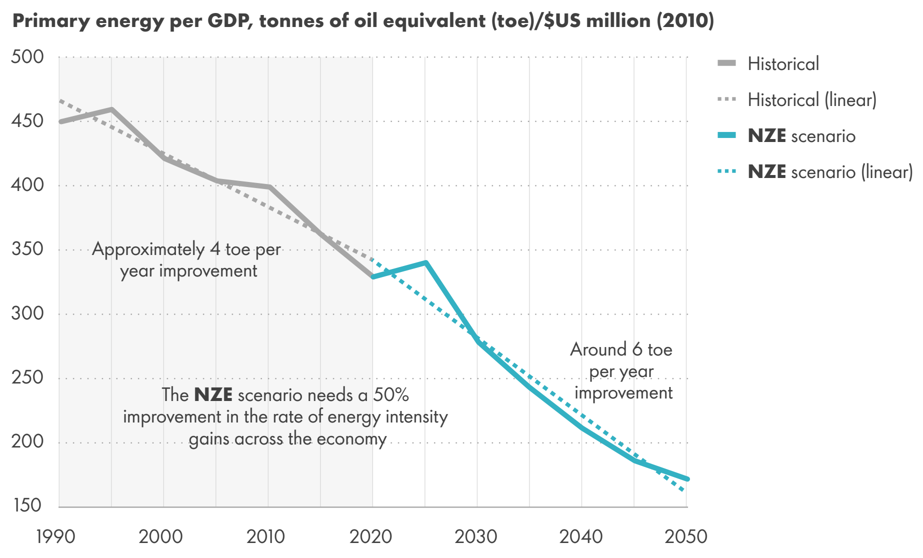
The main challenge India faces in developing a net-zero emissions energy system is how to effectively adopt and deploy new and efficient technologies and avoid expanding the economy through legacy systems and approaches. Targeting net-zero emissions by around mid-century sets a tight adoption timeline and will challenge the widespread use of current energy technologies. New energy technologies and efficient practices will need to be advanced in all sectors of the economy. Every choice made from now on will be important, due to the long lifespan of energy infrastructure.

Specific challenges could be overcome through modal shifts, such as a focus on high-speed rail as an alternative to domestic air travel or the use of 3D printing technologies for local manufacturing, rather than relying on long-haul freight from manufacturing centres. Shape-forming materials will still require haulage, but they may be common across a wide range of goods, leading to efficient distribution into cities.

Energy efficiency

A transition towards more efficient processes, technologies and end uses will further improve the energy intensity of the economy. This is critical for decarbonisation and is already a key component of India's energy security and climate mitigation strategies. Improvements in energy efficiency are particularly significant in the industrial, residential, commercial and agricultural sectors.

Figure 9: Efficiency improves the energy intensity of the economy



Source: TERI and Shell analysis based on IEA, World Bank and TERI data

As renewable power generation increases, decarbonisation of the commercial sector will require a transition towards more efficient buildings that are powered only by electricity. The success of the **NZE** scenario depends on creating an enabling environment for commercial builders to follow the Energy Conservation Building Code 2017[13] that renders a complete shift to efficient buildings by 2050. Furthermore, public infrastructure such as lighting should meet the highest achievable efficiency standards by 2050. Such a move would build on the current national street lighting programme that is targeting replacement of all India's conventional street lights with more efficient LED variants.

In the residential sector, benchmarking of energy-efficient appliances with star-labelling to inform consumer choices can facilitate a complete switch to efficient electric appliances by 2050.

Energy is used at various stages in the agricultural sector, ranging from tilling and irrigation to harvesting and threshing; the most energy-intensive operations being land preparation and irrigation. A pathway towards net-zero-carbon emissions in the agricultural sector requires targeted efficiency interventions at these stages, such as a complete switch to efficient agricultural machinery including pumps, tractors and tillers.

Industry sector decarbonisation requires attaining maximum levels of industrial energy efficiency, along with electrification of processes or switching to zero-carbon or low-carbon fuels. The focus on improving industrial energy efficiency through programmes such as Perform Achieve and Trade[14] should continue, so that efficiencies in core industries reach the global best levels by 2050 in all sub-sectors.

While the transport sector relies heavily on fossil fuels at present, electrification drives significant efficiency improvements and emission reduction aspirations in the sector.

As India rapidly develops, with growth around 5% annually on average through to 2050, efficiency measures and electrification of energy services limit growth in primary energy demand to double that of current levels. This represents an improvement in energy use per GDP of nearly 60% and a rate of improvement well above historical levels.

Carbon pricing and a vibrant market

Putting a cost on CO_2 emissions continues to be the preferred driver for change in the energy system. Carbon pricing can be enacted in many ways, with the most direct and effective approaches being taxation (e.g. British Columbia's Carbon Tax) or the development of an emissions trading system such as that of the EU. These approaches result in an explicit carbon price; governments can even set specific prices in the case of taxation. India currently has a compensation rate on coal production, called the Goods and Services Tax Compensation Cess, which is set at 400 rupees per tonne.

Many countries are considering adopting carbon pricing as the implementation of the Paris Agreement gains global momentum. However, there are also concerns that carbon pricing could leave the country exposed competitively. There are several ways of addressing this issue, the most popular being the implementation of border tax adjustments based on the carbon footprint of imported goods. Countries without domestic carbon pricing could find their export industries undermined by such developments.

The government can use the revenue raised by explicit domestic carbon pricing to compensate people and communities for the price impact that the mechanism creates. Alternatively, governments might consider introducing an implicit carbon price, through a carbon standard implemented within the energy value chain. In such cases, the financial impact is still there but it is far less transparent.

Should the government implement a carbon pricing system underpinned by tradable compliance units, consideration could be given to allowing the units to be exported or permitting equivalent units to be imported from other countries for compliance. This trade would be governed by the rules of Article 6 of the Paris Agreement; it offers flexibility and a likely lower-cost route for India to deliver on its nationally determined contributions. Export of carbon units could bring valuable foreign investment into the energy system as project developers seek to make use of the market opportunity presented by the Article 6.4 mechanism.

Material efficiency[15]

By 2050, half of India's population will live in cities, and municipal solid waste could increase to more than 400 million tonnes a year. This is considerably more than the 62 million tonnes of municipal solid waste generated by cities in 2016. Only 70% of that waste was collected, with the remainder disposed of in open landfills, without proper treatment or containment. In rural areas, agricultural waste, including crop and animal residues, are often burnt in the fields or used as traditional household fuels. Much of this waste could be used beneficially as renewable energy or materials, but new transformative solutions are needed rather than incremental improvements.

> "By 2050, half of India's population will live in cities, and municipal solid waste could increase to more than 400 million tonnes a year."

In the circular economy, industrial and consumer waste will replace virgin materials, in effect eliminating inefficient and harmful waste disposal. Many existing waste streams are underused. For example, 85% of municipal solid waste comprises a mixture of biomass and other combustible materials, offering a potential energy-rich fuel. Likewise, coal combustion residues from power plants – such as fly ash, bottom ash, boiler slag and flue gas desulfurisation residues – can be used in concrete and cement production, structural fills and some building products.

By collaborating across industry boundaries, companies can avoid landfill costs and reduce material procurement expenditure by converting industrial or municipal waste into feedstock for other industrial processes, thus turning waste into profit. Policy intervention will be required to drive substantial change, and successful implementation will require stimulus for innovative demonstration programmes at local and regional levels.

Consumer and business choices

Simple domestic changes across a very large country such as India can lead to huge transitional impacts and potential economic opportunities. For example, in the USA more than 80% of Americans have flown in a plane,[16] but most people in India have yet to do so. This will change rapidly as household income rises, but high-speed rail running on renewable electricity could offer a much lower carbon emissions alternative, at least for domestic travel. At the local level, Indian families occupy dwellings with an average size of 50 square metres,[17] but in Japan an average dwelling is nearly twice the size[18] and double that again in the USA.[19]

India has a population of almost 1.4 billion people in some 300 million households. At the household level, ownership of domestic appliances such as washing machines, refrigerators and air conditioners is relatively low, varying between 15% and 30%, depending on the appliance.[20] As the country develops over the coming 30 years, appliance ownership may well head towards the 90% level seen in much of the world. Once in use these appliances will consume energy, so the choice of model and efficiency rating will be important. These appliances could add 300-500 terrawatt-hours a year to electricity demand, nearly a third of that generated in 2019, but lower efficiency choices might double this amount.

India has already committed to the further development of its vast rail network through the introduction of high-speed trains. In 2016, the National High Speed Rail Corporation Limited was incorporated with the objective to finance, construct, maintain and manage the proposed high-speed rail corridors between major cities in India. Several high-speed rail corridors have been identified, and a survey of the proposed link between Delhi and Varanasi is already under way.

In the transport sector, vehicle choices will be important. Set foot in any city in India and it is the ubiquitous three-wheeler, often known as a tuk-tuk or auto rickshaw, that is bound to offer a ride within moments. Today, there are some 10 million three-wheelers offering taxi services, ride-sharing and local freight haulage in India. The majority are running on diesel fuel, but compressed natural gas is also popular.

The government has initiatives under way to electrify three-wheelers, with the goal of all sales (currently around 650,000 a year) being electric by 2030. But a rapid transition towards net-zero emissions needs to see the entire fleet operating on electricity by 2030. Choices made by drivers as they enter the tuk-tuk market or buy a new vehicle will be critical for a faster rate of change.[21]

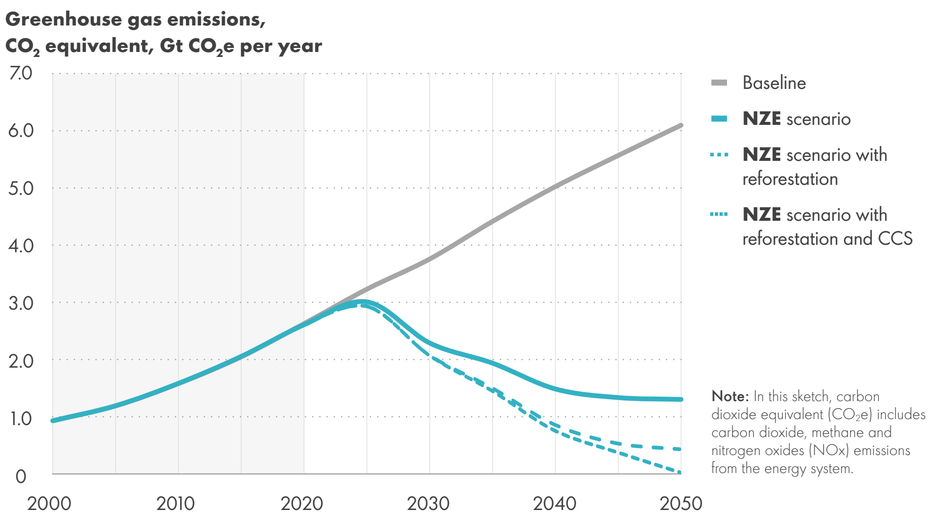
A three-wheeler transition also offers the opportunity for Indian businesses to develop and deliver the first generation of electric transport infrastructure, gaining experience and technological advantage in a market that needs to change. With the large export market for three-wheelers, such a transformation could further strengthen India's position in the global market.

PART 3: REMOVE UNAVOIDABLE EMISSIONS

Focusing on the available levers should not divert attention away from the need to address the unique issues related to hard-to-abate sectors. These are sectors where the pathway to decarbonisation may not be apparent or where it rests on technologies which are still in development. Foremost among these is aviation, which is growing rapidly in India. By 2050, air traffic in India could reach the same level as the USA in 2019. However, long-haul freight will also grow quickly. Both aviation and heavy transport will require solutions ranging from synthesised hydrocarbon fuels, initially from biomass, to the use of hydrogen or possibly stored electricity for some short routes. These could take several decades to mature, which requires balancing the emissions from these sectors with carbon removal using nature or technology.

Significantly, the **NZE** scenario does not plot a pathway to full decarbonisation. Fossil fuel dependency remains through to mid-century and beyond, although in the **NZE** scenario this is largely limited to the industrial sector. The ongoing use of fossil fuels points to the need for India to deploy CO_2 sinks in some form.

Figure 10: Technology and nature are required to remove remaining emissions



Note: In this sketch, carbon dioxide equivalent (CO_2e) includes carbon dioxide, methane and nitrogen oxides (NOx) emissions from the energy system.

Source: TERI analysis

The **NZE** scenario has residual emissions of 1.3 billion tonnes in 2050, primarily from industry. To achieve net-zero emissions, forestry can, at best, sequester 0.9 billion tonnes,[22] including a contribution from trees outside forests. The remaining 0.4 billion tonnes will still need sequestration through other options, such as carbon capture and storage (CCS), carbon capture and use (CCU), expanding wetland areas and CO_2 removed from the atmosphere by India's extensive coastal ocean ecosystems, such as mangroves. India is home to more than 7% of the world's mangrove forests, which cover 8% of the Indian coastline.

Carbon capture and storage

Carbon capture and storage (CCS) technologies have been deployed in many locations globally with individual projects storing as much as 4 million tonnes of CO_2 a year. CO_2 typically requires geological storage at depths of two or more kilometres. The cost of implementing CCS is dependent on specific local circumstances, but opportunities normally exist[23] around $50 per tonne of CO_2. CCS could be applied in three ways:

- in direct use at industrial facilities, such as a cement plant, to capture both combustion and process emissions;
- in combination with the combustion of biomass in power stations or the processing of biomass into biofuels (known as bioenergy with carbon capture and storage, BECCS), offering the opportunity for negative emissions (a net removal from the atmosphere because carbon absorbed during biomass growth is then stored geologically). This can balance emission sources from sectors such as aviation, where the direct application of CCS is not possible; and
- in combination with the emerging direct air capture technology which also offers the opportunity to generate negative emissions.

There is uncertainty about the overall geological storage potential in India. The Global Carbon Capture and Storage Institute estimates there is around 47 gigatonnes of storage potential,[24] but acknowledges that India requires a national study of deep saline formations and of a depleted oil and gas field to identify effective storage potential.

While biomass in power generation is limited in the **NZE** scenario, the significant biofuels industry that develops could offer the opportunity for negative emissions with BECCS. For example, a synthesis gas production route to aviation fuels from biomass also produces CO_2 within the process.

A further option is CCU. Instead of the CO_2 being geologically stored, it is used to make specific products. Where the products remain in society for an extended period of time, for example embedded in the built environment, the effect is similar to geological storage, albeit not as long lived.

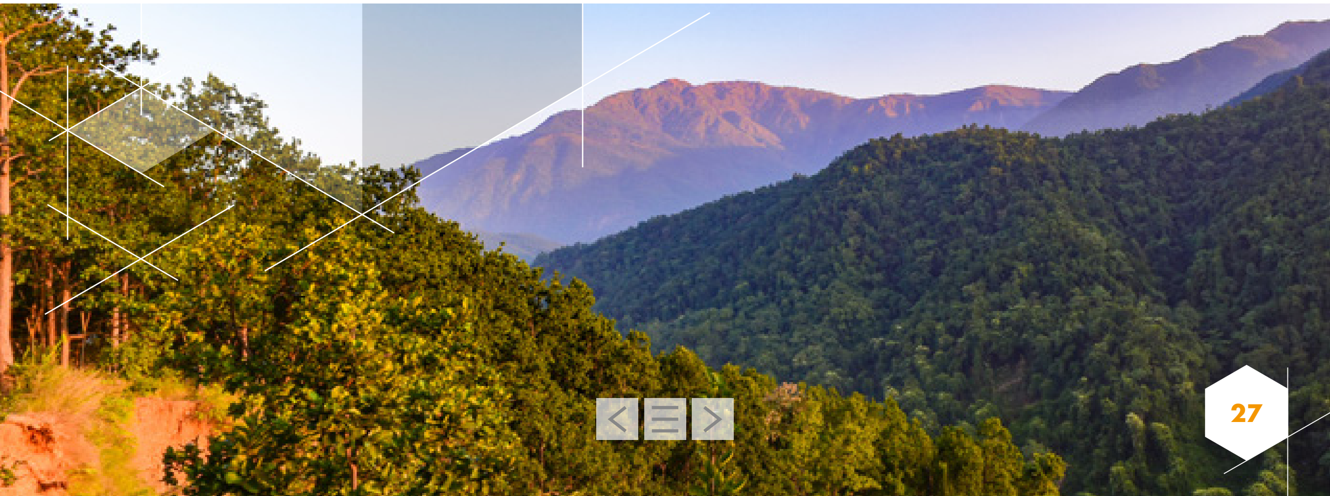
The deployment of CCS requires a focused policy approach with CCS being a very specific desired outcome. To date, only the USA has anything close to an established CCS sector, through a combination of commercial drivers for enhanced oil recovery and tax credits for CCS projects. Canada has two landmark projects but remains a distant second alongside Australia and Norway.

The challenge faced by industry in India requires the capture and geological storage of 400 Mt CO_2 per year by mid-century. This means construction needs to begin in the near-term. These projects could be linked to various industrial facilities, including cement plants, biofuel production plants and iron ore smelters.

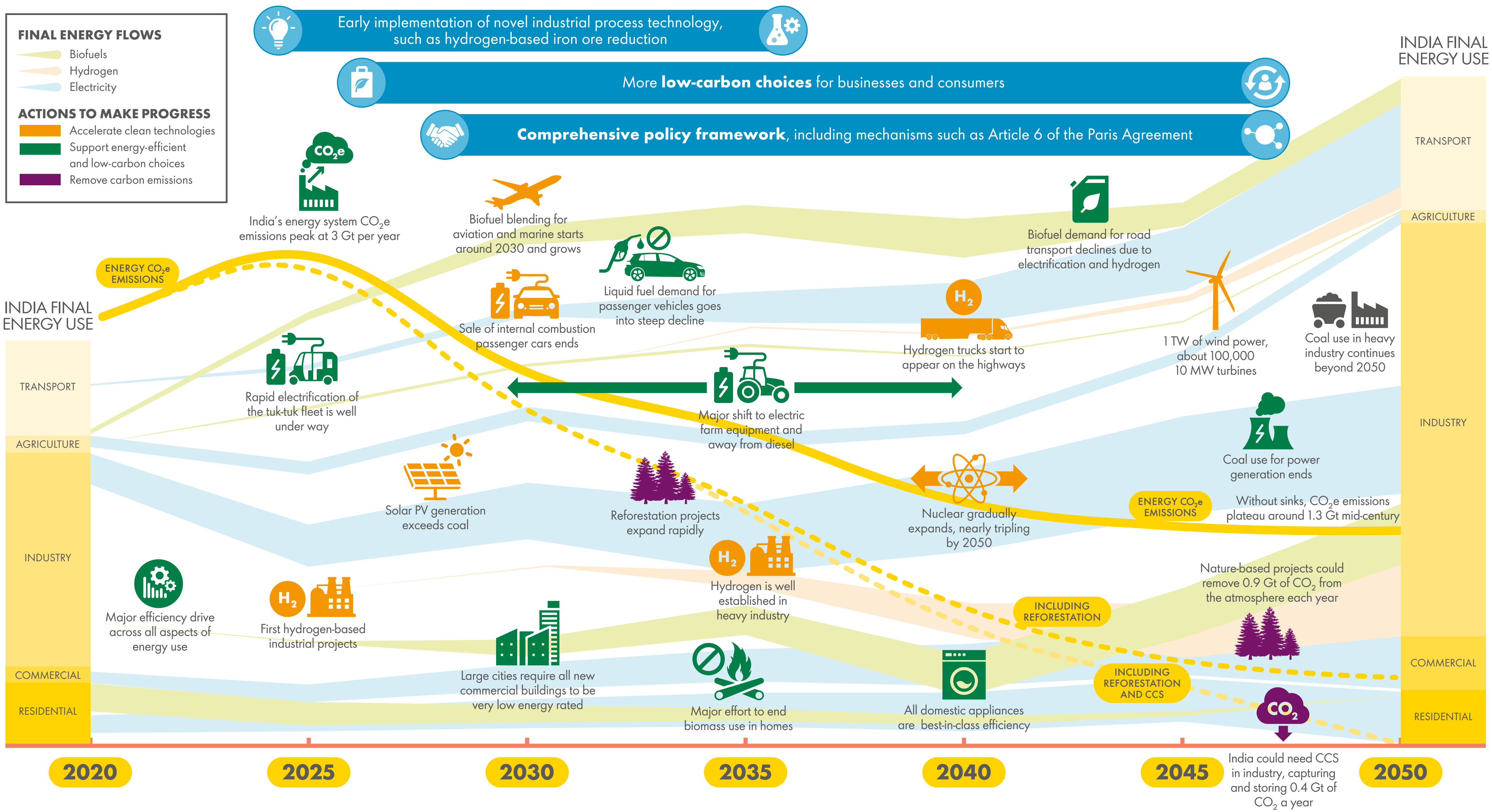
Nature-based carbon removal solutions

In tandem with the development of CCS and carbon capture, utilisation and storage, the expansion of forest cover in India through large-scale nature-based projects can act as a CO_2 sink. Nature-based solutions can potentially offer a rapid pathway to nearly 1 gigatonne of CO_2 removal per year once the necessary scale is reached. Removal at this scale may become essential if India is limited on geological storage capacity or if the direct carbon capture industry is slow to establish itself. Removing 0.9 gigatonnes of CO_2 a year by 2050 could require some 30-40 million hectares of additional forest cover – an area equivalent to Rajasthan – as well as a concerted effort to plant trees outside forests.

Reforestation projects could lead India to work in cooperation with other countries under Article 6 of the Paris Agreement to help balance remaining global emissions, potentially becoming a trader of forestry sinks as carbon removal units.



INDIA: TRANSFORMING TO A NET-ZERO EMISSIONS ENERGY SYSTEM



In the India scenario sketch carbon dioxide equivalent (CO_2e) includes carbon dioxide, methane and nitrogen oxides (NOx) emissions from the energy system.

SECTION TWO

A NET-ZERO EMISSIONS ENERGY SYSTEM

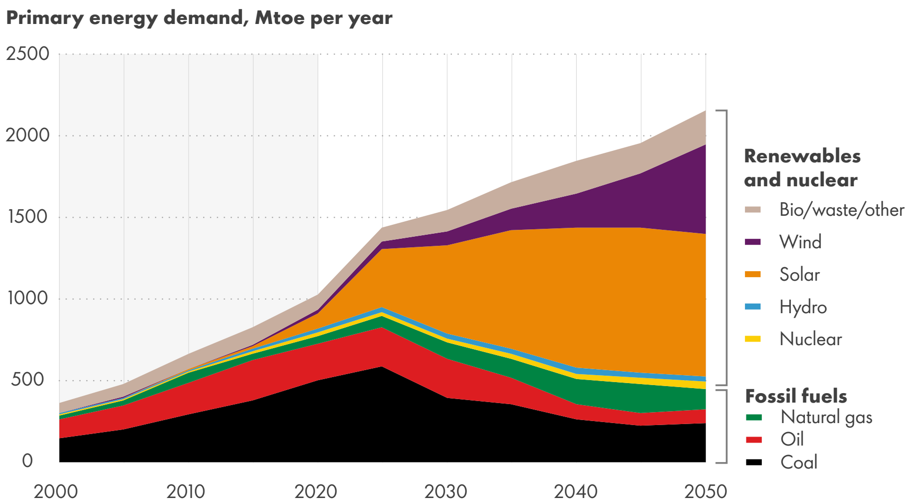
A ROADMAP TO NET-ZERO EMISSIONS

India's pathway to a net-zero emissions energy system will require unprecedented co-operation. Society must make cleaner energy choices and every sector will need to play a part. The transition to a final energy system based on electricity, hydrogen and biofuels must be matched by a primary energy transformation to solar, wind, nuclear and biomass. That transition is under way in India today and the country is making progress towards its 2030 Nationally Determined Contribution of 40% installed non-fossil (solar, wind, hydro, biomass and nuclear) generation capacity. But the pace of change will need to accelerate, both to keep up with increasing demand and to progressively reduce demand for coal, oil and gas.

TRANSFORMING THE ENERGY MIX

India is currently dependent on coal, oil and traditional biomass for its energy needs, but solar becomes the dominant energy source in the late 2030s in the **NZE** scenario. This builds on recent developments in India where solar generation has increased sharply, up by nearly 30% in 2018 alone.

Figure 11: Energy production transforms from fossil to primarily non-fossil fuels



Source: TERI analysis

In India today, there is a successful programme of solar PV installation under way, but by 2030 as solar starts to dominate the generation mix in the **NZE** scenario, it will need to be matched by large-scale energy storage to manage intermittency. More than 1,000 gigawatts of solar PV, 700 GW of which with matching storage, needs to be installed through the 2020s, far exceeding the amount of solar PV installed over the last decade. This level of deployment is challenging, even in global terms. In 2019 global solar module production[26] was about 140 GW, but growing at some 20% per year. Even if growth continues at this rate through the 2020s, the demand in India for modules under **NZE** would still equate to 20% of global supply.

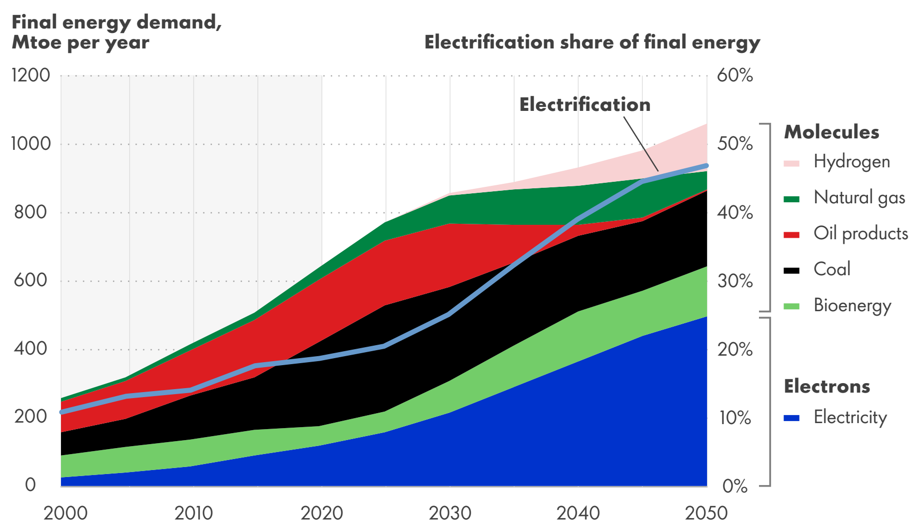
The 2020s will need to see the emergence of offshore wind, as well as a tripling of onshore wind capacity and a 50% increase in nuclear.

In the **NZE** scenario crude oil peaks around 2030 but declines after that as electric vehicles permeate transport. By the 2040s, oil products hardly feature in the final energy mix, as both transport and domestic users have switched to electricity.

Natural gas demand continues to increase in India through to the 2040s, but by 2050 demand is falling. While there is some initial growth of compressed natural gas use in transport, this declines in the 2040s as electrification and hydrogen take hold. The largest growth in natural gas demand comes from industry, as new facilities shift away from coal, which quadruples natural gas demand from 2020 to 2040.

The transformation of the final energy mix is a story of rapid electrification, although fossil fuels continue to make up a third of India's energy mix in 2050, albeit they are in decline over the longer term. Coal continues to meet an important part of energy demand for industry, but no additional coal-based power generation capacity is installed after 2030.

Figure 12: Deep electrification of the economy, predominantly from renewables; molecules are still required



Source: TERI analysis

> The largest growth in natural gas demand comes from industry, as new facilities shift away from coal, which quadruples natural gas demand from 2020 to 2040.

Sector emission outcomes

The **NZE** scenario outlines a turning point for the major emitting sectors in the economy by 2030 at the latest.

In the power sector, nearly two-thirds of existing coal generation is retired in the second half of the 2020s, with solar backed up by storage rising rapidly to be the major source of electricity. Over the following two decades both wind and solar grow rapidly, such that by 2050 they make up nearly 90% of the generation mix. The electricity system grows by a factor of more than four by 2050, yet emissions fall from current levels. By mid-century, around 100 million tonnes of emissions a year remain due to natural gas use, which helps balance the intermittency of solar.

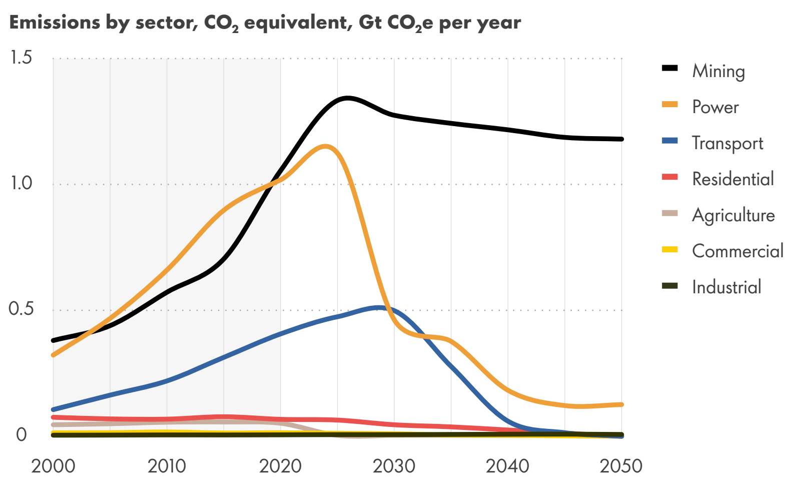
The future pathway for transport assumes rapidly growing availability of electric vehicles throughout the 2020s, with only electric vehicles being sold by 2030. Buses, vans and trucks follow, either as electric or fuel cell vehicles, the latter powered by green hydrogen produced by electrolysis. As the vehicle fleet turns over through new sales, emissions from transport fall rapidly. The growth in low-carbon biofuels reduces remaining emissions from sectors such as aviation.

Emissions from energy use in the industrial sector reaches a plateau, not a peak, largely due to the lack of readily available alternative technologies in India. While industry begins the transition to hydrogen, it is insufficient to counter the continued rapid growth of traditional industries. The ongoing emissions in this sector in 2050 highlights the need to deploy carbon capture and storage technologies during the 2020s and to make use of natural carbon sinks.

In both the commercial and residential sectors, the transition to electricity is virtually complete by 2050, with a small demand for biogas for residential cooking remaining in some places.

By 2050, the agricultural sector makes a rapid transition to net-zero emissions, depending largely on local solar power for farm equipment, but larger tractors and mobile machinery continue to use biodiesel.

Figure 13: Decline in energy emissions for most sectors; remaining emissions are removed using nature and technology



Source: TERI analysis

Box 1

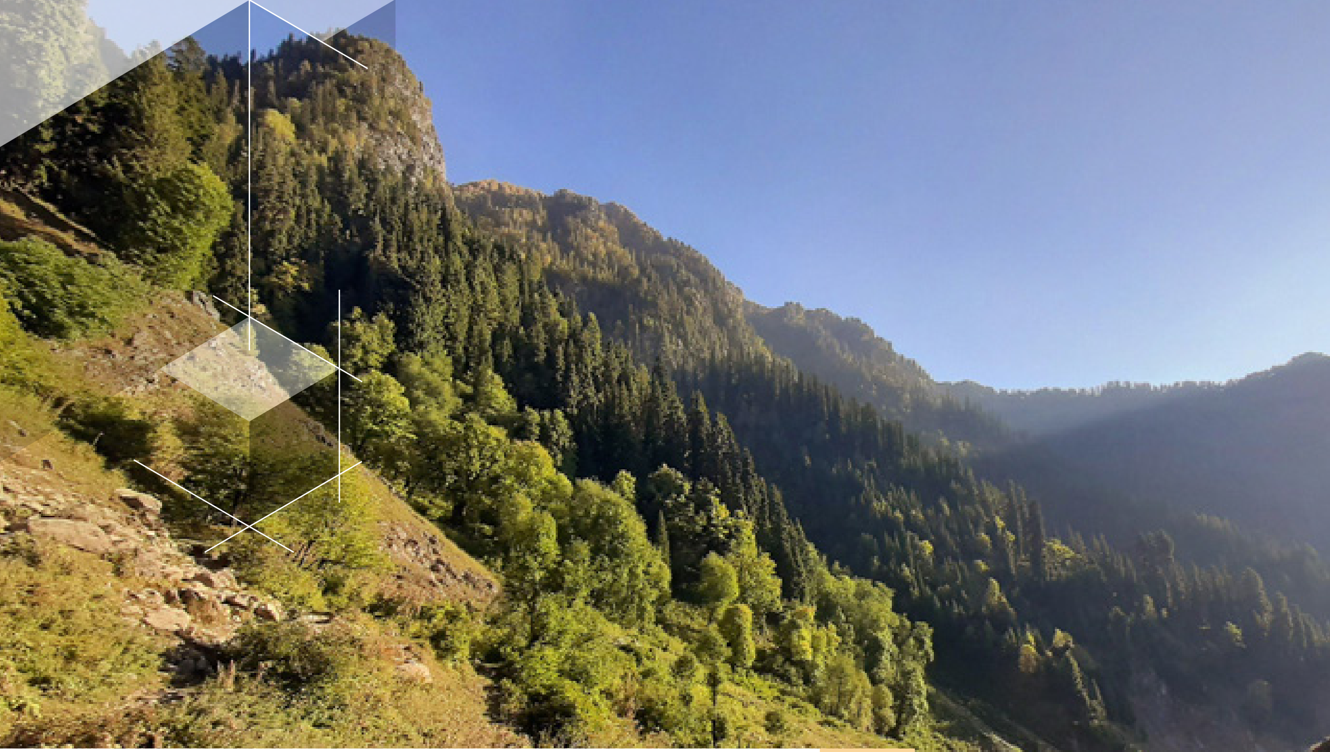
BARRIERS TO TRANSITION

During development of the **NZE** scenario, we identified the many barriers that could slow progress of an energy system transition of this scale. We captured these insights in a second scenario called **Towards Net-Zero (TNZ)**. In the **TNZ** scenario, the transition proceeds, but at a slower pace; key energy trends lag by about a decade, sometimes longer.

- **Electrification:** While the **NZE** scenario assumes rapid electrification in all sectors, **TNZ** identifies several technological and behavioural constraints. In agriculture, smaller farm vehicles can quickly electrify, but the replacement of large, powerful diesel tractors is more limited, due to cost constraints and battery weight. A preference for flame cooking lingers in homes and technological hurdles emerge in industry, limiting electrification. While electric passenger vehicles are now available, mass production, cost reductions and better financing mechanisms all need to be in place to increase the market share of electric cars. The **NZE** scenario places a heavy reliance on storage technology to support solar PV, but battery storage has yet to fully develop as a long duration backup for intermittency.

- **Hydrogen:** The adoption of hydrogen for heavy transport, shipping, aviation and industry is highly anticipated but technology development to use hydrogen at scale is only just emerging. A pilot plant is being built in Europe to demonstrate iron ore smelting, but there is no visible progress of hydrogen in aviation, although the sector has made some announcements. Large-scale green hydrogen production is still a nascent industrial process and while costs are coming down, more progress is required.

- **Bioenergy:** The use of biomass and biofuels will require considerable transition in existing supply chains. In some cases, this will involve moving to more centralised collection for large-scale industrial use, switching the type of biomass collected for alternative biofuel production and adapting existing processes to meet new demand, such as for the very stringent aviation market. While biomass availability is not an issue, getting the right biomass in the right place may well take some time to implement.



SECTION THREE
HOW TO MAKE PROGRESS

The **NZE** scenario for India illustrates a technically possible, but highly challenging, pathway for the country to achieve a net-zero emissions energy system by 2050. Below we look in more detail at how to make progress and, importantly, how to accelerate the actions already taking place in India.

UNDERSTANDING THE ECONOMIC AND SOCIAL IMPACTS OF THE ENERGY TRANSITION

The transition of India's energy system to net-zero emissions will require fundamentally changing how the country produces and uses energy. Today, India has a chance to deliver economic growth that is environmentally sustainable and socially inclusive rather than seeing issues emerge that have arisen historically in other economies. Take the UK where fossil fuels – particularly coal – underpinned the industrial revolution of the late 18th and early 19th century, creating negative environmental consequences, including air pollution and health issues. But new energy choices are available in the 21st century that were not viable options then. India can take a different development path, relying on less polluting sources of energy to deliver economic growth and improved standards of living. The energy transition also provides opportunities for balanced and sustainable economic development that delivers a better quality of life for all.

Macroeconomic impacts

With modest existing dependency on fossil fuels, India is well placed to pursue an energy pathway to net-zero emissions with minimal impact on longer-term economic output. This is due to the significant cost reductions seen in solar PV, wind and battery technologies in recent years, combined with the increasing availability of new practices, technologies and approaches that deliver much greater energy efficiency. The macroeconomic resource costs of making the transition to a lower-carbon economy could be relatively modest given the scale of the change. By one estimate, GDP is expected to be 4% lower in 2050 than it would be otherwise and with no significant impact on per capita consumption due to higher efficiencies and lower investment costs associated with the production of goods and services.[27]

These costs are consistent with other estimates at the global level and in a country context. In its "Making Mission Possible: Delivering Net-Zero Emissions" report, the Energy Transitions Commission estimates that transition to a zero-carbon emissions economy will have a very modest – less than 0.5% – impact on 2050 living standards in developed and developing countries alike.[28] According to a TERI study, the country can achieve 30% of power generation from variable renewables and 45% of zero-carbon generation (including hydropower and nuclear) by 2030 at no extra cost to the system, as long as policies and other measures are put in place to increase system flexibility.[29]

WHAT NEEDS TO CHANGE +	HOW TO MAKE PROGRESS =
Increase electrification, primarily renewable	Redirect reseources across the economy
Develop new lower-carbon energy supply	Seize new business opportunities
Improve energy and material efficiency	Address negative transition impacts
Offer more lower-carbon solutions	Drive economy-wide change for an orderly transition
Use geological storage	Accelerate sectoral transitions through coalitions
Use natural sinks	Create societal support for action

NET-ZERO EMISSIONS ENERGY SYSTEM

Naturally, there are additional costs of building transmission and distribution networks to support this scale of electrification. However, investment in electricity infrastructure – to build new and/or expand existing transmission lines, enhance distribution networks and build a smart grid through digitalisation – can boost jobs and demand in the near term while increasing the economy's capacity for growth in the long term, through better and more access to energy. Renewable energy projects in India are already providing significant job opportunities. The International Labour Organization has estimated that by 2022 more than 300,000 workers will be employed in India's solar and wind energy sectors to meet the country's target of generating 175 gigawatts of electricity from renewable sources.[30] Moreover, much of the investment in electricity infrastructure will not require additional resources but a redirection of planned investments to support a lower-carbon electricity grid.

While overall resource costs of the energy transition may be relatively modest, it will require significant realignment and reallocation of investment, and not just in the electricity sector.

At the global level, supporting the energy transition will require significant investment in lower-carbon energy supply, from a little under $1.6 trillion in 2018 to around $2 trillion a year on average between 2025-30, according to the International Energy Agency's Sustainable Development Scenario.[31] A significant portion of this can be met by reallocating capital within the energy sector, primarily from building new fossil fuel infrastructure and expanding the power sector. However, some additional investment will be required to drive energy efficiency improvements and to develop lower-carbon energy solutions.

Given the falling cost of new energy technologies, the investment needed to develop along a net-zero emissions pathway will not be significantly different to that required by conventional energy to transform India into a largely developed economy by the second half of the century. Unlike developed economies with large legacy (fossil-based) energy systems, India has an opportunity to build an energy system based on new lower-carbon technologies and fuels. Some legacy components exist but they represent a smaller proportion of the system, thus reducing the risk for lock-in to traditional fossil fuel infrastructure and/or stranded assets. However, it will require clear targets and policies to level the playing field between fossil fuel and non-fossil fuel energy and redirect economic resources towards the latter. Delaying action will only add to the cost of making the transition.

Finally, the transition to a lower-carbon system can increase self-sufficiency and reduce the risk of macroeconomic instability as a result of India's reliance on energy imports. Energy imports as a share of total energy use have risen almost continuously since the 1990s. According to the National Institution for Transforming India (NITI Aayog), India imported about 46% of its total commercial[32] primary energy needs in 2015-16.[33] The large volume of energy imports has triggered balance of payments concerns during past periods of high oil prices and contributed to macroeconomic instability. Based on the **NZE** scenario, total primary energy demand is expected to double between 2020 and 2050. India's abundant renewables potential can help the country achieve greater energy self-sufficiency in meeting this demand. Electrifying many energy end uses – and meeting demand through domestic renewable resources such as solar, wind and hydropower – can reduce the need for oil and gas imports. Similarly, a transition to lower-carbon fuels, such as green hydrogen and biofuels, can further reduce dependence on fossil fuel imports.

Energy transition business opportunities

As the world shifts towards lower-carbon energy, there are new growth industries in lower-carbon fuels, technologies, products and solutions. India has a relatively young population, with an average age of 29 years in 2020 and with half the population under 25. Combined with the country's strong focus on technical education, India is well placed to be at the forefront of these new growth sectors.

> India has a relatively young population; combined with the country's strong focus on technical education, India is well placed to be at the forefront of new growth sectors.

As the preceding analysis illustrates, the industry and transport sectors generate the largest emissions. Developing new lower-carbon industrial production processes and mobility solutions will not just reduce domestic emissions but could also position India as a global market leader in these areas. The country is already seeing a boom in the shared economy, which had grown into a $2 billion industry by the end of 2020[34] and could potentially be leveraged into a range of global products and services. Moreover, the scale of electrification and deployment of renewable generation required to decarbonise India's energy system could position India as the leading producer of technologies, such as energy storage and demand-side response solutions, to address intermittency issues.

Harnessing this opportunity will require an integrated and ambitious industrial policy to:

- promote new industries such as the manufacture of solar panels, wind turbines, batteries and hydrogen electrolysers;
- develop lower-carbon industrial processes such as green steel produced using green hydrogen;
- install carbon capture, utilisation and storage at cement production facilities;
- steer the automobile industry towards lower-carbon vehicles; and
- apply innovative digital solutions to reduce emissions from urban transport.

Setting a clear strategic direction, supported by measures to create a business friendly environment, will help foster business creativity and innovation in developing lower-carbon solutions. The scale of the domestic market, combined with ease of doing business and a skilled labour force, will also be attractive to foreign investment, bringing capital and technology to support decarbonisation of high growth sectors such as transport and construction.

Social impacts

According to the Intergovernmental Panel on Climate Change's 1.5°C report, climate mitigation actions have significant synergies with the United Nation's 17 sustainable development goals (SDGs).[35] For example, transforming energy supply to lower carbon can help deliver SDG 7 on access to affordable, reliable, sustainable and modern

> Making progress requires that the economic, social and environmental benefits of the energy transition are shared by all of India's diverse society, especially those most impacted by the transition.

energy for all. Transforming energy demand through lower-carbon consumer and business choices has significant synergies with: SDG 3 on healthy lives and well-being for all ages; SDG 9 on building resilient infrastructure, promoting sustainable industrialisation and fostering innovation; and SDG 11 on making cities inclusive, safe, resilient and sustainable.

India already has ambitious goals to improve access to energy and bring electricity and modern energy services to the whole population, with a focus on investment in rural communities to enable them to play a role in the transition and generate sustainable rural development. Moreover, using electricity earlier in the development pathway can avoid later issues such as air quality deterioration that can emerge as villages develop into towns and then cities. The digitalisation of the economy also offers greater and more efficient access to energy services and their delivery.

Making the most of the synergies between the climate and sustainable development objectives will help to sustain progress in the energy transition. In the long term, a net-zero emissions energy system will produce significant societal benefits – for example, through more efficient energy consumption and better environmental outcomes. However, given the scale and scope of the change, economic activity and resources associated with the energy transition will not be equally spread across states, industries and people of different economic means. Making progress requires that the economic, social and environmental benefits of the energy transition are shared by all of India's diverse society, especially those most impacted by the transition. For example, lower income groups spend a higher share of their income on energy and can therefore be disproportionately affected by higher energy costs during the transition. Around half a million people are currently employed as coal miners in India[36] and many more have jobs in associated industries and businesses. As jobs and livelihoods change, retraining and reskilling workers will be important for a smooth transition.

The energy transition is also likely to lead to regional shifts in economic activity. The decline in fossil fuels in the energy mix will require resources and economic activity to be reallocated at the state and regional level. For instance, coal mining tends to be concentrated in various eastern states where entire economies, societies and livelihoods

> Policy has a fundamental role in driving the energy transition and making the transition to a net-zero emissions energy system technically possible in India by 2050.

are oriented around it. But the energy transition will also create new regional opportunities for other lower-carbon energy sources and technologies, such as in the renewables-rich regions of the south and west. The implications of these changes at the sub-national level will be far-reaching, both challenging existing industries and presenting opportunities for new industries to grow and add jobs. Diversifying the economy away from fossil fuels and seizing opportunities in the new lower-carbon energies will be essential for all regions and states to play their part in enabling the national transition.

As the world moves towards achieving the goal of the Paris Agreement, it will be important to ensure communities are resilient to future climate impacts, such as a rise in sea level, through investment in adaptation in affected areas. Making progress in the energy transition will require ensuring these communities benefit equally from climate mitigation and the adaptation opportunities presented by the energy transition.

The energy transition provides an opportunity to create a more prosperous and equitable society and deliver a cleaner environment for everyone. Low-income and marginalised areas tend to overlap with high pollution levels, whether disproportionately hosting potentially toxic industrial and waste facilities or being affected by the health impacts of poor air quality, indoor and outdoor. Women in these communities are likely to be most affected through environmental impacts on their health and fertility.[37]

Successfully managing the economic and social impacts will be critical for a smooth and rapid transition to net-zero emissions in the next 30 years. It will require all levels of government to advance policies that ensure all states, regions and income groups are able to participate in and manage the energy transition. Well-designed policies at the national and sub-national level are required to keep overall macroeconomic costs manageable, to address transition challenges and fully harness the opportunities the transition presents and to ensure more resilient and environmentally just outcomes for the most vulnerable and under-served communities.

A comprehensive, coherent and credible policy framework to support the energy transition

Climate change has been called the result of the greatest market failure the world has seen.[38] Markets alone will not deliver the change required in the time available. Policy has a fundamental role in driving the energy transition and making the transition to a net-zero emissions energy system technically possible in India by 2050. It can speed up technology development, commercialisation and diffusion and it can improve the economics of low-carbon goods and services. Policy can also help to progress the building of the necessary infrastructure. Finally, policy is central to managing the wider economic and social impacts of the transition. The key elements of an effective long-term policy framework, covering the range of economic, sectoral and social policies are outlined in Box 2.

Box 2

ELEMENTS OF AN EFFECTIVE POLICY FRAMEWORK

Drive economy-wide change

1. **Set credible and robust decarbonisation targets and a clear trajectory for achieving them** to reduce policy uncertainty and incentivise necessary investments over time.

2. **Adopt economic mechanisms, such as carbon pricing,** to improve business and household energy efficiency, incentivise low-carbon choices as they become available and bridge the remaining cost difference to low-carbon fuels and technologies.

3. **Rewire the economy with low-carbon electricity** by investing in low-carbon generation, optimising system performance, expanding transmission and distribution networks, and investing in electrification infrastructure such as electric vehicle charging networks.

Accelerate sectoral transitions

4. **Encourage better coordination within sectoral value chains** for hard-to-electrify sectors in transport (aviation, shipping, heavy road freight) and industry (steel, cement, chemicals).

5. **Provide time-limited fiscal and financial incentives** to drive investment in and commercialisation of low-carbon molecules such as hydrogen and advanced biofuels.

6. **Create markets and demand for these low-carbon fuels** by, for example, sectoral carbon pricing, emissions performance standards and policy mandates.

7. **Support infrastructure planning and investment** to support the commercial adoption of low-carbon molecules.

8. **Establish governance for carbon removals** to establish both natural carbon sinks and carbon capture, utilisation and storage, particularly during the transition, to keep the world within its carbon budget and prevent overshoot.

Create societal support

9. **Create clear and predictable policies** that keep overall macroeconomic costs of the transition manageable.

10. **Adopt fair and equitable policies** that mitigate regional, sectoral and distributional impacts of the transition.

11. **Establish transparent and inclusive policies** that encourage wide societal innovation and participation in change.



While a comprehensive long-term policy framework is required to drive and sustain the energy transition over the next 30 years, India is not currently on a path to achieve a net-zero emissions energy system by 2050. To accelerate towards that goal requires early policy action this decade in five key areas.

To drive economy-wide change, greater electrification with renewable and nuclear generation is the backbone of the **NZE** pathway and will require accelerated action this decade.

1. **Expand and enhance electricity transmission and distribution networks**

   The electricity transmission and distribution networks must be expanded and enhanced to significantly electrify the economy, primarily with renewables. This includes connecting the renewables-rich regions of the country to demand centres; increasing the number of interconnections between regional power grids to improve reliability; improving network and smart grid capabilities to balance diverse sources of electricity supply and demand; and strengthening networks to support greater electrification of energy end use, such as EV charging.

   Policy plays a fundamental role to support investment in electricity infrastructure, for example: coordinating efforts across regions, states and municipalities (for example, the Green Energy Corridor[39] programme) to deliver integrated grid infrastructure, redirect existing investment and raise additional financing; reforming power distribution companies to ensure their financial viability; and driving wider electricity market reforms, such as location and time-of-day pricing, fair and open third-party access to transmission and distribution networks, and incentives for investment in grid-scale energy storage.

2. **Ramp up renewables investment**

   The transition away from coal will require increased investment in renewables and electricity market reform to accommodate the different characteristics of renewables[40] compared to thermal generation. While solar PV is close to grid parity with thermal generation, investment in renewable energy will continue to require policy support to bridge the remaining gap and provide revenue certainty for investors in the longer term once electricity generated from renewables becomes cost competitive. Policies will also need to incentivise investment to address renewable intermittency (through energy storage, backup generation and demand-side response). Mechanisms that can support investment include competitive auctions to procure efficient and reliable electricity and power purchase agreements based on system-wide requirements rather than specific types of generation.

> "The electricity transmission and distribution networks must be expanded and enhanced to significantly electrify the economy, primarily with renewables."

To accelerate sectoral transitions, action will be required this decade, particularly in hard-to-electrify sectors.

3. **Increase the use of hydrogen and bioenergy to decarbonise hard-to-abate sectors**

   Hydrogen and lower-carbon production of biomass and biofuels will be required to decarbonise hard-to-electrify sectors, including steel and aviation. Moreover, developing India's sustainable bio-resource potential can deliver significant benefits beyond the energy system, creating jobs and stimulating the rural economy to support environmentally responsible economic development.

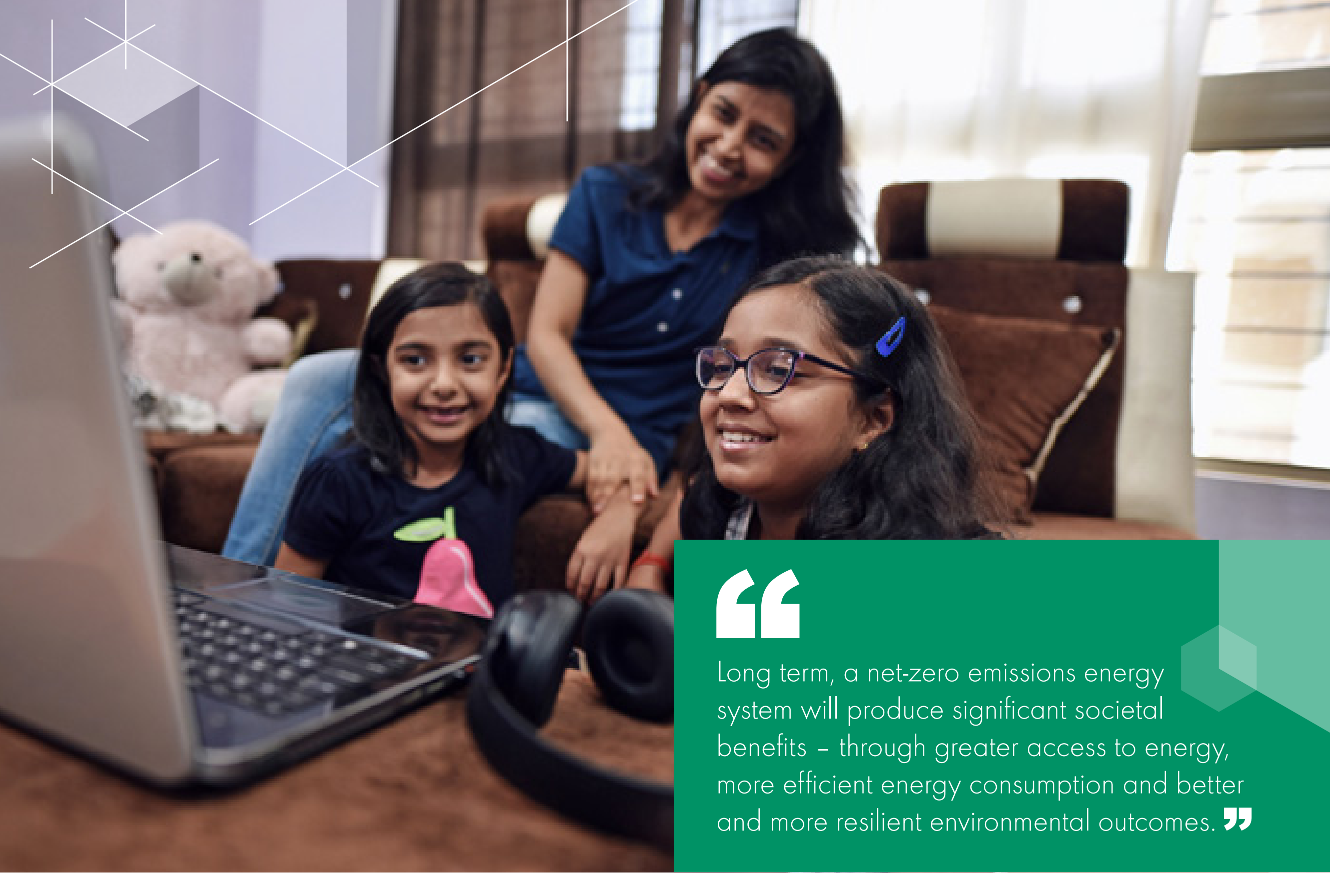
Policy support such as fiscal incentives, research and development programmes and public-private partnerships will be necessary to accelerate the development of these fuels, spur technological progress and drive down costs. For example:

- Lower electrolyser costs combined with policies to support the development of new supply and demand could help reduce the cost of green hydrogen by more than 50% by 2030.[41] In addition, policies to incentivise and facilitate domestic production of electrolysers (for instance, as part of the Make in India[42] programme) could build India's competitive advantage in green hydrogen, meet domestic needs and capture a significant share of the growing global market.
- Developing the bioeconomy will require a systematic and coordinated policy approach to shift away from the open burning of biomass and support more efficient and cleaner uses of commercial biomass. Specifically, there is a need to combine federal and state policies to build on regional strengths, align public and private resources, incentivise local supply chains and take advantage of the different uses for bio-resources in decarbonising the energy system.

4. Develop a vibrant lower-carbon manufacturing industry

A vibrant lower-carbon manufacturing industry in India (e.g. new industrial processes and products, as well as lower-carbon vehicles, technologies and digital solutions) supports domestic decarbonisation, particularly for industry and transport. It also positions India as a market leader in this global growth industry.

This will require a clear and sustained industrial strategy based on a rising carbon



Long term, a net-zero emissions energy system will produce significant societal benefits – through greater access to energy, more efficient energy consumption and better and more resilient environmental outcomes.

price over time to drive energy efficiency and the transition to new fuels and technologies. In addition, such a strategy will provide targeted and time-limited fiscal and financial incentives for the development and adoption of innovative lower-carbon energy solutions. This also makes it easier to attract domestic and foreign investment into these areas.

To create societal support, social policies to manage inevitable frictions and dislocations will be essential in the early stages of the energy transition.

5. **Harness the energy transition to drive wider sustainable development goals**

Long term, a net-zero emissions energy system will produce significant societal benefits – through greater access to energy, more efficient energy consumption and better and more resilient environmental outcomes. There will, however, be impacts as economic activity and resources shift towards lower-carbon energy sources, for example from coal to renewables. That impact will not be spread uniformly across states, industries and demographic groups. Ensuring the energy transition moves at pace and does not disadvantage the most vulnerable is at the core of a fair transition.

Well-designed policies at the national and sub-national level are required to ensure that vulnerable and disadvantaged communities have access to affordable and reliable energy and are resilient to potential climate impacts. Labour market policies to retrain and reskill workers in carbon-intensive industries will be important for a smooth and orderly transition, as will policies to support states and regions negatively affected by the transition.

REFLECTIONS

Raising the climate ambition

India has set major targets to grow its economy and progress its national development in the years to come. In tandem, it is determined to manage its emissions to address local pollution and climate change. Together, these two goals pose a significant challenge for the country, but by setting clear objectives and a trajectory, creating an enabling policy environment and making the right investments, India can make major progress.

Importantly, the two goals need not compete. In fact, sustaining economic growth in the long-term will require a healthy environment to support economic activities and well-being.

At this stage in its growth, there is an opportunity for India to take a leading position in the development and deployment of modern energy technologies and infrastructure that generate domestic industrial advantages and unlock economic opportunities in the process, while also supporting domestic emissions reductions and the transition to a prosperous lower-carbon economy. In doing this, India also has a crucial role to play in bolstering the global response to climate change, benefitting vulnerable populations both in India and elsewhere.

This scenario sketch sets out a pathway for India to achieve net-zero emissions from its energy system. Key elements of the pathway are:

- increase the generation of electricity fourfold from 2,000 terrawatt-hours (TWh) in 2020 to nearly 9,000 TWH in 2050, and raise electricity's share of final energy from 18% today to 45% in 2050;
- shift the electricity mix from about 65% generated by fossil fuels in 2020 to almost 90% generated by wind and solar in 2050; phase out coal by 2050, with some gas (up to 5% of generation) remaining;

> ...India also has a crucial role to play in bolstering the global response to climate change, benefitting vulnerable populations both in India and elsewhere.

- raise the share of hydrogen from negligible levels today to around 13% of final energy consumption in 2050, mainly as a fuel for industry and heavy duty transport;
- increase the use of bio-resources (biomass and liquid biofuels) more than twofold, with residential biomass use declining and commercial biomass use (primarily in industry) increasing substantially to account for two-thirds of all uses by 2050;
- invest in infrastructure – particularly urban and industrial infrastructure – to reduce the energy intensity of the economy by around 50% between 2020 and 2050; and
- establish significant carbon removal projects (using technology and nature) to achieve net-zero emissions in India's energy sector by 2050, primarily to capture residual emissions from hard-to-abate industries such as cement and to offset emissions from fast-growing sectors like aviation.

Primary energy demand will double between 2020 and 2050, but will still remain 20% lower than a business-as-usual pathway due to the significant energy efficiency gains from electrification and the deployment of lower-carbon energy infrastructure.

These are hard choices, but India has an enormous opportunity ahead – to become a prosperous pioneer in deploying lower-carbon energy resources and approaches that help to address both domestic and international climate challenges while simultaneously improving the economic well-being of its citizens. Together, Shell and TERI offer this analysis to assist decision-makers in India, as the government continues to shape policy to meet its growth ambitions while making progress in its transition to a lower-carbon energy system.

teri
The Energy and Resources Institute

GLOSSARY

Article 6 of the Paris Agreement	Article 6 of the Paris Agreement was established to allow cross-border cooperation between countries attempting to fulfil their nationally determined contributions (NDCs). Parties to the agreement are crafting the details of Article 6 to create a foundation for trade in carbon units.
Article 6.2 (internationally transferred mitigation outcomes)	Article 6.2 establishes an accounting framework for the transfer of mitigation outcomes between Parties to the Paris Agreement, which could be in the form of tradable carbon credits or allowances from compliance systems such as the EU Emissions Trading System.
Article 6.4 Mechanism	Article 6.4 establishes a central UN mechanism to create carbon credits from emission reductions generated through specific projects.
Bioenergy	Bioenergy is one of many diverse resources available to help meet demand for energy. It is a form of renewable energy that is derived from recently living organic materials known as biomass, such as agriculture crops, animal and plant waste, algae or wood. It can be used to produce transport fuels, heat, electricity and other products and includes solid biomass, biofuels and biogases.
British Columbia's Carbon Tax	In 2008, the Canadian province implemented North America's first broad-based carbon tax, proving that it is possible to reduce emissions while growing the economy. The carbon tax applies to the purchase and use of fossil fuels and covers around 70% of provincial greenhouse gas emissions.
Competitive auctions in power markets	In most cases involving electricity auctions, the sellers, such as generators, are the ones bidding their products, as they are interested in selling power contracts to government, large consumers or distribution companies, with the bidding process designed in part to select the lowest price. In renewable energy markets, an auction is a competitive process for procuring electricity generated from renewable energy. An auction enables a policymaker to secure renewable energy at competitive prices while advancing specific country development and energy policy goals.
Demand-side response measures and technologies	Demand-side response is an approach used in power markets that allows end-use customers to reduce their electricity use during periods of higher power prices. Customers need to be willing to reduce power consumption – within seconds – whenever the grid requires it. Various technologies enable these fast switches, which happen automatically.
Electric-arc furnaces	An electric-arc furnace uses high-current electric arcs to melt steel scrap and convert it into liquid steel of a specified chemical composition and temperature. About a quarter of the world's steel is produced by this method.

EU Emissions Trading System	The EU Emissions Trading System (EU ETS) is a cap-and-trade style mechanism that covers all large point sources of emissions (mainly thermal power stations and industrial facilities) across all 27 countries of the EU. The overall emissions cap is agreed by the 27 countries and has been progressively lowered since the system started in 2005. The intention is that it will reduce to zero in 2050. Facilities within the system are either allocated tradable allowances by national governments or must buy them in auctions or from the market. The total number of allowances introduced into the system each year is equivalent to the agreed cap for that year. These allowances, each representing a tonne of carbon dioxide emitted, must be surrendered against emissions from any given facility.
GST Compensation Cess	The Goods and Services Tax (GST) in India was launched with the cooperation of the states and the central government. The GST Compensation Cess is imposed as a levy in addition to the regular GST taxes. The cess (also called a tax or levy) is imposed on the supply of certain luxurious and demerit goods and services that attract 28% GST. The cess rate usually ranges from 1% to 25% and is levied over and above the GST rate.
Intergovernmental Panel on Climate Change's Special Report	The Intergovernmental Panel on Climate Change is the United Nations body for assessing the science related to climate change.
Nationally Determined Contribution (NDC)	The proposed actions countries will take to reduce greenhouse gas emissions under the Paris Agreement over a future five or ten-year period.
Power purchase agreements	A power purchase agreement (PPA) is a contract between two parties which defines the commercial terms for the sale of electricity between the two parties. A PPA is the key instrument for project finance and is widely used for renewable energy projects.
Star-labelling	Star-labelling in India is the hallmark or certificate of energy-efficient product quality. The star label allows consumers to make informed choices on energy and money saving potential, in addition to an assurance of a better quality product.

ENDNOTES

Shell and TERI wish to thank the many people consulted externally in the development of this sketch. Special thanks go to the following for the use of source data and references: the India Ministry of Statistics and Programme Implementation, the International Energy Agency, the World Bank, the World Steel Association, the Energy Transitions Commission, and the Forest Service of India. Data used by TERI for the analysis has been derived from diverse sources, including annual statistical publications from different ministries and national organizations, statistical handbooks, annual statistical reports and journal articles.

1 Like the **Sky 1.5** scenario developed by Shell, **NZE** is a normative scenario. That means we deliberately look for pathways that result in a rapid transition to net-zero emission energy services, driven by market and policy trends, rather than exploring how the energy system and the provision of energy services might evolve of their own accord.

2 In this sketch, net-zero emissions in the energy system includes carbon dioxide (CO_2), methane (CH_4) and nitrogen oxides (NOx) emissions related to the provision of energy. This is referred to in terms of CO_2 equivalent or CO_2e.

3 A Better Life with a Healthy Planet, published by Shell in 2016: **Link.**

4 Carbon Dioxide Information Analysis Center, Environmental Sciences Division, Oak Ridge National Laboratory, Tennessee, USA.

5 The first India NDC presented at the time of the Paris Agreement: **Link.**

6 As a starting point for this work, TERI developed a baseline case for India. It follows a business as usual trajectory and results in a significant rise in national emissions. Total energy demand grows by 170% through to 2050 and fossil fuel more than doubles in the same timeframe. Solar PV still has the fastest growth over the period, increasing by a factor of five.

7 Intergovernmental Panel on Climate Change Special Report: **Link.**

8 In developing this sketch we have drawn on data and analyses available within TERI and Shell and on data from external sources such as the International Energy Agency, the World Steel Association, the World Bank and the International Renewable Energy Agency. Data used by TERI for the sketch has been derived from diverse sources, including annual statistical publications from different ministries and national organisations, statistical handbooks, annual statistical reports and journal articles.

9 Explore the impact of the COVID-19 pandemic in two sets of Shell scenarios, looking at the 2020s then more broadly at the shifting energy landscape through the 21st century.

- Rethinking the 2020s: **Link.**
- The Energy Transformation Scenarios: **Link.**

10 Muller et. al., Patterns of Iron Use in Societal Evolution, Environmental Science & Technology, Vol. 45, No. 1, 2011.

11 In the IPCC SR15, Table 2.2 gives a maximum carbon budget of 420 Gt CO_2, at the 67% point of the normal distribution of temperature outcomes, measured from 2018 onwards, for limiting temperature rise to 1.5°C.

12 Duncan G. Fullerton, Nigel Bruce and Stephen B. Gordon, Indoor air pollution from biomass fuel smoke is a major health concern in the developing world, Transactions of the Royal Society of Tropical Medicine and Hygiene, 2008, 102(9), pp.843–851: **Link.**

13 Energy Conservation Building Code, Bureau of Energy Efficiency, India: **Link.**

14 The Perform Achieve and Trade (PAT) scheme is a programme of the Bureau of Energy Efficiency: **Link.**

15 Joseph Fiksel, Praveena Sanjay, Kavya Raman, Steps toward a resilient circular economy in India, Clean Technologies and Environmental Policy, October 2020: **Link.**

16 US Department of Transport.

17 National Sample Survey Office, Ministry of Statistics and Programme Implementation, Government of India.

18 Japan Statistical Yearbook.

19 US Census Bureau.

20 The hidden truth behind India's low refrigerator ownership: **Link**, and an article on the reasons for the comparatively low consumer interest in washing machines in India: **Link.**

21 India's Rickshaw Revolution Leaves China in the Dust; why there are more e-rickshaws in India than battery-powered passenger cars in China: **Link.**

22 TERI analysis assuming the average annual productivity of forests increases over time by some 30% and a doubling of productivity for trees outside forests.

23 William J. Schmelz, Gal Hochman and Kenneth G. Miller, Total cost of carbon capture and storage implemented at a regional scale: north-eastern and mid western United States, The Royal Society, August 14, 2020: **Link.**

24 Global Carbon Capture and Storage Institute; Global storage portfolio: a global assessment of the geological CO_2 storage resource potential: **Link.**

25 In comparison, the Shell Quest CCS project in Canada geologically stores about 1 Mt per year of CO_2.

26 Madhumitha Jaganmohan, Global module manufacturing production 2000-2019, Feb 2, 2021: **Link.**

27 K. Parikh, J. Parikh and P. P. Ghosh, Can India grow and live within a 1.5 degree CO_2 emissions budget?, Energy Policy, 120, 2018.

28 Energy Transitions Commission. Making Mission Possible: Delivering a Net-Zero Economy: **Link.**

29 T. Spencer, N. Rodrigues, R. Pachouri, S. Thakre and G. Renjith, Renewable Power Pathways: Modelling the Integration of Wind and Solar in India by 2030, TERI Discussion Paper, 2020.

30 World Employment Social Outlook 2018: Greening with jobs: **Link.**

31 IEA, World Energy Investment 2019: **Link.**

32 Non-commercial energy demand (mainly biomass for residential use) accounted for about 25% of total energy use in 2015-16, mainly comprising biomass for residential use.

33 Anil Kumar Jain, Our Rising Energy Imports – What All do [*sic*]They Mean?, NITI Aayog blog: **Link.**

ENDNOTES CONTINUED...

34 Economic Times of India, February 27, 2020.

35 IPCC Special Report on 1.5°C, published in 2018: **Link.**

36 Quartz India. India needs nearly 30 times more solar power to phase out coal jobs: **Link.**

37 Julie Carré, Nicolas Gatimel, Jessika Moreau, Jean Parinaud and Roger Léandri, Does air pollution play a role in infertility? A systematic review, Environmental Health, July 2017: **Link.**

38 Goulder, L.H. and Pizer, W.A., The Economics of Climate Change, National Bureau of Economic Research, January 2006: **Link.**

39 The Green Energy Corridor Project aims to synchronise electricity produced from renewable sources, such as solar and wind, with conventional power. India's Ministry of New and Renewable Energy sanctioned the Intra State Transmission System (InSTS) project for the development and deployment of large-scale renewable energy.

40 Variable renewables, such as wind and solar, generate on an as-available basis rather than on-demand, requiring the sun to shine or the wind to blow to generate electricity. They also have a zero or very low marginal cost of operation once they have been built. In combination, this reduces the ability of existing wholesale electricity markets to deliver the necessary long-term investment in capacity for low-carbon generation and the required flexibility to balance renewables variability.

41 Will Hall, Thomas Spencer, G. Renjith and Shruti Dayal, The Potential Role of Hydrogen in India: A pathway for scaling up low-carbon hydrogen across the economy, TERI and ETC, 2020: **Link.**

42 Make in India initiative: **Link.**

LEGAL DISCLAIMER

In developing this scenario sketch, TERI and Shell have adopted a goal-oriented approach towards achieving net-zero emissions from the energy sector in India by 2050. It is rooted in stretching but realistic development dynamics today, but explores a goal-oriented way to achieve that ambition. We worked back in designing how this could occur, considering the realities of the situation today and taking into account realistic timescales for change. Although ambitious in its goal and assumptions, we believe today it is still a technically possible, but highly challenging pathway for the Indian economy. However, we believe the window for success is quickly closing and without significant action it may take longer for India to achieve a net-zero energy system. Of course, there are other possible paths for India to take towards a net-zero energy system – these depend on the technologies and policies the country prioritises.

This scenario sketch is more ambitious in its goal and assumptions than Shell's **Sky 1.5** scenario in some respects, but not all. For example, the India **NZE** scenario is more ambitious on the 2050 emissions profile of the energy system, but less ambitious on the role of CCS. Shell believes different places and sectors will move towards net-zero emissions at different paces, and all should move as fast as possible for society to achieve the goal of the Paris Agreement. This scenario sketch is not intended to be projections or forecasts of the future. Shell scenarios, including scenarios in this document, are not Shell's strategy or business plan. When developing Shell's strategy, our scenarios are one of many variables that we consider. Ultimately, whether society meets its goals to decarbonize, is not within Shell's control. While we intend to travel this journey in step with society, only governments can create the framework for success.

The companies in which Royal Dutch Shell plc directly and indirectly owns investments are separate legal entities. In this content "Shell", "Shell Group" and "Royal Dutch Shell" are sometimes used for convenience where references are made to Royal Dutch Shell plc and its subsidiaries in general. Likewise, the words "we", "us" and "our" are also used to refer to Royal Dutch Shell plc and its subsidiaries in general or to those who work for them. These terms are also used where no useful purpose is served by identifying the particular entity or entities. ''Subsidiaries'', "Shell subsidiaries" and "Shell companies" as used in this content refer to entities over which Royal Dutch Shell plc either directly or indirectly has control. Entities and unincorporated arrangements over which Shell has joint control are generally referred to as "joint ventures" and "joint operations", respectively. Entities over which Shell has significant influence but neither control nor joint control are referred to as "associates". The term "Shell interest" is used for convenience to indicate the direct and/or indirect ownership interest held by Shell in an entity or unincorporated joint arrangement, after exclusion of all third-party interest.

Shell's operating plan, outlook and budgets are forecasted for a ten-year period and are updated every year. They reflect the current economic environment and what we can reasonably expect to see over the next ten years. Accordingly, Shell's operating plans, outlooks, budgets and pricing assumptions do not reflect our net-zero emissions target. In the future, as society moves towards net-zero emissions, we expect Shell's operating plans, outlooks, budgets and pricing assumptions to reflect this movement.

This content contains forward-looking statements (within the meaning of the U.S. Private Securities Litigation Reform Act of 1995) concerning the financial condition, results of operations and businesses of Royal Dutch Shell. All statements other than statements of historical fact are, or may be deemed to be, forward-looking statements. Forward-looking statements are statements of future expectations that are based on management's current expectations and assumptions and involve known and unknown risks and uncertainties that could cause actual results, performance or events to differ materially from those expressed or implied in these statements. Forward-looking statements include, among other things, statements concerning the potential exposure of Royal Dutch Shell to market risks and statements expressing management's expectations, beliefs, estimates, forecasts, projections and assumptions. These forward-looking statements are identified by their use of terms and phrases such as "aim", "ambition", ''anticipate'', ''believe'', ''could'', ''estimate'', ''expect'', ''goals'', ''intend'', ''may'', ''objectives'', ''outlook'', ''plan'', ''probably'', ''project'', ''risks'', "schedule", ''seek'', ''should'', ''target'', ''will'' and similar terms and phrases. There are a number of factors that could affect the future operations of Royal Dutch Shell and could cause those results to differ materially from those expressed in the forward-looking statements included in this content, including (without limitation): (a) price fluctuations in crude oil and natural gas; (b) changes in demand for Shell's products; (c) currency fluctuations; (d) drilling and production results; (e) reserves estimates; (f) loss of market share and industry competition; (g) environmental and physical risks; (h) risks associated with the identification of suitable potential acquisition properties and targets, and successful negotiation and completion of such transactions; (i) the risk of doing business in developing countries and countries subject to international sanctions; (j) legislative, fiscal and regulatory developments including regulatory measures addressing climate change; (k) economic and financial market conditions in various countries and regions; (l) political risks, including the risks of expropriation and renegotiation of the terms of contracts with governmental entities, delays or advancements in the approval of projects and delays in the reimbursement for shared costs; (m) risks associated with the impact of pandemics, such as the COVID-19 (coronavirus) outbreak; and (n) changes in trading conditions. No assurance is provided that future dividend payments will match or exceed previous dividend payments. All forward-looking statements contained in this content are expressly qualified in their entirety by the cautionary statements contained or referred to in this section. Readers should not place undue reliance on forward-looking statements. Additional risk factors that may affect future results are contained in Royal Dutch Shell's Form 20-F for the year ended December 31, 2019 (available at **www.shell.com/investor** and **www.sec.gov**). These risk factors also expressly qualify all forward-looking statements contained in this content and should be considered by the reader. Each forward-looking statement speaks only as of the date of this content, March 23, 2021. Neither Royal Dutch Shell plc nor any of its subsidiaries undertake any obligation to publicly update or revise any forward-looking statement as a result of new information, future events or other information. In light of these risks, results could differ materially from those stated, implied or inferred from the forward-looking statements contained in this content.

We may have used certain terms, such as resources, in this content that the United States Securities and Exchange Commission (SEC) strictly prohibits us from including in our filings with the SEC. Investors are urged to consider closely the disclosure in our Form 20-F, File No 1-32575, available on the SEC website **www.sec.gov**.

50 YEARS
#ShellScenarios

@Shell_India
@teriin