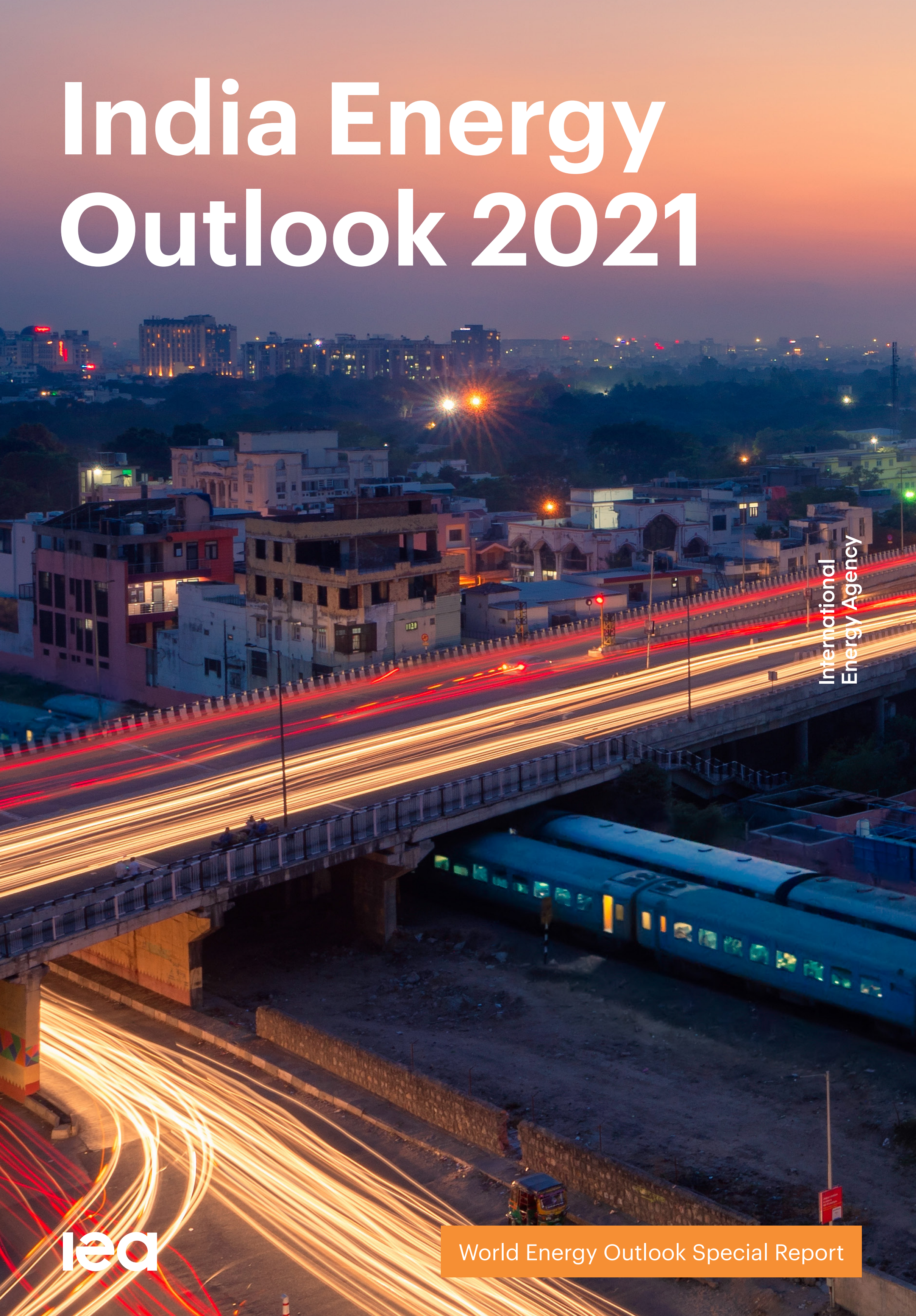
India Energy Outlook 2021



International Energy Agency

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World Energy Outlook Special Report

INTERNATIONAL ENERGY AGENCY

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The International Energy Agency (IEA) last released a *World Energy Outlook* special report on India in 2015. Six years later, it is remarkable to consider the changes that have taken place.

The global energy sector has shifted a great deal over that period, particularly in terms of efforts to strengthen policies to tackle the threat of climate change. The growing number of net-zero emissions pledges by countries and companies reflects the increasing sense of urgency and accelerating momentum around clean energy transitions.

Most recently, the Covid-19 pandemic brought unprecedented disruptions to our societies and economies, with major consequences across the energy world. The damage to lives and livelihoods – and to many parts of the energy sector – will last for years to come.

Focusing on India's energy system in particular, I would like to highlight two extremely positive developments that stand out to me. The first is India's success in bringing electricity connections to hundreds of millions of its citizens in recent years. This is a monumental achievement that has improved the material well-being of a huge number of people, and I heartily congratulate the Government of India for it.

The second greatly encouraging development is the way in which India has grasped the transformative potential of renewables, and solar in particular. As this report shows, the growth of India's renewable energy sector has been highly impressive – and India is set to lead the world in areas like solar power and batteries in the coming decades.

This has also been an exciting period for India-IEA relations. Less than four years after joining the IEA family as an Association country, India recently agreed with IEA members to enter into a Strategic Partnership. Marked by a signing ceremony involving dignitaries from India and IEA members, this was a major milestone that could eventually lead to full membership for India, which would be a game-changing moment for global energy governance.

I hope that the depth and insight of the analysis in this new special report bears testament to the close working relationships and understanding that we have built over these years between India and the IEA.

As our new report makes clear, many challenges remain for India – in terms of energy security, access, affordability, emissions and more. But India's decision makers have shown on many occasions the value of well-designed policies. A compelling example is the roll-out of efficient LED lighting to millions of households all across the country, making electricity more affordable and sustainable at the same time.

What this report makes clear is the tremendous opportunity for India to develop and successfully meet the aspirations of its citizens without following the high-carbon pathway that other economies have pursued in the past. Seizing this opportunity is critically important for India, and critically important for the world.

In its endeavour to bring affordable, clean and reliable energy to all its citizens, the Government of India can count on the enduring support and partnership of the IEA. We sincerely hope this report will be of use to decision makers across the Indian energy sector as they seek to build a brighter future for a country that will remain at the heart of global energy trends for decades to come.

I would like to commend the dedicated team behind this report – from across the Agency – for their hard work under the excellent leadership of Tim Gould, with outstanding support from Peter Zeniewski in Paris and Siddharth Singh in Delhi. And I would like to thank the Government of India for its support – and all the experts and friends of the IEA in India and worldwide who contributed their time and insights.

Dr Fatih Birol
Executive Director
International Energy Agency

This study was prepared by the *World Energy Outlook* (WEO) team in the Directorate of Sustainability, Technology and Outlooks (STO) in co-operation with other directorates of the International Energy Agency (IEA). The study was designed and directed by **Tim Gould**, Head of Division for Energy Supply and Investment Outlooks. **Peter Zeniewski** and **Siddharth Singh** co-ordinated the work and were the lead authors.

Other principal authors of the report were **Simon Bennett** (innovation, clean energy); **Arthur Contejean** (access); **Davide D'Ambrosio** (power); **Szilvia Doczi** (flexibility); **Insa Handschuch** (air quality); **Zoe Hungerford** (flexibility); **Inchan Hwang** (investment and finance); **Christophe McGlade** (carbon emissions); **Sarbojit Pal** (transport); **Ryszard Pospiech** (supply); **Lucila Arboleya Sarazola** (investment and finance); **Michael Waldron** (lead on investment and finance); **Molly Walton** (water) and **Brent Wanner** (power). **Thomas Spencer** from The Energy and Resources Institute (TERI) was the lead on demand and industry. The report relied on the modelling and analysis of the entire *WEO* team and the guidance of **Laura Cozzi**, the IEA's Chief Energy Modeller.

Other key contributors were **Yasmine Arsalane** (macro-economy), **Aayushi Awasthy** (affordability, gender); **Stéphanie Bouckaert** (end-use modelling); **Amrita Dasgupta** (gender); **Tomás de Oliveira Bredariol** (water); **Timothy Goodson** (buildings and efficiency); **Astha Gupta** (bioenergy, affordability); **Paul Hugues** (bioenergy); **Peter Janoska** (air quality); **Tae-Yoon Kim** (fuels); **Toru Muta** (overview); **Pawel Olejarnik** (supply modelling); **Apostolos Petropoulos** (transport); **Sree Sanyal** (gender); **Andreas Schroeder** (industry); **Rebecca Schulz** (coal); **Ashish Sethi** (gas, captive power); and **Daniel Wetzel** (jobs). **Laszlo Varro**, the IEA Chief Economist, and **Nicole Thomas**, India programme manager, provided valuable guidance and support. **Eleni Tsoukala**, **Teresa Coon** and **Marie Fournier-S'Niehotta** provided essential support.

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Prasoon Agarwal	International Renewable Energy Agency (IRENA)
K.V.S. Baba	Power System Operation Corporation Limited (POSOCO)
Abhay Bakre	Bureau of Energy Efficiency
Manjushree Banerjee	Independent consultant
Paul Baruya	IEA Clean Coal Centre
Samuel Beatty	US Department of Energy
Shikha Bhasin	CEEW
Nick Butler	King's College London
Russell Conklin	US Department of Energy
Anne-Sophie Corbeau	BP
Rita Roy Choudhury	Federation of Indian Commerce and Industries (FICCI)
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Enrique De Las Morenas Moneo	ENEL
Kaushik Deb	King Abdullah Petroleum Studies and Research Center (KAPSARC)
Pamli Deka	World Resources Institute
Vivek Kumar Dewangan	Ministry of Power
Swati D'Souza	National Foundation for India
Navroz Dubash	Centre for Policy Research
Ashwin Gambhir	Prayas Energy Group
Arunabha Ghosh	CEEW
Abhishek Goel	Global Infrastructure Partners India
Akash Goenka	Alliance for an Energy Efficient Economy (AEEE)
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Kavita Jadhav	UK Department for Business, Energy and Industrial Strategy (BEIS)
Dinesh Dayanand Jagdale	Ministry of New and Renewable Energy
Amit Jain	World Bank
Anil Jain	Ministry of Coal
Neelima Jain	Center for Strategic and International Studies (CSIS)
Gauri Jauhar	IHS Markit
Madhura Joshi	Natural Resources Defense Council (NRDC)
Premanand Jothy	Ministry of External Affairs
Satish Kumar	AEEE
Marc LaFrance	US Department of Energy
Jennifer Li	US Department of Energy
Sangeeta Mathew	AEEE
Ajay Mathur	The Energy and Resources Institute (TERI)
Rohit Mittal	World Bank
Mitheel Mody	Tata Cleantech
Swetha RaviKumar Bhagwat	Florence School of Regulation Global (FSR)
Rajnath Ram	NITI Aayog
Bijoy Samanta	Ministry of Coal
Rakesh Sarwal	NITI Aayog
Chandana Sasidharan	AEEE
Gurdeep Singh	NTPC
Kartikeya Singh	CSIS

Raina Singh	National Institute of Urban Affairs (NIUA)
Sumant Sinha	ReNEW Power
Scott Smouse	US Department of Energy
Glenn Sondak	Shell
Jim Spaeth	US Department of Energy
Elena Thomas-Kerr	US Department of Energy
Rahul Tongia	Centre for Social and Economic Progress (CSEP)
Nikos Tsafos	CSIS
Tomoko Uesawa	Mitsubishi
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The individuals and organisations that contributed to this study are not responsible for any opinions or judgements it contains. All errors and omissions are solely the responsibility of the IEA.

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Comments and questions are welcome and should be addressed to:

Tim Gould

Directorate of Sustainability, Technology and Outlooks
International Energy Agency
9, rue de la Fédération
75739 Paris Cedex 15
France

E-mail : weo@iea.org

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India's future prosperity will hinge on affordable, clean and reliable energy…

India has seen extraordinary successes in its recent energy development, but many challenges remain, and the Covid-19 pandemic has been a major disruption. In recent years, India has brought electricity connections to hundreds of millions of its citizens; promoted the adoption of highly-efficient LED lighting by most households; and prompted a massive expansion in renewable sources of energy, led by solar power. The gains for Indian citizens and their quality of life have been tangible. However, the Covid-19 crisis has complicated efforts to resolve other pressing problems. These include a lack of reliable electricity supply for many consumers; a continued reliance on solid biomass, mainly firewood, as a cooking fuel for some 660 million people; financially ailing electricity distribution companies, and air quality that has made Indian cities among the most polluted in the world.

…and the scope for further growth in energy demand and infrastructure is huge

India is the world's third-largest energy consuming country, thanks to rising incomes and improving standards of living. Energy use has doubled since 2000, with 80% of demand still being met by coal, oil and solid biomass. On a per capita basis, India's energy use and emissions are less than half the world average, as are other key indicators such as vehicle ownership, steel and cement output. As India recovers from a Covid-induced slump in 2020, it is re-entering a very dynamic period in its energy development. Over the coming years, millions of Indian households are set to buy new appliances, air conditioning units and vehicles. India will soon become the world's most populous country, adding the equivalent of a city the size of Los Angeles to its urban population each year. To meet growth in electricity demand over the next twenty years, India will need to add a power system the size of the European Union to what it has now.

India has a wide range of possible energy futures before it

This special report maps out possible energy futures for India, the levers and decisions that bring them about, and the interactions that arise across a complex energy system. The increasing urgency driving the global response to climate change is a pivotal theme. India has so far contributed relatively little to the world's cumulative greenhouse gas emissions, but the country is already feeling their effects. This report's analysis is based on a detailed review of existing or announced energy reforms and targets. These include the aims of quadrupling renewable electricity capacity by 2030, more than doubling the share of natural gas in the energy mix, enhancing energy efficiency and transport infrastructure, increasing domestic coal output, and reducing reliance on imports. Progress towards these policy goals varies across our report's different scenarios, none of which is a forecast. Our aim is rather to provide a coherent framework in which to consider India's choices and their implications.

- The **Stated Policies Scenario** (STEPS) provides a balanced assessment of the direction in which India's energy system is heading, based on today's policy settings and constraints and an assumption that the spread of Covid-19 is largely brought under control in 2021.

- The **India Vision Case** is based on a rapid resolution of today's public health crisis and a more complete realisation of India's stated energy policy objectives, accompanied by a faster pace of economic growth than in the STEPS.
- The **Delayed Recovery Scenario** analyses potential downside risks to India's energy and economic development in the event that the pandemic is more prolonged.
- The **Sustainable Development Scenario** explores how India could mobilise an additional surge in clean energy investment to produce an early peak and rapid subsequent decline in emissions, consistent with a longer-term drive to net zero, while accelerating progress towards a range of other sustainable development goals.

Covid-19 will leave lasting scars

Prior to the global pandemic, India's energy demand was projected to increase by almost 50% between 2019 and 2030, but growth over this period is now closer to 35% in the STEPS, and 25% in the Delayed Recovery Scenario. The latter would put some of India's hard-won gains in the fight against energy poverty at risk, as lower-income households are forced to fall back on more polluting and inefficient sources of energy. It would also extend the slump in energy investment, which we estimate to have fallen by some 15% in India in 2020. Even though the pandemic and its aftermath could temporarily suppress emissions, as coal and oil bear the brunt of the reduction in demand, it does not move India any closer to its long-term sustainable development goals.

India's size and dynamism will keep it at the heart of the global energy system

An expanding economy, population, urbanisation and industrialisation mean that India sees the largest increase in energy demand of any country, across all of our scenarios to 2040. India's economic growth has historically been driven mainly by the services sector rather than the more energy-intensive industrial sector, and the rate at which India has urbanised has also been slower than in other comparable countries. But even at a relatively modest assumed urbanisation rate, India's sheer size means that 270 million people are still set to be added to India's urban population over the next two decades. This leads to rapid growth in the building stock and other infrastructure. The resulting surge in demand for a range of construction materials, notably steel and cement, highlights the pivot in global manufacturing towards India. In the STEPS, as India develops and modernises, its rate of energy demand growth is three times the global average.

The Indian electricity sector is on the cusp of a solar-powered revolution…

Solar power is set for explosive growth in India, matching coal's share in the Indian power generation mix within two decades in the STEPS – or even sooner in the Sustainable Development Scenario. As things stand, solar accounts for less than 4% of India's electricity generation, and coal close to 70%. By 2040, they converge in the low 30%s in the STEPS, and this switch is even more rapid in other scenarios. This dramatic turnaround is driven by India's policy ambitions, notably the target to reach 450 GW of renewable capacity by 2030, and the extraordinary cost-competitiveness of solar, which out-competes *existing* coal-fired power by 2030 even when paired with battery storage. The rise of utility-scale renewable projects is underpinned by some innovative regulatory approaches that encourage pairing solar with other generation technologies, and with storage, to offer "round the clock" supply. Keeping up momentum behind investments in renewables also means tackling risks relating to delayed payments to generators, land acquisition, and regulatory and contract uncertainty. However, the projections in the STEPS do not come close to exhausting the scope for solar to meet India's energy needs, especially for other applications such as rooftop solar, solar thermal heating, and water pumps.

...while rising demand for air-conditioning pushes up the peak in power demand

India's electricity demand is set to increase much more rapidly than its overall energy demand. But a defining feature of the outlook is a sharp rise in variability – both in electricity output, from solar PV and wind, and in daily consumption. On the supply side, output from renewables in some Indian states is set to exceed demand on a regular basis (typically around the middle of the day) before 2030. On the demand side, the key contributor to variability comes from rapid growth in ownership of air-conditioning units. Energy efficiency measures targeting both cooling appliances and buildings avoid around a quarter of the potential growth in consumption in the STEPS, but electricity demand for cooling still increases six-fold by 2040, creating a major early evening peak in electricity use.

India requires a massive increase in power system flexibility

The pace of change in the electricity sector puts a huge premium on robust grids and other sources of flexibility, with India becoming a global leader in battery storage. India has a higher requirement for flexibility in its power system operation than almost any other country in the world. In the near term, India's large grid and its coal-fired power fleet meet the bulk of India's flexibility needs, supported by hydropower and gas-fired capacity. Going forward, new power lines and demand-side options – such as improving the efficiency of air conditioners or shifting the operation of agricultural pumps to different parts of the day – will need to play a much greater role. But battery storage is particularly well suited to the short-run flexibility that India needs to align its solar-led generation peak in the middle of the day with the country's early evening peak in demand. By 2040, India has 140 GW of battery capacity in the STEPS, the largest of any country, and close to 200 GW in the Sustainable Development Scenario.

As solar takes power, the focus for coal switches to industry …

Coal's hold over India's power sector is loosening, with industry accounting for most of the increase in coal demand to 2040 in the STEPS. Once the coal-fired power plants currently under construction are completed over the next few years, there is no net growth at all in India's coal fleet. Coal-fired generation was most exposed to the dip in electricity consumption in 2020. It picks up slightly in the STEPS as demand recovers, since renewables do not cover all of the projected increase in electricity demand. However, coal suppliers looking for growth increasingly have to turn to India's industrial consumers rather than the power sector. The share of coal in the overall energy mix steadily declines in the STEPS, from 44% in 2019 to 34% in 2040, and more rapidly in other scenarios.

…while oil continues to dominate a fast-growing transport sector in the STEPS

Energy demand for road transport in the STEPS is projected to more than double over the next two decades, although this growth is cut dramatically in the Sustainable Development Scenario. Over half of the growth in the STEPS is fuelled by diesel-based freight transport. An extra 25 million trucks are travelling on India's roads by 2040 as road freight activity triples, and a total of 300 million vehicles of all types are added to India's fleet between now and then. Transport has been the fastest-growing end-use sector in recent years, and India is set for a huge expansion of transportation infrastructure – from highways, railways and metro lines to airports and ports. Today's policy settings are sufficient to prevent runaway growth in transport energy demand. And some parts of the system shift rapidly to less energy-intensive options, with one example being a strong increase in the use of two-or-three-wheeled vehicles for road transport. Nonetheless, in the STEPS, India's oil demand rises by almost 4 million barrels per day (mb/d) to reach 8.7 mb/d in 2040, the largest increase of any country. In the Sustainable Development Scenario, by contrast, a much stronger push for electrification, efficiency and fuel switching limits growth in oil demand to less than 1 mb/d.

India's building spree will shape its energy use for years to come

India is set to more than double its building space over the next two decades, with 70% of new construction happening in urban areas. The model of urbanisation that India follows and the extent to which new construction follows energy-efficient building codes will shape patterns of energy use far into the future. The shift towards urban living accelerates transitions in residential energy use away from solid biomass and towards electricity and modern fuels. Buoyed by rising appliance ownership and demand for cooling, the share of electricity in residential energy use nearly triples. Nonetheless, in the STEPS, firewood and other traditional fuels are still widely used for cooking by 2030. It would take an additional push – as in the India Vision Case and the Sustainable Development Scenario – to move all households to LPG, improved cook stoves, gas or electricity.

Today's clean energy momentum enables India to outperform its Paris pledges

In the STEPS, India exceeds the goals set out in its Nationally Determined Contribution (NDC) under the Paris Agreement. The emissions intensity of India's economy improves by 40% from 2005 to 2030, above the 33-35% set out in its existing NDC. And the share of non-fossil fuels in electricity generation capacity reaches almost 60%, well above the 40% that India pledged. India's leadership in the deployment of clean energy technologies expands its market for solar PV, wind turbine and lithium-ion battery equipment to over $40 billion per year in the STEPS by 2040. As a result, 1 in every 7 dollars spent worldwide on these three types of equipment in 2040 is in India, compared with 1 in 20 today. India's clean energy workforce grows by 1 million over the next ten years. If the approach embodied in today's policies can be realised in full, as in the India Vision Case, higher economic growth than in the STEPS need not mean higher energy demand and emissions. In this Case, and especially in the Sustainable Development Scenario where the equipment market for solar, wind, batteries and water electrolysers rises to $80 billion per year, the industrial and commercial opportunities from clean energy are even larger.

The path to a "gas-based economy" is not fully mapped out

The market for natural gas is growing fast in India, but its role varies by sector, by scenario and over time. The 6% share of natural gas in India's current energy mix is among the lowest in the world. It almost doubles in the STEPS as gas use rises in the industrial sector and in city gas distribution. In the India Vision Case, natural gas also helps to displace coal in power generation, bringing India's aspiration of a "gas-based economy" closer still. However, affordability is a sensitive issue for consumers, especially given the complex patchwork of additional charges and tariffs that, on average, doubled the cost of wholesale gas by the time it reached end-users in 2019. As India builds out its gas infrastructure, natural gas can find multiple uses in India's energy system, including to help meet air quality and near-term emissions goals if supply chains are managed responsibly. But the Sustainable Development Scenario also underlines that a long-term vision for gas needs to incorporate a growing role for biogases and low-carbon hydrogen, for which India has large potential.

India's faces energy security hazards ahead

India's combined import bill for fossil fuels triples over the next two decades in the STEPS, with oil by far the largest component, pointing to continued risks to India's energy security. Domestic production of oil and gas continues to fall behind consumption trends and net dependence on imported oil rises above 90% by 2040, up from 75% today. This continued reliance on imported fuels creates vulnerabilities to price cycles and volatility as well as possible disruptions to supply. Energy security hazards could arise in India's domestic market as well, notably in the electricity sector if the necessary flexibility in power system operation does not materialise. An additional systemic threat to the reliability of electricity supply comes from the poor financial health of many electricity distribution companies. Improving the cost-reflectiveness of tariffs, the efficiency of billing and collection and reducing technical and commercial losses are key to reforming this sector.

Booming industry and transport push up CO_2 emissions and harm air quality

A 50% rise in India's CO_2 emissions to 2040 is the largest of any country in the STEPS, even though India's per capita CO_2 emissions remain well below the global average. The increase in India's emissions is enough to offset entirely the projected fall in emissions in Europe over the same period. The remarkable rise of renewables arrests the growth in India's power sector emissions in the STEPS, although this still leaves the coal-fired fleet – the fifth-largest single category of emissions worldwide today – as a major emitter of CO_2. Alongside the option of early retirement in some cases, this puts a strong premium on policy approaches that can retool this fleet for more limited and flexible operation and/or on technologies such as carbon capture, utilisation and storage (CCUS). But the main reasons for the increase in

India's CO_2 emissions in the STEPS lie outside the power sector, in industry and transport (especially from trucks). These two sectors are also responsible for a much larger share of air pollutant emissions than the power sector in the STEPS, and a rising urban population means that more people are exposed to air pollution and suffer its ill effects. Water stress is likewise an increasingly important factor for India's energy sector and its technology choices.

All roads to successful global clean energy transitions go via India…

As the world seeks ways to accelerate the pace of transformation in the energy sector, India is in a unique position to pioneer a new model for low-carbon, inclusive growth. Many aspects of such a model are already evident in India's policy vision, and many more are highlighted in the Sustainable Development Scenario that points the way for India towards net-zero emissions. If this can be done, it will show the way for a whole group of energy-hungry developing economies, by demonstrating that robust economic expansion is fully compatible with an increasing pace of emissions reductions and the achievement of other development goals. India is already a global leader in solar power – and solar combined with batteries will play a massive part in India's energy future. But India will need a whole host of technologies and policies to chart this new path. As new industrial sectors emerge and clean energy jobs grow, India will also need to ensure that no one is left behind, including in those regions that are heavily dependent on coal today.

…and India's energy destiny will be forged by government policies

More than that of any other major economy, India's energy future depends on buildings and factories yet to be built, and vehicles and appliances yet to be bought. Within 20 years, the majority of India's emissions in the STEPS come from power plants, industrial facilities, buildings and vehicles that do not exist today. This represents a huge opening for policies to steer India onto a more secure and sustainable course. India's ambitious renewables targets are already acting as a catalyst for the transformation of its power sector. A crucial – and even more challenging – task ahead is to put the industrial sector on a similarly new path through more widespread electrification, material and energy efficiency, technologies such as CCUS, and a switch to progressively lower-carbon fuels. Electrification, efficiency and fuel switching are also the main tools for the transport sector, alongside a determined move to build more sustainable transport infrastructure and shift more freight onto India's soon-to-be-electrified railways. These transformations require innovation, partnerships and capital. The additional capital required for clean energy technologies to 2040 in the Sustainable Development Scenario is $1.4 trillion above the level in the STEPS. But the benefits are huge, including savings of the same magnitude on oil import bills. Government policies to accelerate India's clean energy transition can lay the foundation for lasting prosperity and greater energy security. The stakes could not be higher, for India and for the world.

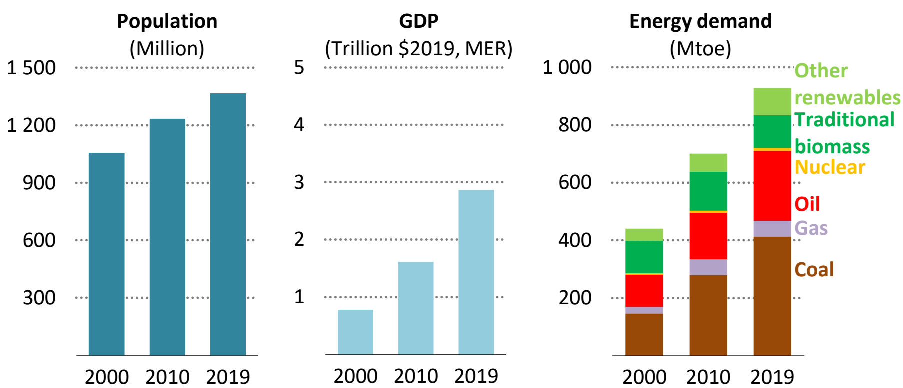
Energy in India today

Is 2020 a turning point?

SUMMARY

- India is a major force in the global energy economy. Energy consumption has more than doubled since 2000, propelled upwards by a growing population – soon to be the world's largest – and a period of rapid economic growth. Near-universal household access to electricity was achieved in 2019, meaning that over 900 million citizens have gained an electrical connection in less than two decades.
- India's continued industrialisation and urbanisation will make huge demands of its energy sector and its policy makers. Energy use on a per capita basis is well under half the global average, and there are widespread differences in energy use and the quality of service across states and between rural and urban areas. The affordability and reliability of energy supply are key concerns for India's consumers.
- The Covid-19 pandemic has disrupted India's energy use; our updated assessment shows an estimated fall of about 5% in the country's energy demand in 2020 due to lockdowns and related restrictions, with coal and oil use suffering the biggest falls. The pandemic has also hit investment in the energy sector, which fell by an estimated 15% in 2020, exacerbating financial strains across the board, in particular among India's electricity distribution companies. How long the impacts last will depend on how quickly the spread of the virus is brought under control, and on the policy responses and recovery strategies that are put in place.

Figure 1.1 ▷ Selected indicators for India, 2000, 2010 and 2019



Rising population and incomes since 2000 have underpinned a doubling of energy use in India, but per capita energy use is still less than 40% of the world average.

- Over 80% of India's energy needs are met by three fuels: coal, oil and solid biomass. Coal has underpinned the expansion of electricity generation and industry, and remains the largest single fuel in the energy mix. Oil consumption and imports have grown rapidly on account of rising vehicle ownership and road transport use. Biomass, primarily fuelwood, makes up a declining share of the energy mix, but is still widely used as a cooking fuel. Despite recent success in expanding coverage of LPG in rural areas, 660 million Indians have not fully switched to modern, clean cooking fuels or technologies.
- Natural gas and modern renewable sources of energy have started to gain ground, and were least affected by the effects of the Covid-19 pandemic in 2020. The rise of solar PV in particular has been spectacular; the resource potential is huge, ambitions are high, and policy support and technology cost reductions have quickly made it the cheapest option for new power generation.
- India is the third-largest global emitter of CO_2, despite low per capita CO_2 emissions. The carbon intensity of its power sector in particular is well above the global average. Additionally, particulate matter emissions are a major factor in air pollution, which has emerged as one of India's most sensitive social and environmental issues: in 2019, there were well over one million premature deaths related to ambient and household air pollution.
- India has a wide range of policies in place that aim to bring about a secure and sustainable energy future. This *Outlook* does not have a single view on how India's energy future might look. Instead, based on a detailed examination of today's energy markets, technologies and policies, our scenarios explore the implications of different circumstances and choices, and the linkages between them.
- The **Stated Policies Scenario (STEPS)** assumes that the pandemic is gradually brought under control in 2021. Against that backdrop, it assesses the direction in which today's policy settings and targets seem likely to take the energy sector in India, taking into account a range of real-life constraints that might affect their realisation in practice.
- The **India Vision Case (IVC)** takes a more optimistic stance on the speed of economic recovery and long-term growth, and also on the prospects for a fuller implementation of India's stated energy policy ambitions.
- The **Delayed Recovery Scenario (DRS)**, by contrast, examines the implications of a more prolonged pandemic with deeper and longer-lasting impacts on a range of economic, social and energy indicators than is the case in the STEPS.
- The **Sustainable Development Scenario (SDS)** takes a different approach, working backwards from specific international climate, clean air and energy access goals, including the Paris Agreement, and examining what combination of actions would be necessary to achieve them.

1.1 Introducing the India special focus

It has been six years since the International Energy Agency (IEA) last completed a special focus on India in its *World Energy Outlook* series. This new report updates and expands the analysis of India, and it does so from the exceptional starting point of 2020. Many things have changed in India and in global energy since the last *India Energy Outlook* was published, but the Covid-19 pandemic has caused more disruption to the energy sector than any other event in recent history. The impacts will continue to be felt, in India and around the world, for years to come.

However, while the pandemic affects the new *Outlook* in numerous ways, it does not alter the fundamental considerations underpinning this special focus on India. The potential for growth in energy demand and energy infrastructure in India remains enormous. How these needs are met will have a crucial impact on the aspirations of what will soon become the world's most populous country. It will also have a huge influence on global trends, including the prospects for a successful global response to climate change.

As a result of the country's own efforts and the falling global costs of some key clean energy technologies, there is scope for India to chart a course for its energy development that is significantly less emissions-intensive than those followed by other countries in the past. In India, there are signs – especially in the power sector – that such a clean energy transition is under way. But there is still a wide range of possible ways in which it could play out, with much depending on near-term uncertainties over the pandemic and the shape of the economic recovery, as well as on the policy choices that India makes. The next decade will be critical to India's energy future, since many of the policy actions taken today – including short-term actions to manage the effects of the pandemic – are likely to have long-lasting consequences.

Our aim in this new *India Energy Outlook* is not to prescribe these choices or to forecast the future, but rather to provide a coherent framework in which India's options can be assessed. And, while very different, there is one thing on which all our scenarios agree: whichever way the global energy economy evolves from here, India will be firmly at its centre.

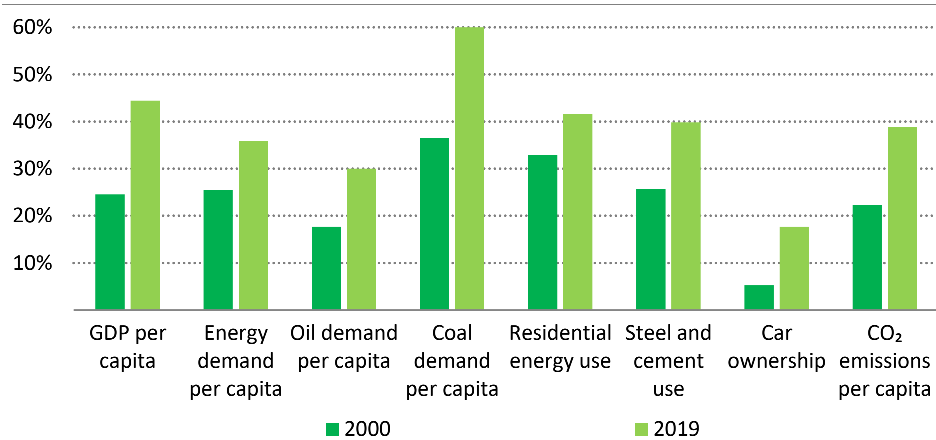
After this introductory chapter, which sets the scene, the remainder of this *Outlook* contains deep dives into topics that will define India's energy landscape in the coming years. Chapter 2 explores the key factors that will drive energy demand in India, including urbanisation, buildings, transport and industries. Chapter 3 looks at aspects of energy supply, including transformations in the power sector, the potential for natural gas in India's economy, and the role of bioenergy and coal in a rapidly changing energy system. The final chapter explores the implications of developments in energy on the United Nations (UN) Sustainable Development Goals (SDGs), including energy access, air quality and greenhouse gas (GHG) emissions; the implications for energy investments and finance; and the emerging role of India in the energy world.

1.1.1 The context

India has a major presence on the world stage. It is currently the world's second-most populous country after the People's Republic of China (hereafter, "China"), and is set to become the most populous in the 2020s. India has been one of the world's fastest-growing economies in recent years, and has become the fifth-largest in nominal terms, behind the United States, China, Japan and Germany. Expressed in terms of purchasing power parity (PPP), which adjusts for Indian buying power relative to other countries, India is the third-largest economy behind China and the United States. However, India continues to be a low-income economy, with a PPP per capita income that is less than half of the world average. With half of India's population under the age of 25, India's economy has the potential to grow very rapidly.

Since 2000, India has been responsible for more than 10% of the increase in global energy demand. On a per capita basis, energy demand in India has grown by more than 60% since 2000, although there are widespread differences across different parts of the country as well as across socio-economic groups. On a range of economic and energy-related indicators, India has been catching up with the rest of the world in recent years (Figure 1.2). Coal demand per capita increased from 25% of the world average in 1990 to 60% in 2019 and, mainly for this reason, carbon dioxide (CO_2) emissions per capita increased from a little over 15% of the world average to a little under 40% over this period.

Figure 1.2 ▷ Key indicators in India as a percentage of global averages



Key energy and economy indicators of India are well below the global average, although they have been steadily rising.

Note: GDP = gross domestic product.

There is huge potential for further growth in energy service demand in India due to an expanding economy and the forces of urbanisation and industrialisation. There are, however, critical questions about how demand growth will be met. With the notable exceptions of solar, coal and wind, India is generally resource-constrained. India is also very densely populated, with relatively high levels of water stress and land-use constraints, and structural poverty and other socio-economic factors mean that the affordability of energy is a major issue.

India is characterised by the co-existence of shortage and abundance in several parts of its energy system. India possesses the world's fifth-largest coal reserves, but nonetheless is one of the world's major coal importers. India is a major centre for global oil refining, but relies overwhelmingly on imported crude. Many consumers face unreliable electricity supply, and there are significant commercial and technical losses at the distribution level, but in aggregate there is currently a surplus of generation capacity over demand. There is significant potential consumer demand for liquefied natural gas (LNG), but this cannot always be met because of infrastructure bottlenecks and pricing constraints.

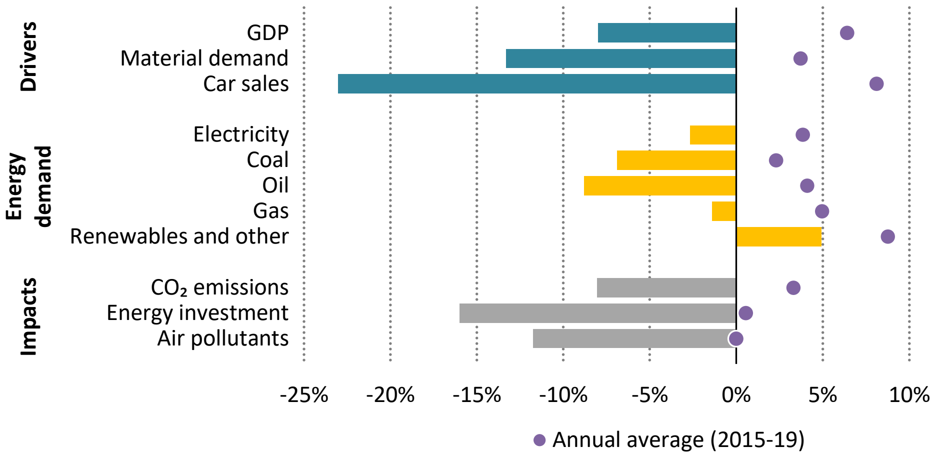
The choice of per capita or absolute values for India makes a big difference in the way India looks in energy terms. The absolute values are large and growing, while per capita values remain low by international standards. Despite India being one of the world's largest energy users, Indians on average still consume significantly less than their counterparts elsewhere in the world, and much less than in advanced economies. India's annual CO_2 emissions are now the third-highest in the world, but barely make the top 100 as measured by emissions per capita, and are lower still if historical emissions per capita are considered.

1.1.2 The impact of Covid-19

A lot has changed in India's energy sector since the last in-depth *India Energy Outlook* was published in 2015 (Box 1.1). While there has been progress on many fronts over these years, the extraordinary disruption caused by the Covid-19 pandemic in 2020 has cast a cloud over the future. To avoid the spread of the virus, the Indian government put in place a series of lockdowns starting in late March 2020, with varying levels of stringency, with the latest estimates showing a contraction in GDP of about 8% in 2020 (IMF, 2021). There was inevitably a considerable impact on energy demand. Full-year estimates see India's primary energy demand falling 5% from 2019 levels, with coal and oil expected to take the largest hit due to far-reaching restrictions on mobility and a reduction in economic activity. Natural gas demand has been resilient, as low prices have offset some of the forces driving down demand. Renewables have also fared relatively well, with generation from wind and solar growing by 15%.

The pandemic is not over, and its full implications are not yet visible. In the coming decade, India might see some durable, structural changes alongside temporary adjustments and breaks in trend. As we survey India's energy landscape, we explore how the outlook for various sectors might be affected by the shock caused by Covid-19. This new *Outlook* has been conducted during a period of extraordinary disruption, felt across all parts of Indian society. Its scenarios consider and incorporate the impact of this in different ways, including in the form of reduced GDP growth rates, reduced demand, a slightly lower turnover of capital stock, and a lower rate of investment across different parts of the energy sector.

Figure 1.3 ▷ Percentage annual change in key indicators for India in 2020



Covid-19 has caused a significant break in India's development trajectory; a key uncertainty is the extent to which changes lead to structural shifts or temporary disruption.

Sources: IEA analysis and IEA (2020b); IEA (2020c); IEA (2021); IEA (2021b); IMF (2021); POSOCO (2021).

Box 1.1 ▷ What has changed since the 2015 *India Energy Outlook*?

In the six years since the last *India Energy Outlook* was published, India's GDP has grown at an annual average rate of 6.7%. Among a range of economic reforms, one of particular importance was the introduction of the Goods and Services Tax (GST), which has created a uniform tax code for most economic activity in India, with the notable exception of petroleum products, natural gas and electricity.

Electricity access has been achieved much more quickly than projected in the 2015 *Outlook*, reflecting a major additional policy push on this issue. Over the last decade, India has provided electricity to nearly 50 million new users every year, equal to the entire population of Spain. This is one of the most significant achievements in global energy in recent years. However, issues of reliability remain.

Progress on renewables deployment has been immense since 2015, especially for solar: in 2019, India added nearly five times as much solar capacity as it did in 2015. A key driver of this has been the global decline in costs. The actual deployment of solar photovoltaic (PV) has been nearly identical to what was projected in the *India Energy Outlook 2015* under the Indian Vision Case scenario, helped by ambitious policy targets and auctions.

India has also made some significant progress on energy efficiency policy. The commercial building Energy Conservation Building Code was revised and strengthened in 2017, and Eco-Niwas Samhita, the energy conservation code for residential buildings, was launched in 2018. The existing industrial efficiency programme was expanded to include additional consumers and targets, and new appliances were added under the standards and labelling programme. Despite the growing deployment of renewables, air pollution has taken on much greater significance. India is home to some of the most polluted cities in the world. Visibly improved air quality from the nationwide lockdown in 2020 illustrated the impact of air pollution very clearly.

Despite a new policy for hydrocarbons exploration and production, domestic production of natural gas has been lower than projected in 2015, while demand growth has been marginally higher. India is emerging as a bigger player in global gas markets, with the industry expecting India to absorb a large part of LNG supply growth.

Globally, crude oil prices have fallen since 2015 and have remained at a much lower average level than before then. The previously high price levels had increased India's petrol and diesel subsidy burden, which has since been slashed to zero on the backs of subsidy reform and low crude prices. The focus of subsidies has now shifted to liquefied petroleum gas (LPG) to meet clean cooking access objectives.

The share of coal in the energy mix has not really changed since 2015. The tremendous growth in renewables has tempered growth in coal capacity, but not prevented it. The rise in installed coal-fired capacity was in fact higher than that of solar and wind over the 2015-19 period (58 gigawatts [GW] coal thermal capacity installed versus 49 GW solar and wind), although renewables have outpaced coal-fired capacity additions since 2017, and there have also been a number of cancellations in the pipeline of approved coal projects.

Oil consumption has increased in lockstep with urbanisation and GDP growth. There are signs of growth in the use of alternative fuels for transport, but increasing levels of petrol and diesel vehicle ownership (and the growing popularity of sports utility vehicles [SUVs] in particular) means emissions trends continue upwards. There has also been some growth in urban light rail, although cities in general lack modern mass transit options.

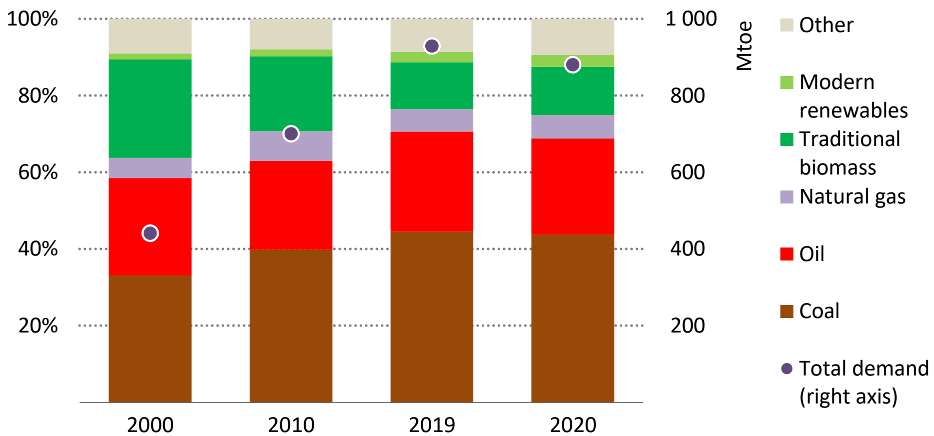
Electricity distribution companies continue to remain in poor financial health despite policies and reforms to address a range of issues.

1.2 Mapping India's energy system

India's energy needs are largely met by three fuels – coal, oil and biomass. These sources have, in aggregate, consistently met over 80% of India's total energy demand since 1990. Coal has strengthened its role as the dominant energy source, maintaining its strong position in power generation as well as being the fuel of choice for many industries (especially heavy industries such as iron and steel). Coal demand nearly tripled between 2000 and 2019, accounting for half of primary energy demand growth. Today, coal meets 44% of India's primary energy demand, up from 33% in 2000. Coal has played a significant role in India's economic development while also contributing to air pollution and growing GHG emissions.

Traditional biomass – primarily fuelwood but also animal waste and charcoal – was the largest energy source in India in 2000 after coal, constituting about one-fourth of the primary energy mix. Overall energy demand has doubled since then, but the share of traditional biomass in the energy mix has been decreasing: it fell to 12% in 2019, largely as a result of efforts to improve access to modern cooking fuels, in particular LPG.

Figure 1.4 ▷ Total primary energy demand in India



India's energy demand has tripled over the last three decades: the share of traditional biomass has fallen, leaving coal and oil dominant.

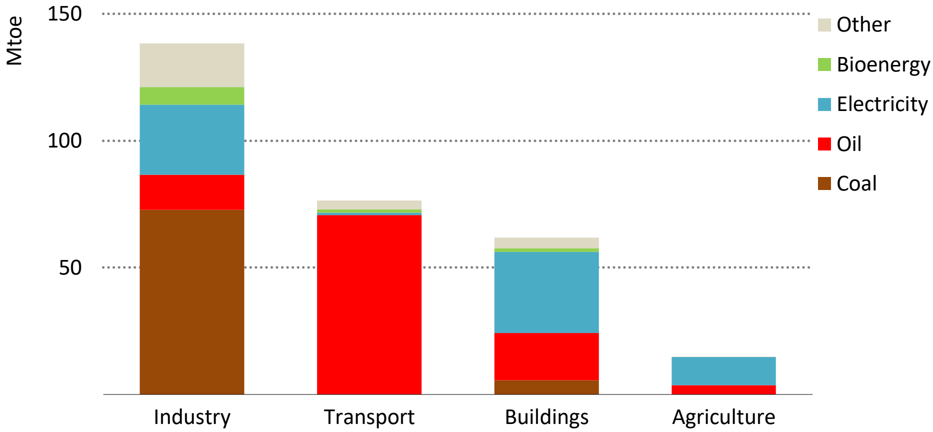
Note: Mtoe = million tonnes of oil equivalent.

Oil demand has more than doubled since 2000 as a result of growing vehicle ownership and road transport use. LPG has also contributed to the growth of oil demand, in part because its use in cooking applications has been subsidised and promoted by the government. A lack of domestic resources means that India's dependence on imports of crude oil has been steadily rising, reaching around 75% in 2019.

Among end-use sectors, India's industry sector has been the main source of energy demand growth since 2000, around half of which was met by coal. Transport energy demand grew 3.5 times, while demand in buildings has grown by 40% since 2000, largely as a result of growing appliance ownership and increased access to modern cooking fuels. The declining share of agriculture in India's economic output, and the continued use of traditional farming methods, mean that the agriculture sector has seen the smallest amount of growth in energy use.

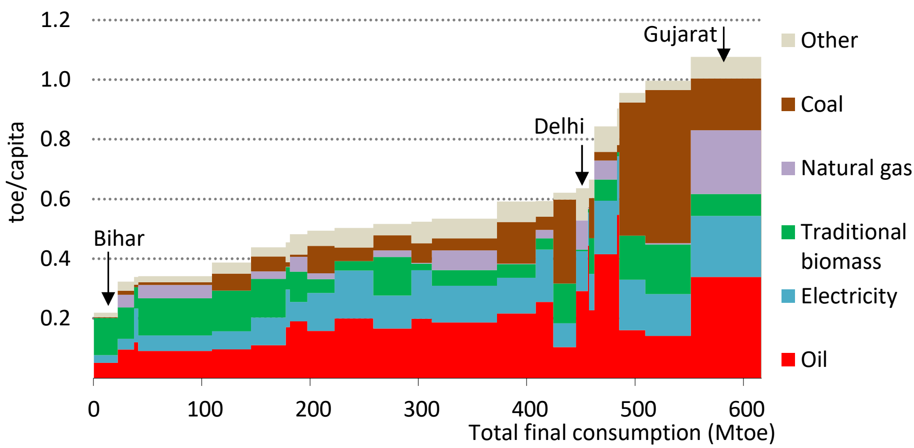
Electricity consumption has nearly tripled over the past two decades – growing faster than total energy demand – as urbanisation and rising incomes push up the use of household appliances. Industry has also contributed to the increase in electricity demand through its increasing use of electrical motors and other machinery. On the supply side, coal remains the predominant force in the power sector, contributing over 70% of total generation in 2019. Solar PV and wind accounted for 18% of the capacity mix in 2019, but their combined share of generation was less than 10%.

Figure 1.5 ▷ Change in energy demand by fuel in selected end-use sectors, 2000-19



Among end-use sectors, the growth in energy demand has been larger in industries than in transport and buildings, and this growth has largely been fuelled by coal.

Figure 1.6 ▷ Final energy consumption per capita by state, 2018



The traditional use of biomass dominates in states with lower per capita energy use; states with an energy-intensive industrial base account for the bulk of direct coal use.

Note: toe = tonnes of oil equivalent.

Within India, there is considerable variation in overall energy use across states, resulting from differences in economic and demographic trends, resource availability and industrial profiles. While India's total final energy consumption per capita is a third of the global average, a detailed review of the available state-by-state data shows that the range between the lowest-consuming and highest-consuming states varies by a factor of five (Figure 1.6 and Table 1.1). Average citizens in Delhi consume about half of the global average, while their counterparts in Bihar consume less than 20% of the global average. In states with lower per capita incomes, traditional fuels for cooking dominate. In states with higher per capita incomes, the share of electricity and oil products – which include transport fuel and also LPG – is higher, and it rises with increasing energy use.

Table 1.1 ▷ Energy and economic indicators in selected states in India, 2018

	Urban population (million)	Rural population (million)	GDP per capita (PPP) ($)	Total final consumption per capita (toe)	Electricity demand per capita (kWh)
Higher income	192.7	233.8	12 159	0.6	1 615
Delhi	16.4	0.4	19 970	0.6	1 548
Haryana	8.8	16.5	12 900	0.8	2 082
Telangana	13.6	21.4	11 170	0.5	1 896
Karnataka	23.6	37.5	11 520	0.6	1 396
Kerala	15.9	17.5	11 150	0.5	757
Gujarat	25.7	34.7	10 790	1.1	2 378
Uttarakhand	3.0	7.0	10 860	0.5	1 467
Maharashtra	50.8	61.6	10 480	0.5	1 424
Tamil Nadu	34.9	37.2	10 590	0.5	1 866
Middle income	84	220.6	6 540	0.5	1 129
Punjab	10.4	17.3	8 470	0.6	2 046
Andhra Pradesh	14.6	35	8 260	0.5	1 480
Rajasthan	17	51.5	6 040	0.5	1 282
West Bengal	29.1	62.2	5 980	0.4	703
Chhattisgarh	5.9	19.6	5 290	1.0	1 961
Odisha	7	35	5 200	1.0	1 628
Lower income	88.7	352.1	3 930	0.3	647
Madhya Pradesh	20.1	52.6	4 970	0.4	1 084
Assam	4.4	26.8	4 490	0.3	341
Jharkhand	7.9	25.1	4 150	0.6	938
Uttar Pradesh	44.5	155.3	3 640	0.3	606
Bihar	11.8	92.3	2 400	0.2	311

Notes: kWh = kilowatt-hours. Delhi is a union territory rather than a state but is included here as the capital of India.

Source: IEA analysis, MoSPI (2020)

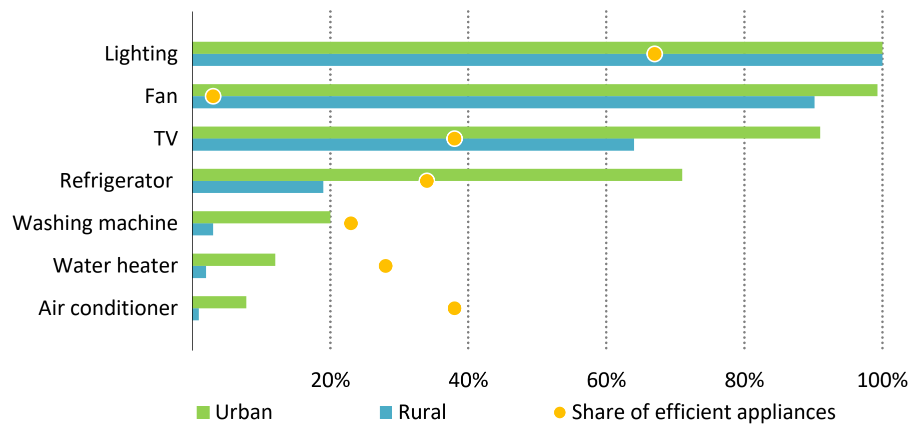
1.2.1 Key issues for energy demand

Electricity and modern life

In 2019, India achieved a historic landmark of reaching near-universal household connectivity to electricity, meaning that over 900 million citizens have gained an electric connection to their households since 2000 – a remarkable achievement. There are still challenges in providing reliable, affordable and sustainable access to all potential consumers, but electricity consumption in buildings has nearly doubled over the past decade, outpacing electricity consumption in the wider economy. This has been driven by growing appliance use, even though electricity use in Indian households is largely limited to powering light-emitting diode (LED) bulbs, ceiling fans and televisions.

Appliance use in Indian households differs starkly between urban and rural areas, with the exception of lighting and ceiling fans, which are very widely owned (Figure 1.7), and of televisions (TVs) and smartphones, which have ownership levels of over 60% in rural areas. Rural areas have relatively low adoption rates of other energy-consuming appliances, with fewer than one in five households owning a refrigerator, electric water heater or washing machine. Urban households are nearly four times as likely as rural households to own a refrigerator, seven times as likely to own a washing machine, and nearly nine times as likely to own an air-conditioning unit (AC) (Agarwal, et al., 2020).

Figure 1.7 ▷ Percentage of households using appliances, 2019



Most Indian homes own lighting, ceiling fans and TVs, while the ownership of other appliances is concentrated in urban areas.

Source: IEA based on Agarwal et al (2020)

Note: Efficient appliances are those with 4 or 5 stars on India's standards and labelling programme, except for lighting where it refers to LEDs.

India has seen a strong emphasis in recent years on the deployment of energy-efficient appliances, a policy push that has led to considerable energy savings. With the exception of three Indian states, LEDs are now used in over 80% of households thanks to a major effort to move away from more inefficient bulbs. The government's flagship Unnat Jyoti by Affordable LEDs for All (UJALA) scheme, launched in 2015, has led to the deployment of 366 million LEDs (Ministry of Power, 2020), while the LED Street Lighting National Programme has led to the installation of over 10 million LED smart streetlights by the Energy Efficiency Services Limited, a government-owned energy services company. The government estimates that energy savings of about 54 terawatt-hours (TWh) per year have been achieved through these measures (PIB, 2020).

India's standards and labelling programme is meanwhile influencing consumer choices and the deployment of efficient appliances. This programme, introduced in 2006, is operated and managed by the Bureau of Energy Efficiency. As of 2020, over one-third of TVs, refrigerators and air conditioners and over one-quarter of washing machines and water heaters in use were classed as efficient, with 4 or 5 stars on India's standards and labelling programme.

While the number of air conditioners in India is still low, sales are expected to grow sharply in the coming years. In anticipation, the government launched the India Cooling Action Plan in 2019. This aims to reduce cooling energy demand through a range of energy efficiency measures targeted at appliances and at building design and construction, while acknowledging the principle of "thermal comfort for all".

Access to clean cooking

Having electrified nearly every household in the country, one of the next big energy sector challenges for India is to achieve a full transition to clean cooking. Some 660 million Indians remain without access[1] to modern, clean cooking fuels or technologies. Access to clean cooking goes beyond technical availability: it also extends to issues of adequacy, reliability, convenience, safety and affordability.

While the government has broadened availability to LPG through different schemes to reach most Indian dwellings, nearly half of all households in 2019 continued to rely on traditional uses of biomass for cooking, mostly in rural areas. The premature deaths of around 800 000 Indians every year are attributable to household air pollution, much of which is caused by the traditional use of biomass for cooking (Health Effects Institute, 2020). The damaging health effects are felt disproportionately by women and children, and the time and effort involved in collecting biomass impose an additional cost that is again overwhelmingly borne by women.

Affordability is the key factor that has made biomass hard to dislodge as a cooking fuel. In rural India, biomass and other traditional fuels are practically free or are available at a very low cost, compared with a significantly more expensive cylinder of LPG. To overcome this affordability barrier, the government has put in place two subsidy schemes to increase the uptake and regular use of LPG in rural areas: Pradhan Mantri Ujjwala Yojana (PMUY) and Pratyaksh Hanstantrit Labh (PAHAL). As a result of the push towards clean cooking over the

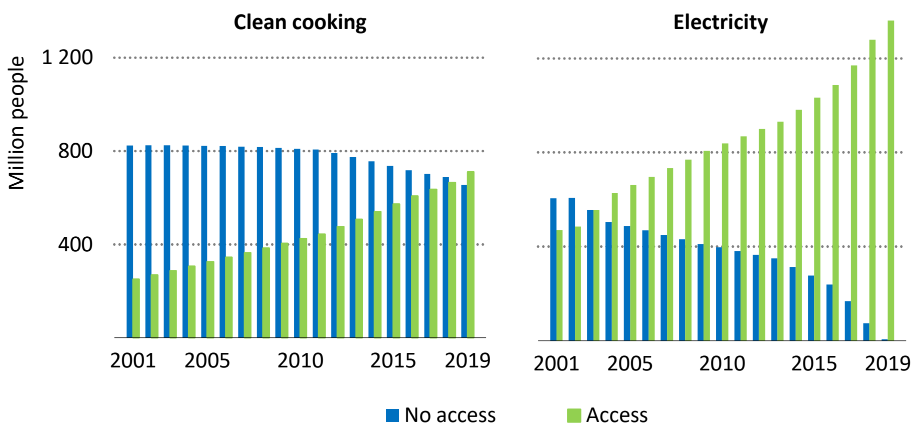
[1] A full description of the *World Energy Outlook* energy access methodology can be found at www.iea.org/articles/defining-energy-access-2020-methodology.

past decade, more than 200 000 premature deaths are estimated to have been prevented between 2010 and 2019 (Health Effects Institute, 2020).

The PMUY scheme provides LPG connections to households living below the poverty line. It was originally launched in 2016 with the objective of providing 50 million LPG connections by 2019. This target was later increased to 80 million connections by 2020, and was achieved ahead of schedule. Under the PMUY scheme, the beneficiaries have access to an interest-free loan facility for the cost of stove and first refill.

Once a household has an LPG connection, it continues to receive a subsidy through the Direct Benefit Transfer of LPG scheme, also known as PAHAL. Every residential consumer in India is eligible for this subsidy. PAHAL was launched in stages in 2013 and was scaled up to a nationwide scheme in 2015. Under PAHAL, a customer purchases an LPG cylinder at market price, and the subsidy is subsequently transferred to their bank account. In parallel, the government launched the "Give It Up" campaign to persuade high-income households to opt out, which led to at least 10 million households forgoing this subsidy.

Figure 1.8 ▷ Access to electricity and clean cooking in India



India connected almost half a billion people to the electricity grid during the last decade; attaining universal access to clean cooking is the next big challenge.

Note: A full description of the *World Energy Outlook* energy access methodology can be found at www.iea.org/articles/defining-energy-access-2020-methodology.

Despite these schemes, household surveys reveal continued reliance on biomass for cooking, due in part to the burden of upfront payments. Even with the LPG subsidy, biomass is abundantly available at no or very little monetary cost for a significant number of households, particularly in rural India. Households may also choose to use biomass alongside LPG depending on their cooking preferences. This practice of using multiple fuels for similar purposes as the household income level increases is known as fuel stacking. Survey data indicate that fuel stacking appears to be common among users of the PMUY, who often procure LPG well below their allocations (CAG, 2019). Barriers to access, including the long distances sometimes involved in LPG supply, further contribute to continued reliance on biomass.

Additional measures to promote LPG uptake such as the provision of cheaper 5 kilogramme (kg) cylinders (compared with standard cylinders that weigh 14.2 kg) have so far not been very successful. These cylinders accounted for only 0.2% of the cylinders sold by the end of 2019, and significant increases in sales are likely to require active promotion and awareness building. The Covid-19 crisis added another dimension to the access challenge, with reverse flows of migrant labour back to rural areas and unemployment further reducing the affordability of LPG cylinders. To address this, the government announced that it will arrange for the distribution of three free full-sized cylinders to all 80 million PMUY beneficiaries.

The total cost to the government of subsidising LPG depends on oil prices and rates of uptake. In 2019, it amounted to 23 000 crore Indian rupees (INR) ($3 billion).

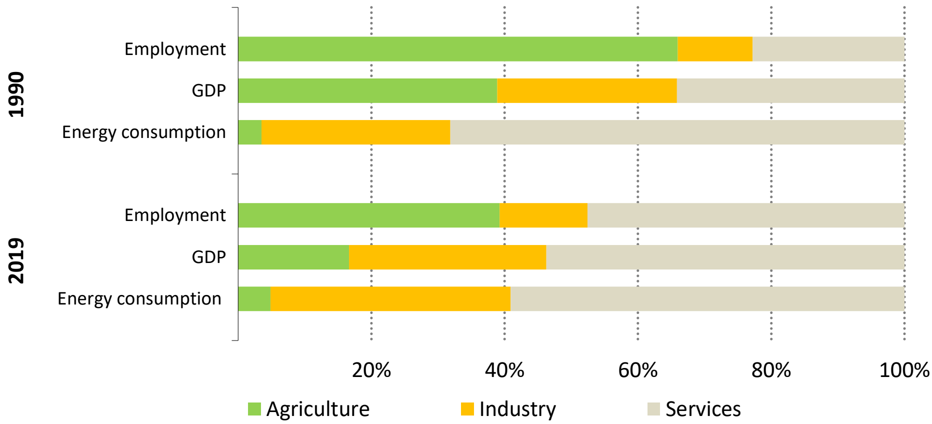
Alongside the increasing use of LPG in rural areas, there has also been growth in the use of pipeline natural gas (PNG) in urban areas. In April 2019, there were 5 million domestic PNG connections, over 90% of which were concentrated in four Indian states. The government now has plans to expand this city gas distribution network to cover 70% of all households by 2030. There is also potential for an accelerated uptake of induction and other electric cooking appliances, especially in urban areas, even though they accounted for less than 1% of cooking energy demand in 2019.

Employment

India has a large and diverse workforce employed in activities that can be broadly grouped into three sectors: industry, including manufacturing; services, including transport, utilities, information technology and retail; and agriculture. The share of the labour force in the agricultural sector has declined from about 70% in 1990 to less than about 40% today (meaning that the headcount of workers in agriculture declined by around 58 million even as India's overall labour force increased by over 110 million). There has been a corresponding rise in labour demand from the industry and services sectors, in which employment has more than doubled in the past three decades (MoSPI, 2019). This has gone hand in hand with growing urbanisation, with the share of the urban population increasing from 26% in 1990 to 34% in 2019, and many cities experiencing rapid growth.

The resulting construction activity has led to rising demand for steel, cement, aluminium, plastics and chemicals. India has also emerged as a manufacturing hub for vehicles, electronics and pharmaceuticals. The Perform, Achieve and Trade (PAT) scheme has set energy saving targets for each industrial subsector and enables the trading of energy efficiency certificates, and this has helped to improve technical efficiencies. As energy demand from industry has tripled over the past three decades, its share in final consumption has risen to 36% today, higher than industry's nearly 30% share of GDP. The services sector's share of final consumption is also higher than its share of GDP: it accounts for 54% of GDP and 59% of energy use. By contrast, agriculture makes up 17% of GDP but only 5% of final energy consumption.

Figure 1.9 ▷ India's sectoral shares in employment, GDP and energy consumption



The sectoral composition of employment and GDP has shifted away from agriculture over recent decades, but agriculture remains a big source of employment in rural areas.

Source: IEA analysis based on MoSPI (2019); NSSO (2018).

India has long pursued a structural economic shift towards manufacturing, and the government announced the landmark Make in India initiative in 2014 with the intention of turning India into a global manufacturing hub. This programme had a stated goal of raising the share of manufacturing in GDP to 25% by 2022 and creating 100 million jobs. However, despite reform measures attracting some foreign direct investment, the total number of manufacturing jobs – around 65 million – has remained broadly static since 2014, and the share of GDP attributable to manufacturing has remained around 17%. The sector has seen an annual average growth rate of 7%, outpacing agriculture but growing more slowly than the services sector (RBI, 2020). A higher share of industries in GDP and the material intensity of future economic growth would have profound implications on the outlook for the energy sector.

Mobility and transport

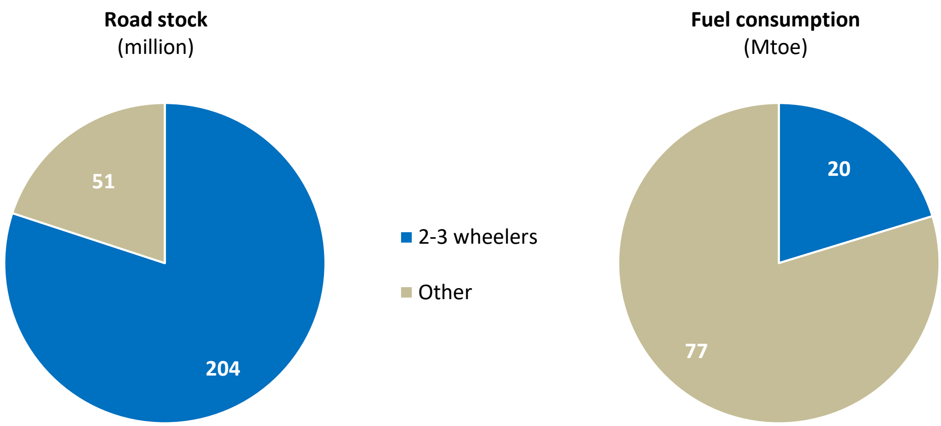
With a growing economy, Indians are now travelling farther than ever before. On average, Indians travel nearly 5 000 kilometres (km) each year, a threefold increase since 2000.

Vehicle ownership per capita has grown five-fold since 2000, with particularly significant growth in the fleet of two- and three-wheelers (Figure 1.10). Today, with a stock of just over 200 million, there are five times more of these vehicles than passenger cars. Three-wheelers in India are widely used in shared mobility and public transport, complementing a relatively low stock of 2 million buses that serve mass and public transport needs. Freight activity also quadrupled between 2000 and 2019, alongside a fivefold increase in the stock of light commercial vehicles, and a thirteen-fold increase in the stock of heavy freight trucks.

The rapid growth of mobility has been enabled by the expanding road network in India, which increased from 3.3 million km in 2000 to 5.9 million km in 2016 (MoRTH, 2019). India's total road network is now the second-largest in the world, behind the United States.

Indians are also travelling on rail twice the distance they did in 2000. India's per capita distance travelled on rail increased from 430 km in 2000 to nearly 860 km in 2019 (Figure 1.11). With over 8 billion trips annually, rail continues to be one of India's most preferred ways to travel (Ministry of Railways, 2019). Freight activity similarly more than doubled on India's vast railway network, reaching 740 billion tonne kilometres (tkm) in 2018, although the share of freight that moves on railways has been falling.

Figure 1.10 ▷ Two- and three-wheelers in Indian road transport, 2019



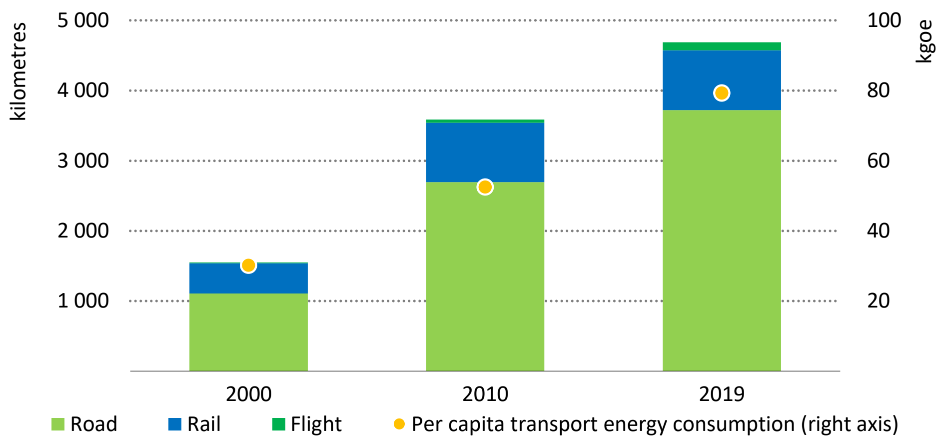
Two- and three-wheelers dominate India's road transport fleet, but account for a relatively small proportion of total energy demand in the transport sector.

While air travel remains out of reach for most Indians, there has been a steady growth in India's aviation industry over the past decade. The per capita distance flown in India was 110 km in 2019, which is three times as much as 10 years ago. Domestic passenger numbers, too, have nearly tripled in the last decade to over 140 million, up from around 50 million in 2010 (DGCA, 2019). There has been an increase in short-distance flights in recent years, enabled by policies that have supported the development of small airports and made flying more affordable. India has added 50 domestic airports in the past five years, taking the total to about 150 airports with commercial operations.

As Indians travel more and transport freight in larger volumes, the transport sector has become the fastest-growing energy end-use sector in the country. Energy use in India's transport sector has increased fivefold over the past three decades, reaching more than 100 Mtoe in 2019. While other sectors are fuelled by relatively diverse sources of energy, transport is heavily reliant on oil, with 95% of demand being met by petroleum products. Just under half of India's oil demand is accounted for by transport.

The Covid-19-related lockdowns and economic recession had a significant impact on transport demand in 2020. Overall road transport activity fell by 12% compared with 2019. While energy demand fell across all transport modes, it was most pronounced in domestic aviation and rail, falling about 20% in both these sectors. In time, however, the trends that have led to growing demand for transport are set to return, together with a range of challenges arising from this growth. Key among these challenges are road congestion, urban air pollution and growing dependence on imported oil. In India, about 75 000 vehicles of all types are sold daily, and there are now at least 42 cities and towns in India that have over a million vehicles each (MORTH, 2019). This large stock of vehicles has in turn contributed to an air quality crisis in urban areas.

Figure 1.11 ▷ Annual distance travelled per capita



Indians have been travelling farther every year, resulting in growing energy demand from transport.

Note: kgoe = kilogrammes of oil equivalent.

Sources: IEA based on DGCA (2019); Indian Railways (2019).

India has responded to these challenges by instituting a range of policies to improve fuel quality and energy efficiency and to diversify the energy use of the sector. In April 2017, India put in place corporate average fuel consumption (CAFE) fuel efficiency norms for passenger cars, and these will become more stringent from 2022. The government mandated the leapfrogging of vehicle fuel standards from Bharat Stage-IV to Bharat Stage-VI for all new vehicles sold starting April 2020. This standard is in line with Euro-6. The Ethanol Blended Petrol (EBP) programme was launched in 2003 with an ambition to blend an average of 5% ethanol into petrol, but it eventually fell short of this target owing to supply chain and procurement difficulties and a lack of attractive pricing. A more comprehensive National Policy on Biofuels (NBP) was approved in 2018 that envisages a target of 20% blending of ethanol in petrol and 5% blending of biodiesel in diesel by 2030 (MoPNG, 2018).

India's push for compressed natural gas (CNG) in transport over the past decade has resulted in the doubling of CNG use in transport since 2010. There are now over 3 million CNG-fuelled vehicles registered in the country, 92% of which are concentrated in four Indian states. These vehicles are largely three-wheelers, buses and cars, most of which are used for shared mobility, for example as taxis, or for public transport.

While India has a range of policies that support the increased adoption of a wide variety of electric vehicles (EVs) (section 2.3.2), electrification in road transport so far has largely come from two-and three-wheelers. The number of electrified two-and three-wheelers has grown by more than 60% each year on average since 2015, and there were 1.8 million such vehicles in 2019. Despite this rapid rise, they still constituted only 3% of overall two-and three-wheeler sales that year. The electrification of transport has accelerated in other modes of transport too. India's railway network now has a target of 100% electrification of its tracks by 2022, up from 51% of the railway network (in route kilometres) in 2019. There has also been a rapid increase in urban light rail in cities. In 2020, over 650 km of metro rail was operational in 18 cities (MOHUA, 2020).

1.2.2 Key issues for energy production and trade

Coal

Coal remains the bedrock of India's energy economy, commanding a 44% share of the primary energy mix, the third-highest among Group of 20 (G20) countries. India is the world's second-largest coal market, with plentiful domestic reserves. Indian mines produce over 700 million tonnes (Mt) of coal per year, mostly in the eastern part of the country in Odisha, Chhattisgarh, Jharkhand and Madhya Pradesh. The vast majority of production comes from open pit mining. Since the 1970s, government-owned Coal India Limited (CIL) has been the dominant coal producer and today it is the world's largest coal mining company, supplying over 80% of the country's domestically produced coal.

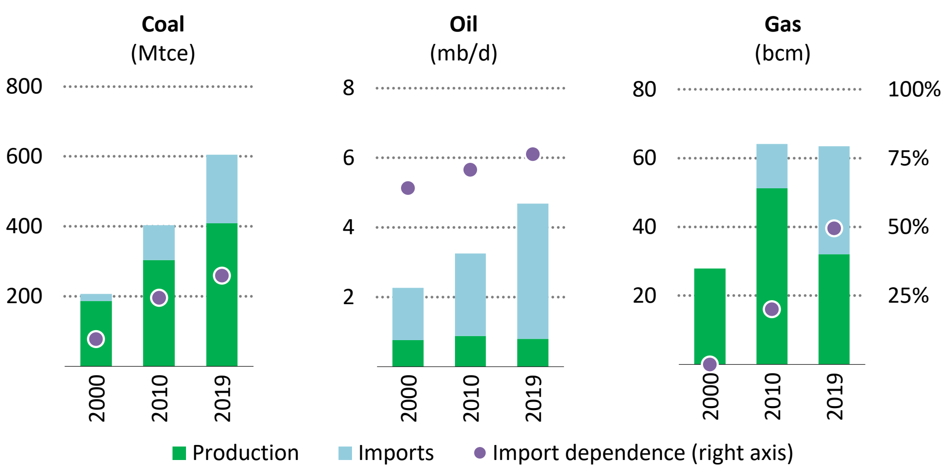
Since the 1990s, the government has also made provision for "captive mining", which enables end users to mine their own coal, as CIL could not keep up with growing coal demand. At the outset it simply allocated captive mining rights, but since 2015 it has auctioned them through a competitive bidding process. However, this has not translated into meaningful growth in production from captive mining. To encourage further private investment, the government permitted commercial mining of coal in March 2020 and opened the sector to foreign investment.

India has the world's fifth-largest proven coal reserves, but domestic production has been unable to keep pace with demand. This has resulted in a steady rise in imports in recent years (Figure 1.12), although the growth of import dependence on thermal coal has slowed since the mid-2010s as a result of increased domestic production and lower demand growth. Part of the import requirement arises from the steel industry's need for coking coal, which is far less abundant domestically than thermal coal. In addition, around 18 GW of coal-fired power plants (8% of the total fleet) are located in coastal areas and are designed to use imported coal rather than lower-quality domestic grades. Domestically produced coal also has high ash content and a low calorific value, raising operational, transport and maintenance costs. Despite these challenges, the government has a target to eliminate imports by 2025 by encouraging domestic coal production.

The supply of coal is regulated by the government to ensure that coal reaches priority sectors while keeping transport and logistics costs down. Most domestically mined coal in the east ends up having to travel considerable distances by rail to reach consumption centres in the north and west. As a result, coal uses up almost half of all railway capacity for bulk commodity transport, and freight costs make up a considerable amount of the delivered cost of coal, particularly as they are used to cross-subsidise passenger rail fares.

Coal is largely supplied at prices notified in fuel supply agreements (FSAs) by public-sector companies. These prices are set at a level intended to maintain average profitability across supplier companies rather than being dynamically linked to production costs or market forces. Notified coal prices are lower for "priority" customers such as power plants. Additionally, there are e-auctions where flexible quantities of coal can be supplied at a premium price, although only a small proportion of coal is traded this way. Coal mining also attracts a lower GST rate than other mining, but on the other hand it is subject to an added coal levy of INR 400/tonne (about $5.5/tonne) which acts as a de facto green tax. When this levy was first introduced in 2010, the revenues collected were directed to a National Clean Energy and Environment Fund (NCEEF). Upon the introduction of the GST in 2017, however, the original levy (the "coal cess") and NCEEF were abolished and replaced with a GST Compensation Cess on coal to make up for the shortfall in overall tax revenues.

Figure 1.12 ▷ India production and trade of coal, crude oil and natural gas



India's domestic production of fossil fuels has not been able to keep pace with demand, leading to a rapid rise in import dependence over the past two decades.

Note: Mtce = million tones of coal equivalent; mb/d = million barrels per day; bcm = billion cubic metres.

Oil

Unlike coal, India has limited domestic resources of oil, largely relying on imported crude to meet its needs. India has become the second-largest net oil importer after China. Crude oil is brought in by tanker from the Middle East, Latin America and Africa to Indian refineries along the western coast. India's dependence on imported crude oil has been rising, and currently stands at around 75%.

To address the risks that could arise from growing import dependence, the government has expanded its strategic petroleum reserve (SPR). As of mid-2020, India held around 40 million barrels of oil in its SPR, equivalent to about 10 days of the country's net oil imports. India has a long-standing ambition to reduce oil import dependence, and the government announced in 2015 an ambition to reduce this dependence by 10 percentage points by 2022. This was to be achieved through a variety of policies, including policies to expand the use of alternative transport fuels such as bioethanol, biodiesel and CNG, and through the expansion of domestic oil production. To encourage domestic exploration and production, the government adopted the Hydrocarbon Exploration and Licensing Policy (HELP) in 2016 to provide a level playing field for the exploration of all types of hydrocarbons under a revenue sharing model.

These policies have not so far succeeded in reducing India's oil import dependence, which has continued to rise, broadly tracking the increase in demand, while domestic oil production has remained broadly flat since 2015, as it has for the past three decades. Over these decades, however, India has proactively expanded its refining capacity, making it a net exporter of refined products. India's refining capacity stands at 250 Mt per year, making it the fourth-largest in the world. While production is largely in the hands of publicly owned companies, India's largest refineries are privately owned, notably the Reliance-owned Jamnagar refinery on the western coast of Gujarat, which is the world's largest.

The prices of transport fuels, gasoline and diesel are determined by fuel retailers based on prevailing market conditions. The government has removed regulated prices and subsidies, and has progressively increased excise duties on these fuels during periods of lower crude oil prices.

Natural gas

While the share of natural gas in India's primary energy mix has largely remained flat in recent years at around 6%, overall energy demand has risen rapidly, and there have been significant shifts in demand for natural gas in specific sectors of the economy. The use of natural gas as a fuel in industry has increased about tenfold since 2010, against the background of an overall 50% increase in energy use in the sector. This has increased the share of natural gas in industry from less than 2% to nearly 10%. Similarly, natural gas use in buildings has tripled over the past decade, albeit from a low base. These increases have, however, been partly offset by a fall in the use of natural gas for power generation. The pressures that have led to this fall remain: nearly 60% India's natural gas-based power generation capacity is facing extreme financial pressure and operating on very low capacities on account of lack of affordable gas.

India has a stated ambition to increase the share of natural gas in its primary energy mix to 15% by 2030, up from 6% in 2019. The government has been taking a range of measures in support of this ambition in order to expand domestic production, facilitate imports and encourage demand. To expand production, HELP allows for pricing and marketing freedom for gas produced from deepwater, ultra-deepwater and other complex reservoirs. The gas price from all other fields is determined on a half-yearly basis by a formula linked to hub prices in other countries, including the United States, Canada, the United Kingdom and the Russian Federation. In 2020 the government also launched the Indian Gas Exchange (IGX), a trading platform for natural gas. The relatively low level of gas prices over the past few years has, however, acted as a disincentive for significant investments in domestic production.

Growth in India's gas demand has outpaced domestic production, leading to rising dependence on imported LNG. Imports of natural gas have risen from 20% of India's total gas demand in 2010 to 50% today. To facilitate these imports, India has six LNG terminals. Although there are some infrastructure bottlenecks, India already has a 17 000 km network of pipelines to transport gas to centres of consumption, and it has ambitions to expand this grid significantly. India's downstream regulator, the Petroleum and Natural Gas Regulatory Board, is in charge of overseeing this expansion as well as of regulating tariffs for users of this infrastructure. In addition to this long-distance pipeline network, India has ambitious plans for city gas distribution (CGD) networks to cater to households, commercial establishments and factories within cities. There are currently 18 states with CGD networks, and successive bid rounds have awarded CGD licences with the aim of reaching 70% of all households by 2030.

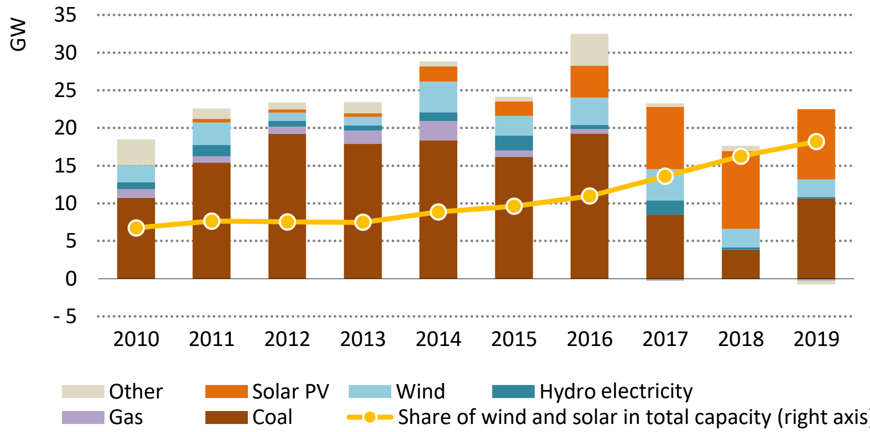
Solar and wind

The most remarkable story in India's power sector in recent years has been the growth of solar PV and wind**,** which have rapidly increased their share of the overall energy mix in recent years as coal and hydropower capacity growth has slowed (Figure 1.13). Over the past five years, solar PV capacity has grown at an average growth rate of around 60% and wind capacity of around 10%, outpacing the 7% growth in overall installed capacity. This rapid growth reflects government policy support and falling equipment costs.

In 2015, the Indian government announced a target of 175 GW of renewables by 2022 (excluding large hydro), which included 100 GW of solar and 60 GW of wind capacity. Published a year after India had set these aggressive targets, the 2015 *India Energy Outlook* projected that India's solar capacity would reach 28 GW in 2020 under the prevailing policy framework in the New Policies Scenario (the forerunner of today's Stated Policies Scenario [STEPS]), but that it could reach 48 GW under a more aggressive Indian Vision Case. The *Outlook* identified several challenges that would need to be overcome to scale up renewables in India, including difficulties in acquiring land, the financial difficulties faced by distribution companies, and the long-term nature of existing contracts with conventional producers. Partly owing to the effective management of these risks, India's solar capacity reached 38 GW by 2019 (mostly utility scale), with wind adding a further 38 GW of capacity.

Together, they now constitute nearly 20% of India's installed capacity. In 2019, India announced a new target of 450 GW of renewable electricity capacity by 2030.

Figure 1.13 ▷ Annual power sector capacity additions



With coal capacity growth slowing down and solar PV and wind ramping up, the share of variable renewables in installed capacity has doubled since 2014.

The policy actions that have facilitated the growth of grid-connected renewables include reverse auctions resulting in progressively falling prices, lower corporate tax rates for developers, renewable purchase obligations mandating utilities to procure a certain minimum purchase of renewable power (in 2019-20, the guideline set by the central government was 17.5%, although state regulators have their own targets), investment in transmission infrastructure, and support for solar parks that help reduce project development and land acquisition risks.

The rise of renewables in India's power sector has been a major success story; wind and solar PV now account for 7% of total generation, twice their share in 2014. In renewable-rich Indian states, wind and solar contribute as much as 15% of power generation. In some states, they contribute nearly 50% of power generation during those parts of the year when wind speeds are at their strongest. Solar PV and wind have been relatively resilient during the crisis in 2020; even though overall electricity demand was down sharply in the second quarter, coal accounted for most of the reductions in generation.

However, there are still important structural, regulatory and institutional challenges that could hamper further growth, and progress has been uneven across different renewable technologies. The challenges include the poor financial position of many state distribution companies, difficulties in obtaining access to finance and in acquiring land, grid congestion, and uncertainties over grid infrastructure development. The expansion of rooftop solar has lagged behind the growth in utility-scale projects, constrained by higher costs and the lack of attractive financial models for consumers. Rooftop solar had a share of 40 GW in the 100 GW solar target for 2022, but deployment remains at well under 10 GW. This sector is now a focus area for the government as 2022 gets closer.[2] Similarly, despite an identified potential of 10 GW to 20 GW, offshore wind has not yet taken off in India owing to the high cost of capital and to supply chain and infrastructure bottlenecks.

Other technologies and fuels

Growth in the share of wind and solar PV in the Indian power system needs to be accompanied by a strengthening of **grid infrastructure**. To address this, the government has been focusing on flexibility in operations, technologies and infrastructure. The Green Energy Corridors initiative is one attempt to boost flexibility; it aims to expand and improve transmission infrastructure, facilitate the integration of renewable energy management centres and energy storage options, and enhance the flexibility offered by India's thermal power fleet.

Storage technologies are also set to be vital to India's electricity security. Of the country's 4.8 GW of installed pumped storage hydro capacity, 3.3 GW is operational; total pumped storage hydro potential has been estimated at 90 GW (CEA, 2019). Battery storage will also have an important part to play. The government estimates that India will require 27 GW of grid-connected battery storage by 2030 (CEA, 2019), and has established a National Mission on Transformative Mobility and Battery Storage in 2019 with the aim of becoming a competitive battery manufacturer. In May 2020, the government also announced the result of the first ever "round the clock" renewable energy auction, which will lead to the development of 400 MW of generation capacity that will supply power through the day through a combination of solar and other generation and storage technologies. India also announced in November 2020 a production-linked incentive (PLI) scheme for the domestic production of high-efficiency solar PV modules and advanced chemistry cell storage batteries.

India has significant potential to expand its modern **bioenergy** sector, which can be done using the vast quantities of organic waste generated by the agricultural sector as well as a growing amount of municipal solid waste, used cooking oil and wastewater. There are a number of supporting policies, some of which have been strengthened in recent years, notably new biofuel blending targets and plans to expand India's bio-compressed natural gas infrastructure.

India has also made initial steps towards exploring the potential of **hydrogen** as a source of energy. The first roadmap for the fuel was produced in 2006 by the Ministry of New and Renewable Energy, and the government has since been investing in research and development via various public sector institutions.

[2] Solar PV has also grown in off-grid applications, notably to power street lighting and water pumps in rural areas. With policy support, over 3 million solar-powered streetlights had been installed by the start of 2019. There is also a government programme in place for solar-powered irrigation pumps and decentralised ground-mounted grid-connected renewable power plants with a combined target of 31 GW by 2022.

1.3 Energy and India's development path

India's energy choices are inextricably linked to wider socio-economic developmental goals. The use of energy, development of energy markets and deployment of technologies are not ends in themselves, but means for the country to reach wider objectives including economic growth and improvements in the quality of life and the environment. This section explores the linkages between the energy sector and wider economic, social and environmental issues.

1.3.1 Energy and the economy

The year 1991 was a seminal one in India's economic history. India took important steps in that year to liberalise its economy, initiating a change towards a more market- and services-based economy. This altered the trajectory of its development, expanding per capita incomes, attracting higher levels of private and foreign investment, stimulating competition, and leading to new manufacturing capacity, new service-sector firms, productivity gains and a falling poverty rate. Along with greater economic activity came increasing competition for land resources and growing levels of emissions and pollutants, presenting new challenges for society at large.

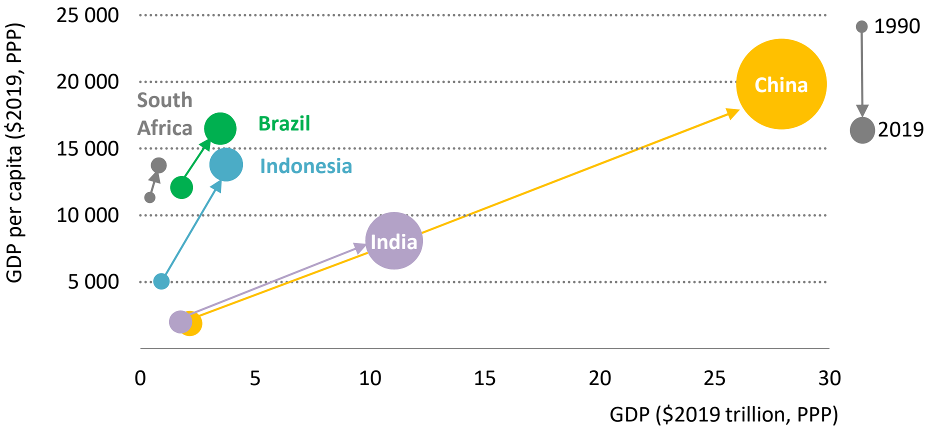
In the period between 1991 and 2019, India's GDP grew at an annual average rate of 6.8%, outpacing the average annual growth of 4.2% in the two decades before that. India was one of the world's fastest-growing large economies in this period, second only to China (Figure 1.14). With GDP having nearly doubled over the past 10 years, India has become the world's third-largest economy in PPP terms and the fifth-largest in nominal terms.

India's per capita annual income has quadrupled since 1991 and reached $8 100 (PPP) in 2019. Although this remains well below the world average of $18 500 (PPP), the rapid rise in per capita incomes has led to a significant fall in India's poverty rate. India's Poverty Headcount Ratio[3] fell from 48% in 1993 to 13% in 2015 (World Bank, 2020). This has been accompanied by a rise in standards of living and development indicators. India's Human Development Index value has increased from 0.43 in 1990 to 0.65 in 2018, representing a growth in life expectancy, education access and incomes (UNDP, 2019).

Growth in the economy has fuelled the demand for energy, and the growing supply of energy has fuelled India's economic growth. Indians on an average now use nearly twice as much energy as they did three decades ago, as a result of rising vehicle ownership, demand for construction material and a rise in appliance ownership. However, India's energy intensity of GDP has improved at an average rate of 3% per year during these three decades, meaning it has required less energy over time to produce an additional unit of economic output. This has happened as a result of the growth in the Indian services sector, energy efficiency improvements and a transition away from inefficient biomass towards modern fuels.

[3] The percentage of the population living on less than $1.90 a day at 2011 prices.

Figure 1.14 ▷ GDP and GDP per capita for selected countries, 1990 and 2019



While India is now the world's third-largest economy in PPP terms, it lags behind other emerging economies in terms of per capita incomes.

Note: Bubble size indicates GDP ($2019).

The Covid-19 pandemic has given India an abrupt economic shock, with April-June quarterly GDP falling by 23.9% and an estimated contraction of about 8% for the whole of 2020. This contraction, which has had a significant impact on energy demand across fuels and sectors, was caused by the disruption of the global economy due to the pandemic, and by the lockdown measures taken by India to address the spread of the virus. To counter its impact on the economy, the Indian government in May 2020 announced an economic recovery package with the overarching theme of Atmanirbhar Bharat ("Self-Reliant India"). This included welfare transfers to farmers, free LPG cylinders for the least well off, concessional loans for the medium and small industrial sector, the injection of liquidity into power distribution companies, and tax changes. The government also included measures to promote manufacturing in India and government procurement from domestic companies.

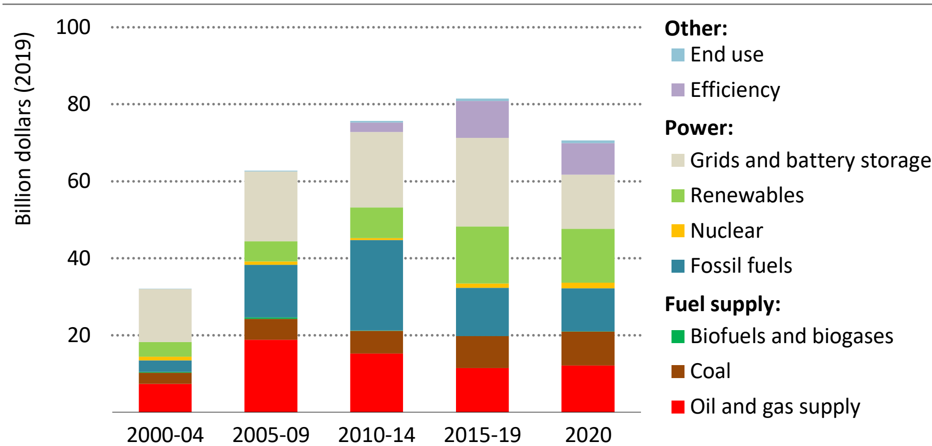
India's economy had been witnessing a slowdown even prior to the pandemic. Its annualised economic growth had fallen to 4.7% in the final quarter of 2019, the lowest in five years. Other economic indicators such as growth of private consumption, capital investments, exports and industrial activity also indicated a slowdown. In particular, capital investments, exports and the Index of Industrial Production registered negative growth in the second half of 2019. The year also saw a decline in vehicle sales and a slowdown in the growth of steel consumption and in sales of fast-moving consumer goods. The government had already introduced measures in 2018 aimed at simplifying and streamlining aspects of economic life, such as the GST. The post-pandemic recovery will not only have to address the disruption caused by Covid-19 but also to build on these measures and tackle structural obstacles to economic growth that existed prior to the crisis.

Investment and finance

Over the past decade, investment across the whole of India's economy has surged, with gross fixed capital formation doubling to $770 billion in 2019 from 2010 levels. Most of this has come from domestic sources: foreign direct investment inflows amounted to $50 billion in 2019. Public finances have also improved considerably in recent years. The fiscal deficit has stayed slightly above 3% (as a share of GDP) and the government debt-to-GDP ratio has declined since the early 2000s. In addition, foreign reserves held by the Reserve Bank of India (RBI) have increased by 1.5 times since the early 2010s, and tenfold since the early 2000s, providing an additional buffer during periods of financial stress.

Key economy-wide investment indicators weakened in 2020 due to the crisis. Rising debt and equity market risk premiums have more than offset a reduction in base lending rates by the RBI, increasing the economy-wide cost of capital by around 30 basis points, while bank credit growth across all sectors has stalled. Faced with economic uncertainty and strained balance sheets, corporations responded by reducing investments. In September, new non-financial capital projects declined to their lowest level since 2007, while the number of projects outstanding dipped to a four-year low. Fiscal pressures have pushed down central government capital expenditures by 12% through September for fiscal year 2020-21 compared to the same period in 2019-20. In the energy sector, we estimate that investment is set to decline by almost 15% to around $70 billion in 2020 compared to 2019 following five years of stable spending at around $80 billion, with larger falls in grid networks (Figure 1.15).

Figure 1.15 ▷ Investment trends in energy, 5-year annual averages (2000-19) and 2020



Investment in renewables exceeded fossil fuel power investment for the fifth year in a row in 2020, while investment in networks has been falling recently in absolute and relative terms.

Notes: Efficiency and other end use investment estimates are not available prior to 2014. Other end use includes carbon capture, utilisation and storage (CCUS) in industry, spending to meet the incremental cost of EVs, and investment in private EV charging infrastructure.

India's energy investment trends vary across different parts of its energy economy, reflecting differences in market conditions, policies, capital allocation and costs. Investment in oil and gas supply was hit hard by lower demand, prices and revenues in 2020, and fell by 20% to $12 billion compared to 2019. In recent years, reforms brought about through the HELP programme, putting all hydrocarbons under a single exploration and production policy, have underpinned stronger spending.

Coal supply investment reached an average of around $10 billion in 2017-19, although it is estimated to have fallen by nearly 15% in 2020. Ongoing reforms aim at increasing investment, in particular through the opening of the coal sector to commercial mining by domestic and international companies. However, challenges remain, including the pressure from international investors, which restricts financing options.

The power sector accounts for over half of energy investment in India. Capital investment amounted to almost $50 billion in 2019, a 4% decline from 2018, and a further drop of over 15% is expected in 2020. Investments in renewable power surpassed those in coal power plants for the fifth year in a row in 2020. Spending on coal power has moderated in recent years, though it remains above $10 billion a year, with up to 60 GW of coal-fired capacity designated as being under construction. However, a stark decline in final investment decisions for new plants since 2016, as well as more constrained bank lending, points to much lower investment levels in the years ahead.

Recent momentum in the power sector has been driven by investment in renewables, which grew by 60% over 2015-19 to $18 billion. Utility-scale solar PV and wind have led this growth, underpinned by supportive policies, competitive auctions, improved economics and a maturing industry. Although investment in these technologies is set to decline in 2020, interest has remained high, and the capacity awarded through auctions between January and June 2020 rose for the third consecutive year. The pandemic has nevertheless added uncertainty over India's ability to attract a diverse pool of private finance to meet ambitious deployment targets in the years ahead (see Chapter 4). Moreover, progress in other technologies such as distributed solar PV and bioenergy remains slow, with new financing challenges emerging. New hydropower investments have also been slow to materialise, although recently announced measures could help facilitate fresh investment. These include the creation of a hydro purchase obligation (HPO) to encourage hydropower purchases, and budgetary support for flood control and hydro energy storage projects.

The financial and operational performance of state distribution companies – key developers of grids, purchasers of power and integrators of new technologies – continues to constrain capital availability, despite efforts such as the Ujwal DISCOM Assurance Yojana (UDAY) initiative. This initiative involved writing off debt and restructuring loans against a commitment to improve performance. However, investors and developers continue to be concerned about the risks involved in power purchase projects. An $18 billion backlog of payments to generators emerged in 2020, and further reforms are required to enable distribution companies to return to profitability, including measures to achieve cost-reflective pricing.

Investment in grids has trended downwards in recent years from more than half of power investment in 2015 to around one-third in 2020, reflecting the challenging financial situation of distribution companies, while spending on battery storage is at an early stage and remains low. The government is, however, working to expand inter- and intra-state transmission capacity, which is key to the successful integration of a rising share of renewables. The first Green Energy Corridor project – a 1 800 km high-voltage transmission line – began construction in 2017, with the aim of transporting power from resource-rich states to other states more effectively than at present; the project will cost more than $5 billion (Ministry of Power, 2020). The government is also looking at new ways to procure flexible resources, for example by integrating batteries in utility-scale renewable tenders.

Spending on energy efficiency, electric mobility and the direct use of renewables accounts for just over 10% of energy investment. Over 40% of efficiency investment has occurred in industrial sectors, supported by the PAT scheme, while investment in more efficient appliances and buildings accounts for another quarter. Sales of EVs and EV charging installations are low, but are set to grow rapidly. Investment in solar thermal heaters has expanded rapidly to nearly $1 billion in 2019, supported by government grants and rising interest among industrial users.

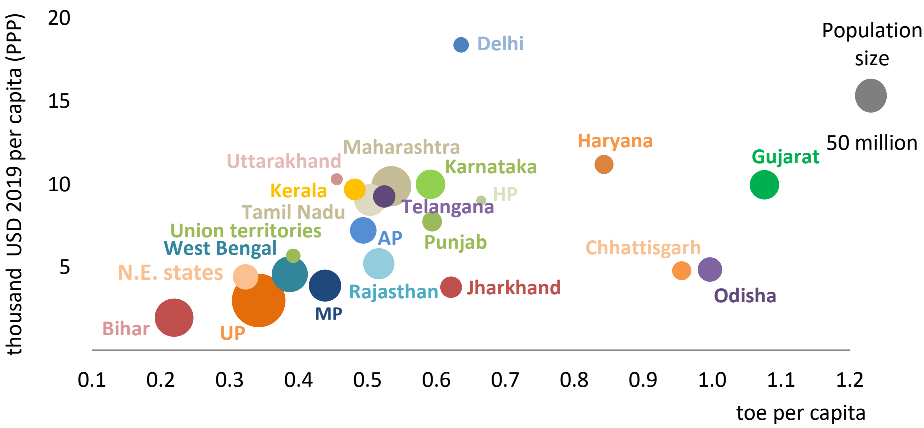
1.3.2 Energy and society

Growth in average per capita income and a fall in poverty means that increasing numbers of Indians are able to afford private modes of transport, clean cooking technologies, modern appliances and larger homes. However, income growth has been characterised by various kinds of inequities that are reflected in energy consumption levels, in particular in terms of interstate variances, poverty, the rural-urban divide, gender and caste. The provision of access to energy and opportunities to use it needs dedicated interventions that focus on gender, caste and class (Patnaik & Jha, 2020).

The 12 wealthiest states in India, including Goa, Haryana, Maharashtra, Kerala and Tamil Nadu, have an average per capita income that is at least twice as high as the bottom 8 states, including Bihar, Uttar Pradesh, Jharkhand and Madhya Pradesh. With an urban population of 44%, the wealthiest states are also twice as urbanised as the lower-income ones. These two groups of states have similar population sizes.

In terms of energy, the total final consumption of these higher income states is 40% higher than those with low per capita incomes. This trend holds true on a per capita energy use basis too (Figure 1.16). There are a few notable outliers, including Jharkhand, Chhattisgarh and Odisha, which combine relatively low per capita incomes with high energy use owing to the size of energy-intensive industries such as steel and cement in those states. Nearly 40% of Indians reside in states with both low per capita incomes and low per capita energy use.

Figure 1.16 ▷ Population size, GDP per capita and energy use per capita by state and union territories in India, 2018



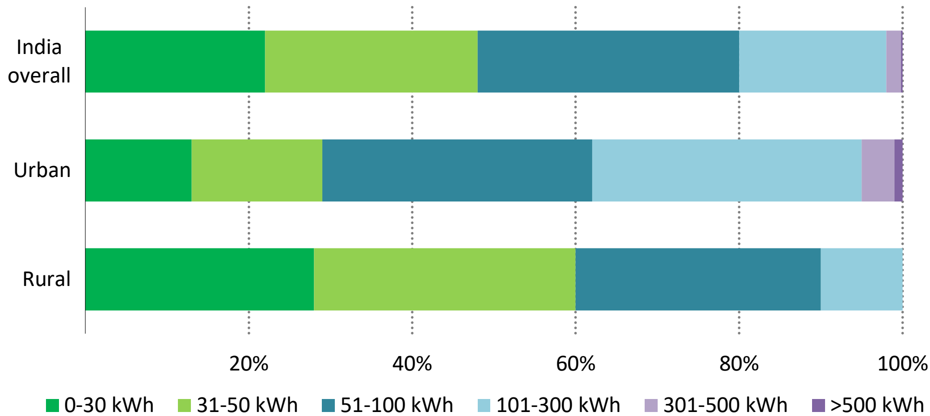
There is considerable variation in energy consumption across the states of India. The biggest coal-producing states challenge the normal relationship between economic output and energy use.

Notes: UP = Uttar Pradesh, AP = Andhra Pradesh, MP = Madhya Pradesh, HP = Himachal Pradesh. Delhi is shown separately from the remaining union territories, as the capital of India.

The state-by-state differences are overlaid by a pervasive rural-urban divide in energy use, as well as by major gender differences (see Spotlight). The rural-urban divide is linked to a range of factors, including income and appliance ownership levels, which feed through into electricity consumption (Figure 1.17). In 2014, the bottom 60% of households in rural India consumed less than 50 kWh of electricity per month, compared with an average of 100 kWh in urban areas. This rural-urban divide extends to access to clean cooking and the materials used in the construction of houses. In 1990, only 30% of rural homes were built using modern building materials, compared with 75% of homes in urban areas; the rest were built using traditional materials such as unburnt mud, cow dung and other organic materials. This gap in terms of housing is narrowing, however: by 2018, 79% of rural and 97% of urban houses were being constructed using modern materials.

Another dimension to inequity that is unique to India is the caste system. Historically, marginalised caste groups categorised as Scheduled Castes and Scheduled Tribes have had less access to electricity and clean cooking after controlling for factors such as income and education. These groups make up about 16% of India's population (Saxena & Bhattacharya, 2017).

Figure 1.17 ▷ Household electricity consumption per month in urban and rural India



Rural households consume considerably less electricity than urban households.

Source: Data from 2014, based on Prayas (2016).

S P O T L I G H T

A long way to go: Women's participation in India's energy sector

The issue of women's access to and participation in the energy sector is a key aspect of inequity in India. Economic progress in recent decades has not been matched by progress towards women's equal economic participation. The World Economic Forum's Global Gender Gap Index 2020 ranks India 112th out of 153 countries in offering equal opportunities to women and men, and women often lack the same access to health care and education as their male counterparts.

Between 1990 and 2019, the female participation rate in the workforce fell from 30% to 15% while the male participation rate remained largely constant at around 55%. India's declining female labour force participation has been particularly pronounced in rural India, with rural women leaving India's workforce at a faster rate than urban women (WEF, 2020). This low and falling participation rate among women has significant impacts on energy inequity in several ways: it leads to low workforce participation in the energy sector, lower demand for appliances, lower access to safe mobility, and lower clean cooking access and affordability.

Globally, women hold only around 22% of jobs in the energy sector as a whole, and 32% in renewables (IRENA, 2019). In India, the percentage of women with jobs in the energy sector is even lower, at less than 10%, and many of these jobs are non-technical (IEA-CEEW, 2019). In the rooftop solar sector, women account for an estimated 11% of the workforce.

India’s low labour force participation rate for women is due in part to the gender wage gap, a lack of safety policies and flexible work arrangements, and cultural norms regarding women’s work. Indian women are often required by their families to prioritise domestic work. A social stigma continues against women working outside the house, especially for those who can afford not to work. These trends risk being further aggravated by Covid-19, as the sectors most impacted by the pandemic are those with higher shares of female labour participation.

Poor access to safe and affordable transport for women imposes further constraints on their access to health care, education, and other social facilities and services, thereby effectively limiting their opportunities to participate in the country’s workforce to the same extent as their male counterparts. Globally, it is estimated that safety concerns and limited access to transport reduce the probability of women participating in the labour market by 16.5% (ILO, 2018). Understanding and responding to women's mobility needs, which are different from those of men, is essential to enable more equitable participation in the energy sector and economy more widely.

Energy transitions can have important implications for gender gaps and equality in employment and remuneration. India has a high share of female graduates in engineering, and the renewable energy sector tends to attract a relatively high proportion of women. Accelerating the deployment of renewables could therefore mean an acceleration of employment in this sector for women. Codifying policies to provide a safe place for women to work, including accommodation, sanitation facilities and transport, would help to make this happen. Equal opportunities also implies protection from discrimination and access to maternity and parental leave allowances.

Achieving universal access to clean cooking options would also provide an important improvement in health for women together with major time savings and increased employment opportunities. Women are disproportionately exposed to household air pollution from the burning of traditional biomass, leading to a higher prevalence of asthma, pulmonary diseases and lung cancer among households that use biomass for cooking (Kankaria, Nongkynrih and Gupta, 2014). Women in these households also spend significant amounts of time collecting fuel. The PMUY scheme issues LPG connections specifically to women in poor households, and in some states women play a key decision-making role in processes that aim to accelerate the transition away from the traditional use of biomass.

Reliability and affordability

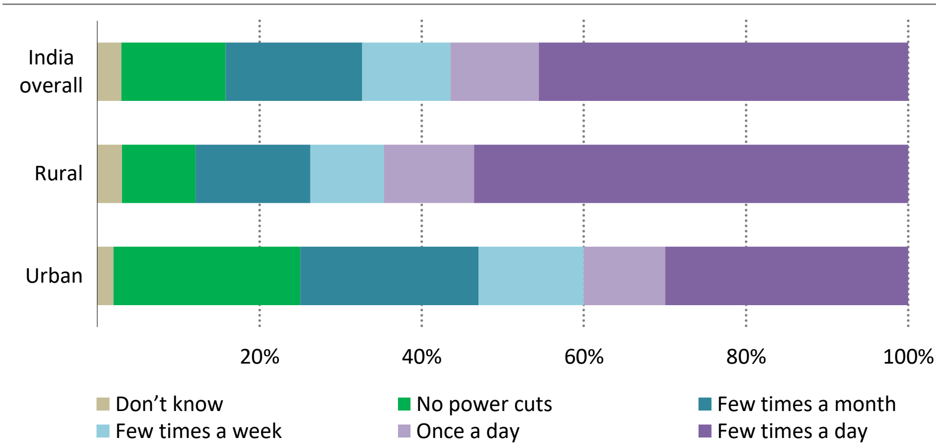
Reliability and affordability are key concerns for Indian consumers, and they are closely intertwined. Affordability is also a key consideration for clean cooking fuels (see section 1.2.1).

Satisfaction with electricity services is highly correlated with the hours of electricity that households enjoy (Alkin et al., 2016). Urban households receive about 22 hours of electricity a day on average, and rural households receive about 20 hours. Lack of reliability is an important issue. In rural areas 53% of households experience multiple power cuts in a day compared with 30% of their urban counterparts.

Unreliable power is a major barrier to economic and social development, and imposes additional financial burdens on consumers, not least in terms of the expense of maintaining backup sources of power (Box 1.2). The use of such backups is widespread. In 2017, even as electricity access was improving, many rural households continued to use kerosene for lighting (Jain, 2018). In urban areas, diesel generators are common, especially in modern high-rises, while individual households often have rechargeable batteries to help them cope with power cuts. Similarly, about 35% of rural enterprises appear to be dependent on non-grid electricity sources such as solar home systems, rechargeable batteries, mini-grids, and diesel generators. These additional sources of power or lighting increase the financial burden on already low- and middle-income households (Smart Power India and ISEP, 2019).

Affordability is a key component of energy access, and tariffs for the Indian residential sector are much higher in PPP terms than in other developing countries (see Chapter 3). These relatively high tariffs, coupled with low per capita incomes, mean that energy costs account for a significant share of household expenditure. To address this issue of affordability, state governments have been cross-subsidising consumers by providing inexpensive electricity to households with low consumption. Electricity tariffs also tend to be fixed, and are often below cost price, leading to financial losses in distribution companies which in turn lead to frequent bailouts. The state governments in charge of such bailouts often struggle to make timely and complete payments, and this has prompted the central government to step in with loans and policy reforms (see Chapter 4.3).

Figure 1.18 ▷ Share of electrified households affected by power outages, 2019



Most Indian households report multiple daily power cuts.

Source: Agarwal et al. (2020).

In addition to subsidised prices, distribution companies suffer from high aggregate technical and commercial losses, and from difficulties in billing and revenue collection. Their consequent financial difficulties lead to a vicious circle of under-investment in infrastructure and poor quality of service (Figure 1.18). In line with its objective to provide reliable and continuous power, the government is deploying a range of policies to address these linked reliability and affordability barriers, while encouraging efforts by the utilities to improve the efficiency of their billing and revenue collection and to reduce aggregate technical and commercial losses.

One important government initiative is to replace 250 million analogue meters with smart meters across India over the next three years to improve metering and consumption transparency, and avoid the errors and costs that come with manual billing. Energy Efficiency Services Limited, a government-owned energy services company, has already installed 1 million smart meters in Uttar Pradesh, Haryana, Bihar and New Delhi (Economic Times, 2020). In 2020, the government also announced that it was considering a new tariff policy penalising unscheduled power cuts to incentivise investment in power infrastructure.

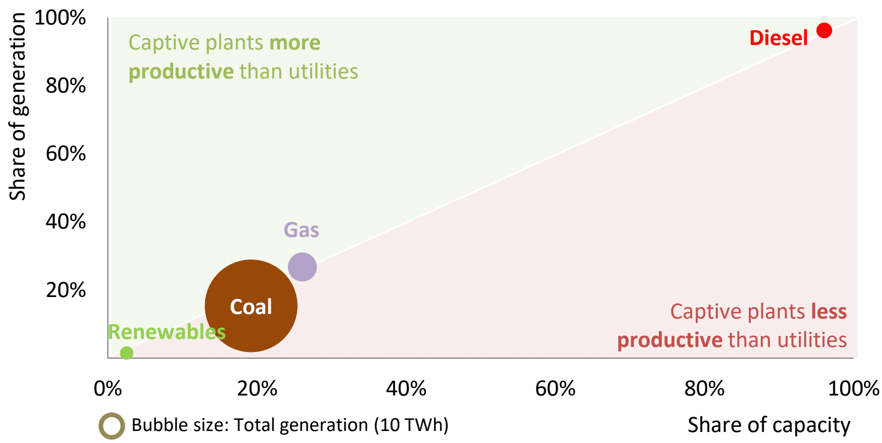
Box 1.2 ▹ Electricity security and the role of captive power

Captive power plants provide a localised source of power to an energy user. They play a crucial role in India's electricity generation, accounting for 75 GW of installed capacity and around 15% of total generation in 2018 (Figure 1.19). This is higher than the global average of around 7% and much higher than the advanced economies average of 4%. These facilities serve a wide variety of consumers from households and small businesses to large industrial plants, but the motivation is the same in all cases: to provide a hedge against unreliable supply from the grid, and – especially for large consumers – to benefit at times from cheaper power than that supplied by the grid.

As in the broader electricity mix, coal is the most common fuel source for captive plants, accounting for nearly 90% of captive generation (the bubble size in Figure 1.19 represents captive generation). Natural gas, with 10% of total captive generation, is the second-largest fuel source and is mainly used by petrochemical and fertiliser industries, which also use gas as feedstock for their production processes. The cost-effectiveness of these captive plants is helped by the structure of electricity tariffs, under which industrial and commercial users effectively cross-subsidise residential and agricultural customers (the price of grid electricity for industry is on average 70% higher than for residential users). Many of these industrial captive units are relatively old assets that have been fully depreciated.

The true extent of diesel generator use across India is unclear, as official data only include units of more than 1 MW; studies based on manufacturer data indicate that total capacity may be as much as 90 GW (The Indian Express, 2014). The many smaller units implied by this data are relatively expensive to operate and are also a source of local pollution, even if used only sparingly.

Figure 1.19 ⊳ Captive power as a share of total generation and capacity by fuel, and total captive generation by fuel, 2018



Almost all diesel-based generation in India takes the form of captive power for small businesses and households; coal-fired plants play a significant role for large industries.

Source: IEA analysis based on MoSPI (2020).

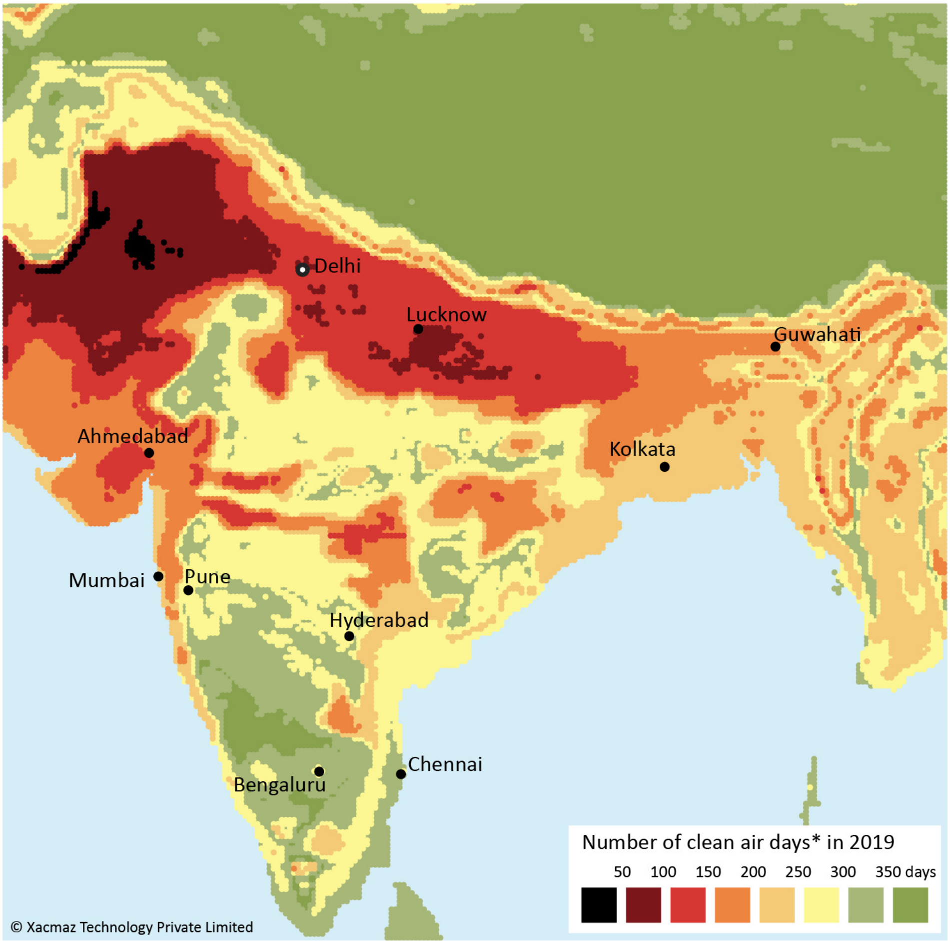
Rooftop solar is another potential source of captive power that is being increasingly taken up by both residential and commercial users, although adoption has fallen short of official targets. As rooftop solar schemes gain momentum and the cost of integrated solar-plus-battery offers falls further (and as government schemes make it easier for people to sell excess power back to grid), small-scale renewables are likely to go a long way towards replacing diesel backup. As gas networks expand within cities, gas-based generation could also become viable for larger users.

1.3.3 Energy and the environment

Air quality

Air pollution has emerged as one of India's gravest environmental problems in recent years, and energy use is at the heart of it. In 2019, there were well over one million premature deaths related to ambient and household air pollution; only China has a higher toll of premature deaths. The Central Pollution Control Board (CPCB) and National Green Tribunal has identified 124 cities across 24 of India's 36 states and union territories as "non-attainment cities" for exceeding pollutant levels set under the National Ambient Air Quality Standards (NAAQS) in 2009 (CEA, 2019). Although already a substantial number, the total of 124 cities may be an underestimate because not all of India's nearly 500 cities have air quality monitoring stations.

Figure 1.20 ▷ Number of clean air days in India, 2019



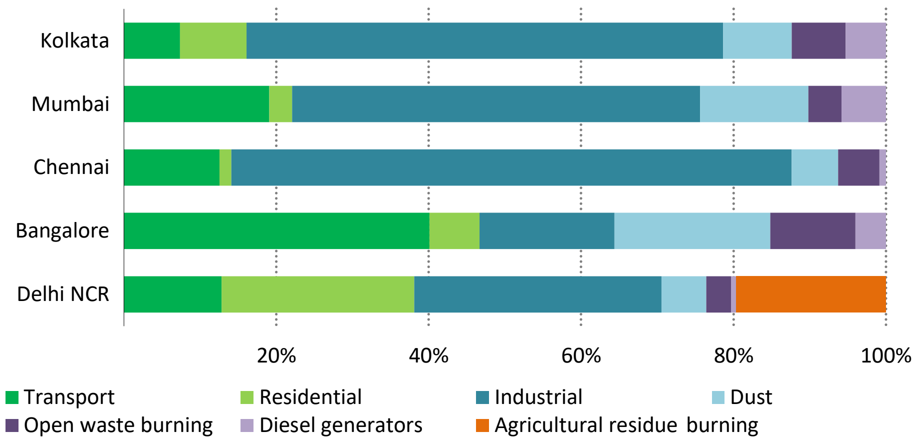
Nearly half of India's population lives in regions with fewer than 200 clean air days a year.

Notes: Clean air days are defined as days where the 24-hour average of fine particulate matter ($PM_{2.5}$) was lower than the CPCB safe limit of 60 microgrammes per cubic metre. This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Source: Blue Sky Analytics (2020).

While air pollution in India is perennial and affects all parts of the country, northern states suffer with particular acuteness in winter, and this contributes to making northern India one of the world's most polluted regions (Figure 1.20). The high levels of air pollution in northern India in the winter have much to do with the region's geographical and meteorological conditions, but the source of this pollution is anthropogenic, and stems primarily from the use of energy. From 70 to 90% of the particulate matter emissions in India's five largest urban agglomerations are a result of energy use (Figure 1.21).

Figure 1.21 ▷ Sectoral origin of $PM_{2.5}$ emissions in selected urban agglomerations



Energy consumption accounts for the majority of air pollutants in India's largest cities.

Notes: NCR = National Capital Region. Industrial emissions includes power generation; data for Bangalore and Chennai are from 2015, while the data of Kolkata, Mumbai and Delhi NCR are from 2018; the NCR includes the cities of Delhi, Noida, Ghaziabad, Gurgaon, Faridabad and other districts that are a part of the geographic entity of NCR; all urban agglomerations considered include some non-urban areas that are a part of the surrounding areas.

Source: IEA analysis based on UrbanEmissions.info (2020) and TERI (2018).

The contribution of human activity to air quality was illustrated during India's Covid-19 related lockdowns, which brought a halt to almost all economic activity. During the six-week lockdown that started in late March, $PM_{2.5}$ levels were 58% lower in Delhi, 45% lower in Bangalore and 30% lower in Chennai than in the same period in the previous year. Similar steep drops were observed in various Indian cities and for all key air pollutants including sulphur dioxide, nitrous oxides and carbon monoxide (Navinya, Patidar, & Phuleria, 2020). These improvements were short-lived, however, and air quality deteriorated quickly as restrictions linked to the pandemic were eased.

The sources of pollutants vary depending on the region and time of the year. The largest contributors across regions tend to be transport, industry, power generation, and biomass or waste burning. One key trigger of rapidly deteriorating air quality in northern India every year is agricultural residue burning in October and November, although transport, industry and other energy sector sources continue to account for a large share of emissions even at this time of the year.

While the focus of research, monitoring and action has largely been on urban areas, air quality levels are also very poor in rural India, where ambient air pollution is compounded by poor household air quality due to the traditional use of biomass for cooking. The overall result is that air pollution has emerged as one of India's deadliest killers and therefore a major public health issue.

The Government of India responded by launching the National Clean Air Programme (NCAP) in 2019, with a target to reduce $PM_{2.5}$ and coarse particulate matter (PM_{10}) concentrations by 20-30% by 2024 from 2017 levels. While such a reduction will not necessarily ensure that cities meet the standards under NAAQS, this is the first time that an air quality improvement target has been linked to a specific date for delivery.

Meeting the target by the date set in the NCAP is likely to be challenging, not least because it will depend on changes in sectors that are not within the remit of the Ministry of Environment, Forests and Climate Change, which is the ministry with responsibility for the NCAP. The changes required are likely to need to include electrification and modal shifts in transport, the universal adoption of clean cooking fuels, a more consistent and stable supply of electricity along with higher levels of renewables generation, and action on industrial emissions through greater energy efficiency and the use of alternative sources of energy to reduce pollution. In northern India, where agricultural residue burning is a key contributor to air pollution in the winter, there is an opportunity to expand the use of agricultural residues in the (currently small-scale) production of bio-based fuels and electricity.

Land

Historically, the primary land challenges relating to energy in India arose from hydropower projects. Despite much of this hydropower capacity being added many years ago, a number of difficult legacy issues remain, including the resettlement and rehabilitation of populations that were displaced during the construction of dams. More recently, India's push for utility-scale solar has also thrown up challenges around land procurement and use. The National Institute of Solar Energy has estimated that 750 GW of solar PV would need only 3% of India's wasteland areas (TERI, 2017). However, wasteland areas have declined over the past few decades, and such wasteland may not always be ideally located for solar projects. In those cases where agricultural land is to be procured for solar projects, the approval of such land for non-agricultural uses can be a time-consuming and contentious process. Land is a state-level responsibility in India, meaning that approvals are needed from the relevant departments of state governments, and from village-level administrations. Improperly maintained land records can lead to patches of land being claimed by multiple entities, and this can slow down land acquisition or lead to litigation.

There are other obstacles too. In some states, there are land ceiling limits which restrict the amount of land that individual owners can acquire. The high population density in most parts of the country, and the tendency of land holdings to be fragmented, compound the difficulties. The average farmland holding was 1 hectare in 2015 (Business Standard, 2018). With the Solar Energy Corporation of India (SECI) stating a minimum land requirement of

1.5 hectares per megawatt, this implies that developers have to deal with multiple landowners.

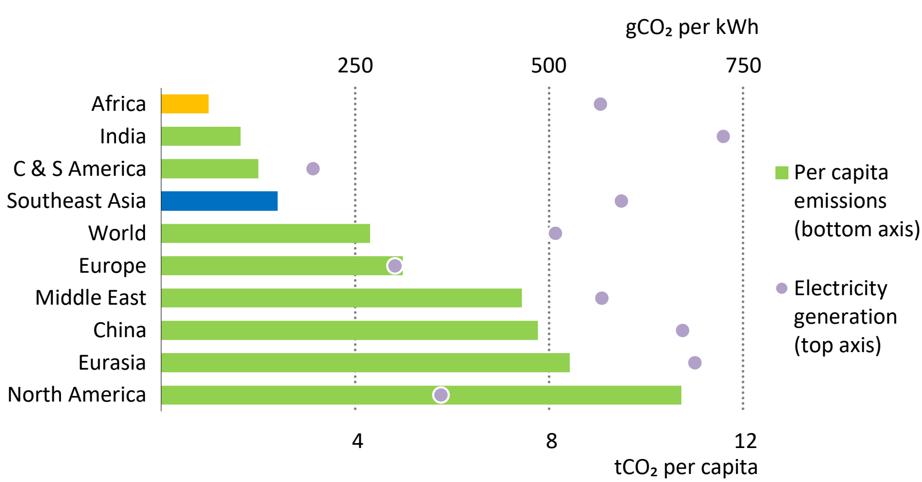
Measures have been introduced to overcome these problems and facilitate the acquisition of land for the development of solar capacity. The SECI has been developing solar parks with state governments, and in these cases the issue of land acquisition is handled by the government. Single-window clearances have also been set up in a few states to expedite approvals. Nonetheless, the lack of a transparent and uniform land acquisition policy, combined with the multiplicity of approvals required, means that land acquisition continues to be a problematic issue for many developers.

Carbon dioxide emissions

Per capita emissions in India remain low by international standards, but 14% of global energy-sector emissions growth since 1990 has nonetheless come from India. India's energy-sector related CO_2 emissions have more than quadrupled since 1990, with the major sources of emissions growth being power generation, industry and transport.

Emissions growth from power generation over this period has been nearly twice total emissions from all sectors in 1990. Coal meets 45% of India's primary energy demand, but is responsible for 70% of India's energy sector CO_2 emissions. The carbon intensity of India's power sector is 725 grammes of CO_2 per kilowatt-hour (g CO_2/kWh), compared with a global average of 510 g CO_2/kWh, underlining the predominant role of inefficient coal-fired generation (Figure 1.22).

Figure 1.22 ▷ CO_2 emissions per capita and emissions intensity of electricity generation by region, 2020



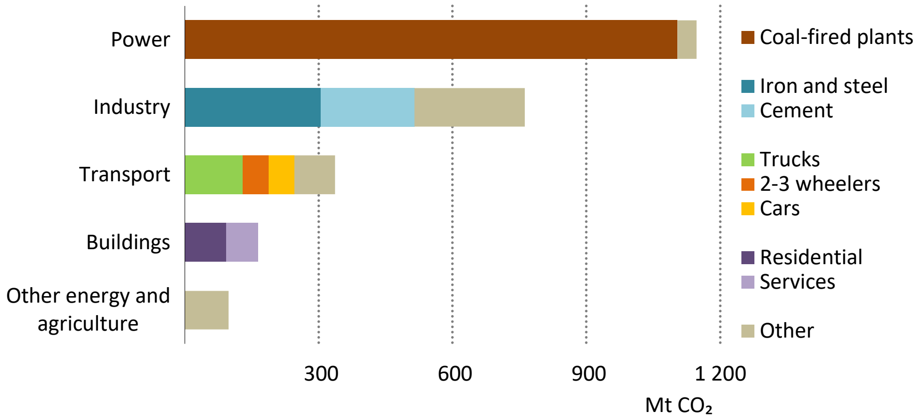
India's per capita CO_2 emissions are 60% lower than the global average, but the emissions intensity of its electricity generation is among the highest of any country.

Notes: tCO_2 = tonnes of carbon dioxide; C&S America = Central and South America.

After power generation, the next highest emitting sector is industry (Figure 1.23). India provides just over 6% of steel production globally, and the iron and steel sector is the largest industrial subsector in terms of emissions: it is responsible for around 30% of India's industrial energy consumption. Coal provides around 85% of the energy used for iron and steel, and the sector makes relatively little use of recycled scrap. This means that India's steel industry is more emissions-intensive than its counterparts in many other countries.

India provides around 8% of global cement production, and this is the second-largest emitting industrial subsector. Although coal and oil are the main fuels used to provide heat for its cement industry, a number of energy efficiency measures have been introduced at Indian cement plants, and total emissions (including indirect emissions from the use of electricity) per tonne of production are nearly 15% lower in India than in China.

Figure 1.23 ▷ CO_2 emissions from the Indian energy sector, 2019



India's power sector is the largest contributor to its CO_2 emissions, and coal-fired power plants are responsible for the great majority of power sector emissions.

Note: *Other* includes other energy sector and agriculture

Oil demand for road freight transport in India has tripled since 2000, highest after China. More than 45% of emissions from road transport in India come from trucks. India's heavy-freight trucks have a relatively high level of fuel consumption per tonne kilometre compared with other countries, but the implementation of new engine standards in 2020 should help to reduce the emissions intensity of activity in the future.

Emissions from passenger road transport in India have also quadrupled since 2000. India has a high share of two- and three-wheelers in its vehicle fleet (four-fold of passenger cars), and this helps to explain why passenger cars in India accounts for only 18% of its overall transport emissions (merely 36% even if two- and three-wheelers is added). This is much lower than many other countries; in the United States, for example, passenger cars account for 57% of total transport emissions.

The direct use of fossil fuels in the buildings sector resulted in just over 160 Mt of CO_2 emissions in 2019, with a further 460 Mt of indirect emissions coming from the use of electricity. India has been seeking to improve the energy efficiency of its buildings through mandatory building energy codes and voluntary rating schemes, as well as through programmes to improve the efficiency of appliances and equipment.

Water

With just 4% of the world's water resources but 18% of its population, India counts as one of the world's most water-stressed countries. Around 45% of its population faces acute water shortages. Groundwater, which provides 85% of the country's rural drinking water and about 60% of its irrigation water, is being rapidly depleted (Kim, 2018). A third of India's groundwater reserves are currently overexploited, meaning more is pumped out than is naturally recharged by rainfall. Moreover, almost 70% of India's water is contaminated (NITI Aayog, 2018). India also suffers frequently from natural disasters: between 1996 and 2015, 19 million people a year in India were impacted by flooding and 17.5 million people a year were affected by drought (UN Water, 2019).

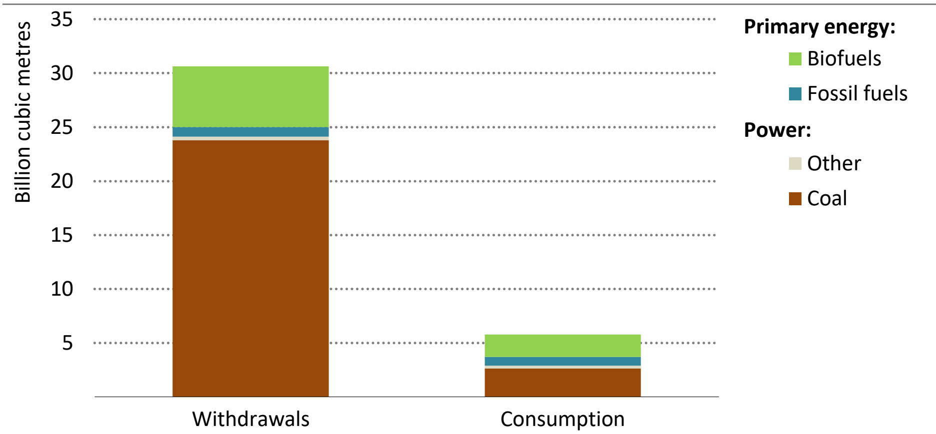
Agriculture accounts for 80% of India's water demand. Water-intensive rice, sugar, maize and cotton are the most prevalent crops grown, and their export means that India is effectively the world's biggest water exporter. Agriculture in India is significantly dependent on irrigation, with over 30% of its agriculture relying on it. A legal framework allowing farmers to extract as much water as they want from underneath their land has contributed to the rapid decline of India's groundwater resources. To improve agricultural productivity and boost incomes, India has undertaken an aggressive campaign to deploy almost 3 million solar pumps. Up to 2018, roughly 180 000 had been deployed. This initiative does not, however, help to tackle the problem of declining groundwater resources, and may exacerbate it.

The problems have been made worse by inefficient irrigation practices, such as flood irrigation. On average, targeted irrigation is deployed on just 10% of irrigated areas across states. The upshot is that water use efficiency on farms in India is among the lowest in the world: three to five times more water is used than on farms in China or the United States to produce the same amount of crops (NITI Aayog, 2018). Switching from low- to high-water-saving irrigation practices could save up to 47% of irrigation water by 2030 (Vaibhav, 2020).

Today, the energy sector withdraws roughly 30 bcm of water (the volume of water removed from a source) and consumes almost 6 bcm (the amount withdrawn but not returned to a source) (Figure 1.24). Coal-fired power generation accounts for 80% of the water withdrawals made by the energy sector, with the water being used mainly for cooling and ash disposal. The energy sector accounts for less than 5% of India's total water withdrawals and less than 2% of consumption, but water availability is nonetheless essential for India's energy security.

India's thermal power plants are already being impacted by water stress: droughts and water shortages caused India to lose 14 TWh of thermal power generation in 2016 (Luo, Krishnan, & Sen, 2018). Recognising the risks posed by potential future water shortages, the government introduced a requirement for new and existing thermal power plants to switch to cooling towers (which withdraw less water than once-through systems) and to comply with water consumption limits per megawatt-hour. Compliance is self-reported, however, and a recent study found that only half of thermal plants for which data could be obtained were compliant with the rules (Manthan Adhyayan Kendra, 2019).

Figure 1.24 ▷ Water use in India's energy sector by fuel and power generation type, 2019



Coal-fired power generation accounts for 80% of India's energy sector water withdrawals.

India has made significant progress towards providing access to clean drinking water and sanitation for all (UN SDG 6). Over 90% of the population now has access to a basic water service.[4] However, more work remains to be done: nearly 200 000 Indians die each year from a lack of access to safe drinking water, 60% of India's wastewater is released untreated, and 40% of the water supply is lost to leaks or theft (Kim, 2018; NITI Aayog, 2018), while 40% of India's population does not have an improved drinking water source available.

For those who do not have access to water, its collection is often done by women, who obtain it from tankers in urban areas or by walking on average 5 km to 20 km a day to a source of water in rural areas (Chandran, 2018). For those who do have access to water, the quality can be poor and intermittent. In many cities, supply is available for just two to three hours a day on average (Chattopadhyay, S., 2020). The government has pledged to provide access to safe and adequate drinking water to all by 2022 and a piped water connection to each household by 2024 via the Jal Jeevan Mission.

Increasing water demand, declining per capita water availability, problems with water quality, lack of storage options, and changing patterns of use all mean that water will remain

[4] A basic water service is access to an improved drinking water source that can be collected in 30 minutes or less round trip. Safely managed drinking water services, the set target under SDG 6.1, are defined as use of an improved drinking water source which is accessible on premises, available when needed and free from contamination.

a challenge for India in the years to come. On current trends, it is estimated that half of India's water demand will be unmet by 2030 (NITI Aayog, 2018). The government of India established the Ministry of Jal Shakti in May 2019, which seeks to prioritise water needs and co-ordinate policies and actions affecting water and water-related activities. Given the importance of water for its energy future, it will be necessary to assess the existing and potential future water needs of the energy sector in order to avoid potential choke points and to identify synergies where they exist.

Several synergies emerge when the SDGs are viewed through an integrated lens, especially between SDG 6 (water and sanitation for all) and SDG 7 (energy for all). For example, technologies being deployed to provide access to electricity can also help with the provision of clean drinking water through the use of pumps and filtration systems. Approaching water and electricity access in an integrated way may shift the emphasis from off-grid solutions towards mini-grid or grid-connected solutions, especially if productive uses are considered, for example the use of water and electricity in agriculture. Managing the energy-water-food nexus is going to be essential in the effort to reach development and climate goals.

1.4 Which way from here?

The projections in this *Outlook*, described in detail in the chapters that follow, describe possible pathways for the future of Indian and global energy systems. They largely follow the overall scenario structure in the IEA *World Energy Outlook 2020*, but there is also an additional case that is specific to this report. The main variable that differentiates the various pathways is the way that government policy preferences and implementation evolve over the coming decades, but our analysis also allows us to explore the implications of a rapid recovery from the Covid-19 crisis, as well as a pathway in which a prolonged pandemic has longer-lasting effects on India's economic development.

- The **Stated Policies Scenario** (STEPS) assumes that significant risks to public health are brought under control gradually over the course of 2021, allowing for a steady recovery in economic activity. This scenario incorporates our assessment of all the policy ambitions and targets that have been legislated for or announced by the Indian government and by other governments around the world. These include nationally determined contributions (NDCs) under the Paris Agreement. An overview of the policy aims incorporated into the STEPS is included in the next section. It is important to note, especially in the light of the IVC, that broad energy and environmental policy objectives are not automatically assumed to be met in the STEPS. They are implemented to the extent that, in our assessment, they are backed up by specific measures and funding. This is not a judgement of the feasibility of the government's ambitions or its commitment to them, but a reflection of our view of the real-life constraints – including regulatory, financial and administrative barriers – that have to be faced.
- The **India Vision Case** (IVC) takes a more optimistic view of the prospects for full implementation of India's stated policy aims (Box 1.3). On the economic front, the IVC implies not just a rapid resolution to the public health crisis caused by Covid-19, but also successful structural reforms that raise the long-term growth potential of India's

economy, meaning that the assumed rate of economic growth is higher than in the STEPS. In the energy sector, it assumes that key targets are met to the extent possible. One important finding from this analysis is that it is not possible to hit every target; for instance, the government's volumetric target to expand domestic coal production is not met in the IVC partly because of the expansion of renewables and improvements in efficiency in line with other government targets. The IVC in this year's edition follows a similar case included in the 2015 *India Energy Outlook*, allowing us to explore how India's vision has evolved over the last five years.

- By contrast, the **Delayed Recovery Scenario** (DRS) examines downside risks to economic and social development, linked to the possibility that the Covid-19 pandemic turns out to be more prolonged than assumed in other scenarios. The overarching policy assumptions are similar to those in the STEPS, but the assumed rate of economic growth is lower. The global outcomes in this scenario are explored in full in *World Energy Outlook 2020*; insights into the implications for India are introduced at various points in the chapters that follow.
- The **Sustainable Development Scenario** (SDS) takes a different approach from the other scenarios and cases in this *Outlook*. Whereas the others take a set of initial assumptions and see where they lead, the SDS works back from the achievement of specific outcomes and assesses what combination of actions would be required to get there. The key outcomes that this scenario delivers are drawn from the UN SDGs: effective action to combat climate change by holding the rise in global average temperature to "well below 2°C … and pursuing efforts to limit [it] to 1.5°C", as set out in the Paris Agreement; universal access to affordable, reliable and modern energy services by 2030; and a substantial reduction in air pollution. In the SDS, India is on track to reach net zero emissions beyond the modelling horizon – in the mid-2060s.

None of these scenarios is a forecast of what will happen over the coming years; the IEA does not have a single view of how the future will look. With myriad near-term uncertainties, our aim is more modest and, we hope, more useful: to highlight the range of possible futures, and the actions and circumstances that might bring them about.

The projections in each of these scenarios are generated by the IEA World Energy Model, an energy systems model that has been developed over many years to provide insights into energy and environmental trends. A key asset of this integrated modelling is that it allows us to investigate the interconnections among different parts of the system, both within India and between India and the rest of the energy world. This generates insights into the trade-offs and co-benefits that exist between different policy objectives and courses of action.

India faces the need to pursue multiple policy objectives in parallel in order to support a growing population and economy, including energy access, energy security and sustainability. In order to do so effectively, there is a need to approach energy policy making and planning with a view to the system-wide impacts of different policy choices. For example, road or rail transport policies formulated by the respective ministries in India have potential implications not only for transport demand, but also for power generation capacity, refinery configurations, natural gas supply infrastructure, GHG emissions and air quality. And India's choices also have significant impacts for global trends. The scenarios and analysis in this *Outlook* allow us to highlight these interlinkages.

Box 1.3 ▷ How is the India Vision Case different?

The IVC reflects the energy, environment and economic targets of the Indian government. It goes beyond stated policies and tests the following aspirations against the outcomes of *WEO* modelling:

- Achievement of 450 GW of non-hydro renewable capacity by 2030. A greater degree of financial de-risking, underpinned by a favourable regulatory environment, allows public and private actors to scale up investment in clean energy technologies. Compared with the STEPS, there is much greater uptake of rooftop solar and wind energy.
- A substantial increase in the share of natural gas in India's primary energy mix by 2030. There is a much greater use of gas for electricity generation than in the STEPS, and gas is used in particular as a source of flexibility. Gas also displaces fuels including diesel in the captive power sector.
- An acceleration in the uptake of alternative fuels in the transport sector. The share of EVs in total road vehicle sales reaches 38% by 2030 (25% of sales in the case of passenger cars), and bioenergy, including both bioethanol/biodiesel as well as bio-CNG, start to be used.
- A rapid and widespread implementation of efficiency measures across the energy economy, especially in buildings but also in industry.
- Achievement of India's energy access goals in full by 2030, meaning that traditional uses of biomass are entirely phased out by this date.
- A longer-term focus on deep decarbonisation of the industrial sector, which translates into a ramp-up of carbon capture and storage technologies, together with early efforts to explore hydrogen pathways that yield some initial production from low-carbon sources.

1.4.1 India's energy policies

India's energy policies and ambitions are often disparate and sector-specific because they emanate from different ministries and agencies (Box 1.4). However, these policies and ambitions all relate to the overall goal of providing affordable, reliable and sustainable energy services.

India's NDC under the Paris Agreement is an important reference point for energy and climate policy. In the NDC, India has committed to improve the emissions intensity of its economy by 33-35% by 2030, compared with 2005 levels, and to achieve a 40% share of non-fossil fuels in electricity generation capacity by 2030. The prime minister of India has also articulated seven focus areas for its energy economy, including a move towards a “gas-based economy”, cleaner use of fossil fuels, greater use of biofuels, rapid scaling up of renewables, a focus on electric mobility, a shift towards emerging fuels including hydrogen, and digital innovation across energy systems.

There are specific targets to be achieved by 2030, including 450 GW of renewable power capacity, a 15% share of natural gas in the primary energy mix, a 30% share of passenger car sales for EVs and a 20% blending of biofuels in petrol. There are also targets for increased energy efficiency across sectors, affordable housing for all, the electrification of railways, the reduction of crude oil imports, and the ending of coal imports in the 2020s. While they all come under the overarching framework described above, many of these targets were decided independently of one another.

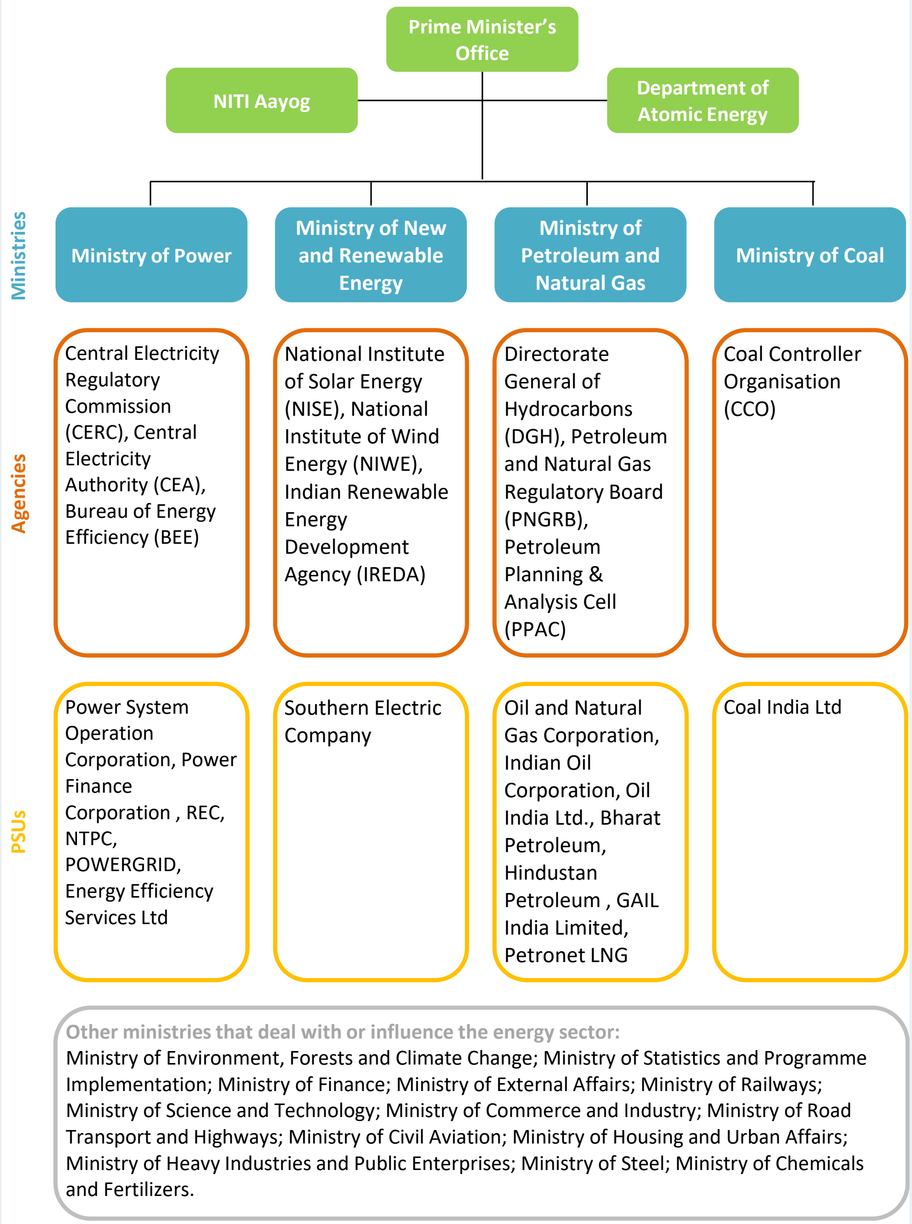
In addition to central government targets, there are subnational targets announced by state governments, especially in the case of electricity, EVs and energy efficiency. For instance, the state of Gujarat announced in 2019 that it will no longer invest in new coal-fired power capacity. Some states also have targets and policies on rooftop solar and electric mobility in their respective jurisdictions.

Box 1.4 ▷ India’s energy governance and institutional arrangements

India’s energy sector is subject to the central and state governments in different ways. Under India’s constitution, the petroleum, natural gas, aviation and railways sectors come within the legislative ambit of the central government, whereas electricity comes within the legislative ambit of both the central and state governments. As a result, India’s energy sector is governed by multiple ministries and agencies at both the central and state levels.

In the central government, various ministries and agencies have energy-related responsibilities under the overall purview of the Prime Minister’s Office (PMO). Each of these in turn has under it a range of specialist agencies and regulatory bodies, as well as public sector undertakings (PSUs), which are publicly owned companies (Figure 1.25). There are also agencies under the 28 state governments with responsibilities related to electricity, road transport, buildings and energy efficiency; these include State Electricity Regulatory Commissions (SERCs) in charge of managing intra-state transmission, distribution, trade and other aspects of electricity supply. There is also a Forum of Regulators (FOR) to facilitate co-ordination among the multiple state regulatory agencies and the central regulator.

Figure 1.25 ⊳ Governance of the energy sector by the central government



India has multiple bodies in central government with a range of energy-related competencies and functions.

1.4.2 Economic and population growth

Alongside energy policies, the other principal determinants of energy demand growth in our scenarios are the rates at which economic activity and population are assumed to grow. These indicators are naturally subject to a wide level of uncertainty, which has been exacerbated – particularly for the economy – by the effects of the Covid-19 pandemic. With this in mind, this *India Energy Outlook* considers multiple possible trajectories for future growth in India's GDP.

After an unprecedented drop of around 8% in economic output in 2020, uncertainties over employment and strains to balance sheets and household finances are feeding through into constrained investment, despite government attempts to stimulate activity and limit the economic damage (see section 1.3.1). Against this backdrop, the near-term shape of the economic recovery is closely tied to success in tackling the spread of the virus. However, the longer-term outlook also depends on building out India's physical and social infrastructure (a major focus for India's stimulus spending), as well as on progress in tackling structural challenges affecting investment such as complicated permitting processes, tax arrangements and land acquisition processes.

Table 1.2 ▷ Real GDP average growth assumptions by scenario

		STEPS			IVC	DRS
	2010-19	2019-25	2025-40	2019-40	2019-40	2019-40
India	6.6%	4.5%	5.7%	5.4%	6.0%	4.9%
World	3.4%	2.7%	3.1%	3.0%	3.1%	2.6%

Note: Calculated based on GDP expressed in year-2019 US dollars in PPP terms.

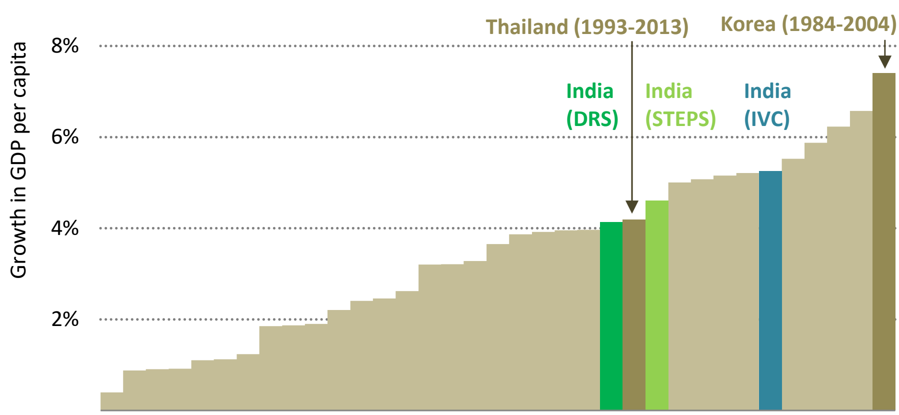
Sources: IEA analysis based on IMF (2020b); IMF (2020c); Oxford Economics (2020).

Our baseline assumption in the STEPS and in the SDS is that the pandemic is gradually brought under control in the course of 2021, allowing for a steady but far from V-shaped recovery in economic activity. In these scenarios, the supply side effects of the pandemic are significant, but are limited by the relatively short duration of the crisis together with effective policy responses, and the trend rate for growth in Indian GDP post-2022 moves back towards the level assumed before the crisis. The Indian economy is nonetheless smaller in 2040 than it was in the same scenarios in the *WEO 2019*.

In the IVC, a swift and effective recovery from the effects of Covid-19 is accompanied by a range of structural reforms that allow India to recover the lost ground in full and raise its long-term growth potential. In this case, India becomes a $5 trillion economy before the end of the decade, somewhat later than targeted by the Indian government. Conversely, the DRS illustrates the risks arising from a prolonged pandemic. In this scenario, unemployment and fragile finances hit demand and investment across the entire economy, and rising debts limit the scope and effectiveness of government action.

To put these growth trajectories in historical context, we looked at macroeconomic data since 1950 to see how other countries fared from the moment that they achieved a similar level of economic development to today's India, and compared the subsequent economic performance of those countries with the assumptions in our scenarios. Despite the shock of Covid-19, the assumed rates of growth in all our India scenarios are in the upper part of the historical range (Figure 1.26). The IVC is in the top 10% of the sample, and the only countries that have performed better than India does in the IVC are East Asian exporters such as Korea that saw sustained rates of rapid growth. In the STEPS and SDS, India's projected growth would come in slightly ahead of the post-1993 record of Thailand (a period that includes the effects of the Asian financial crisis).

Figure 1.26 ▻ India's economic outlook by scenario in a historical context



The GDP growth rate outlook considered in the IVC is in the top 10% of the sample of countries with similar levels of per capita income in the past.

Notes: Figure shows the average change in GDP per capita over a 20-year period for a sample of countries, starting when GDP per capita was comparable to India today. Data since 1950, excludes major hydrocarbon exporters.

Source: IEA analysis based on data from Penn World Tables (2020).

Our population assumptions for India are derived from the median variant of the United Nations projections (UNDESA, 2019). According to these estimates, India's population rises from 1.37 billion in 2019 to 1.59 billion in 2040, meaning that it becomes the most populous country in the world by the mid-2020s. India's total fertility rate in 2017 fell to 2.2, implying that every woman was giving birth to 2.2 children. Since then it is likely to have fallen close to the "replacement level" mark of 2.1 — and will continue to fall in the next two decades — thereby moderating the population growth to 2040. The share of India's population living in urban areas is currently around 34%, but this is assumed to rise to 46% by 2040, meaning that India's urban population is projected to rise by some 270 million people over the coming two decades. This is the equivalent of adding a new city the size of Los Angeles every year.

1.4.3 Energy prices[5]

The equilibrium prices for our scenarios (where comparable scenarios exist) have been revised down as a result of the pandemic, because of the effect of the crisis on global demand and because of changes to producer strategies and cost structures on the supply side. However, although the price trajectories are smooth, the possibility of price spikes and volatility cannot of course be discounted, and may indeed have increased as a result of very sharp cuts to investment and strains on producer finances.

In the case of oil, prices rise in the STEPS in order to stimulate a rebound in investment, after which they settle in a range between $75/barrel to $85/barrel, a level at which global supply – including from US shale – is quite elastic. Natural gas prices rise gradually as the current global surplus erodes: India's imports are increasingly assumed to be priced off indices that reflect Indian market dynamics rather than the cost of competing fuels. International coal prices remain subdued, reflecting lower global consumption as well as the ambition in India to satisfy a larger share of demand from domestic supply.

Table 1.3 ▷ India fossil fuel prices by scenario

			STEPS		IVC		SDS		DRS	
Real terms ($2019)	2010	2019	2025	2040	2025	2040	2025	2040	2025	2040
Crude oil ($/barrel)	91	63	71	85	71	85	57	53	59	72
Natural gas ($/MBtu)	9	11	10	9	9	9	5	6	9	9
Steam coal ($/tonne)	71	68	65	63	62	60	58	51	61	59

Notes: MBtu = million British thermal units. The crude oil price is a weighted average import price among IEA member countries. Natural gas prices are averages for imported gas, expressed on a gross calorific value basis. Steam coal prices are weighted averages adjusted to 6 000 kilocalories per kilogramme. The steam coal price is solely for imports. India prices for natural gas and steam coal are both wholesale prices.

Prices in the IVC are assumed to be broadly similar to those in the STEPS, as the changes in Indian demand are not in themselves large enough to affect global equilibrium prices. Natural gas could have been an exception to this, but the upward pressure on global prices created by extra Indian LNG imports in this scenario is assumed to be offset by the creation of a deeper and better functioning gas market, which in itself is sufficient to bring forward additional investments in supply.

Prices in the DRS are lower for each fuel than in the STEPS because demand is lower and it takes longer to work off the existing overhang in supply capacity. In the SDS, fuel prices stabilise at still lower levels because of considerably lower demand for fossil fuels, removing the need to develop higher-cost resources.

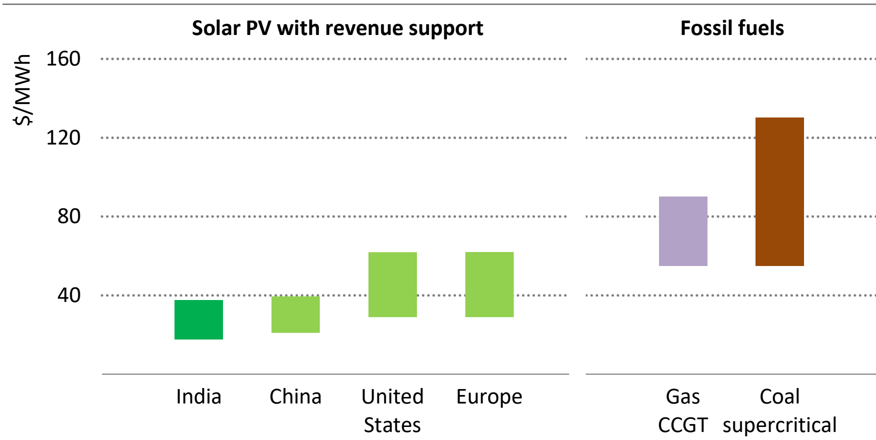
[5] See the *World Energy Outlook 2020* for additional details on the global price trajectories

1.4.4 Technology innovation, deployment and costs

A wide range of technologies are deployed to meet energy demand in our scenarios, and the cost of each of these is influenced in the World Energy Model by a continuous process of technology improvement and learning. This applies across the board to appliances and motors purchased by end users; infrastructure for transporting energy products, including smart grids; and technologies for electricity generation, energy extraction and transformation.

A crucial dynamic for the India outlook is the way that key renewable electricity production and storage technologies – including solar PV, wind and batteries – are expected to continue getting cheaper quickly through a combination of research, economies of scale and improvements in manufacturing and installation processes (Figure 1.27). The pace of change varies by scenario according to levels of deployment, linked in turn to the policies that are in place. However, with revenue support mechanisms in place that bring down financing costs in countries including India, new solar PV projects are now estimated to have levelised cost of electricity (LCOE) of $20 per megawatt-hour (MWh) to $40/MWh in India, entirely below the range of LCOE for new coal-fired power plants and approaching parity with the operating costs of some existing coal-fired plants. Coal-fired plants may be able to capture some additional market value because of their ability to match system needs, indicating a closer competition than one based solely on costs alone. But it remains the case that utility-scale solar PV is already very well placed as a preferred technology for new generation, and there are innovative ways in which solar is being bundled together with other technologies to increase its value (see section 3.2).

Figure 1.27 ▷ Utility-scale solar PV LCOE under revenue support mechanisms, 2020 final investment decision



Utility-scale solar PV is now consistently cheaper than new gas- or coal-fired power plants due to technology gains and revenue support mechanisms.

Note: CCGT = combined-cycle gas turbine.

Oil and gas costs around the world are structurally lower than in previous *WEO*s, although in many cases resources gradually become more expensive to extract over time (as continued upstream innovation and technology improvements are offset by the effects of depletion on costs). As a result, these fuels face increasingly stern competition in a growing number of applications from low-carbon energy supplies.

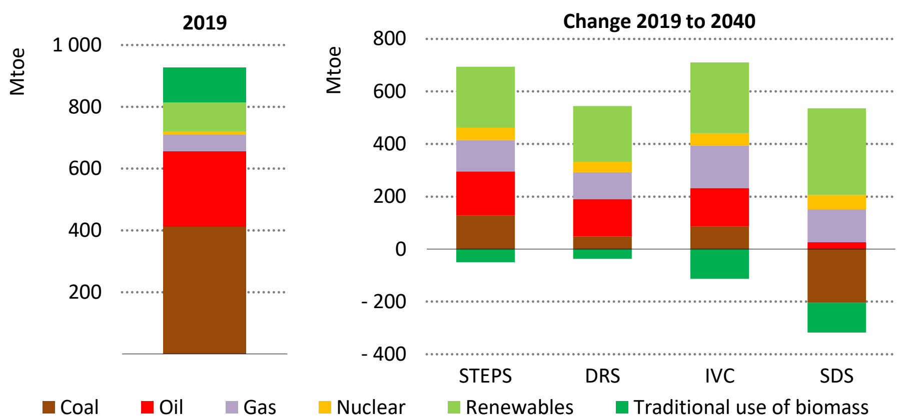
Urbanisation and industrialisation in India

Building an energy future

SUMMARY

- The Covid-19 pandemic has introduced major new uncertainties into the outlook for India's energy sector, but it has not altered the key underlying drivers. Chief among them are urbanisation and industrialisation. Up until now, India's economic growth has been driven mainly by the services sector, rather than the more energy-intensive industry sector, and the rate at which India has urbanised has been somewhat slower than in other emerging countries. How fast India urbanises and industrialises over the coming decades, and which policies govern these processes, will be of crucial significance for its energy future and for global trends.
- Over the period to 2040, an estimated 270 million people are likely to be added to India's urban population, the equivalent of adding a new city the size of Los Angeles every year. Even with such rapid urbanisation on a very large scale, the share of India's population living in urban areas in 2040 is still expected to be less than 50%.

Figure 2.1 ▷ Total primary energy demand in India by fuel and scenario



India leads global energy demand growth in every WEO scenario, although the way this demand is met depends on the interaction of policies, technologies and market forces.

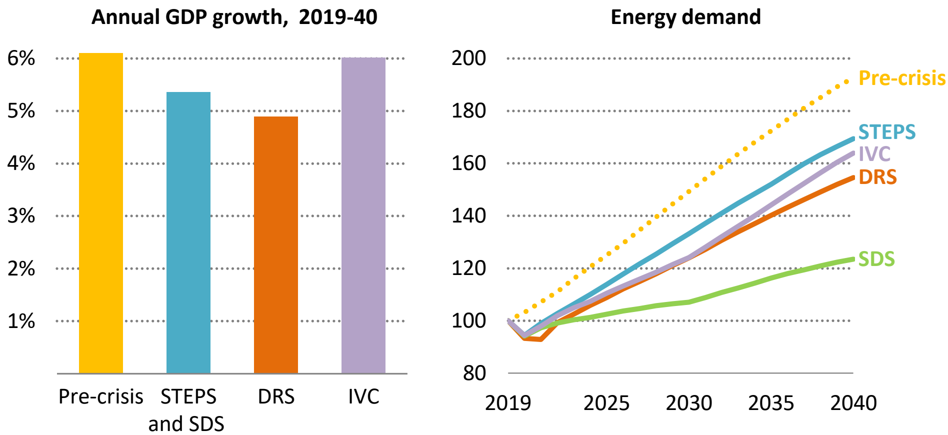
- Most of the buildings that will exist in India in 2040 have yet to be built. Urbanisation underpins a massive increase in total residential floor space from less than 20 billion square metres today to more than 50 billion in two decades' time. This prompts huge growth in demand for energy-intensive building materials. In the STEPS, demand for cement more than doubles to 2040, and demand for steel nearly triples.

- Urbanisation is also a spur for a transition in household energy use away from solid biomass and towards electricity. Rising ownership of appliances and demand for air conditioners mean that the share of energy demand taken by electricity in India's buildings sector rises from a quarter today to around half by 2040 in the STEPS. There is considerable scope for India to expand the application of its Energy Conservation Building Codes and further tighten appliance standards to limit future strains on its energy system.
- Transport is currently the fastest-growing end-use sector in terms of energy demand, and urbanisation will foster further growth. In many Indian cities, increasing demand for transport has so far led to much congestion and poor air quality. This has prompted a range of policy initiatives on fuel efficiency and quality, mass transit, and the electrification of transport. However, today's policy settings are not yet enough to avoid a large projected increase in oil demand for road transport, which doubles in the STEPS by 2040.
- Industry is the end-use sector that currently uses most energy, and its share in total final consumption rises from 36% today to 41% by 2040 in the STEPS. As coal use for power generation flattens out, industry accounts for almost two-thirds of the growth in India's coal demand and becomes the major source of growth in emissions. Moreover, since the majority of goods transported in India move by road, industrial expansion translates into rapid growth in diesel use for road freight, despite initiatives to shift more of the freight market onto the railways.
- Efforts to promote energy efficiency and material efficiency, and greater use of natural gas and electricity, in particular for lighter manufacturing, all mitigate the rise in industrial energy use in the STEPS, but there is considerable potential for further efficiency gains. These gains are seen to some extent in the IVC and more comprehensively in the SDS.
- Different scenarios inevitably produce different outcomes. In the DRS, energy demand and emissions are suppressed by a lower level of economic activity. Positive environmental outcomes therefore come at a very high cost. By contrast, the IVC delivers both higher economic growth and lower emissions than the STEPS as a result of policy actions which increase efficiency and achieve a faster transition to clean electricity and natural gas.
- The SDS goes further in the direction of improving efficiency and the use of low-carbon technologies. Alongside improved air quality and enhanced energy access, India sees an early peak in energy-related CO_2 emissions and a rapid subsequent decline, putting the country on track for net zero emissions by the mid-2060s.

2.1 Overview of energy demand

India, in common with much of the rest of the world, has been severely affected by the Covid-19 pandemic, in terms of both the immediate toll on human life and the broader impact on livelihoods due to lockdowns and other restrictions. There are multiple possible pathways that India could follow as it emerges from today's crisis (Figure 2.2).

Figure 2.2 ▷ Growth in India GDP and energy demand to 2040 by scenario



Differences between scenarios to 2030 are explained by duration of the pandemic (in DRS) and a faster pace of structural changes in energy production and use (in IVC and SDS).

Note: Pre-crisis shows the *WEO 2019* STEPS projections.

One key near-term uncertainty is the effectiveness of measures to limit the spread of the virus, including how quickly vaccines are made available and distributed. The DRS examines the effects of a prolonged pandemic and a slow economic recovery.

Another key uncertainty is the policy response from the Indian government and others to today's challenges. This includes the extent to which they incorporate energy and sustainability into their recovery strategies, and the extent to which they address structural issues that characterised the economy even before the Covid-19 pandemic. Different assumptions about these policy responses underpin the differences in energy and economic outcomes between the STEPS, the IVC and the SDS.

The electrification of the Indian energy economy continues apace in all scenarios. The share of electricity in total final consumption grows in all sectors, and particularly in the buildings sector, where there is a continued pivot away from traditional biomass and a steady uptake of appliances. In the STEPS, the share of demand met by electricity rises from around 17% today to nearly a quarter by 2040, displacing 60 Mtoe of oil, coal and biomass.

The dominance of coal in India's energy system continues to recede. Coal is the slowest-growing energy source in the STEPS, meaning its share in the energy mix falls from 44% in

2019 to 34% by 2040. As the incumbent fuel in the power sector, coal faces strong competition from renewables in general and from solar PV in particular. However, greater electricity demand and a near-doubling in the use of coal in industry means that the overall demand for coal still rises by over 30% from 2019 to 2040, reaching 770 Mtce.

Oil demand, by contrast, sees a relatively swift comeback from Covid-induced disruption. There is a doubling in oil demand in road transport by 2040 in the STEPS, largely as a result of the addition of 170 million passenger cars and 25 million trucks to the vehicle stock between 2019 and 2040. Oil consumption is also lifted by a tripling of feedstock demand in the petrochemical industry.

Natural gas is the fastest-growing fossil fuel in the STEPS, and the roll-out of gas infrastructure makes the fuel accessible to a growing share of India's industrial base as well as to residential consumers. The share of industrial energy demand accounted for by gas doubles to reach 20% by 2040. Policy support for gas use in transport, both as conventional CNG and bio-CNG, results in a threefold increase in CNG demand.

The energy mix in India becomes much more diverse. Today coal, oil and traditional biomass meet more than 80% of demand. In 2040 modern bioenergy and renewables including solar, wind and hydropower meet nearly a quarter of India's total energy demand in the STEPS. Primary energy use per unit of GDP falls by half as the link between economic growth and energy consumption weakens further.

In the STEPS, total CO_2 emissions in 2040 are 45% higher than in 2019, and emissions per capita also rise, but emissions intensity goes down significantly. India's NDC under the Paris Agreement include a reduction by 2030 in the emissions intensity of GDP by 33-35% compared with 2005 levels. The energy sector achieves this target under the STEPS, with a CO_2 emissions intensity reduction of over 40% by 2030.

In the IVC, key Indian policy objectives are met in full, and this delivers higher economic output together with lower energy demand and lower emissions than in the STEPS. India moves more quickly towards a gas- and renewables-based economy, and the use of traditional biomass in particular fades rapidly as modern cooking fuels gain ground.

The SDS sees a far more profound transformation of India's energy sector. Demand in 2040 is nearly 30% below the level in the STEPS, as the move away from traditional biomass is complemented by concerted efforts to improve energy efficiency across a wide range of end uses. There is a decisive shift away from coal, and solar PV eclipses coal's share of electricity generation a full decade ahead of the STEPS. Oil demand reaches a plateau by the end of the 2020s as the share of alternative fuels in road transport – electricity, gas and bioenergy – rises: together these alternative fuels meet 35% of road transport demand by 2040. Fossil fuels account for less than 60% of primary energy demand by 2040, compared with 72% in the STEPS, while the traditional use of biomass falls to zero by 2030, as clean cooking goals are fully achieved. In the SDS, India sees an early peak in energy-related CO_2 emissions and a rapid subsequent decline, putting the country on track for net zero emissions by the mid-2060s.

Table 2.1 ⊳ Energy demand by scenario

			STEPS		SDS		IVC	
	2000	2019	2030	2040	2030	2040	2030	2040
Primary energy demand (Mtoe)	**441**	**929**	**1 237**	**1 573**	**994**	**1 147**	**1 153**	**1 526**
Total final consumption (Mtoe)	**315**	**621**	**853**	**1 123**	**703**	**843**	**783**	**1 075**
Electricity demand (TWh)	**369**	**1 207**	**1 959**	**3 146**	**1 922**	**2 980**	**2 087**	**3 433**
CO_2 emissions (Gt)	**0.9**	**2.5**	**3.2**	**3.8**	**2.4**	**1.8**	**3.0**	**3.4**
Coal demand (Mtce)	**208**	**590**	**712**	**772**	**454**	**298**	**660**	**712**
Power generation	147	397	453	444	232	60	371	362
Industry	37	141	198	255	169	185	193	240
Natural gas demand (bcm)	**28**	**63**	**131**	**201**	**144**	**210**	**159**	**260**
Power generation	11	17	25	33	49	61	62	95
Industry	4.3	24	61	106	50	84	60	107
Buildings	0.3	3.9	7.3	11	5.2	7.0	9.0	15
Transport	0.1	4.1	9.2	12.1	9.6	11.9	10.9	15.6
Low-carbon gases (bcm)	**0.0**	**0.0**	**6.4**	**21**	**20**	**47**	**10**	**31**
Oil demand (mb/d)	**2.3**	**5.0**	**7.1**	**8.7**	**6.2**	**5.8**	**7.0**	**8.3**
Road transport	0.6	1.9	2.9	3.8	2.4	2.1	3.0	3.8
Aviation and shipping	0.1	0.2	0.4	0.6	0.3	0.4	0.4	0.6
Industry and petrochemicals	0.6	0.9	1.5	1.8	1.2	1.3	1.4	1.7
Buildings	0.4	1.0	1.3	1.4	1.4	1.1	1.4	1.5
Biofuels (Mboe/d)	**0.0**	**0.0**	**0.1**	**0.2**	**0.2**	**0.2**	**0.1**	**0.2**

Notes: Gt = gigatonnes; Mboe/d = million barrels of oil equivalent per day.

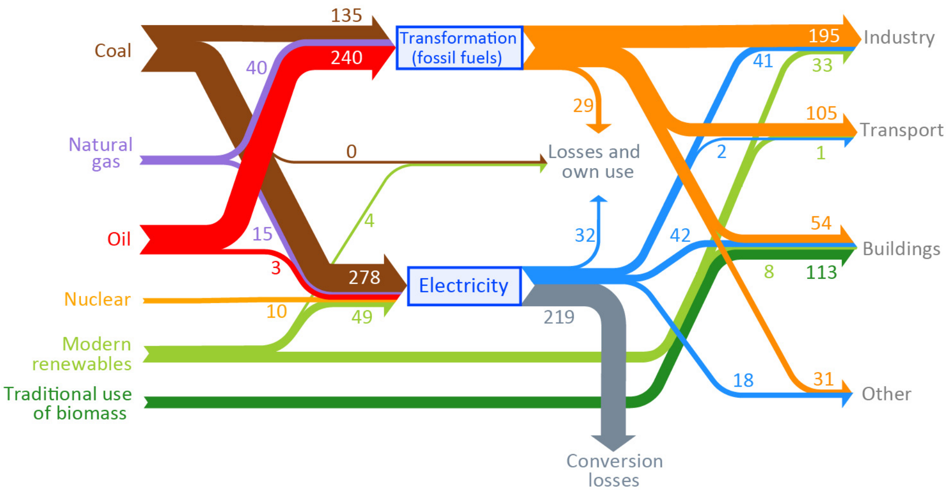
The diagrams in Figure 2.3 provide a visual representation of the flows of energy in India's energy system, and show how they change from 2019 to 2040 in the different scenarios. The diagrams include the various transformation processes used for electricity and for fuels (e.g. refining), and also illustrate the substantial conversion losses that occur in the process of electricity generation. These losses are dramatically reduced in the SDS because of the shift towards non-combustion renewable sources of power.

The flows do not, however, capture the efficiency with which different energy carriers provide useful energy services to consumers. The IVC, for example, leads to a marginally smaller overall energy system than the STEPS in 2040, but supports a larger economy. The SDS is even more efficient, as well as being much less carbon-intensive. This partly stems from its high degree of reliance on electricity. Given that electricity delivers useful energy services with better efficiency than other fuels, the role of electricity is greater in practice than its share in final consumption would suggest.

Figure 2.3 ▷ Evolution of India's energy system by scenario (Mtoe)

2019

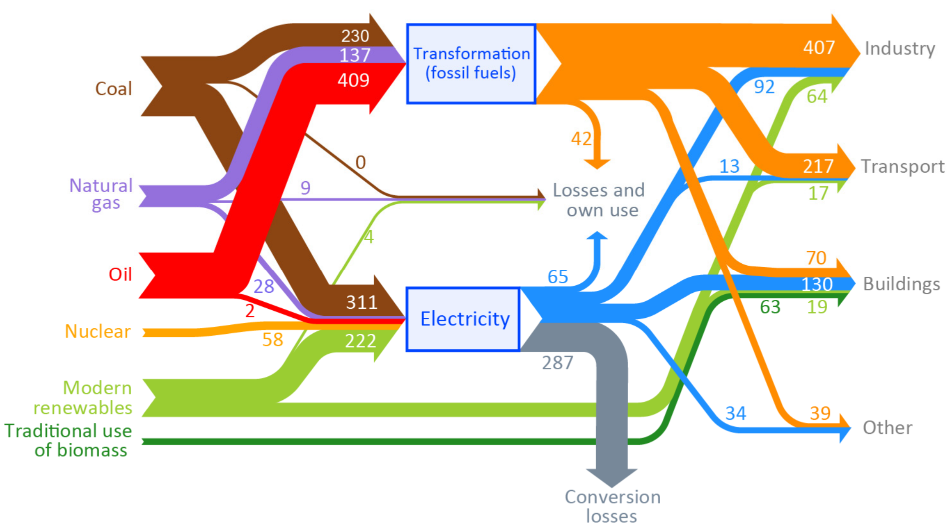
GDP $2.9 trillion[1]



Coal, oil and biomass meet over 80% of India's energy demand today.

STEPS 2040

GDP $8.6 trillion

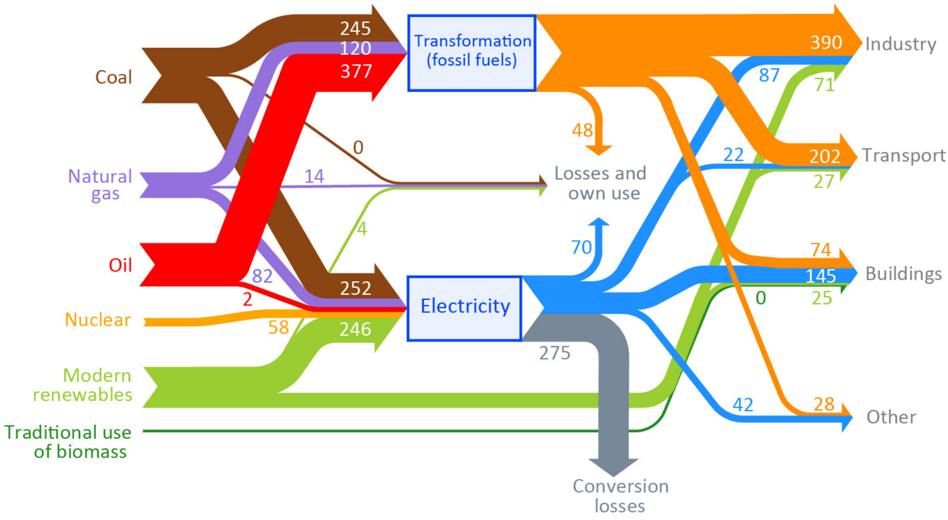


By 2040, India's energy consumption nearly doubles in the STEPS.

1 All GDP values in this figure are $2019 at market exchange rates.

IVC 2040

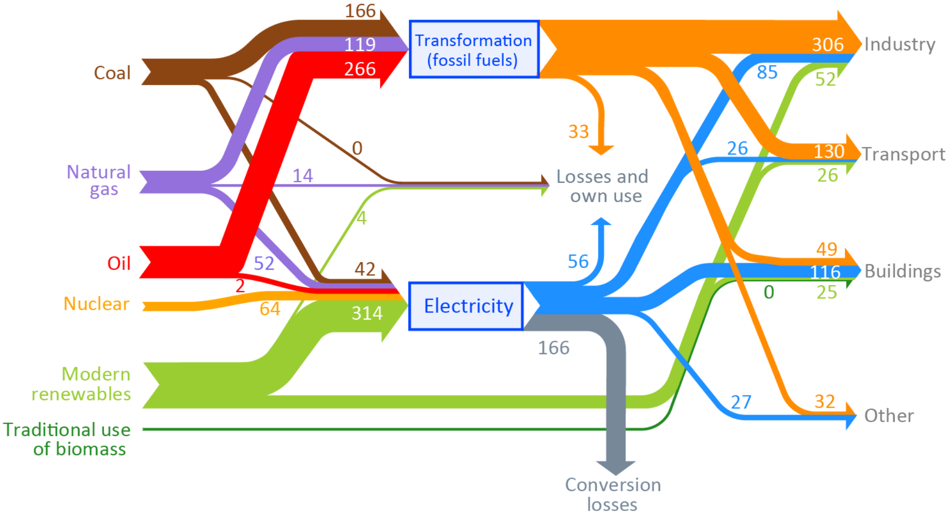
GDP $9.8 trillion



Despite producing a smaller energy system than the STEPS in 2040 the IVC supports a larger economy.

SDS 2040

GDP $8.6 trillion



In 2040, the SDS is more efficient and less carbon-intensive than the STEPS and the IVC.

2.2 The forces and uncertainties shaping energy demand

Despite brisk economic growth in recent decades, India is still a lower-middle-income country. Even measured at PPP, its GDP per capita is almost 85% lower than that of advanced economies. Against this background, India's government wants to see substantial economic growth to raise living standards and reduce poverty. Over the projection period of this *Outlook*, 2019 to 2040, India's GDP is set to grow substantially. This will undoubtedly mean significant growth in demand for energy services. How this demand is met, which fuels and technologies are available and at what price, is a crucial issue for the aspirations and livelihoods of India's citizens. India's choices will in turn have a huge influence on global trends, against a backdrop of accelerating global action on climate change and commitments to reach net zero emissions. The objective of this section is to understand the macroscale drivers and uncertainties of demand growth in this new context. It starts with a brief review of historical energy demand growth before turning to the outlook period.

2.2.1 GDP and energy intensity

Between 1990 and 2019, India's GDP increased more than sixfold, while total final consumption increased only by a factor of 2.5. In other words, GDP grew more than twice as fast as energy consumption. Three main factors contributed to this rapid improvement in the final energy intensity of GDP.

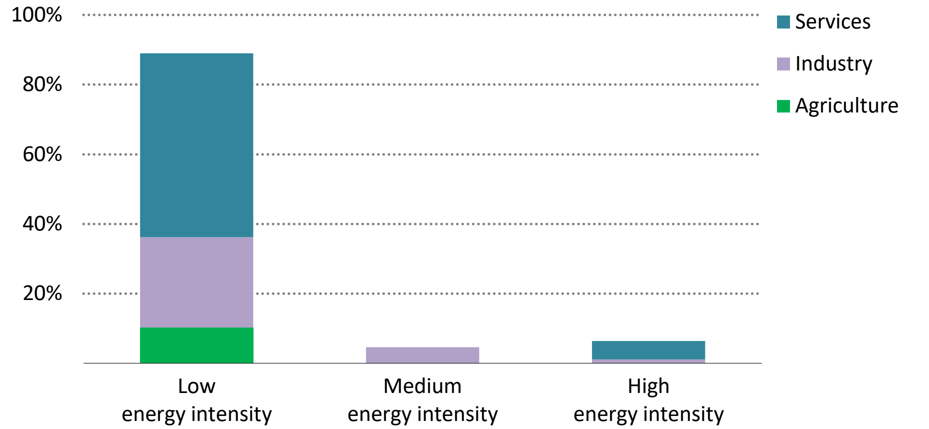
The first was the structural transition away from traditional biomass as a fuel in the residential sector. Although India still consumes a large amount of traditional biomass, the share of total final consumption accounted for by biomass fell from 42% in 1990 to 18% in 2019, as widespread electrification took place, oil consumption in transport grew and the buildings sector transitioned towards modern fuels. This transition in the buildings sector entailed a shift from traditional sources of biomass with very low conversion efficiencies (in the order of 5-10%) towards higher efficiency fuels such as LPG and electricity. The efficiency gains from fuel switching helped to enable substantial growth in economic activity without commensurate growth in energy consumption: the decline in traditional biomass was responsible for nearly 60% of the decline in energy intensity between 1990 and 2019.[2]

The second driver of this dramatic improvement in energy intensity was the structure of India's economic growth model. Unlike East Asian or some Southeast Asian countries, such as Korea, China and Viet Nam, India's economic growth has historically been driven by the services sectors, not the more energy-intensive industry sectors. This is illustrated in Figure 2.4, which shows that nearly 90% of total value-added growth in the period 1990-2017 came from sectors in the lowest energy intensity category. These include large retail service

[2] This may seem like a windfall that should not be recorded as an improvement in energy intensity per se. However, given the real economic costs of traditional biomass use, notably the time required to collect it and the health costs of indoor pollution, the transition away from traditional use of biomass is a driver of greater economic efficiency and thus rightfully recorded in indicators such as falling energy intensity of GDP.

sectors such as trade as well as very productive "low footprint" sectors such as business and financial services. India's service-oriented model of international trade has further embedded these less energy-intensive sectors in the domestic economy.

Figure 2.4 ▷ Share in value-added growth by sector and level of energy intensity, 1990-2017



The vast majority of value-added growth in the Indian GDP since 1990 has come from low-energy-intensity sectors.

Note: Energy intensity is calculated as the ratio of the value of energy inputs to the value of gross output in thousand rupees, with a range of 0-100 classified as low, 100-200 as medium, and >200 as high.

Source: IEA analysis based on RBI (2020).

The third driver of the improvement in energy intensity has been the technical efficiency of production and consumption processes. Low levels of energy use per unit of physical output have been driven by relatively high energy prices, price sensitivity among consumers, a young capital stock, and a robust policy framework in a number of sectors. For example, the average on-road fuel efficiency of a new passenger car purchased in India is around 5.7 litres/100 km, comparable with cars purchased in the European Union. The thermal energy intensity of clinker production in India is 20% lower than in the European Union.

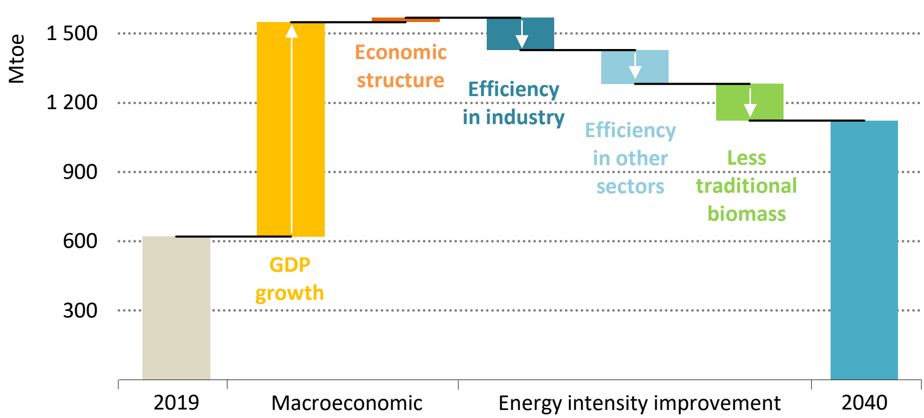
Looking at India's recent energy demand growth, the picture that emerges is one of a relatively frugal energy system. Rapid improvements in energy intensity have been driven by a transition to more efficient fuels, a structure of economic growth dominated by services, and high technical efficiencies in many sectors. The extent to which these trends continue will be crucial in determining the future growth of Indian energy demand.

2.2.2 Outlook for GDP growth and economic structure in the STEPS

Between 2019 and 2040, Indian GDP is projected in the STEPS to triple in size, growing 5.4% annually, while India's economic structure changes in ways broadly consistent with the historical trajectory charted by other countries. Agriculture continues to decrease as a share of GDP, albeit more slowly than in the past. By 2040, it accounts for about 11% of GDP. Consistent with India's services-driven development model, the share of industry in total GDP is projected to remain broadly stable over the outlook period, rising slightly from 30% in 2019 to 31% in 2040. The share of services in GDP continues to increase, rising from 54% in 2019 to 57% in 2040, with accompanying growth in service sector energy demand (see section 2.3).

The tripling in GDP in the STEPS is accompanied by less than a doubling of total final energy consumption, which rises from 620 Mtoe in 2019 to just over 1 100 Mtoe in 2040. As in the past, a reduction in energy intensity is anticipated to play a substantial role in reducing energy demand growth relative to GDP growth. This is evident from a decomposition of different factors affecting demand growth (Figure 2.5).

Figure 2.5 ▷ Drivers of total final energy consumption growth in India in the STEPS, 2019-40



The transition away from traditional biomass and an economy-wide improvement in energy efficiency reduce consumption growth by almost 50% over the period to 2040.

Notes: TFC = total final consumption. Economic structure represents the impacts of the change in the share of industry value-added in GDP. Energy intensity improvements include gains from energy efficiency as well as transitions to more conversion-efficient energy sources, such as electricity. Less traditional biomass represents the efficiency gains from switching away from traditional use of biomass towards modern fuels.

As Figure 2.5 shows, GDP growth without any improvement in energy intensity would increase final energy consumption in India to more than 1 500 Mtoe by 2040, and a slightly expanded share of industry in the economy would add a little to this. However, this increase is in practice moderated by improvements in industrial energy intensity, which avoid around 140 Mtoe (explored further in section 2.4). The transition away from traditional use of biomass continues, as its share in final consumption contracts from 18% in 2019 to 6% in 2040, thereby avoiding a further 160 Mtoe. Finally, energy intensity improvements in all other end-use sectors and fuels bring about an additional reduction of 150 Mtoe. Together, these three factors drive a cumulative reduction in the growth of total final consumption of over 440 Mtoe, an amount equivalent to Japan's total energy demand today.

2.2.3 Similar destinations, different pathways: Exploring the IVC and DRS

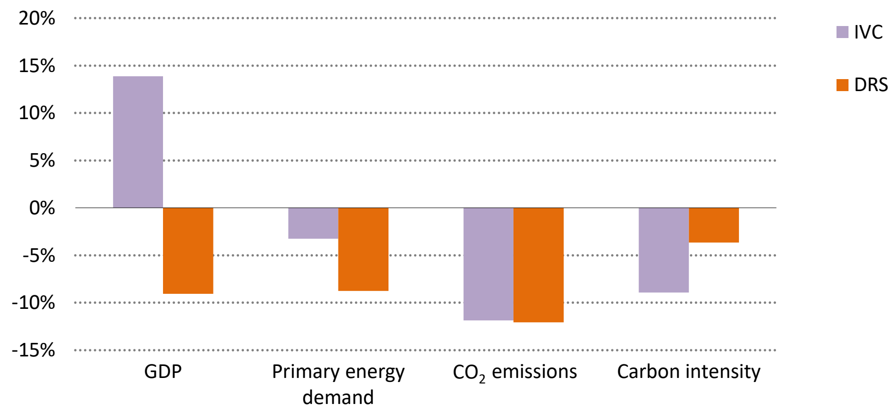
The disruption from Covid-19 has caused an unprecedented level of uncertainty about the future of the global economy. India has suffered a significant economic contraction as a result of the pandemic and the ensuing lockdowns, and its economic output is expected to have fallen by around 8% in 2020 (IMF, 2021). In the STEPS, India's GDP returns to an annual average growth rate of around 5.4% per year between 2019 and 2040. However, substantial uncertainty remains about the depth and duration of the downturn induced by Covid-19, and the speed of the subsequent recovery in GDP growth rates. For this reason, two alternative scenarios have been used in this report alongside the STEPS and the SDS, namely the DRS and the IVC.

In the IVC, GDP growth is higher across the outlook period, reflecting a scenario in which substantial structural reforms boost the long-term growth potential of the economy, despite the short-term shock of Covid-19. This scenario also assumes the achievement of ambitious government policy objectives related to energy efficiency, deployment of renewable energy, and the provision of modern fuels to households. The DRS, on the other hand, reflects a scenario in which the shock of Covid-19 continues to weigh on the subsequent economic recovery: precautionary household saving, high corporate debt levels and a strained fiscal deficit result in a slower rate of economic growth. Consequently, the structural transition in the energy system is also delayed, with fewer improvements in energy efficiency, slower deployment of renewables and natural gas, and a slower transition away from traditional biomass.

The IVC sees an annual average GDP growth rate of 6% in the period 2019-40, compared with an annual average growth of 5% in the DRS. As a result, the size of the economy in 2040 is 14% bigger in the IVC than in the STEPS, whereas it is 9% smaller in the DRS. On the face of it, one would expect that these differences in 2040 would drive substantial differences in energy demand and CO_2 emissions. However, this is not the case. In the IVC, total final consumption of energy is actually lower than in the STEPS, and similar to that in the DRS. Stronger improvements in energy efficiency and faster moves towards more efficient fuels, notably electricity and gas, reduce the rate of final consumption growth in the IVC, notwithstanding its higher GDP. The similarly low level of demand in the DRS, by contrast, is a result of slower GDP growth and more prolonged economic challenges, which reduce the rate of improvement in energy efficiency and delay the transition towards more efficient fuels.

Overall, energy-related CO_2 emissions are around 12% lower in both the IVC and the DRS relative to the STEPS in 2040, but the reasons for these similar-sized reductions are very different (Figure 2.6). In the IVC, emissions growth is lower as a result of faster energy efficiency improvements compensating for rapid economic growth; modern renewables partially compensating for the accelerated transition away from the traditional use of biomass; and the shift within the fossil mix towards natural gas. In the DRS, by contrast, emissions reductions come from low GDP growth, and from the persistence of traditional biomass in the energy mix, which reduces the carbon intensity of total primary energy demand relative to the STEPS but also means higher levels of air pollution and a greater number of premature deaths. Given the imperative of achieving economic growth, poverty reduction and the transition to welfare-enhancing modern fuels, these CO_2 reductions are achieved at a very high social and economic cost.

Figure 2.6 ▷ Relative differences in key energy system indicators in the IVC and DRS, compared with the STEPS, 2040



Similar changes in energy demand and CO_2 emissions are seen in the IVC and DRS relative to the STEPS, but for very different reasons.

2.2.4 Urbanisation

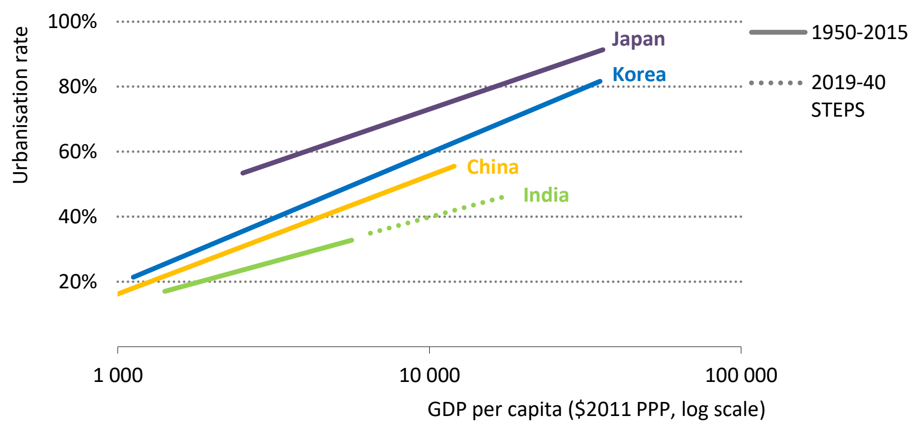
Throughout history, the urban share of the population has increased as countries have become richer. Urbanisation is one of the most consequential elements of the process of economic development. It facilitates larger markets for goods, services and labour, allowing the economy to increase its productivity. It also enables the growth of the more productive service and industry sectors that drive high incomes.

At the same time, the process of urbanisation is energy- and material-intensive. It generates much of the global demand for steel, cement and plastics, and hence is closely linked to energy demand. Because urbanisation facilitates higher average household incomes, it also drives higher average household energy consumption, as city dwellers spend a share of extra income on purchasing more energy services. Finally, a country's urbanisation model locks in very long-lived patterns of energy demand; for example, sprawling urbanisation with little public transport demand can lock in higher transport energy consumption.

How fast India urbanises, and with what urbanisation model, is therefore of material significance for its energy future. Exploring the long-term relationship between GDP per capita and the urbanisation rate offers some clues, comparing India with the East Asian late-industrialising countries, Japan, Korea and China (Figure 2.7). Across the historical period assessed, the speed of India's urbanisation process, as its GDP per capita has grown, has been slower than in these other countries. India is projected to continue this historical trend and remain a relatively rural country in our scenarios, even as its GDP per capita grows. By 2040, India's urbanisation rate is projected to be just 46%, which is some 15-30 percentage points lower than in the comparison countries at similar levels of GDP per capita.

Despite this relatively low urbanisation rate, India's huge population means that there is still a massive absolute growth in the total urban population, from about 470 million in 2019 to nearly 740 million in 2040. This increase in urban population is the equivalent of adding 13 cities the size of Mumbai to India by 2040. By contrast, India's rural population is expected to fall by 40 million in this period.

Figure 2.7 ▻ Relationship between GDP per capita and the urbanisation rate in selected economies



India has not so far urbanised as fast as other countries have done historically.

Sources: IEA analysis based on data from UN DESA (2018); Maddison Project Database (2018).

India thus looks set to buck the global trend between GDP per capita and urbanisation. This raises a number of important questions for India's energy future. First, given the strong relationship between development and urbanisation seen in economic history, will India be able to sustain a high level of GDP growth while retaining a high rural share of the population? Second, if India does retain a high share of rural population in the coming decades, what are the implications for India's energy future, given the observed differences between rural and urban households in terms of energy services demand and ownership of energy-consuming equipment?

There is some uncertainty about whether the rather stringent definition of urbanisation that India applies belies the country's actual level of urbanisation. Indeed, India's definition of urbanisation has long been subject to debate. Indian states have an incentive to label areas as rural because this enables them to receive subsidies and exemptions that they would not otherwise be entitled to. Alternative definitions exist, based on population density per square kilometre, or the percentage of the population employed outside of agriculture. Other metrics, increasingly based on remote sensing, continue to provide mixed signals about India's "true" level of urbanisation.

However, while there is debate about the stringency of India's definition of urban areas, it is clear that the definition is meaningfully reflected in energy indicators such as household appliance ownership. Persistent divergences have been evident in rural versus urban household appliance ownership for a long time, particularly for large, expensive energy-intensive equipment such as cars or air conditioners. The extent to which there will be convergence in the pattern of energy service demand between rural and urban households is a question of great importance for India's future energy demand, given the large projected rural population share in 2040. The extent and physical model of India's urbanisation process – compact versus sprawling, high-rise versus low-rise, formal versus informal – will likewise be crucial in determining demand for energy-intensive materials such as steel and cement, as well as transport demand.

2.3 The built environment and mobility

Two-thirds of the buildings that exist in 2040 in the STEPS have not yet been constructed. India is also facing a huge expansion of transportation networks – from highways, railways, and metro lines to airports and ports – to move an ever-increasing number of people and goods across the country. In the STEPS, around 300 million vehicles are added to India's roads by 2040, and there is a threefold increase in freight activity. How the built environment and India's transport systems interact is a crucial question for India's energy future.

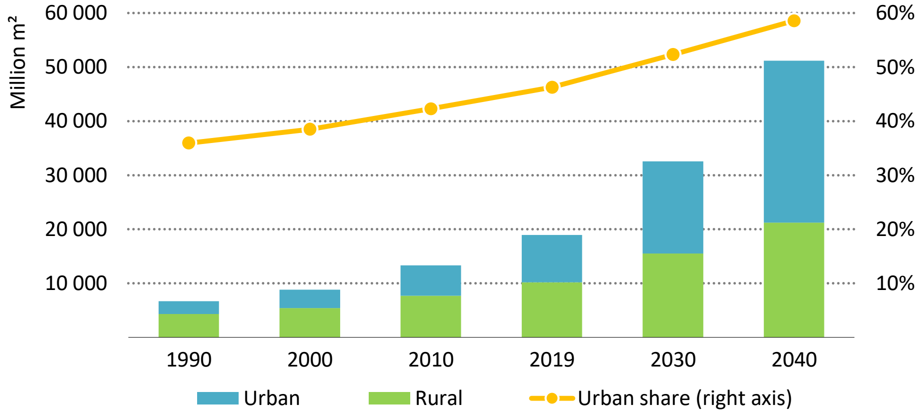
2.3.1 The built environment

There are three trends that underpin buildings energy demand in India. First, new construction activity is increasingly being concentrated in urban areas, making urbanisation a key driver for material demand; second, informal settlements and traditional built structures are being replaced by new buildings that use modern and energy-intensive materials such as bricks, cement and steel; third, there has been a steady growth in appliance use, with air conditioners emerging as the single most significant source of electricity demand in the buildings sector.

Material demand in the buildings sector

In the STEPS, urban floor space more than triples by 2040; this far outpaces projected growth of floor space in rural areas (Figure 2.8). This predominance of urban growth is a result of continued migration towards urban areas, rising incomes in urban areas that drive home ownership and investments in real estate, and a reduction in the number of people per household which reflects falling fertility rates and the splitting of larger families into multiple households.

Figure 2.8 ▷ Residential floor space in India in the STEPS



Historically, most built spaces in India were in rural areas, but urban demand for floor spaces is set to outpace rural demand over the next 20 years.

Note: m^2 = square metres.

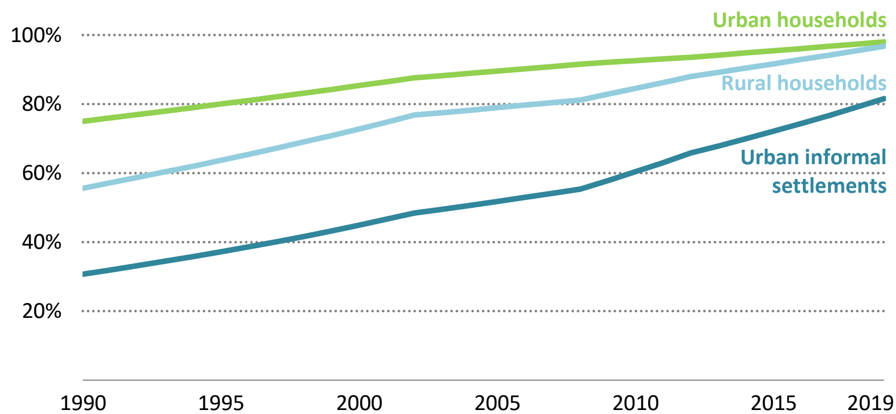
Source: IEA analysis based on NSSO (2018).

Indian cities have emerged as hubs for construction activity. India now has over 53 cities with more than a million residents, and a further 8 000 urban agglomerations, defined as areas with over 5 000 residents with a majority share of non-agricultural employment. The prevalence of multi-dwelling and multi-storey apartment buildings has steadily increased, with over half of all households in India's eight largest cities (each with a population of over 5 million) located in buildings of this kind in 2018, up from a third in 2002 (Sai, 2020).

India's construction boom has also been fuelled by a renewed focus on public housing. More than 150 million Indians live in unorganised informal settlements that lack basic infrastructure and services, and are often built as non-permanent structures on land that does not belong to the residents. These settlements have been targeted for replacement through public housing programmes that stretch back several decades. The government's various efforts in this direction were merged into the Pradhan Mantri Awaas Yojana (PMAY) scheme in 2015 with the overarching goal of "housing for all" by 2022. This public housing scheme aims to provide a house built with modern building materials for all those who are homeless and all those living in dwellings made using traditional building materials.

This focus on public housing has had significant impacts on building energy demand: in the six years leading to March 2020, more than 15 million houses were constructed, and a further 7 million are now under construction in urban areas. The government reported that 60 Mt of cement and 14 Mt of steel were used for the urban component of the construction (MOHUA, 2020). Moreover, as a part of PMAY, some informal settlements have been transformed into high-rise neighbourhoods, contributing to the growth in urban India's per capita floor space.

Figure 2.9 ▷ Share of households in India using modern building materials



There has been a steady increase in the share of new buildings constructed using modern, energy-intensive building materials such as cement, bricks and steel.

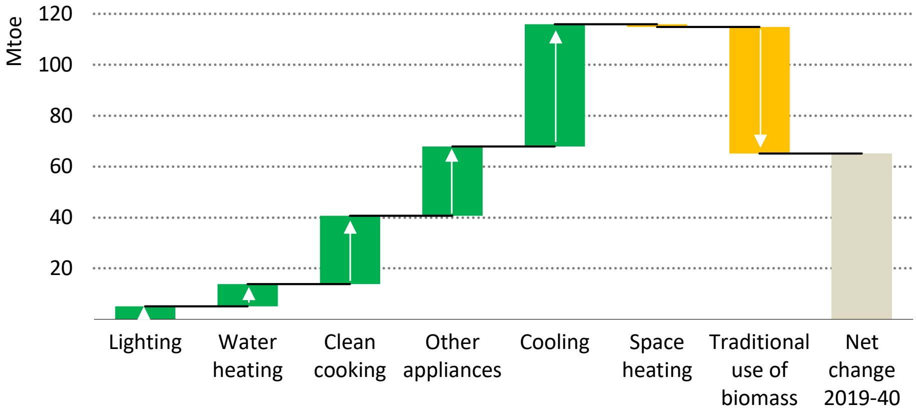
Source: IEA analysis based on NSSO (2018).

In the past, there were clear differences in the way in which rural and urban houses were built. In 1990, only 30% of rural homes were built using modern building materials, compared with 75% homes in urban areas. The rest were built using traditional materials such as unburnt mud, cow dung and other organic materials. That has been changing rapidly. By 2018, 80% of rural and 97% of urban houses were being constructed using modern materials (Figure 2.9). Overall, steel and cement production in India in the STEPS nearly triples by 2040 as a result of growth in the stock of housing and of a further closing of the gap between urban and rural areas in terms of their use of modern building materials.

Cooking and appliance ownership

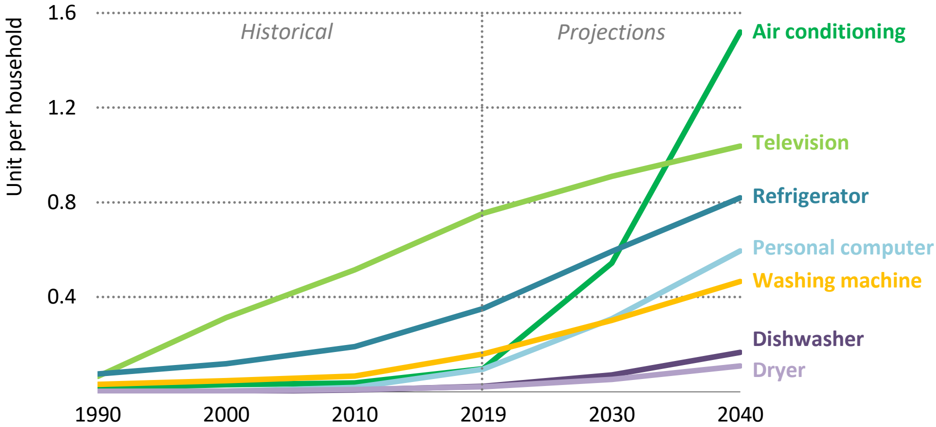
Cooking, heating, cooling and appliances are the four pillars of energy demand in buildings. In the STEPS, clean cooking (cooking that uses LPG, electricity, natural gas), appliances and cooling are responsible for the overwhelming majority of energy demand growth until 2040. The use of traditional cooking fuels and heating using biomass halves by 2040, and is replaced by cleaner alternatives including LPG and electric space heaters (Figure 2.10). The share of buildings in final energy consumption falls on account of falling biomass use, but the widespread uptake of cooling and appliances means the share of buildings in total electricity consumption rises from 41% in 2019 to 48% in 2040. Under the IVC, households move away completely from traditional bioenergy by 2030 as they adopt clean cooking technologies.

Figure 2.10 ▹ Change in energy demand in residential buildings in India in the STEPS, 2019-2040



Clean cooking, cooling and appliances are responsible for the overwhelming majority of energy demand growth in buildings to 2040, while there is a fall in traditional biomass use.

Figure 2.11 ▹ Appliance ownership in Indian households in the STEPS



AC units see faster growth than any other household appliance over the period to 2040 in the STEPS.

Appliance ownership in India has been growing and diversifying. In 1990, the only appliance that most households had was a ceiling fan. By 2019, televisions had also become quite commonplace, and the number of refrigerators was steadily increasing. By 2040, air conditioners, personal computers and washing machines are expected in the STEPS to become much more common, particularly in urban areas. Air-conditioning (AC) units see faster growth than any other household appliance over the period to 2040, and become the largest single driver of energy demand growth in buildings (Figure 2.11).

Focus on cooling

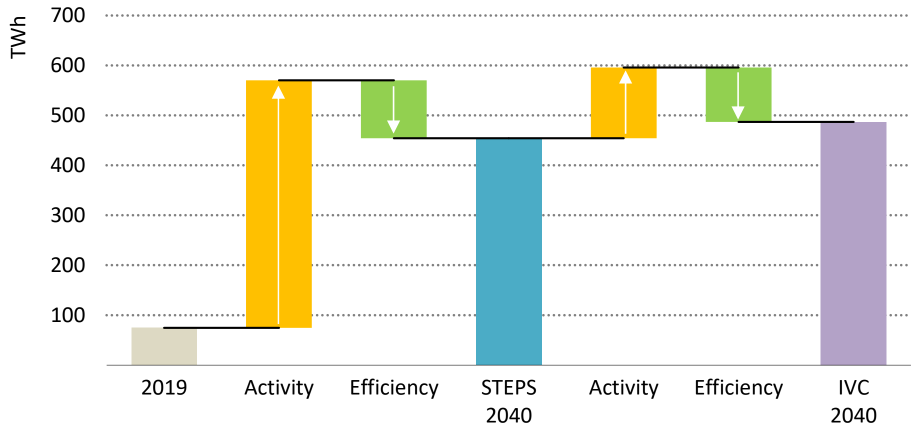
AC ownership is driven by the frequently hot and humid weather conditions in large parts of India. These conditions are being made more acute by rising temperatures stemming from global climate change and the "heat island effect" that affects urban areas in particular: as vegetation on land surfaces and water bodies have been replaced with impermeable and high-emissivity surfaces as part of the built environment, there has been an increase in temperatures in urban areas. With rising urban temperatures and per capita incomes, the growth in ownership of ACs is likely to become more broad-based, and it is expected to be led over the coming decades by mid- and low-income households in urban India (Kachhawa, Kumar, & Singh, 2019).

In the STEPS, air conditioner stock reaches 670 million in 2040, up from 30 million today. As a result, India's consumption of electricity for cooling grows sixfold to reach 650 TWh by 2040, which is more than the total electricity consumption of Germany today, and accounts for around half of all electricity consumption in buildings. Around two-thirds of this demand comes from the residential sector, with the remainder stemming from a steady rise in office buildings, retail, education, hotels and hospitals. Given that cooling demand peaks at certain times of the day and year for both residential and commercial buildings, this could put a considerable strain on India's ability to balance its grid and maintain reliable supply (see Section 3.2).

The growth in cooling demand could be mitigated by energy efficiency improvements in ACs, as well as thermally efficient building design, cool roofs and the adoption of other more efficient cooling appliances including desert air coolers. Government action has the potential to underpin mitigation efforts, and the India Cooling Action Plan (ICAP), which was launched in 2019, sets the scene for the future: it adopts the principle of "thermal comfort for all" including low-income groups, alongside a target to reduce cooling energy requirements by 25-40% by 2037-38, although the precise nature of this commitment is not clearly defined.

A range of policies and measures that could lower cooling demand and the resulting energy use is already in place. The Energy Conservation Building Codes for commercial buildings and the Eco-Niwas Samhita for residential buildings already set energy performance standards for new buildings that have a minimum energy consumption threshold or floor area, while the standards and labelling programme covers 10 appliance categories including air conditioners. Under the STEPS, nearly a quarter of electricity demand growth for residential space cooling is avoided by efficiency measures by 2040, broadly in line with the target set out under ICAP. In the IVC, a more robust implementation of energy efficiency policies means that the electricity demand arising from an additional 130 million air conditioners is almost entirely offset by efficiency gains (Figure 2.12).

Figure 2.12 ▷ The impact of efficiency measures on electricity demand from residential space cooling, 2019-2040



Electricity demand in 2040 from cooling alone will be more than the total electricity consumption in Germany today; energy efficiency measures can moderate this growth.

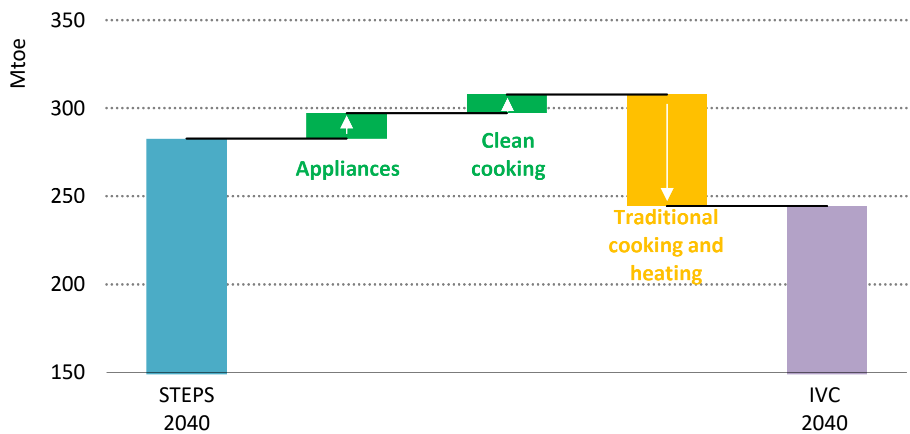
Building energy demand in the India Vision Case

In the STEPS, India's energy demand from buildings in 2040 is 30% higher than in 2019. This net growth figure would be much higher still without the drop in energy demand that comes from the displacement of inefficient biomass by efficient clean cooking fuels such as LPG and PNG. If cooking energy demand were excluded, energy demand from buildings would double in the STEPS in this period, due to increased uptake of electric appliances including water heaters, refrigerators, ACs, TVs and lights.

In the IVC, higher GDP growth means that ownership of appliances rises at a faster rate than in the STEPS, while greater disposable incomes means higher per capita consumption of energy services. These factors serve to push up energy demand, but there are countervailing forces that moderate the overall growth in consumption. First, there is an accelerated move away from traditional biomass towards modern fuels, as well as a parallel increase in appliance ownership, which raises the share of electricity in total energy use in buildings; both factors are instrumental in increasing the overall efficiency of energy use by India's building stock. Second, there are additional efforts to enhance India's efficiency policies, for example through more robust labelling and performance standards, as well as through stricter implementation of building codes covering insulation, shading and glazing, and other passive cooling solutions. As a result of these countervailing forces, energy demand from buildings grows in the IVC by only 12% over 2019 levels by 2040, less than half the level of growth seen in the STEPS.

The stronger push on policy and implementation in the IVC results in important co-benefits for India's built environment. To take one important example, indoor air quality improves drastically on the back of a rapid fall in traditional biomass use, resulting in fewer premature deaths in the IVC than in the STEPS. These gains far outlast the clean cooking transition (which is complete before 2030), with energy demand in 2040 remaining 14% lower in the IVC than in the STEPS (Figure 2.13).

Figure 2.13 ▷ Energy demand in buildings in the STEPS and the IVC, 2040



In the IVC, energy demand from buildings in 2040 is lower than in the STEPS because policies in the IVC bring to an end the traditional use of biomass for cooking and heating.

Note: Appliances includes cooling, lighting and all other electrical appliances.

2.3.2 Mobility

The last three decades have transformed mobility in India. The economic reforms of the early 1990s laid the groundwork for a huge expansion in transport and communication activities. The rapid growth in almost all types of transport infrastructure since then has fuelled economic growth, which in turn has led to a continual increase in demand for mobility for both passengers and goods. These changes have led to both energy use and emissions in the transport sector increasing fivefold over the last three decades.

Outlook for passenger mobility

Around 270 million people are expected to be added to India's urban population in the next two decades. Unless carefully planned, urban transport infrastructure could become a potential bottleneck to India's growth and development. The Indian cities with more than 1 million inhabitants already account for nearly 30% of total registered vehicles in India (MoRTH, 2019), and the level of vehicle ownership in urban households is higher than in rural households: in 2019, the motorcycle ownership rate was 1.4 times higher in urban areas and the passenger car ownership rate was twice as high. With growing disposable incomes and rapidly increasing motorised vehicle ownership, cities across India face the dual challenges of traffic congestion and poor air quality; Indian cities are consistently ranked high on the list of the most congested and the most polluted cities globally.

Following the National Urban Transport Policy (NUTP) of 2006, the last decade has seen the launch of programmes such as the Jawaharlal Nehru National Urban Renewal Mission, 100 Smart Cities Mission, and the Atal Mission for Rejuvenation and Urban Transformation to build and upgrade urban transport infrastructure, with a focus on public transport. These initiatives underpin a planned expansion of metro railways, rapid transit systems and bus services across dozens of cities.

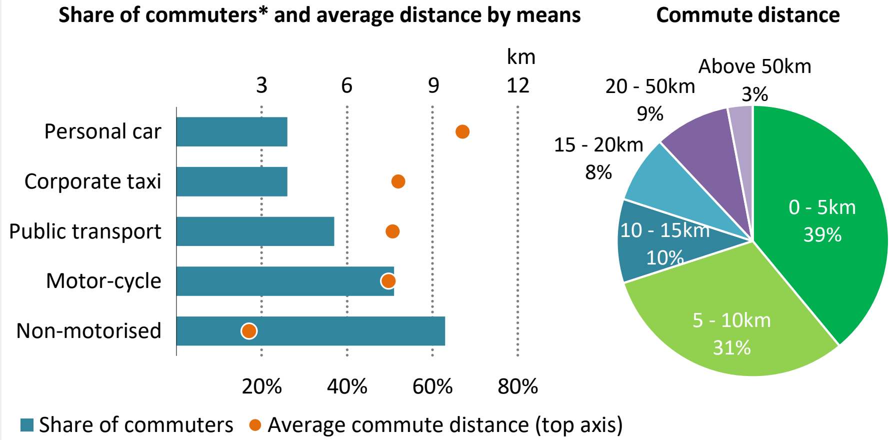
While the focus of transport policies has been on passenger vehicles and mass transit, a significant share of mobility needs in India continue to be met by three-wheeled auto rickshaws, private motorised two-wheelers and non-motorised modes of transport such as cycle rickshaws and bicycles, as well as by walking (Box 2.1).

Box 2.1 ▷ The role of non-motorised transport in urban India

Non-motorised transport plays a major role in mobility in India (Figure 2.14). In urban areas, nearly 40% of trips are 5 km or less. People usually walk or cycle in these cases. In a typical week, over 60% of urban Indians walk or cycle on trips that average 2.5 km. As the average length of journey increases, however, they become more likely to switch to two-/three-wheelers, public transport and personal cars (CEEW, 2019). People using non-motorised transport generally do so because they cannot afford motorised transport. Without an appropriate focus on non-motorised transport infrastructure, these individuals could transition to two-/three-wheelers or passenger cars as their per capita incomes increase.

There is a significant opportunity to avoid energy use in transport by ensuring adequate and safe pedestrian and cycling infrastructure in cities. Currently, Indian cities and towns rarely have extensive networks of walkable sidewalks or dedicated cycle lanes, and this forces non-motorised commuters to use roads meant for vehicular traffic instead, leading to a high number of fatalities from accidents. While the NUTP, launched in 2006, has an objective of “moving people and not vehicles”, this has not yet led to sustained investment in safe infrastructure for non-motorised commuters.

Figure 2.14 ▷ How urban Indians travel, 2019



Most commutes in urban areas in India are short, and most short trips are non-motorised.

Notes: *Share of commuters using a particular mode of transport in any given week. Public transport includes bus, metro, taxi and 3-wheelers.

Source: IEA analysis based on CEEW (2019).

In the STEPS, the fleet of buses in India doubles by 2040 to reach a stock of 4.4 million. Efforts are being made to ensure that new bus fleets operate on fuels such as natural gas and electricity to reduce their impacts on local air quality. With about 6 200 buses, Delhi is home to one of the largest fleets of natural gas-powered buses in the world. However, public buses represent only 8% of India's total bus fleet (MoRTH, 2020). Efforts to transform bus operations therefore also require appropriate regulations and incentives to help private bus fleets move towards more efficient and cleaner fuel types.

While efforts are under way to develop more organised forms of public transport, the growth in the motorisation of mobility in India is largely being driven by increases in numbers of two-/three-wheelers. More than 80% of vehicles in India are two-/three-wheelers, and this vehicle category has grown faster than any other in the last decade (MoRTH, 2019). Three-wheeled auto-rickshaws help meet last and first mile mobility demands and, like buses, act as shared modes of transport operating on specific routes in both urban and rural settings. In some cities, they also operate as a metered service, like taxis. They operate on a wide range of fuels, including gasoline, diesel, LPG, natural gas and, in some recent cases, electricity. In the STEPS, the number of two-/three-wheelers on the road increases by over 55% by 2040.

Passenger cars are the third-fastest-growing vehicle category in India, with annual average growth of around 10% over the last decade. Increasing disposable incomes and a growing range of available models mean that demand for cars is set to rise over the coming decades.

Passenger cars are now subject to a CAFE energy efficiency standard with an upper limit of 5.49 litres/100 km, and this standard will become more stringent from 2022. Together with the Bharat Stage VI fuel quality standards and incentives for purchase of EVs, this should help to reduce the level of energy demand growth. At the same time the increasing use of shared app-based ride-hailing passenger services has the potential to make more efficient use of the stock of passenger cars and to reduce road congestion and local air pollution. In the STEPS, the stock of passenger cars nevertheless still grows fivefold between 2019 and 2040 to reach 200 million, outpacing the growth of all other vehicle categories.

In the SDS, there is a concerted effort to move towards more efficient forms of transportation. As a consequence, the stock of buses and two-/three-wheelers is about 7% higher in 2040 than in the STEPS, while the stock of passenger cars is about 6% lower. In the IVC, buses and two-/three-wheelers grow at much the same rate as in the STEPS, but there are nearly 10% more passenger cars in 2040 than in the STEPS owing to the greater purchasing power of Indians.

The electrification of road transport

Road transport has historically been dominated by gasoline and diesel vehicles, but this is starting to change as a result of a range of policy initiatives and technology trends. India's vision for vehicle electrification was first outlined in the National Electric Mobility Mission Plan launched in 2012, which foresaw rapid growth in both the manufacturing and use of EVs in India.

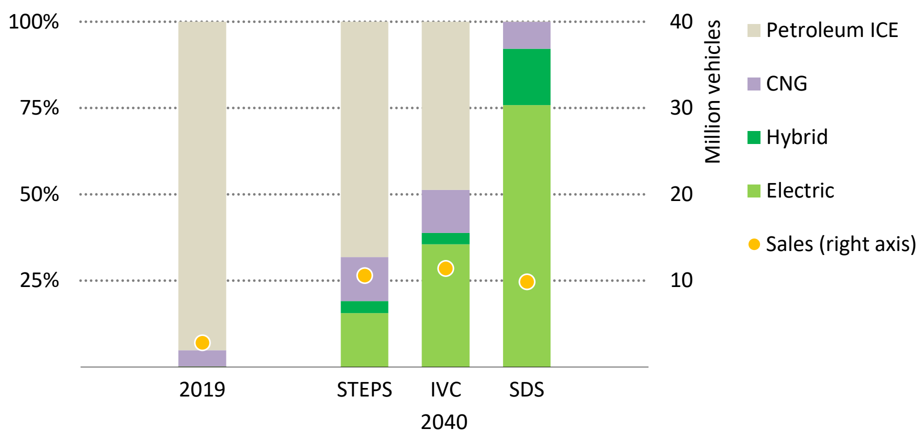
To increase the uptake of EVs, a subsidy programme called the Faster Adoption and Manufacturing of Electric Vehicles (FAME) was introduced in 2015. The second phase of the policy, FAME-II, was approved in 2019 with a budget of $1.4 billion for a three-year period. This includes policy incentives for the purchase of electric and hybrid vehicles as well as for the deployment of charging stations. FAME-II aims to increase the number of electric buses, two-/three-wheelers and cars. Subsidies are available only for vehicles with advanced battery chemistries, rather than lead-acid variants that make up the majority of electric two-/three-wheelers sold today. In addition to these policies, Energy Efficiency Services Limited, India's largest energy services company, has a bulk procurement programme in place to acquire 10 000 EVs for government use, although to date around 15-20% have been acquired. State and city governments have also introduced policies to incentivise the uptake of EVs.

To ensure the development of EV charging infrastructure, the Bureau of Energy Efficiency has laid out targets for the installation of at least one publicly accessible charger within a grid of 3 km by 3 km in cities, and one charging station every 25 km on both sides of highways. There is an additional target of one fast-charging station every 100 km on highways. The government has also complemented its measures to promote the use of EVs and associated infrastructure by announcing a production-linked incentive for the manufacture of advanced chemistry batteries for EVs, renewable energy and other applications.

As many of these incentives are relatively recent, much of the growth in electric passenger car numbers lies ahead. Fewer than 4 000 electric cars were sold in India in 2019. However, supportive policies, a growing global market for EVs and falling battery costs should soon put more EVs within reach of India's increasingly affluent middle classes. In the STEPS, there are nearly 7 million electric cars on the road by 2030, and 27 million by 2040.

A more significant opportunity for electrification exists in the form of two-/three-wheelers. In 2019, India had a stock of 1.8 million electric two-/three-wheelers on the road, and battery-powered electric three-wheelers (also called e-rickshaws) are already serving the demands of over 60 million people per day, mostly in urban areas (Singh, 2019). Sales are modest in terms of the size of the overall market – around 740 000 electric two-/three-wheelers were sold in 2019, accounting for about 3% of total sales – but are set to rise rapidly in the future. In the STEPS, there are 55 million electric two-/three-wheelers on the road in 2030, and they make up 19% of the total stock. This increases to 160 million in 2040, by which time they account for over half the stock of such vehicles.

Figure 2.15 ▷ Passenger car sales by scenario, 2019 and 2040



Two- and three-wheelers see rapid electrification, but the speed at which the car fleet switches away from petroleum-based fuels varies widely by scenario.

Note: ICE = internal combustion engine.

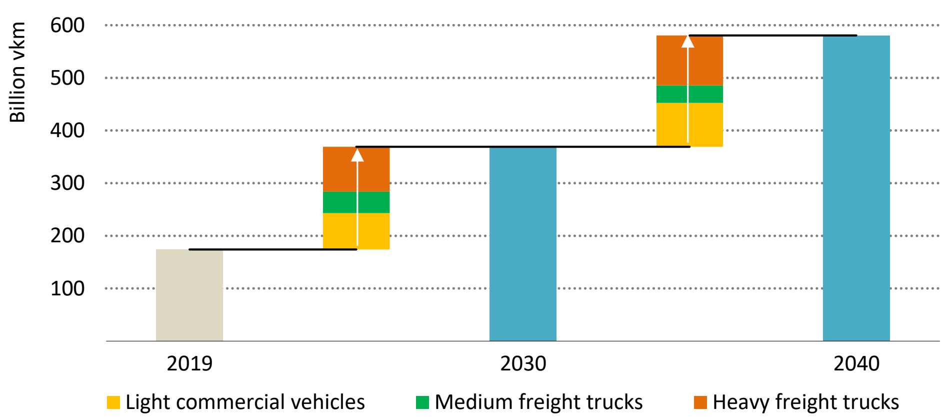
There were very few electric buses on the road in 2019, but there have been recent efforts by the central government jointly with states and municipal corporations to roll out 5 600 electric buses across 64 cities (for both urban and intercity movement) over the next few years (DHI, 2020). The number of electric buses grows to over 500 000 by 2040 under the STEPS, though they still account for only 12% of the stock. Overall, annual sales of EVs rise steadily in the STEPS (Figure 2.15). In all, the EV fleet – including two- and three-wheelers, cars, vans, buses, and trucks – represents 34% of the entire road stock by 2040, with two-/three-wheelers accounting for the vast majority of the total.

Things look different in other scenarios. In the IVC, more aggressive implementation of electrification targets results in 25% of the passenger cars sold and nearly half of the two-/three-wheelers sold being electric by 2030. By 2040, nearly 70% of all vehicles sold are electric. In the SDS, there is a much stronger policy push towards sustainable forms of mobility, together with a set of measures that support the domestic production of batteries, a rapid roll-out of charging infrastructure, and the implementation of building codes that encourage private charging. In the SDS, EVs constitute nearly half of all vehicle sales by 2030, and 86% by 2040. By 2040, 90% of the passenger cars sold are electric, up from 48% in 2030, and nearly 60% of the total vehicle stock is electric.

The future of road freight

India's steadily growing and more interconnected economy has led to a rapid rise in freight transport in recent years. Over 60% of goods transported in India travel by road (MoRTH, 2020). In the past decade, freight road activity and the number of commercial freight vehicles have both doubled, and they are projected to more than triple from current levels under the STEPS, with the stock of commercial freight vehicles reaching 35 million in 2040. Almost 45% of the growth in freight activity between 2019 and 2040 comes from heavy-duty freight trucks, which tend to serve long-distance routes, with a further 38% coming from the use of light commercial trucks, which largely serve urban centres within city limits (Figure 2.16). The growth in freight demand in the STEPS is mainly met by vehicles using diesel, with only small increases in the use of alternative fuels such as CNG. The increasing use of railways to transport freight does, however, avoid some growth in road freight activity (Box 2.2).

Figure 2.16 ▷ Growth of road freight activity in India in the STEPS, 2019-2040



Road freight activity in India more than triples by 2040 in the STEPS, with long-distance trucks and intra-city light commercial vehicles contributing most of the growth.

Note: vkm = vehicle kilometres.

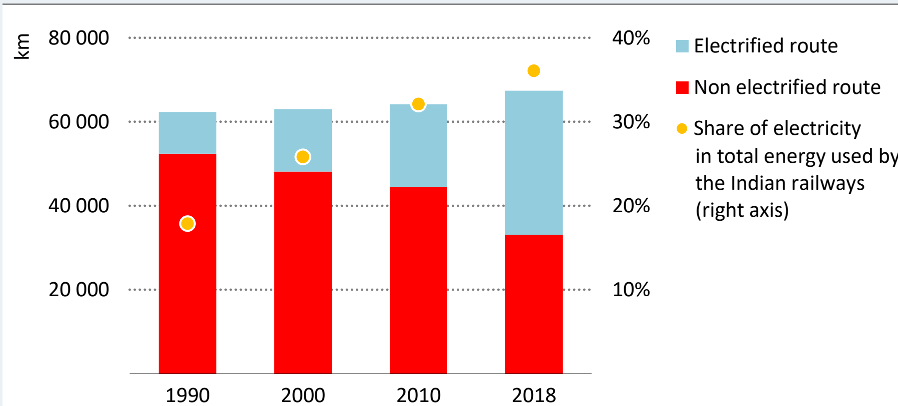
While the level of freight activity in the SDS is similar to that in the STEPS, much more of it is transported by hybrid, electric, hydrogen and natural gas freight vehicles, with around half of the 30 million trucks in 2040 in the SDS being powered by technologies other than diesel ICEs. In the STEPS, by contrast, these alternative technologies account for only 6% of energy demand from India's trucks.

Box 2.2 ▷ The transformation of India's railways

Railways in India have a long pedigree, dating back more than 160 years to the pre-independence era. By the time India gained independence in 1947, its railway network extended for more than 50 000 km. It has since grown to around 67 000 km, making it the fourth-largest railway network in the world. India's railway network was for a long time largely fuelled by coal and diesel. However, the share of electrified tracks has increased in recent decades, rising from 24% in 2000 to just over 50% in 2019. The share of electricity in total energy use by Indian railways has seen a corresponding increase, albeit at a more moderate pace (Figure 2.17).

In recent years, there has been a renewed focus on transforming railways to make them a desirable option for long-distance transport as well as urban public mobility. Indian Railways has an ambition to fully electrify its tracks by 2023, which will entail the electrification of over 30 000 km of track within four years. In parallel, there is an aspiration for rail transport to become "net zero" emissions by 2030 by drawing its entire electrical load from renewable energy.

Figure 2.17 ▷ Electrification of railway routes and operations



Indian railways are rapidly electrifying, with a goal of 100% electrification by 2023.

Source: Ministry of Railways (2019).

There is also an interest in developing high-speed rail in India, with the first line being developed between the cities of Mumbai and Ahmedabad. Further lines are also being explored which could run between Mumbai and Delhi, between Delhi and northern Indian cities such as Amritsar and Varanasi, and between Mumbai and cities in the south. Despite high capital costs, high-speed rail has the potential to displace air traffic, leading to energy savings and emissions reductions.

Railway operators are seeking to double the average speed of freight trains by 2023, and to increase their share of freight movement from 30% in 2019 to 45% by 2032. The Dedicated Freight Corridor (DFC) between India's four largest cities of Delhi, Mumbai, Chennai and Kolkata aims to create over 10 000 km of railway track that would be used solely by freight traffic on a route that accounts for nearly 58% of the revenue-earning traffic on the railways. The DFC is currently under construction, with some sections of it opening to traffic in 2020, and further sections targeted to open in 2022. As well as improving freight rail transport, the DFC will free up other lines for passenger use, which should lead to an improvement in average speeds across the railways.

In addition, urban metro rail is expected to double in length: there are 650 km of lines in 18 cities today, and a further 900 km of lines are now under construction across 20 cities. The most extensive metro network is in New Delhi, but there are growing networks in other cities. More than 4.5 million passengers use the metro in Delhi every day, while the metros in Mumbai and Bangalore each have daily ridership of more than 450 000 people. As lines and stations expand, urban rail networks could potentially carry millions of additional daily commuters. This should reduce personal car travel and so prevent additional emissions and road congestion.

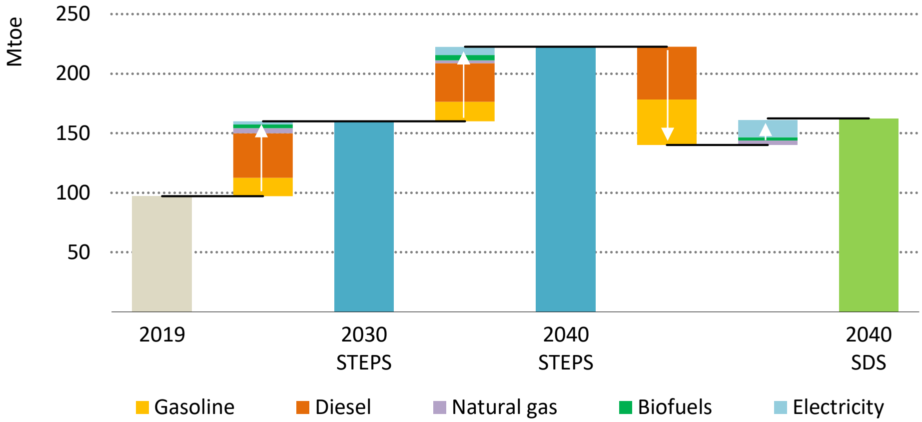
Together, these efforts could help shift some road and flight transport activity to rail, which is among the most efficient modes of transport. The energy used per passenger kilometre in rail is roughly one-tenth that of passenger cars and planes, and one-third that of buses (IEA, 2020).

The outlook for transport energy demand and emissions

Energy demand for road transport in the STEPS more than doubles by 2040 to reach 220 Mtoe (Figure 2.18). Freight transport constitutes half of the overall increase, most of which is fuelled by diesel: in 2019, around 80% of freight transport relied on the use of diesel, a share that remains largely unchanged to 2040. Energy use in passenger cars quadruples over the 2019-40 period. Despite rapid growth in EV sales, especially for two-/three-wheelers, electricity consumption growth constitutes only 7% of the overall growth in road transport energy demand to 2040 under the STEPS. Under the IVC, this rises to nearly 15% of the overall growth in transport energy demand.

Railway energy demand grows by over 80% through to 2040 in the STEPS, with electricity providing only half of the energy used by railways in India in 2040. In the IVC, however, the target of complete electrification is achieved. Energy demand from domestic aviation triples under both the STEPS and the IVC (although it is 10% higher in the IVC); it constitutes less than 1% of energy demand under both scenarios.

Figure 2.18 ▷ Changes in road transport energy demand by fuel/technology and scenario, 2019-2040

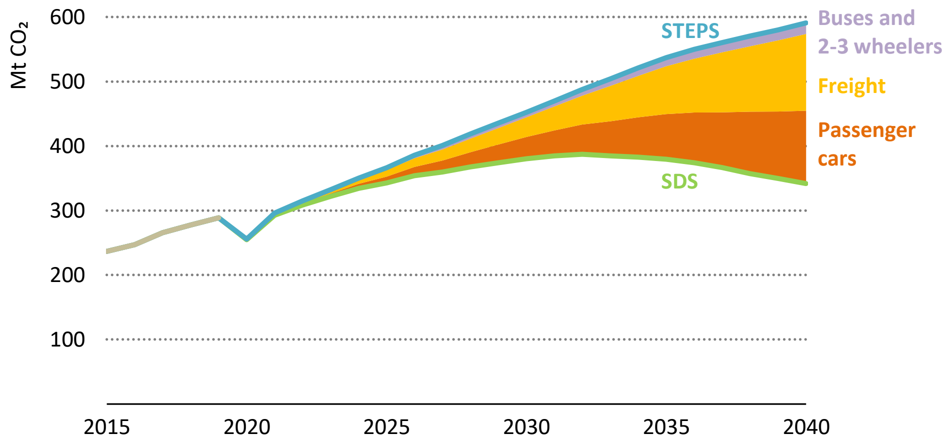


Diesel-based freight transport underpins demand growth in the STEPS to 2040. Greater efficiency and an uptake in electric mobility is key to avoiding demand growth in the SDS.

As a result of these demand increases, CO_2 emissions from road transport double between 2019 and 2040 in the STEPS, with around 65% of this increase coming from freight vehicles; road transport continues to account for nearly 90% of overall emissions in the transport sector. The scale of activity growth in the transport sector means that CO_2 emissions also grow in the SDS in the period to 2040, largely as a result of a doubling in emissions from heavy-duty trucks. However, a number of developments in the SDS help to improve the sustainability of transport. EVs account for a far larger share of new vehicle sales in the SDS than they do in the STEPS; this means that electricity (which is increasingly supplied from low-carbon sources) accounts for nearly one-third of the growth in road transport energy consumption to 2040. More robust efficiency targets also help to lower energy demand and emissions, while the use of biofuels helps to lower the emissions intensity of liquid fuel demand. Alternative fuels including biofuels, electricity and natural gas together meet 30% of road transport sector energy demand in 2040 in the SDS, which is over twice the share in the STEPS.

The result of these developments is that road transport emissions in the SDS begin to decline in the 2030s despite rising vehicle ownership and activity levels, and end up 42% below the level in the STEPS by 2040. This is primarily due to efficiency gains and an increasing share of passenger cars and road freight vehicles running on alternative fuels such as biofuels, CNG and electricity (Figure 2.19); two-/three-wheelers are already increasingly electrified in the STEPS.

Figure 2.19 ▷ CO_2 emissions reductions from road transport between the STEPS and the SDS

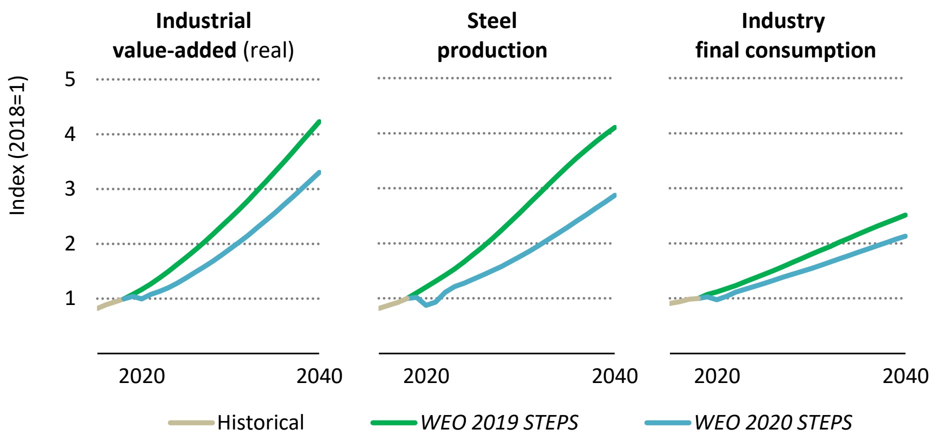


While two-/three-wheelers form a large majority of the stock of vehicles, the biggest opportunity to reduce CO_2 emissions comes from passenger cars and freight transport.

2.4 Industrial transformations

The share of the industry sector in total final energy consumption increased from 28% to 36% between 1990 and 2019, making it the largest end-use sector today, and a vitally important sector for India's energy future.

Figure 2.20 ▷ Indices of industrial activity and energy consumption in the STEPS, compared with *WEO 2019*

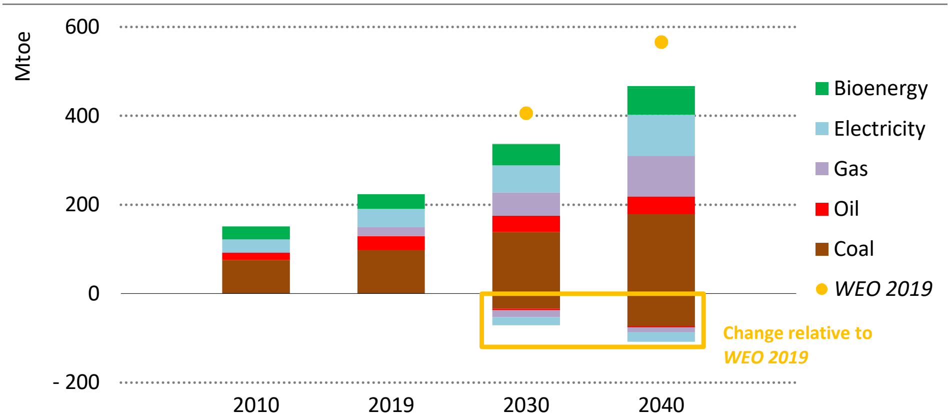


The pandemic leaves a lasting gap for key industrial indices that is not closed in the STEPS.

The Covid-19 pandemic and the nationwide lockdown sharply reduced India's industrial activity. On an annualised basis, in the months from January to August 2020, cumulative production of steel fell by around 20% (OEA DPIIT, 2020). Tentative signs of economic recovery were visible in the second half of 2020, with monthly production of heavy industrial commodities returning towards their pre-crisis levels. However, in the absence of a burst of industrial activity at higher rates than those prior to the crisis, there is likely to be a prolonged reduction in activity relative to pre-crisis projections. For example, compared with the *WEO 2019,* the growth in real industrial value in the period to 2030 in the STEPS has been adjusted down by around 20%, with steel production down by a similar rate. Despite a pickup of economic growth rates after 2020, these industrial indicators remain lower in the STEPS than in *WEO 2019* projections for the whole scenario period through to 2040 (Figure 2.20).

India's industrial energy consumption in 2040 in the STEPS is over 100 Mtoe (or 18%) lower than projected in the *WEO 2019*. This downward adjustment does not, however, affect all fuels equally. The downward revision falls hardest on coal, which is 34 Mtoe lower in 2030 and 73 Mtoe lower in 2040 than projected in the *WEO 2019*. Electricity consumption is down 21 Mtoe in 2040 and natural gas consumption is down 11 Mtoe (Figure 2.21).

Figure 2.21 ▻ Industrial final consumption by fuel in the STEPS, *WEO 2019* versus *WEO 2020*



Covid-19 has dampened the projected rise in industrial energy consumption in India; by 2040, demand is 18% lower than in pre-crisis projections.

2.4.1 Industrial energy demand in the STEPS

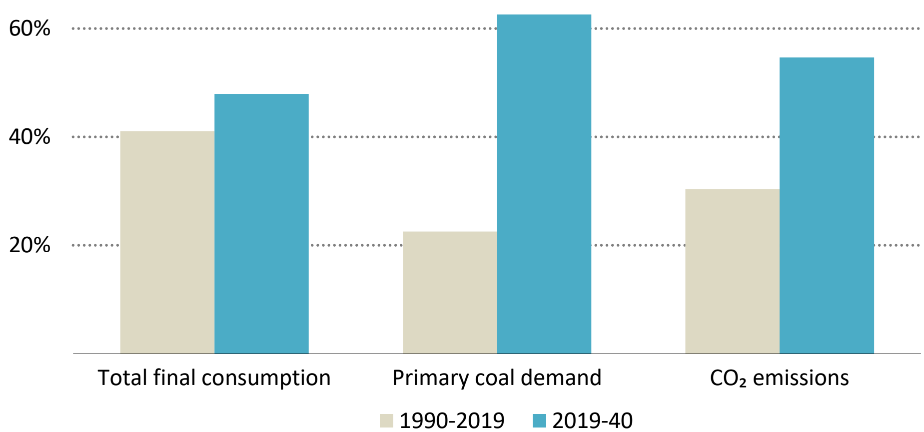
Despite the short-term revisions as a result of Covid-19, the long-term outlook for India's industrial energy consumption is one of substantial growth.

In the STEPS, industrial energy consumption doubles to reach 465 Mtoe by 2040. This represents almost half of the total growth in final energy consumption over this period.

Consequently, industry's share in total final consumption increases from 36% in 2019 to 41% by 2040. In addition to final consumption of energy, the industry sector is responsible for the non-energy use of fossil fuels as industrial feedstocks, for example in petrochemical and fertiliser production. Total feedstock consumption in the STEPS grows from 22 Mtoe in 2019 to 55 Mtoe by 2040, of which oil makes up 40 Mtoe and gas 13 Mtoe (the remainder being hydrogen and biomass feedstocks).

Over the past three decades, almost three-quarters of the growth in coal demand went to power generation. In the STEPS, this dwindles to one-quarter, and instead almost two-thirds of the growth in coal demand comes from industry. As a result, the industry sector accounts for the majority of CO_2 emissions as well as the majority of total demand growth in India between 2019 and 2040 (Figure 2.22).

Figure 2.22 ▷ Industry share in total final consumption, coal demand and CO_2 emissions growth in India in the STEPS

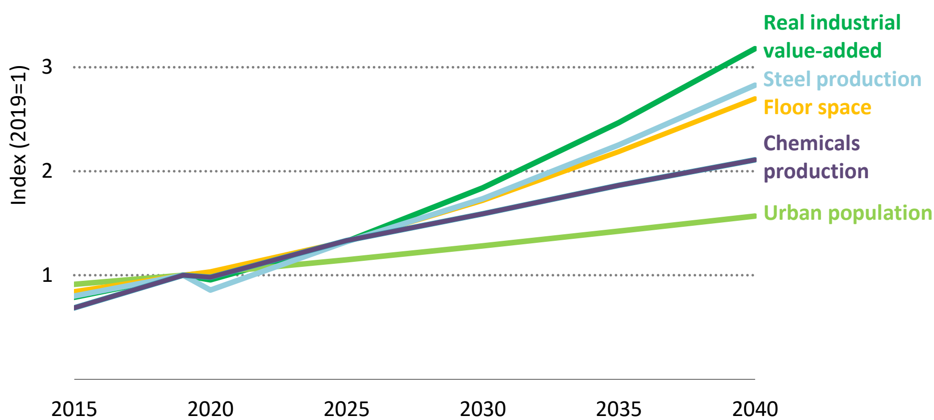


In the STEPS, the dominance of renewables in power means coal pivots from power to industry, making industry responsible for the majority of growth in CO_2 emissions to 2040.

In the STEPS, real industrial value-added grows more than threefold from 2019 to 2040, driven by materials-intensive investments in infrastructure, urban housing, factories and productive equipment. The urban population is projected to grow from 470 million in 2019 to 740 million by 2040, and total residential floor space from 19 billion m^2 to over 50 billion m^2. This massive urban transition underpins rapid growth in energy-intensive materials such as steel and cement. As a consequence of this robust growth in the industrial sector, India becomes increasingly central to global industrial energy demand (see Chapter 4).

Between 1990 and 2019, the energy intensity of India's industrial value-added (i.e. the amount of energy required to produce an additional unit of industrial output) decreased by more than 50%. This was due, in part, to the general wave of economic efficiency improvements that occurred after liberalisation in the early 1990s; it was also a consequence of relatively high energy prices, as well as specific policies such as the PAT scheme. The energy intensity of India's industrial value-added is now relatively low by international standards: in 2019, it was below the G20 average (measured at PPP).

Figure 2.23 ▷ Drivers of India's industrial energy consumption in the STEPS



Improvements in material efficiency and energy efficiency keep the rise in industrial energy consumption below the growth in industrial production and value-added.

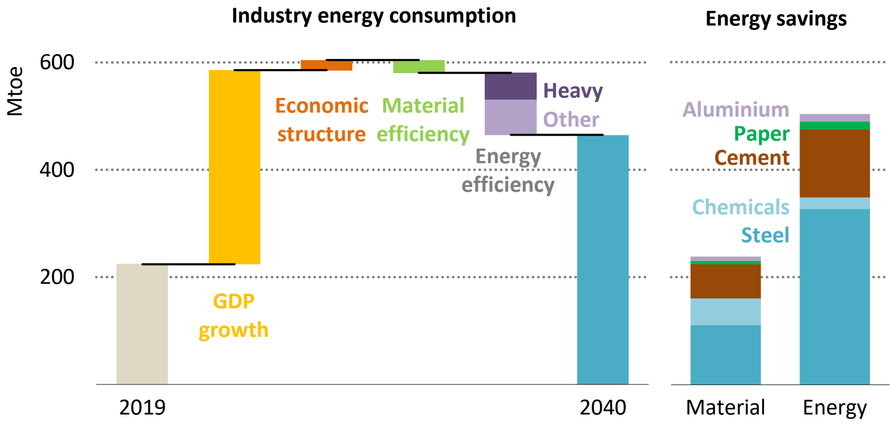
India's economic growth and the increasingly industrialised structure of India's GDP are key drivers of the projected increase in industrial energy demand to 2040.[3] Over the period to 2040, industrial value-added increases faster than the production of physical outputs such as steel and cement (Figure 2.23). Total final energy consumption of the industry sector increases more slowly than either as a result of improvements in efficiency. These are partly the result of natural economic processes, as the economy becomes more efficient at extracting value from the factors of production, including materials and energy. They are also partly driven by policies aiming to improve material efficiency, for example through recycling and material reuse. In the STEPS, material efficiency avoids about 25 Mtoe of industrial energy demand growth over the period to 2040, while reductions in the energy intensity of the physical production of steel, chemicals, cement, paper, and aluminium avoid a further 150 Mtoe (Figure 2.24).

Within the heavy industrial sectors, the largest potential for material and energy intensity improvements lies in the steel sector, which contributes more than half of the total energy savings from these sectors. Although much smaller individually, substantial energy savings from energy intensity improvements also come from India's light industry base. Energy

[3] In the STEPS, the share of industrial value-added in overall GDP increases slightly, meaning there is a modest rise in industrial energy demand attributable to structural economic changes.

savings from a range of less energy-intensive sectors, such as manufacturing, textiles and food processing, amount to a further 65 Mtoe in 2040 in the STEPS. These sectors include many small and medium-sized firms, underlining the importance of policies to tap the energy savings potential in India's large and often informal micro, small and medium-sized industrial sector (MSME). In total, energy savings from this segment avoid one-third of the projected growth in total industrial energy consumption (Box 2.3).

Figure 2.24 ▷ Breakdown of the key drivers of industry energy consumption in India in the STEPS, and reductions in energy use from efficiency



Improvements in the efficiency of material and energy use help to moderate the growth in Indian industrial energy consumption in the STEPS, but it still more than doubles to 2040.

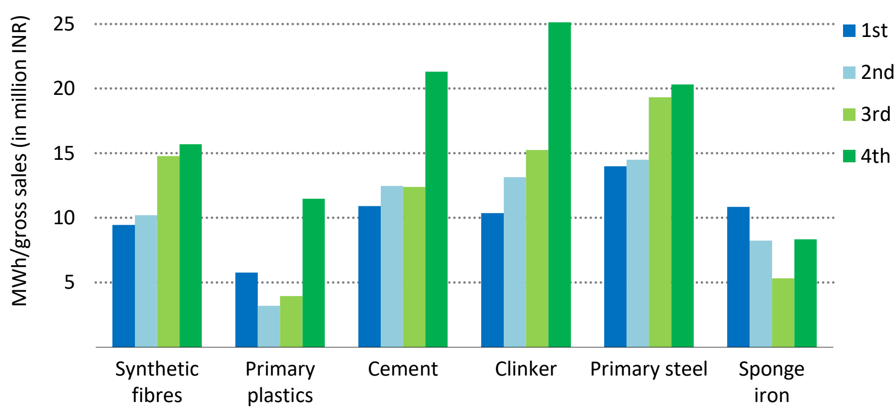
Note: Economic structure represents the impacts of the change in the share of industry value-added in GDP.

Box 2.3 ▷ Energy efficiency in India's small- and medium-sized industries

India's industry sector, like its economy more broadly, is characterised by a large number of small production facilities as well as a small number of large production facilities. The Sixth Economic Census recorded more than 10 million establishments in the manufacturing sector, including the informal sector, employing over 30 million people. This gives a sense of the huge scale of India's informal sector: the average establishment size in terms of employment was just three people. Although comprehensive energy consumption data is not gathered for the informal manufacturing sector, the Annual Survey of Industries provides data on the formal industry sector, and this data can be used to provide a sense of the scope for unlocking energy efficiency in the widely dispersed and fragmented landscape of small industrial installations.

Across India's manufacturing sector, there are many facilities that have relatively little market share but that are substantially more energy-intensive than the best-performing facilities (Figure 2.25). In five of the six manufacturing sectors analysed, there is a clear inverse relationship between market share and energy intensity (based on the electricity intensity of gross sales). Achieving the energy efficiency potential in the MSME sector will require a combination of technical capacity building, regulations and incentives, and access to capital for the necessary investments.

Figure 2.25 ▹ Electricity intensity of selected manufacturing facilities in India by quartile of sectoral market share, 2017



Energy-intensive companies with the highest market share generally benefit from economies of scale and use less energy per unit of value-added than others.

Note: Facilities are divided into quartiles according to their market share across each sector. The 4th quartile includes the smallest facilities up to 25% of the total market, and the 1st quartile includes the largest facilities within the top 25% of the total market.

Source: IEA analysis based on MoSPI (2019).

2.4.2 Pathways to a low-emissions industry sector

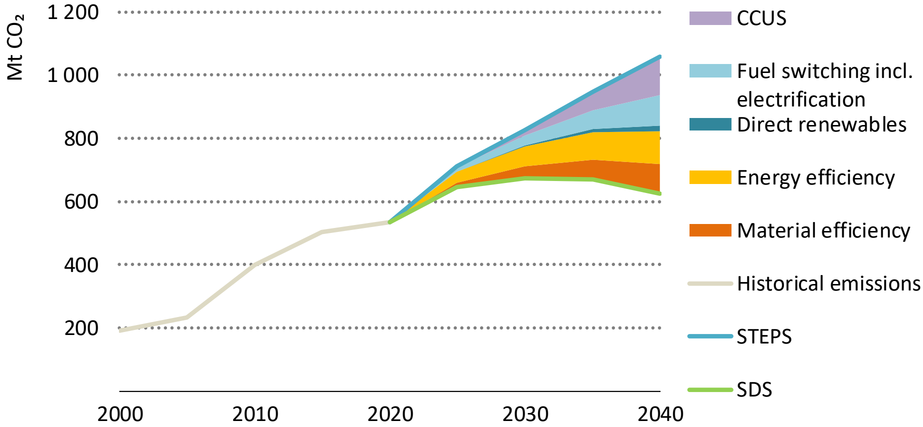
In the STEPS, the industry sector is the largest driver of coal demand and CO_2 emissions in India over the period to 2040. Total direct emissions from the industry sector nearly double, reaching just over 1 Gt CO_2 in 2040. Although coal's market share drops from 44% in 2019 to 38% by 2040, its consumption rises in tandem with India's increasing industrialisation, and it almost doubles from today's levels to reach 180 Mtoe by 2040. Coal remains a mainstay of several industries where there are few technically feasible alternatives for high-temperature process heat.

There are emerging opportunities to bend the industrial emissions curve in India by making further improvements in industrial efficiency, and some of these are reflected in the IVC. As a result, industrial value-added in the IVC is 15% higher than in the STEPS in 2040, even though industrial energy use is 3% below the level reached in the STEPS.

An even bigger transformation of India's industry sector is seen in the SDS, with material efficiency playing an important role in reducing industrial emissions (Figure 2.26). For example, steel production in the SDS is 14% lower than in the STEPS in 2040, thanks to the lightweighting of products, longer product life cycles, and structural changes such as a shift to public and shared transport, which allows the same transport service demands to be met with fewer vehicles and hence fewer materials (IEA, 2019b). The share of energy-intensive clinker in cement drops in the SDS to 62% by 2040, compared with 68% in the STEPS, while the share of energy-saving secondary steel and secondary aluminium production increases by 3-5 percentage points. As well as demand reduction, material efficiency includes a host of process adjustments across multiple industry subsectors that collectively contribute almost a fifth of the additional industry emissions reductions seen in the SDS in 2040.

2

Figure 2.26 ▷ Emissions reductions in the industry sector by abatement option between the STEPS and the SDS



Multiple technologies and policy approaches are deployed in the SDS to bring down India's industrial CO_2 emissions.

Another 25% of the emissions reductions, more than 100 Mt CO_2 in 2040, are achieved through improvements in energy efficiency. Many of these savings in the SDS are frontloaded because they can be delivered faster than savings from other options which rely on the deployment of novel technologies or on lengthy investment projects. Slightly less than a third of the total savings come from large industrial sectors such as iron and steel, cement, aluminium, chemicals, and pulp and paper. Two-thirds come from India's light industries, underscoring again the importance of extending energy savings policies and incentives to smaller energy-consuming sectors.

Relatively few emissions reductions are achieved through the direct deployment of renewable energy in the industry sector, such as biomass and solar thermal for low-grade heat. More substantial emissions reductions are achieved by fuel switching, which covers moving from coal to gas, as well as moving to fuels with no direct emissions or to electricity.

Almost a third of the difference between emissions reductions in the STEPS and the SDS comes from the deployment of CCUS in the SDS. By 2040, 125 Mt CO_2 are captured in the industry sector, largely in the iron and steel, cement, and chemical sectors. Deploying CCUS on this scale would require timely investments in pipeline infrastructure, as well as substantial financial incentives, for example in the form of a carbon price or tax incentive combined with upfront capital support.

A key conclusion emerging from this analysis is the importance of near-term measures to put India's industrial sector onto a sustainable pathway. India's stock of production capacity is relatively young, and is set to experience rapid growth in the coming decade to meet growing demand. Early deployment of best available technologies is the best way to reduce energy consumption and to enable the retrofitting of abatement technologies (IEA, 2020e). The iron and steel sector illustrates this point clearly (see below).

Focus on transition pathways in the iron and steel sector

The iron and steel sector is crucial to the transition of the overall industry sector in the SDS.[4] In 2019, energy consumption in the sector accounted for 13% of total energy-related CO_2 emissions. In the STEPS, this rises to 17% by 2040 as iron and steel production grows and as other sectors, notably power generation, reduce their emissions footprint. The outcome in the SDS, however, is very different: indeed the iron and steel sector accounts for 10% of the difference in emissions reductions between the SDS and the STEPS in 2040 (and almost half of the reductions achieved within the industry sector). However, achieving the level of emissions reductions in the SDS requires a comprehensive portfolio of measures.

Currently, India is the world's second-largest producer of sponge iron, and the great majority of this iron depends on coal-based direct reduced iron (DRI) production. The sponge iron output of the coal-based DRI sector is refined into crude steel in electric arc furnaces and induction furnace sectors. Electric furnace production accounts for about 55% (60 Mt) of India's crude steel production; the other 50 Mt of crude steel production comes from blast furnace-basic oxygen furnaces (BF-BOF). In 2019, coal accounted for 88% of final energy consumption in the iron and steel sector, reflecting the sector's high degree of reliance on coal-based DRI and the low penetration of natural gas DRI. Electricity accounted for 10% of final consumption, with gas and oil products accounting for the remaining 2%.

As in the broader industrial sector discussed above, material efficiency plays a crucial role in reducing the total demand for steel through measures such as vehicle lightweighting, building design optimisation, and design-driven extensions in product and building lifetimes. The 2019 National Resource Efficiency Policy signals government support for moving in this direction. In 2040, material efficiency contributes 36% of the difference in emissions reductions between the STEPS and the SDS in the iron and steel sector.

[4] The IEA recently released a detailed study of transition pathways in the global iron and steel sector, including a focus on India (IEA, 2020c)

Reducing the carbon intensity of fossil energy consumption, mostly through the deployment of CCUS, delivers a further 37% of the difference in emissions reductions between the STEPs and the SDS. By 2040, 63 Mt of CO_2 are being captured from the iron and steel sector, which is 11% of the total CO_2 emissions from the iron and steel sector in the STEPS scenario.

Reducing the energy intensity of steel production contributes another 20% of the difference in emissions reductions achieved between the STEPS and the SDS, or a total of 40 Mt CO_2. In the SDS, the energy intensity of steel production is 8% lower than in the STEPS by 2040. Increased uptake of best available technologies, such as coke dry quenching for coke ovens and top-pressure recovery turbines for blast furnaces, is the key here, supported by regular updating of efficiency targets under the PAT scheme against global standards and benchmarks.

Fuel switching away from fossil fuels, largely towards electricity, contributes an additional 12 Mt CO_2 of emissions reductions, or around 6% of the difference between the STEPS and the SDS in terms of emissions. The potential for this is affected by the strong growth of Indian steel demand; this limits the scope for scrap-based secondary steel production, which is at present the only production method where the use of electricity is feasible. It does not, however, prevent all growth in the production of secondary steel: as a result the use of electricity increases in the SDS, and it accounts for 19% of energy consumption in the iron and steel sector by 2040.

In the longer term, the deployment of alternative steel production routes is expected to play a stronger role in emissions reductions in the iron and steel sector. This includes hydrogen-based direct reduced iron (H_2-DRI), which is deployed from the early 2030s onwards (Box 2.4). H_2-DRI has the potential in time to provide a significant share of total steel production in India (IEA, 2020c).

Box 2.4 ▷ Hydrogen and other low-carbon fuels for India's industrial transformation

Energy efficiency, material efficiency and electrification are essential strategies for reducing emissions from industrial processes, but the technical requirements of these processes and the long lifetimes of existing industrial assets indicate that chemical fuels will continue to play a major role in India for some time to come, especially given the current fuel mix in industry: more than 60% of India's industrial energy demand today is met by the direct use of fossil fuels, more than half in the form of coal. Against this background, there is growing interest in fuel switching to bioenergy or other low-carbon fuels so as to allow the continued use of infrastructure and expertise that have been developed for fossil fuel use.

In the STEPS, bioenergy demand in India's industrial sector rises by 80% between 2019 and 2040. Solid biofuels can substitute for coal in many industrial heating applications, and low-carbon gases have the potential to meet demand for high-temperature heat and chemical feedstocks. India's biomethane consumption increases rapidly in the STEPS, rising above the level in both Europe and the United States by the early 2030s. In the SDS it rises further, displacing 30 Mtoe of potential natural gas demand in the process. We estimate that almost two-thirds of natural gas demand in India in the SDS could be met by biomethane for industrial and transport applications (IEA, 2020d).

Low-carbon hydrogen has particular potential in the context of India's industry sector, since it can be used in place of natural gas, coking coal or oil products. This means that steel, ammonia-based fertilisers and methanol – among other products – could all be produced with low CO_2 emissions.

Low-carbon hydrogen can be produced by electrolysing water with low-carbon electricity, by reforming natural gas in combination with CCUS or, potentially, by methane pyrolysis. Given that India has relatively high natural gas prices, can produce low-cost renewable electricity and faces a high degree of uncertainty about its CO_2 storage potential, water electrolysis is likely to be the favoured option. Where CCUS is not available, the lowest hydrogen production costs are expected to come from pairing dedicated renewable power plants with electrolysers and local hydrogen storage to smooth the daily supply (TERI, 2020). India's existing industrial sites are well located for the use of local solar and wind resources, especially in Gujarat, Maharashtra and West Bengal.

In the best locations, the cost of steady supplies of hydrogen from local renewable electricity could fall to between $20/MBtu and $30/MBtu by 2030 and decline further by 2050, even with the costs of on-site hydrogen storage included. However, such an outcome is subject to many uncertainties. Future cost reductions depend on cumulative deployment across a range of sectors nationally and internationally, and policies to support investment are not yet widely in place. In India, however, the policy outlook brightened in late 2020 with the announcement that a National Hydrogen Energy Mission is to be launched.

In 2020, several governments announced plans to incentivise demand for hydrogen and electrolyser factories as part of their economic recovery spending, and this should benefit technology importers by lowering global prices and demonstrating effectiveness. For steel, in particular, further refinement of hydrogen-based production processes is needed before decisions are made about deployment. If planned projects receive the required funding, then iron reduction with 100% hydrogen could be demonstrated between 2025 and 2030. Among other things, this would provide insights into the optimal balance between oversizing renewable electricity capacity and installing on-site hydrogen tanks for round-the-clock operations, which is a key issue for India. The availability of low-carbon hydrogen at competitive costs could also pave the way for its use in ammonia for fertilisers, depending on the availability of non-fossil carbon for its conversion to urea and the market response to any resulting changes in urea prices. In time, low-carbon hydrogen has the potential to be cost-competitive with natural gas, displace imports and attract investment in the value chain. In the short term, funding for research that develops relevant skills as well as opportunities for entrepreneurs would help hydrogen's prospects. Looking further ahead, India has significant potential to become an international hub for hydrogen technologies if it develops the value chains to support this and offers opportunities for investment (see Chapter 4). This could give India a competitive edge in attracting gas-based and electricity-based industries in the future.

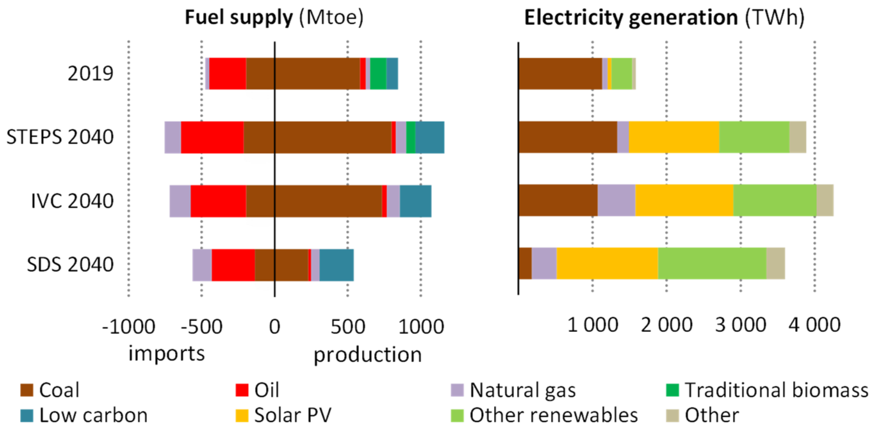
Fuels and electricity in India

Out with the old, in with the new?

S U M M A R Y

- The Covid-19 crisis has exacerbated many of the challenges facing fuel suppliers and electricity generators. To some degree this has worked to India's advantage, as lower prices ease its fuel import bills. But strained balance sheets and uncertainties over demand also affect the prospects for domestic energy investment and supply.
- The longer-term effects of the pandemic are likely to vary significantly by fuel and technology. In the STEPS, India's gas supply (production plus trade) in 2030 is only slightly below the levels projected in *WEO 2019*, but oil supply is down by 5%, and coal is down by one-quarter. The pandemic takes more than 500 TWh off electricity generation in 2030 in the STEPS, compared with pre-crisis projections, with the brunt of the reduction being borne by coal-fired generation.
- Despite the shock from Covid-19, India's electricity demand is still projected to grow by almost 5% per year to 2040 in the STEPS, which is nearly double the rate of energy demand as a whole. India adds capacity the size of that of the European Union to its installed base over the next two decades, with solar PV and wind accounting for more than three-quarters of the capacity additions as their costs fall. By 2030, new solar PV, whether alone or paired with battery storage, becomes competitive with *existing* coal-fired power.
- The rise in demand for electricity brings with it much greater variability in both supply and demand. On the supply side, this reflects the growth in solar PV and wind. On the demand side it is related in large part to a six-fold increase in peak daily electricity consumption for air conditioning to 2040; higher efficiency standards for this equipment could remove the need for $9 billion to $15 billion of investment in peaking plant capacity.
- India's requirement for power system flexibility rises faster than anywhere else in the world in the STEPS, and it is higher still in the IVC and SDS. The achievement of ambitious renewable energy targets which call for 450 GW of non-hydro capacity by 2030 has to be accompanied by a transformation of the power system in order to accommodate this growth, and this requires flexible operation of the coal-fired fleet, robust grids, and battery storage and demand-side response.
- India's ambition to become a "gas-based economy" comes at a time of ample international supply. However, price remains a very sensitive issue for Indian consumers, especially given the complex patchwork of additional charges and tariffs that turn an average wholesale cost of gas in 2019 of $6/MBtu into an estimated average end-user price of $12/MBtu. If all proposed gas infrastructure were to be built, some 70% of India's population would have access to gas, up from around 3% today, but there remain a host of permitting and financing challenges.

Figure 3.1 ▷ Change in fuel supply and installed electricity capacity by scenario, 2019-2040



The outlook for fuels in India varies strongly by scenario, but the expansion of the power system is rapid in all cases.

- In the STEPS, growth in gas consumption is concentrated in the industrial sector and in city gas distribution; in the IVC and in SDS, gas consumption also displaces significant amounts of coal in the power sector. The projections in the IVC and SDS underline that India’s vision for gas cannot be limited to natural gas of fossil origin if the country is to meet its environmental and sustainability objectives; it needs to incorporate an expanding role for low-carbon gases, biomethane and hydrogen, where India has major potential as well.
- India's ambitions to reduce import dependence for oil and coal rest in part on expanding domestic supply. Despite ongoing efforts to improve the investment framework, this is challenging in the oil sector because of the complexity and the relatively limited size of the domestic resource base. In the case of coal, the domestic resource base is large enough to support increased production, but today’s steep coal production targets are difficult to reconcile with India’s evolving energy needs and environmental priorities.
- Adapting India’s coal industry to these evolving needs and priorities requires concerted efforts to improve operational efficiency. It also requires the incorporation of new technologies to relieve environmental impacts, including CCUS, as well as alternative approaches to cooling at coal-fired plants: more than 80% of coal plants today are cooled by freshwater sources, and over half of these are in areas experiencing high water stress.

3.1 Overview of energy supply

3.1.1 Pathways out of today's crisis

Energy supply in India has been affected in multiple ways by the Covid-19 pandemic. The economic effects of the pandemic have exerted strong downward pressure on international energy prices, and a period of well-supplied markets is set to ease India's import bills for some time to come. Given its heavy reliance on imports, this is good news for India. However, the strains on international suppliers are matched in many respects by pressures on domestic producers and investors. In the power sector, the effects have varied strongly by fuel: as in other parts of the world, thermal generation bore the brunt of the downward pressure on electricity demand in 2020, while renewable output was more resilient.

Pathways out of today's crisis are highly dependent on the broader macroeconomic context, linked in turn to the duration and severity of the pandemic. But they also depend on the responses of policy makers and companies. Alongside wider efforts to stimulate the economy, India instituted three important energy market reform steps in mid-2020, which have led to the creation of real-time power markets (RTM), the Green Term-Ahead Market, and the India Gas Exchange (IGX). India is also taking steps to stimulate domestic production as part of a drive to reduce reliance on imports, especially of oil and coal. These efforts may bear fruit in the case of coal, but crude oil and condensate production is projected to fall below 650 thousand barrels per day (kb/d) in the late 2020s in the STEPS, with a slow but steady decline thereafter.

Natural gas is one area where international market conditions and India's aspirations are well aligned. India's ambition to become a "gas-based economy" fits well with the interest among many exporting countries and companies in gaining a foothold in India's market, even though there are uncertainties around the business model for financing new projects. Efforts to expand India's LNG regasification capacity and its domestic gas grid are well under way although, as examined in detail in section 3.3 below, there is still much scope to rationalise a complex regulatory and tariff landscape for gas. Natural gas production, which has seen a significant drop in 2020, is set to rebound relatively quickly as new offshore developments come online.

In the power sector, much will depend on the pace of recovery in industrial and commercial power demand. Approvals of new utility-scale solar have remained robust through the downturn, and a gradual recovery may well lead to much of the growth being taken by a continued flow of new renewable projects. A sharper rebound in demand, if the pandemic can be brought under control quickly, would offer greater near-term upside for conventional generation. In the projections in the STEPS, the pandemic takes more than 500 TWh off electricity generation in 2030, compared with the projections in *WEO 2019*, with coal-fired generation taking most of the hit.

3.1.2 Perspectives to 2040

The effects of the pandemic leave India in the STEPS with an economy that is nearly 20% smaller by 2040 than projected in *WEO 2019*, which means a drop in average annual energy demand growth from 3.2% to 2.5% compared with *WEO 2019*. However, the impact of this downward adjustment is not felt equally across fuels. By 2030, natural gas demand is back to the level projected in the *WEO 2019*, and oil demand is only slightly lower. By contrast, there is a significant downward revision for coal, which is a third lower in 2040 than in pre-crisis projections.

Ambitious efforts to raise the production of coal bear some fruit, meaning domestic output grows by 150 Mtce between 2019 and 2040. However, this is well below the previous level of growth recorded between 2000 and 2019, which saw a doubling in production. India manages to reverse the trend towards an increasing share of imports, keeping the share of imports below 30% through to 2040; the quality of domestic coal and the pivot towards a greater share of coking coal in India's coal balance effectively create a floor for imports.

In the STEPS, India continues to transition away from the traditional use of solid biomass, primarily through the use of imported LPG. Demand for LPG doubles between 2019 and 2040. Most of the rest of oil product demand is met by India's refinery sector, where capacity swells to nearly 8 mb/d by 2040. India's oil production continues to see a moderate decline, as new developments are unable to keep pace with declines from existing fields. By 2040, India's oil import dependence exceeds 90%.

The shift away from traditional biomass occurs in parallel with a rise in the use of modern solid biomass for power generation and industry. At the same time, transport biofuels increasingly make their mark on liquid fuel demand, while biomethane use in the transport sector rises to almost 10 bcm by 2040. Together, these two bioenergy sources reduce oil import requirements by nearly 20 Mtoe (an amount equivalent to a fifth of oil consumption in the road transport sector today). Natural gas is poised for significant growth, backed by ambitious government targets to raise its share in the energy mix. Some offshore deepwater developments in the Krishna Godavari basin support near-term production growth, and there is then a slow but steady rise in coalbed methane production from the 2030s. The level of growth in domestic gas production is, however, insufficient to meet rising demand, and LNG imports satisfy nearly 70% of demand growth, making India a major importer, and an important presence in global gas markets.

In the IVC, total energy demand is slightly lower in 2040 than in the STEPS, even though GDP growth is higher as a consequence of greater energy productivity, particularly as India moves away from the use of traditional biomass. There is much greater progress towards the targeted 15% share of gas in the energy mix, a development that is accompanied by higher domestic gas production. Oil production remains at around the same levels as in STEPS, however, and growth in coal production is muted by an accelerated pace of renewables deployment that further erodes coal's share in power generation.

Table 3.1 ▷ Fuel supply and production by scenario

			STEPS		SDS		IVC	
	2000	2019	2030	2040	2030	2040	2030	2040
Coal production (Mtce)	**187**	**409**	**519**	**560**	**304**	**161**	**472**	**515**
Steam coal	163	369	474	512	270	133	428	470
Coking coal	16	25	23	24	23	23	23	24
Lignite and peat	7.9	14	22	23	11	5.2	21	21
Coal trade (Mtce)	**-20**	**-196**	**-193**	**-212**	**-151**	**-137**	**-188**	**-197**
Natural gas production (bcm)	**28**	**32**	**55**	**78**	**52**	**66**	**65**	**101**
Conventional gas	28	30	47	53	47	55	48	62
Coalbed methane	0.0	1.3	5.7	12	4.7	11	5.9	16
Other production	0.0	0.3	2.0	13	0.4	0.2	12	22
LNG imports (bcm)	**0.0**	**30**	**76**	**124**	**92**	**144**	**93**	**159**
Oil production (Mb/d)	**0.8**	**0.8**	**0.6**	**0.6**	**0.5**	**0.4**	**0.7**	**0.6**
Conventional crude oil	0.6	0.6	0.5	0.4	0.4	0.2	0.5	0.4
Natural gas liquids and other	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.3
Refining capacity (Mb/d)	**0.0**	**5.2**	**6.4**	**7.7**	**5.8**	**5.7**	**6.4**	**7.7**
Refinery runs	0.0	5.1	5.9	7.2	5.0	4.6	5.8	6.8
Other fuels (Mtoe)								
Traditional use of solid biomass	113	113	85	63	0	0	0	0
Modern solid biomass	35	67	93	112	95	117	98	116
Biofuels	0.1	1	5	10	9	14	5	10
Biogas, biomethane, low-carbon hydrogen	0	0	6	19	18	48	10	31

Notes: Nuclear fuels not included. Other natural gas production includes shale and tight gas.

The outlook for fossil fuels is much more subdued in the SDS (Table 3.1). Low-carbon energy sources capture nearly two-thirds of total demand growth to 2030, and by 2040 fossil fuels are largely absent from the new pipeline of projects. The most dramatic change occurs in the power sector, where unabated coal is virtually eliminated by 2040. Oil consumption peaks in the 2030s before entering a decline, creating a host of challenges for India's refining sector: up to 430 kb/d of refinery capacity is "at risk" through the 2030s, remaining largely unutilised in the SDS. Gas demand, by contrast, is relatively robust, as gas is used as a substitute fuel for both coal and oil to a much greater extent than in the STEPS and IVC. As a result, total gas demand reaches around 210 bcm by 2040, which is even higher than the level reached in the STEPS.

Table 3.2 ▷ Electricity demand, generation and capacity by scenario

			STEPS		SDS		IVC	
	2000	2019	2030	2040	2030	2040	2030	2040
Electricity demand (TWh)	**369**	**1 207**	**1 959**	**3 146**	**1 922**	**2 980**	**2 087**	**3 433**
Transport	8.2	18	59	153	93	302	90	228
Buildings	117	489	857	1 512	852	1 345	920	1 688
Industry	158	480	710	1 075	689	991	683	1 011
Agriculture	85	214	324	394	279	313	384	491
Electricity generation (TWh)	**562**	**1 583**	**2 461**	**3 887**	**2 365**	**3 601**	**2 599**	**4 225**
Coal	390	1 135	1 343	1 334	708	181	1 099	1 076
Natural gas	56	71	108	157	240	337	309	509
Nuclear	17	40	109	222	107	247	109	222
Renewables	77	332	893	2 169	1 302	2 832	1 074	2 413
Hydro	74	175	226	307	258	361	226	307
Solar PV	0.0	48	392	1 221	584	1 368	517	1 307
Wind	1.7	66	195	520	343	782	251	677
Other renewables	1.3	42	81	121	118	320	81	121
Capacity (GW)	**114**	**414**	**792**	**1552**	**997**	**1 835**	**931**	**1 747**
Coal	67	235	269	260	221	144	252	231
Natural gas	11	28	30	46	72	134	64	95
Nuclear	2.8	7	16	31	17	36	16	31
Renewables	27	137	436	1 066	641	1 334	542	1 189
Hydro	26	49	76	101	86	117	76	101
Solar PV	0.0	38	248	724	367	806	330	783
Wind	0.9	38	96	217	163	334	121	281
Other renewables	0.2	12	16	25	24	76	16	25
Batteries	0.0	0.0	34	144	40	183	49	195
CO_2 intensity of generation (g CO_2/kWh)	**817**	**725**	**537**	**336**	**319**	**59**	**449**	**285**

Electricity demand grows much faster than overall energy demand in all of the scenarios examined, putting electricity at the centre of India's modernisation (Table 3.2). The transformation of India's electricity sector also gains ground. In the STEPS, variable renewable energy sources make up a larger share of total electricity generation than coal by 2040. Installed solar capacity exceeds 700 GW by 2040, enough to meet nearly a third of India's power demand. This rate of growth is supported by the wide-scale deployment of batteries.

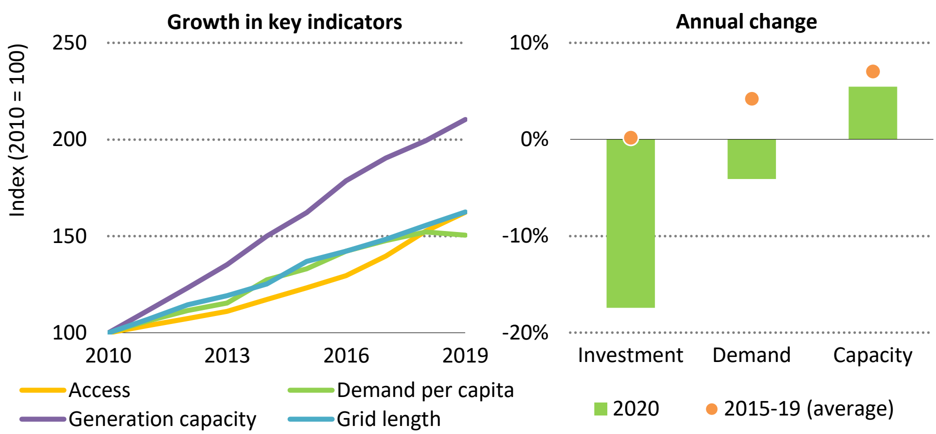
3.2 What's next for India's power sector?

The last decade has been remarkable for India's power sector. Synchronisation of the grid was achieved in 2013, making it one of the world's largest. A large-scale electrification programme has achieved near-universal household access to electricity, and more than $200 billion has been spent on transmission and distribution networks over the last ten years.

As a consequence, India has become the fourth-largest electricity market in the world, after the United States, China and the European Union. Electricity has enabled a burgeoning middle class to own modern appliances and sustain an increasingly digitalised lifestyle. Electricity demand growth is now widely used as a key barometer of India's overall economic performance. On the supply side, the explosive growth of utility-scale PV, supported by competitive auctions, has made India a global leader in the solar market. Six Indian states now source 10-30% of their electricity from variable renewable sources.

There are, however, several challenges ahead. As described in detail in Chapter 4 (section 4.3), a key issue is the fragile financial health of state-owned electricity distribution companies ("discoms"). This fragility has significant knock-on effects on the rest of India's power sector, affecting the finances of power generators and their investment risks, the level of technical and commercial losses in electricity distribution, and ultimately the quality of electricity supply to millions of Indian households and businesses.

Figure 3.2 ▷ Electricity indicators in India, 2010-2020



India has seen remarkable growth in capacity additions and achieved universal access to electricity, but Covid-19 has aggravated a pre-existing slump in demand and investment.

Another key question is how much the pandemic might set back the transformation of the sector (Figure 3.2). So far, renewables have weathered the shock from Covid-19 relatively well; as of September 2020, around 8 GW of new solar capacity had been auctioned during

2020, with tariffs around 4% lower on average than in 2019 (IEA, 2020b). However, there is greater uncertainty around the longer-term outlook for solar PV, with the Covid-19 pandemic sharpening several existing structural challenges. A drop in industrial and commercial demand has left discoms with a customer base that includes a greater share of residential households and agricultural consumers paying tariffs that often lie below the cost of production, while perceived credit risks are growing as several existing projects experience delays and cancellations. The challenges are not restricted to solar: wind capacity additions in 2020 are expected to drop to their lowest level in a decade. The hard-won gains of near-universal household access are also at risk as the economic downturn translates into fewer customers able to afford a basic bundle of electricity services.

Both the opportunities and the challenges that lie ahead are enormous. Auctions have revealed how cost-competitive solar power has become, and long-term renewable deployment targets are well within reach. In the STEPS, India is second only to China in terms of new installed renewable capacity to 2040. However, this rise will have huge implications for the operational flexibility required across India's power sector. Reconciling the desire for a cost-reflective and efficient power system with the imperative to provide affordable, equitable supply of electricity is going to require a skilful balancing act.

3.2.1 India's evolving power system

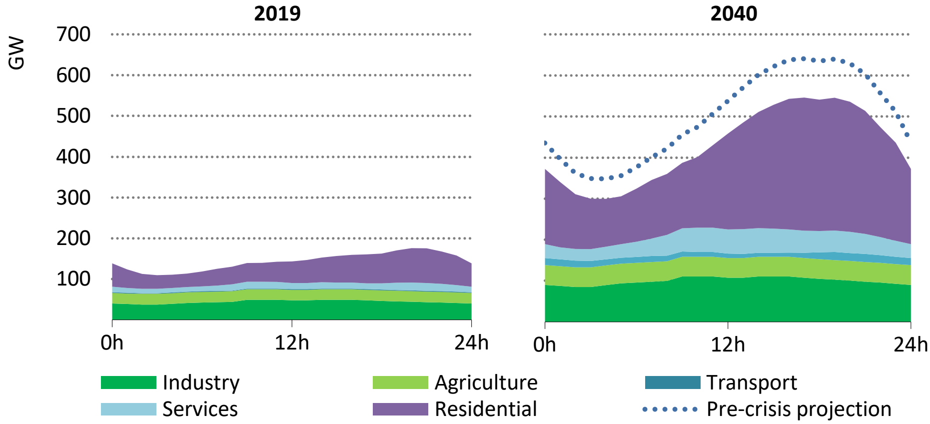
Electricity demand

In the STEPS, India's electricity demand grows by 4.7% each year, nearly double the rate of energy demand as a whole. The widespread uptake of household appliances means that the share of electricity in total energy demand in buildings rises from 20% today to almost 50% by 2040. Further electrification of India's energy system also drives significant demand growth; there is a much greater use of power in certain industrial applications requiring low-temperature heat supply, and a rise in the use of electricity as an input to steelmaking. Higher uptake of EVs, particularly two- and three-wheelers, enables electricity also to make inroads into the transport sector.

In the STEPS, significant additional electricity demand is accompanied by changes in daily, monthly and seasonal load profiles. Currently, the average hourly variation in demand over the course of the year averages around 17 GW. This increases to 100 GW in the STEPS by 2040. Peak daily demand rises nearly threefold, although the downward revision to macroeconomic growth means this rise is 15% lower by 2040 than in pre-crisis projections (Figure 3.3).

Cooling systems are a major driver of the increased variability of demand. By 2040, the difference between the lowest and highest air-conditioning load over the course of a day reaches over 200 GW, compared with less than 40 GW today. This increase in the use of space cooling systems translates into an average annual increase of almost 10% in electricity demand for cooling over the projection period, and into new demand peaks. Commercial cooling systems see their consumption peak around midday, while household air conditioners see a peak in the early evening.

Figure 3.3 ▷ Daily electricity demand in India in 2019 and 2040 in the STEPS



More than half a billion air conditioners and fans are purchased by 2040 in the STEPS, significantly raising the evening peak, although not as high as in pre-crisis projections.

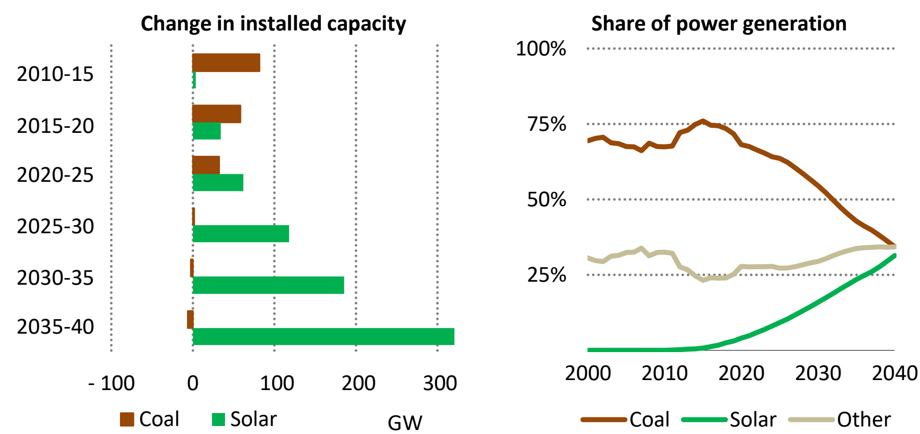
The size of the impact of increased use of cooling systems on the daily peak of electricity demand is subject to several uncertainties. One important factor is how purchases of air conditioners divide between higher- and lower-income households, as higher-income households are more likely to run air conditioning more frequently, with less regard to cost. The efficiency of air conditioners purchased in the coming years will also have a significant impact on the daily peak, and efforts are under way to strengthen minimum performance standards. If measures are implemented that restrict sales of the least efficient models, this could reduce peak demand considerably. However, the timing of such measures is critical, as every year in which standards are not tightened means a progressively larger annual increase in peak demand. If measures are implemented in 2021, more efficient appliances could decrease the contribution of residential cooling to peak daily electricity demand in 2030 by a third, or around 25 GW. This would obviate the need for around $9 billion to $15 billion of investment in peaking plant capacity. It would also be possible to lower peak demand by having ACs operate more flexibly, as part of a demand response programme; improvements in the efficiency of building envelopes or a bigger roll-out of more passive or mixed-mode cooling systems could also contribute to a reduced peak.

In addition to cooling, there are several uncertainties about the shape of electricity demand in other parts of the energy sector. For example, government programmes supporting charging infrastructure in cities or places of work could lead to a greater proportion of electricity demand from transport taking place during working hours, providing a good match with solar PV availability. There are other emerging opportunities for shifting peak load to different times of day to help balance supply and demand, such as off-peak charging or shifting the timing of the operation of agricultural pumps. India could provide a vital testing ground for the larger-scale adoption of such demand-side response (DRS) systems, although there are numerous technological prerequisites, such as advanced load prediction and control tools, real-time metering of electricity, and time-of-use tariffs.

Electricity supply

The task of managing the daily variability of demand, and in particular coping with the level at which demand peaks, is a crucial part of electricity system operation and planning. This task is made more challenging by the scale of growth in variable renewables over the next decade. In the STEPS, India adds nearly 900 GW of wind and solar capacity over the period to 2040. Solar PV leads the charge (Figure 3.4). The vast majority of capacity additions are from large, utility-scale projects; the share of distributed solar PV in the STEPS remains low because of its relatively high cost compared with large-scale solar projects and the logistical and regulatory challenges which have slowed capacity growth to date (Box 3.1).

Figure 3.4 ▷ Changes in coal and solar capacity and share of power generation in India in the STEPS, 2000-2040



India's power sector is on the cusp of a solar-powered transformation which will challenge the long-established position of coal as "king" of India's power sector.

Despite being seen as something of a junior partner to solar, wind is the second-largest source of capacity growth in the STEPS, with an additional 200 GW underpinned by ambitious targets to exploit India's significant potential for both onshore and offshore wind. Although wind power is also a variable resource, it can complement solar effectively in India; the monsoon season from June to September, which is a period of relatively lower solar resource availability, brings higher output from offshore wind projects than the rest of the year (IEA, 2019).

Box 3.1 ▷ A new dawn for rooftop solar?

India has ambitious targets to reach 40 GW of rooftop solar by 2022. However, rooftop PV deployment has been slow, with around 3 GW of capacity installed since 2015 compared with 30 GW for utility-scale solar. This is due in part to the challenge of reconciling different commercial incentives under the current regulatory regime: a large number of residential consumers pay low, cross-subsidised electricity tariffs, reducing or in some cases eliminating the savings possible from self-consumption. Many consumers are also unable to afford the upfront costs of installation, and find it challenging to access finance, despite options to spread low-interest payments over a longer-term loan period. Those consumers that pay higher tariffs have greater incentives to install rooftop solar, especially as net-metering regulations would allow them to benefit from selling surplus solar back to the grid. If they were to move to rooftop solar, however, this would further erode the revenues of financially weak discoms, which lack commercial incentives to expand into rooftop solar.

Some organisations are well-placed to push ahead with distributed solar – these include those with commercial installations on government buildings and entities taking part in the central public sector undertakings scheme. There are several incentives in place, including tax relief, subsidies, grants and credit guarantees for MSMEs. Rooftop PV projects are also eligible for housing improvement loans at preferential rates. There are in addition multiple opportunities for aggregation and economies of scale which have the potential to reduce the cost of supply for self-consumption, and increase the availability of financing. Raising consumer awareness and easing the administrative burdens associated with rooftop PV for households and undertakings, whilst ensuring that discoms share in the benefits of rooftop solar, could also unlock greater growth.

In the STEPS, the vast majority of new solar added from 2019-40 is utility-scale, but a more hospitable regulatory regime ensures a gradual increase in the rate of additions of solar PV in buildings, with total installed capacity reaching 150 GW by 2040.

There are also capacity additions in the STEPS from other low-carbon generation sources, notably nuclear and hydropower. India has a total of six nuclear reactors under construction, and these will add more than 4 GW to the 7 GW fleet by the late 2020s. In the STEPS, India continues to expand its fleet of nuclear reactors to complement the rapid growth of renewables. As modern large-scale reactor designs move past first-of-a-kind projects, construction periods and costs are set to fall, enabling India to add more than 25 GW of nuclear power capacity between 2019 and 2040. Hydropower also expands, with total capacity doubling over the next two decades to about 100 GW in 2040. The vast majority of this growth is in the form of large hydro projects, which manage to overcome significant hurdles such as land access and permitting challenges. Government initiatives to improve project viability, including HPOs and financial support for enabling infrastructure, enable these new projects to tap a significant share of the remaining hydro potential in India.

This supply picture means that variable renewable sources make up three-quarters of new capacity additions over the next two decades. With this immense growth, the question arises: to what extent is there a need for new thermal capacity? Over the next 10 years, the strong growth of renewables is not sufficient in the STEPS to keep up with the projected pace of electricity demand growth, and coal-fired power generation makes up the difference, increasing by over 200 TWh from 2019 to 2030. Much of this increase comes from more intensive utilisation of existing capacity, but new coal-fired capacity of over 20 GW in the next decade is also required in the STEPS to provide additional generation and extra flexibility, with capacity under construction making up for upcoming retirements. As of September 2020, up to 60 GW of coal-fired capacity were designated as being under construction (CEA, 2020), but only half of these are completed by 2030 in the STEPS.

The need for additional fossil-fuelled capacity in India wanes after 2030 in the STEPS. With mature technologies and supply chains, renewables meet about 90% of demand growth in the 2030s in the STEPS. With the additional contribution of nuclear power, there is no need for additional fossil-fuelled generation, and coal-fired capacity begins to decline in the 2030s in the STEPS, with closures outweighing another 16 GW of capacity additions, bringing to an end the consistent growth of the industry over the past 60 years. Gas-fired capacity increases in part to offset reductions in coal, but principally to help meet rising power system flexibility needs.

3.2.2 Unlocking India's system flexibility over the next decade

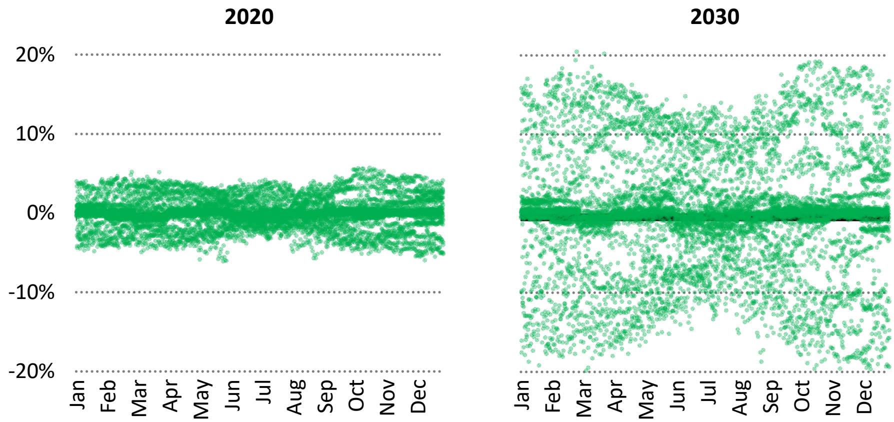
In the STEPS, by 2030 wind and solar PV reach a share of more than 40% in total installed capacity and around a quarter of total generation. The hour-to-hour variation in wind and solar output places increasingly large demands on the rest of the power system to balance supply and demand. *WEO*'s detailed power model shows that hourly variations in these renewable sources in the STEPS increase more than threefold by 2030 (Figure 3.5). This puts India ahead of all other countries in its total requirement for flexibility.

Flexibility requirements are determined by the load shape of demand and the electricity generation mix and capacity that can meet this. The integration of variable renewable energy sources (VRE) into electricity systems can be categorised into six distinct phases, which can help to identify relevant challenges and integration measures (IEA, 2018). The first phase is a situation where VRE has no noticeable impact on the power system, while the sixth phase calls for transformative technologies – such as seasonal power storage – to manage a large-scale surplus or deficit of VRE supply. By 2030, with VRE providing around 25% of India's total power generation (and with some states even further along the curve), advanced technologies and robust grids are necessary to ensure reliable operation of the power system.

Flexibility can be provided by a range of resources with varying levels of maturity. Potential sources include conventional thermal and hydro generation, battery storage, demand response (in areas such as cooling or smart charging of EVs), and – if properly managed –

variable renewable energy itself. There are a number of regulatory mechanisms that India is either implementing or actively exploring which would encourage greater uptake of such flexibility resources. An innovative round-the-clock auction was held in 2020, marking a step forward in ensuring that future renewable power projects are able to deliver power reliably when required. There are also continuing efforts to liberalise markets and, concurrently, to ensure that technical attributes such as ramping capacity are adequately valued.

Figure 3.5 ▷ Hourly change in generation from variable renewables in India as percentage of average annual demand in the STEPS



India faces a huge need for power system flexibility as much more solar and wind are added to the mix.

Coal as a source of system flexibility

In the wake of Covid-19, coal has been acting as the main source of flexibility in India's power system. Changes to regulations have reduced the minimum technical load factors of coal plants run by the central government from 70% to 55% since 2010. Though this entails added costs, particularly for older plants, it improves their ability to support the integration of VRE into the power system.

For many coal-fired power plants in India, power purchase agreements (PPAs) are based on a principle of fixed cost recovery based on declared availability, not actual generation. For these plants, lower output as a result of higher VRE will not lead to financial distress, as fixed costs can be recovered. Nonetheless, lower output and more frequent and faster ramping may lead to increased variable costs, and potentially to some need for investment in technical upgrades, as well as increased wear and tear of equipment. These additional costs will need to be recovered from consumers. Regulatory commissions could address this concern through targeted programmes for upgrades and tariff premiums for flexible operations, and measures of this kind are already being implemented in some states. For coal-fired power plants without long-term PPAs, lower output and higher costs could create more serious financial challenges.

Appropriately remunerating the provision of flexibility services by coal-fired power plants is essential to ensure the wide availability of flexibility that will be critical for operations by the end of the decade. In the STEPS, for example, the load factor across the entire coal fleet in 2030 drops below 25% for parts of the year. Achieving the degree of flexibility needed will require all coal plants to be technically ready, have the appropriate incentives, and be dispatched in a co-ordinated fashion in terms of time and location. Alongside coal-fired power plants, solar PV plus batteries will be an important source of flexibility and its prospects are improving rapidly (Box 3.2).

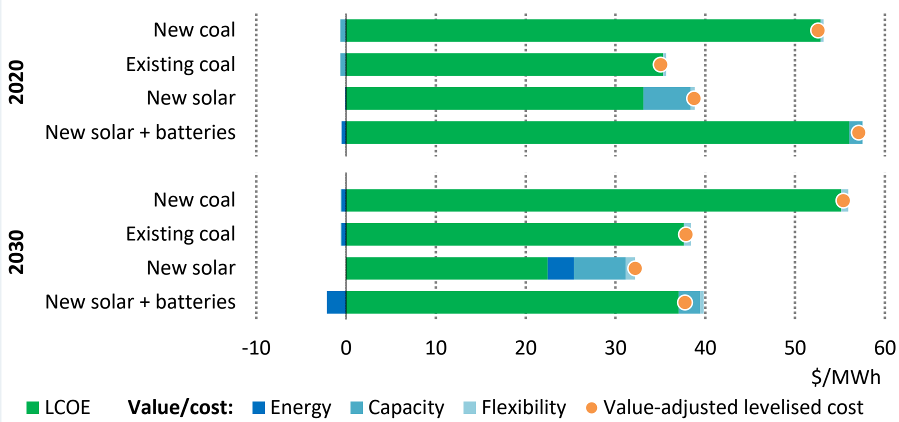
Box 3.2 ▷ Solar PV plus batteries: More competitive than coal?

Solar PV projects are now the cheapest source of new power generation in India, and are among the lowest cost in the world. However, an evaluation of the competitiveness of solar PV in India requires looking beyond the technology costs alone. Taking into account both costs and system value for available options is crucial for effective system planning.

To differentiate sources of power generation not just according to their technology costs, but to their energy, flexibility and capacity value, the *World Energy Outlook* team has developed a metric called the value-adjusted levelised cost of electricity (VALCOE) (IEA, 2018). This metric enables comparisons to be made between VRE and dispatchable thermal plants by simulating the behaviour of future power systems using a detailed hourly power model. The VALCOE does not, however, incorporate grid-related integration costs or environmental benefits such as reductions in air pollution that are not priced in markets; these costs and benefits may well be sizeable, and require separate consideration by policy makers.

In recent years, new solar PV has become more competitive in India than new coal-fired power plants, and the VALCOE of solar PV is currently about 25% lower than that of new coal capacity. That gap is slightly narrower than the traditional LCOE would suggest: compared with coal, solar PV has a lower system value, principally because it makes smaller contributions to system adequacy and flexibility. Pairing short-duration battery storage with solar PV increases both the costs and the system value, making this option near competitive with coal-fired power (Figure 3.6). Although there is a wide variation in the costs of coal generation, solar PV is already competitive against some existing coal-fired power plants with high variable costs or low thermal efficiencies. The fleet-wide average variable cost, however, remains lower than new solar PV, and so displacing existing coal-fired power with new solar PV would in most cases not yet lower total electricity production costs or electricity prices to consumers.

Figure 3.6 ▷ Value-adjusted levelised cost of coal and new solar, with or without batteries, in India in the STEPS, 2020 and 2030



The decline in the costs of solar make it competitive against coal, even taking into account smaller contributions to system value linked to the variability of solar.

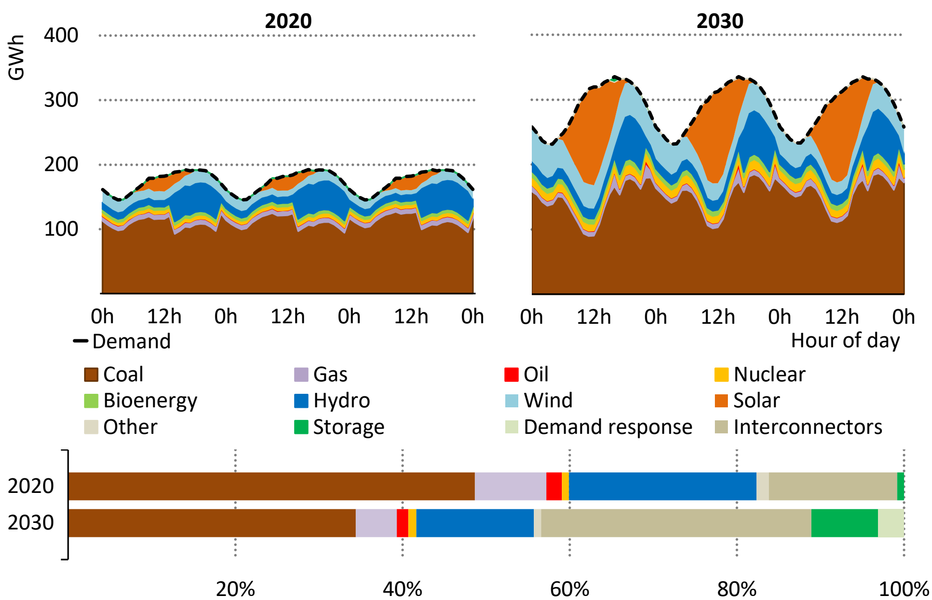
In the STEPS, continuous reductions in the cost of solar PV mean it becomes cost-competitive against most existing coal capacity in India by 2030, even after taking into account the fact that the energy value of solar PV reduces a little as its share of annual electricity generation rises from 3% in 2019 to 16%. Moreover, pairing solar with utility-scale battery storage offsets the reduction in value related to the variability of solar PV: by 2030, the VALCOE of solar PV plus battery storage is 30% below that of new coal-fired power. In other words, the VALCOE of solar PV is lower than existing coal-fired power by 2030, alone or paired with battery storage. This creates an important opportunity for the deployment of solar PV to make electricity more affordable in India.

Other sources of supply- and demand-side flexibility

Hydropower is the second-largest source of flexibility in India today with a total capacity of nearly 50 GW, mostly located at large reservoirs. Its ability to ramp up and down quickly was highlighted on 5 April 2020 when hydropower provided the majority of supply-side flexibility to accommodate the 10-minute Lights Out event in solidarity in the fight against Covid-19. There are also close to 5 GW of pumped hydro storage facilities in India, with significant potential for more that remains largely untapped to date due to regulatory and environmental constraints and to economic factors.

Additional hydropower capacity will play an important part in expanding India's power system flexibility. Installed hydro capacity increases by about 50% to 2030 in the STEPS, and hydropower remains the second-largest flexibility source in India (Figure 3.7), but some challenges remain. Depending on the time of the year, hydropower becomes more or less important due to changing hydro flows. The highest hydro flows are in the monsoon season, while the lowest are generally in the winter. Both seasons can present operational difficulties, with excess and effectively must-run generation in monsoon months, and low generation in winter months. This seasonality can also have an impact on the complementarity of hydro with other renewable energy sources. For example, wind power is also at a maximum during the monsoon season, limiting the quality of the match with hydro in India.

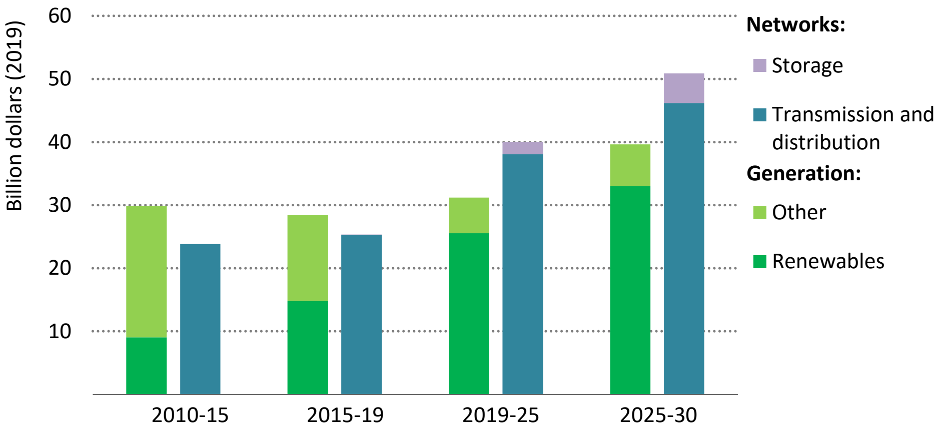
Figure 3.7 ▷ India hourly generation mix and annual share of flexibility by source in the STEPS



Coal remains the main source of flexibility in India, but rising flexibility needs are met by a more diverse set of sources, including battery storage and DSR.

Battery storage systems and DSR also look set to be essential parts of the flexibility portfolio. Battery storage systems are well-suited to the emerging need to shift solar PV output by several hours, from the middle of the day to evening peak demand, in order to better meet demand. By 2030, the STEPS sees nearly 35 GW of battery capacity. DSR, including the shifting of agricultural pumping and cooling loads, can likewise provide flexibility without compromising energy services to consumers by moving demand to times of the day with plentiful supply. Adapting regulation to permit the aggregation of loads could significantly expand DSR availability by enabling residential, agricultural, and smaller commercial and industrial customers to bring their DSR resources to a wide range of potential markets (IEA, 2018), especially since such smaller loads in buildings and agriculture represent the lion's share of DSR potential in India. Tariff design could also facilitate DSR uptake among electricity users; switching to time-of-use pricing, or perhaps even real-time pricing, would provide the necessary price signals to consumers to expand DSR from periodic load shedding in times of system stress to more regular load shifting (IEA, 2019).

Figure 3.8 ▷ Average investment spending on electricity generation and networks in India in the STEPS, 2010-2030



Capital expenditure on India's electricity networks is set to overtake that of generation, with around 15% of spending on networks in 2030 used to connect new renewables.

The transmission system has a crucial part to play in the efficient use of flexible resources over the next 10 years. The system integration of solar PV will require investment in storage and distribution networks to cope with the solar-driven "duck curve" in the morning and evening hours, while transmission and balancing capacity is required to manage wind power's strong seasonality. Better regional interconnections across India's regions are also critical, optimising power flows between states with differing demand and generation profiles. For example, northern parts of India have significant flexibility from hydropower but need to draw on imports during the early evening peak. Thermal plants in the eastern region, by contrast, provide flexibility for demand centres to the south and west, which have high industrial and agricultural loads and may call on imports during periods of low renewables availability.

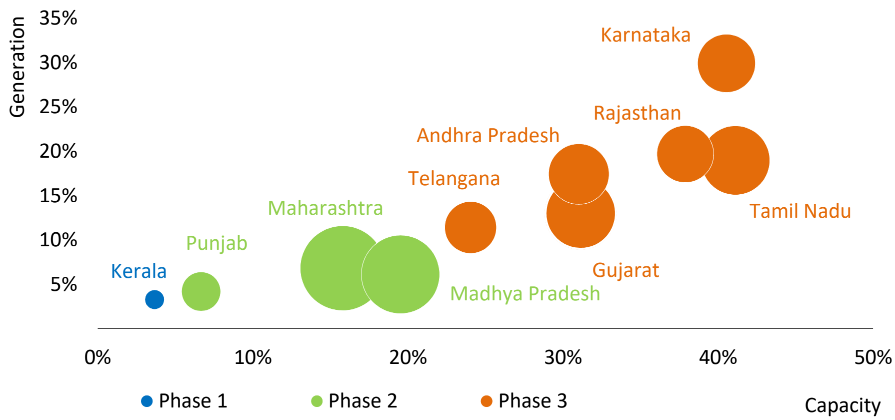
In the STEPS, spending on networks quickly overtakes spending on capacity growth, and investments in batteries start to take hold by the end of the decade, reflecting the way in which the current policy focus on achieving ambitious renewable energy targets is increasingly being complemented by a focus on the transformation of the power system (Figure 3.8).

S P O T L I G H T

Insights from the state-level integration of renewables

The share of solar and wind in India's 10 renewable-rich states is significantly higher than the national average, and these states are already redefining how their power systems are operated. The most significant renewables integration challenges are in Karnataka (where solar and wind meet around 30% of annual electricity demand), Tamil Nadu (19%) and Gujarat (13%) (Figure 3.9). These states are in Phase 3 of the IEA renewables integration framework, described above, and with ambitious targets they will move to Phase 4, putting them ahead of most countries.

Figure 3.9 ▷ Solar and wind generation by state, as a share of annual generation and capacity, 2019



Several Indian states are leading the way in increasing the share of VRE in electricity demand, providing useful case studies for integration challenges.

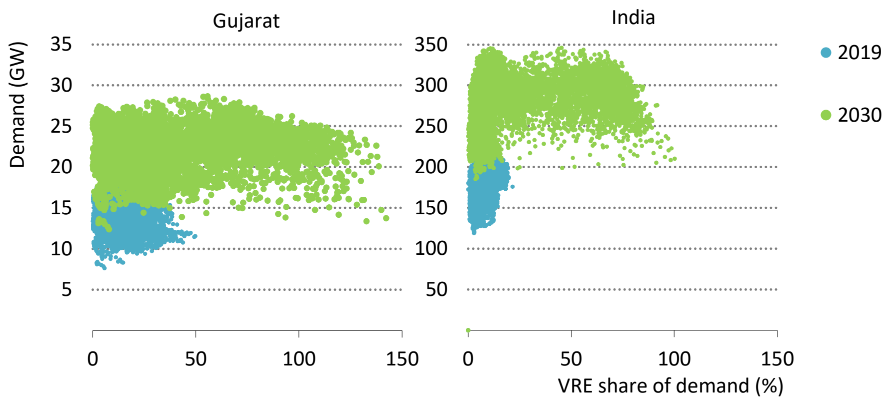
Note: Bubble size corresponds to percentage of electricity generated by VRE in each state relative to total electricity generation in India.

The state of Gujarat is among the most advanced in its power market development, with significant renewables potential and robust deployment targets, financially stable discoms, and a statewide commitment to stop the commissioning of new coal projects from 2021. Gujarat is likely to face renewable integration challenges sooner than other states, and we have explored these challenges through a detailed Gujarat power system model. The model includes separate nodes for each of the discom areas as well as out-of-state trade, and contrasts system operation today with the way it might look in 2030 based on state government targets.

Gujarat's 2030 targets include over 44 GW of solar and wind capacity to satisfy the state's power requirements, along with an additional 20 GW to be contracted to other states.

These ambitions would increase the annual share of solar and wind generation to almost 40% of total generation, from around 13% today. On an hourly basis, it is expected that solar and wind will meet up to 77% of demand at certain times of the day by 2022; by 2030, output exceeds total demand in many hours of the year, posing significant system challenges and dramatically increasing the likelihood of curtailment (Figure 3.10).

Figure 3.10 ▷ Hourly share of available solar and wind generation as percentage of demand in Gujarat versus India as a whole



Renewables-rich states such as Gujarat are already coping with higher hourly shares than the rest of India, and are now facing future integration challenges.

Today Gujarat still has negligible levels of solar and wind curtailment. However, without an increase in flexibility, 44 GW of solar and wind by 2030 would lead to annual curtailment of around 7% of solar and wind generation in 2030 – a significant level of lost output. Avoiding high levels of curtailment, and the additional system costs this may entail, will require action on a broad number of fronts. The results of our modelling exercise show that Gujarat is well-placed to develop three key flexibility resources:

- DSR: agricultural pumping accounts for more than 20% of the state's electricity demand, and shifting this load to the daytime would go some way towards aligning peak demand with solar output. This is achievable in Gujarat because it has a dedicated agricultural feeder system that allows the interruption of agricultural supply without impacting other consumers; this system is already used to manage the timing of agricultural supply today. Adjusting today's predominantly night-time scheduling to the day would reduce the baseline level of curtailment down to 3%, reduce the start-up needs from thermal generation sources by around 40%, and cut operating costs by around 10%.
- Thermal plant flexibility: coal power plants could be operated more flexibly if technical minimum plant load factors were to be reduced from 75% to 55% for older

units and to 40% for newer units. The next decade will see a significant change to the operating practices of coal and gas plants: relatively minor changes in capacity factors will lead to much larger changes in the operating patterns of coal generators, which look set to spend more time at very high or very low output in 2030 relative to today. More flexible operation of coal would allow the power system to cope with higher levels of renewables generation, but depends on the value of increased thermal plant flexibility being recognised and adequately compensated.

- Investment in batteries: a four-hour duration battery storage addition of 4 GW would allow high solar output during the day to be stored for later use to meet evening demand. As dispatchable thermal capacity declines relative to peak demand, battery storage would also help reduce short-term energy purchases and reduce import dependency.

Operational and market design challenges

As India adds a greater share of wind and solar to its energy mix and as its demand profile becomes more variable, it will face new kinds of operational and market-related challenges. This section explores the wider, structural features of India's power system and looks at where reforms could help India meet these challenges.

India has one of the world's largest synchronous power grids, with most of the scheduling and unit commitment carried out at the intra-state level by discoms. Long-term bilateral PPAs are the main way of buying and selling electricity in India, covering 90% of generation in 2019. The remainder is either bilateral trading or transactions on India's power exchange. This means that generators, for the most part, are scheduled by discoms within a limited contractual pool. Hopes are high that India's power exchange will organise more efficient trades in the future, but liquidity is currently fragmented across different products and trading platforms, and the wholesale market currently accounts for less than 5% of all power transactions.

India currently has 40 GW to 50 GW of generation capacity that is financially unviable. This is largely the result of a mismatch in demand and supply which has arisen because the pace of capacity additions has far exceeded demand growth. There is also a mismatch in incentives between generators which develop government- or state-auctioned capacity under attractive payment guarantees, and the discoms that are the primary off-takers for this new capacity. Both face difficulties in fulfilling their roles. Discoms struggle to collect revenue from consumers and face low regulated tariffs (often below the cost of metering), while generators have been unable to sell excess power to the relatively small wholesale market. The result of all this is renewable energy curtailment, asset underperformance, a general mismatch between the costs of producing electricity and the available returns, and a high level of technical and commercial losses, which average around 20% (compared with a global average of 7%).

The Indian power system also has a history of outages, resulting in part from the difficulties faced by the discoms discussed above, which have constrained investment in infrastructure and contributed to the current high level of technical losses. This history has led many consumers to install diesel-fired back-up power, and encouraged larger-scale industrial users to opt out of buying higher-priced grid electricity.

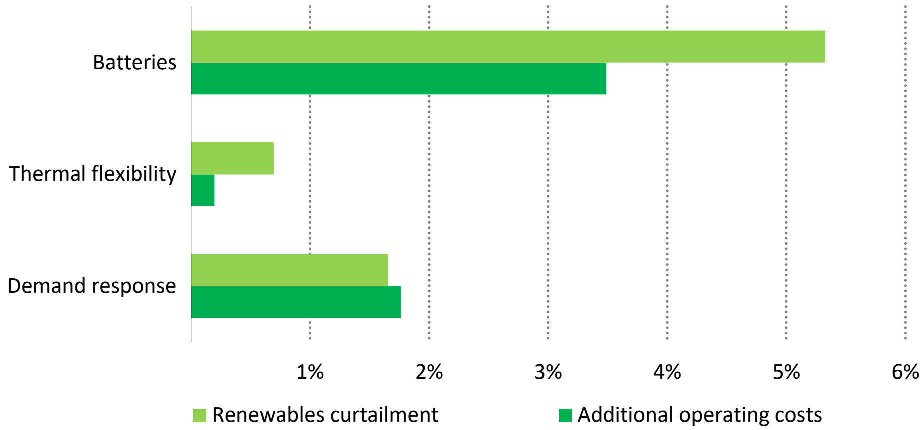
These are well-recognised issues, and the Indian government is pursuing a number of reforms. A key objective is a centralised market for day-ahead scheduling and real-time dispatch with gate closure. There were several developments in 2020: in June, the real-time power market was launched, filling an important gap by providing real-time corrections for intermittent and variable generation such as solar and wind, as well as for demand. This was followed by the launch of the Green Term-Ahead Market, allowing renewable electricity to be traded at a premium (compared with the regular day-ahead market) for buyers looking to fulfil their renewables purchase obligations (RPOs).

Further regional and, eventually, countrywide integration of the power system is crucial to managing the growing share of renewables. Co-ordination between a strong federal structure and supporting states is a central component of system integration, especially since India's power system has a diversified ownership structure, which means that reconciling different interests is a key part of effective regulation and governance. Greater integration and co-ordination are key objectives in the roll-out of renewable management centres and "green energy corridors" across eight renewable-rich states in order to facilitate the transmission of solar and wind to high demand centres.

However, there are several aspects that require further development. The necessary network upgrades rely on the ability of consumers to pay fixed charges and on grid companies to pay for bottleneck management services. Market liberalisation is hindered by a general unwillingness by generators to cancel or renegotiate existing contracts and submit to market-based pricing. Moreover, the business model for utility-scale battery storage in India remains uncertain, in the absence of efficient price signals that would enable batteries to arbitrage between periods of scarce and abundant supply. Far-reaching electricity sector reform would be needed to accommodate the scale of battery deployment required in *WEO* scenarios.

Sensitivity cases were run to explore the implications of slower progress on market reforms and rates of deployment of flexibility resources. In the first sensitivity, India is prevented from fully leveraging its thermal plant flexibility: in this case, there is a continued restriction on older coal plants to maintain a minimum stable operating level of 75% instead of 55%, while new coal plants operate at a minimum of 50%, rather than at 45%. Sensitivities were also run on batteries and DSR, assuming that no further investments would be made in these sources of flexibility after 2020.

Figure 3.11 ⊳ Impacts of limiting flexibility options in India in the STEPS in 2030



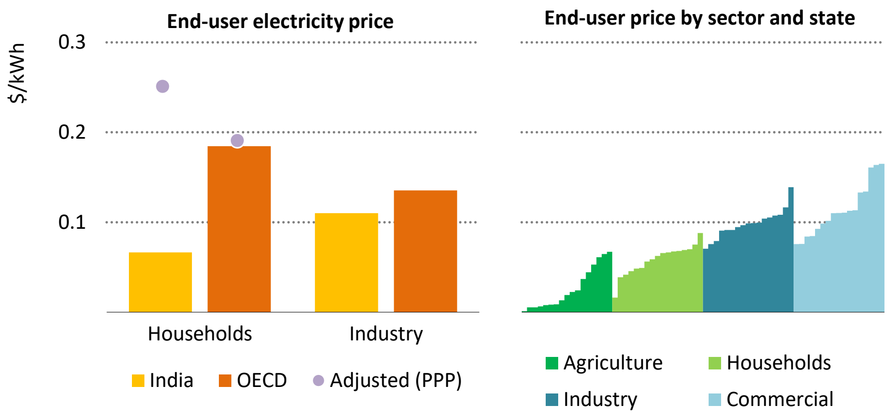
Reduced flexibility from batteries, thermal power plants or demand response in 2030 would lead to increased renewables curtailment and additional operating costs.

A lack of development in any of these three flexibility options would result in increased renewables curtailment and in increased operating costs relative to STEPS; this is particularly the case for batteries, which play a strong role in integrating the increasing share of solar generation (Figure 3.11). However, further cost-benefit analysis would be required to determine whether the value of curtailed renewable energy would exceed the investments required to reduce their curtailment.

Box 3.3 ⊳ How cheap is India's electricity?

Electricity prices in India in nominal terms are lower than the average among member countries of the Organisation for Economic Co-operation and Development (OECD). However, after adjusting for purchasing power, so as to reflect spending on electricity as a share of Indian household income, prices are higher than the OECD average. This is despite the fact that India – like some other emerging and developing economies – has higher end-user prices for more energy-intensive industrial consumers in order to cross-subsidise the lower tariffs paid by vulnerable users in the household and agricultural segment. Prices also vary not just among end users, but also between states, where a complex patchwork of different taxes and subsidy regimes can leave consumers in some states paying five times more for their electricity than their counterparts in neighbouring states (Figure 3.12).

Figure 3.12 ▷ Comparison of electricity prices paid by different end users in India, 2018



Households' electricity tariffs in India are higher than the OECD average, adjusted for purchasing power, despite being subsidised by commercial and industrial consumers.

Note: End-user prices (stacked by state) calculate each state's discom revenue per megawatt-hour for each category of consumer.

The degree to which electricity becomes affordable is primarily a consequence of macroeconomic conditions, particularly the purchasing power of wages and the level of wage growth, but there are also issues endemic to the power sector that create additional challenges, such as high levels of technical and commercial losses and poor billing practices and collection rates. Tariffs sometimes end up four times higher than the purchase cost of power, and some low-income households pay a significant portion of their monthly income to meet electricity bills.

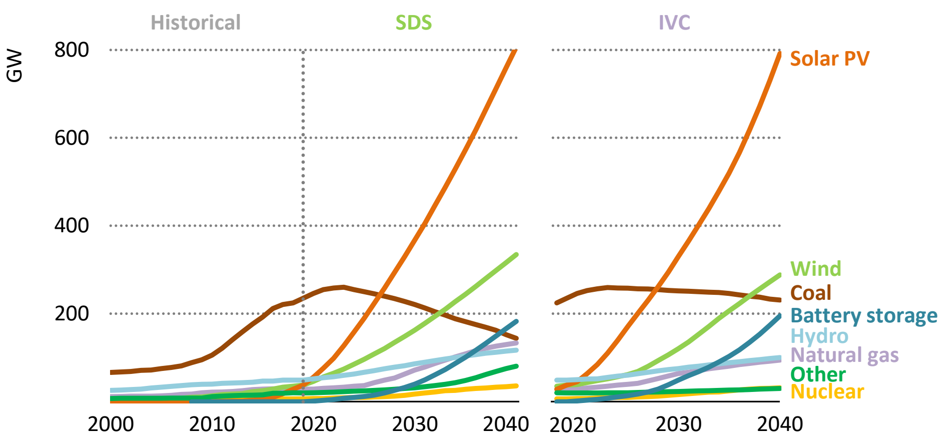
Looking ahead, the rise of renewables is likely to add to the complexity of electricity tariffs because it is likely to lead to billing based on the time of use becoming a more important part of cost-effective system balancing. There is already a case for ensuring that the complex and varied tariffs in place do not disadvantage low-income households, and this further projected increase in the variation in tariffs adds to it.

3.2.3 The power system in the India Vision Case and Sustainable Development Scenario: Charging ahead

The IVC shows a smarter transformation of the electricity sector that more fully exploits the flexibility from thermal power plants, as well as storage, DSR and cross-sector integration, in order to accommodate rising shares of renewable energy. There is also a notable shift to an India-wide, cost-reflective dispatch of generation assets. Timely implementation of market reforms underpins a significant scaling up of investment, as electricity demand is nearly 10% higher in 2030 compared with the STEPS.

The power system of the IVC makes the transition to renewables and away from coal at a faster pace than in the STEPS. By 2030, renewables make up around 60% of total generation capacity and provide 450 GW of non-hydro renewable capacity. Utility-scale solar PV passes the 60 GW mark in 2022, while close to 30 GW of agricultural load is met by solar in the next five years. By 2030, solar PV alone is responsible for meeting 75% of India's 2030 renewable target, and is on track to provide almost 800 GW in 2040. Offshore wind deployment also accelerates in the IVC, with the industry gaining a foothold in the 2020s and capacity eventually expanding to 30 GW in 2040 (Figure 3.13).

Figure 3.13 ▷ Power capacity in India by source in the SDS and IVC, 2000-2040



The ramp-up in renewable capacity in the IVC is almost as rapid as in the SDS.

The development of battery storage systems in India also picks up in the IVC, with greater deployment and deeper cost reductions: at $120/kWh, the cost of a four-hour storage system is 40% lower than in the STEPS in 2040. Batteries are an essential means to integrate additional solar and wind capacity in this case, and reach almost 200 GW of capacity in 2040, 36% higher than in the STEPS. The expansion of battery capacity also serves to limit the amount of coal-fired capacity needed to ensure power system adequacy. The IVC sees in addition a lifting of many of the barriers to DSR: aggregation of loads and access to wholesale and balancing markets for demand-side resources allows DSR to mitigate the increase in peak demand in the IVC, and to facilitate the integration of higher shares of solar PV. Agricultural pumping sees a major transition to solar PV powered pumping solutions, and remaining grid-connected pumping is aligned with power-system needs in the IVC thanks to tariff design and smart controls. Meanwhile more of India's rapidly growing fleet of air conditioners are equipped with smart controls in the IVC, allowing for modulation of electricity demand in line with system flexibility needs.

On the thermal side, captive coal generation capacity is gradually replaced by gas-fired and (to a lesser extent) renewables capacity. Coal-fired capacity peaks in the mid-2020s and then declines steadily. This leads to improvements in air quality in cities in India, while also cutting energy-related CO_2 emissions. The emphasis on gas-fired power also gives a boost to the overall use of natural gas in India.

Overall, the IVC gets India's power system much closer to the trajectory required in the SDS, where renewable capacity additions reach 1 330 GW by 2040 (compared with 1 200 GW in the IVC). However, emissions outcomes remain far apart: in the SDS, total power sector emissions fall by 80% compared with 2019 levels by 2040, and are on course to reach net zero by 2050, whereas in the IVC they remain largely unchanged. This difference is primarily a consequence of existing coal-fired capacity continuing to play a relatively prominent role in India's power system in the IVC, where the rapid growth in renewables avoids new emissions from rising electricity demand but does not displace existing coal-fired capacity. In the SDS, by contrast, a wide range of technologies and measures are deployed to reduce emissions from existing coal assets that would otherwise continue to operate, as in the IVC. They include, for example, measures to reduce the amount of output from existing coal-fired power plants by repurposing them to focus on providing flexibility, by equipping existing plants with CCUS or co-firing with biomass, or by retiring them early if these options are not viable (section 3.4.2).

3.3 Exploring prospects for a gas-based economy

India has long-standing plans to expand the use of gas in its energy mix, and the level of current ambition is high: the government is targeting a 15% share of gas in the energy mix by 2030, up from 6% today and 8% in 2010. Achieving this ambition would still leave the share of gas below today's global average of 23%, but this shift would nonetheless be a momentous one for the Indian energy economy. It would require significant investment and policy support all the way along the value chain to incentivise new upstream activity and gas import capacity, to underpin the construction of new transmission and distribution pipelines, and to install new end-user equipment.

There are reasons to believe that the gas market can grow rapidly, provided that current policies promoting its use are effectively implemented. International gas market conditions are propitious for India: ample supply at low prices helped to avoid a reduction in gas demand in 2020 despite the effects of the Covid-19 pandemic, and is now giving price-sensitive Indian buyers incentives to contract new volumes. Efforts are also under way to enact market reforms that encourage gas trading, and to rationalise the taxes and tariffs applied to different end users across the states of India.

Nonetheless, significant challenges lie ahead. India's gas market today is a complex patchwork of different pricing mechanisms, gas allocation schemes and types of gas (Box 3.4), and there are some distressed gas-fired assets in the power sector as well as some underperforming and underutilised infrastructure. This complexity represents one challenge. It will also not be easy to encourage growth in a market that is likely to be based, in large part, on imported gas, or to find ways of overcoming the persistent competitiveness gap at the end-use level between gas and cheaper local energy sources such as coal and renewables. Ultimately, concerted policy efforts, backed by robust implementation, are key to creating the incentives necessary for gas in India to grow.

Box 3.4 ▷ A gas by any other name

Gas has multiple identities in India, with different terms used to distinguish its origin or end use. Pipeline natural gas, or PNG, mostly consists of domestically produced natural gas. Imported gas is known as r-LNG, or regasified liquefied natural gas. CNG, or compressed natural gas, is natural gas that is bottled and sold at filling stations as a transport fuel. Biomethane, which is biogas upgraded to reach pipeline quality specifications, is a relatively new addition to the gas lexicon, and is being marketed in India as a sustainable variant of CNG, called either CBG or bio-CNG.

All of the above gases are ultimately methane, the primary constituent of natural gas. The exception is biogas, which also consists of CO_2 and other gases such as nitrogen, and when not upgraded to biomethane is used primarily as a source of local heat and power and clean cooking in rural areas. Although often assumed to be in the same category as these gases, liquefied petroleum gas – LPG – is a natural gas liquid and in IEA accounting is classified as a liquid fuel.

The prospect of increased Indian reliance on natural gas provokes a range of views as to the implications for India's economy, its environmental performance and its energy security. Our intention in this section is to untangle these various strands and explore in more detail what a gas-based economy could mean for India, and the extent to which it might meet India's designated policy objectives – notably to diversify the fuel mix towards cleaner alternatives, tackle poor urban air quality and reduce dependence on oil.[1]

3.3.1 Can India afford gas?

The prospects for gas in India hinge on its affordability, and whether there is a way to adequately remunerate gas producers and suppliers while still having a delivered product that is consistently and affordably priced for Indian consumers. There are parts of India, notably in Gujarat, that have been relatively successful in finding this balance, but the overall record – despite numerous reforms and administrative solutions – has been mixed. There is also a very wide variation across different Indian states in terms of today's gas infrastructure and consumption (Table 3.3), although there are ambitious plans to expand pipeline connections and CNG filling stations almost everywhere.

[1] The idea of a "gas-based economy" is often understood to refer to fossil natural gas, but this is not necessarily the case, and we examine also the prospects for low-carbon gases such as biogas, biomethane and hydrogen.

Table 3.3 ▷ Indicators of gas supply, consumption and infrastructure in selected states and union territories of India, 2019

	Prod. (bcm)	TFC (bcm)	Gas-fired power (GW)	LNG regasification capacity (bcm/y)		PNG connections (thousands)		CNG stations	
			Existing	Existing	Planned	Existing	Planned	Existing	Planned
Gujarat	1.4	14.9	7.6	37.4	13.6	2 065	1 018	548	236
Uttar Pradesh	-	10.4	1.5	-	-	159	2 037	128	845
Maharashtra	-	8.5	3.2	6.8	17.7	1 457	1 590	313	303
Madhya Pradesh	-	2.1	-	-	-	56	2 009	43	361
Assam	3.3	2.0	0.6	-	-	34	416	-	72
Delhi	-	1.9	2.2	-	-	1 097	-	482	-
Haryana	-	1.9	0.4	-	-	100	1 185	66	327
Kerala	-	1.9	0.5	6.8	-	1	3 394	4	826
Rajasthan	1.5	1.7	1	-	-	2.2	4 246	5	603
Rest of India	3.8	5.2	7.6	6.8	25.8	109.1	26 513	141	4612
Total	**10**	**50**	**25**	**58**	**57**	**5 100**	**42 400**	**1 730**	**8 190**

Note: Prod. = Production (onshore only), TFC = total final consumption.

Sources: IEA analysis based on Cedigaz (2020); GAIL (2020); MPNG (2020); PNGRB (2020); PPAC (2020).

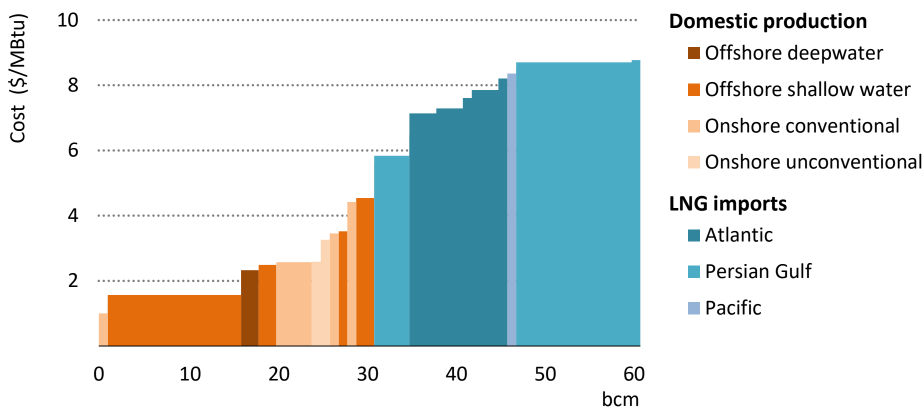
Wholesale gas pricing

On the wholesale side, pricing is split between domestically produced gas and more costly LNG imports (Figure 3.14). Since 2014, the price of domestically produced gas has been set by a formula linked to a basket of international reference prices. This means it is not necessarily reflective of the cost to producers of domestic extraction, nor the affordability – or willingness to pay – of gas to different consumer categories in India. In 2019, this administered price averaged $3.2/MBtu,[2] while the weighted average wholesale price of all sources of gas in India in 2019 was around $6/MBtu once more expensive imports were factored in.

Around half of India's gas supply is imported and, with around 30 bcm of LNG imports in 2019, India is already the world's fourth-largest importer of LNG. The majority of LNG delivered in 2019 was priced either via oil-linked formulas, typically at a premium of 11-15% to crude oil markers, such as Brent or the Japanese Crude Cocktail (JCC), or as hub-indexed spot US LNG delivered under long-term contracts. The remainder was purchased on the spot market, where prices are often determined on the basis of gas-to-gas competition. In recent years, these spot prices have been well below the cost of oil-indexed gas supply, resulting in pressure from the main Indian buyers of LNG – Petronet and GAIL – to renegotiate the terms of these long-term supply contracts. In parallel, the practice of tendering for spot LNG cargoes has strengthened price discovery, which has been bolstered by the creation of the IGX, India's nascent gas market hub. This allows buyers and sellers to trade in both spot and forward contracts across three physical hubs (Box 3.5).

[2] A higher ceiling price averaging $8/MBtu has been set for gas developed in more challenging deepwater or ultra-deepwater zones. To encourage foreign direct investment, the Indian government has also offered pricing and marketing freedom for so-called "non-regulated" fields as part of HELP.

Figure 3.14 ▷ Weighted average cost of natural gas in India by source, 2019



A significant cost gap exists between domestically produced gas, which has been unable to keep pace with demand, and imported LNG, the price of which is mostly linked to oil.

Notes: Domestic costs refer to the break-even costs of developing resources. LNG imports refer to landed costs.

Box 3.5 ▷ India's emerging gas exchange

India took an important step in its gas market evolution in June 2020 with the opening of the IGX. This is a digital trading platform linking three physical LNG-importing "hubs": Dahej and Hazira in Gujarat, and Kakinada in Andhra Pradesh. For the moment, only regasified LNG is tradeable, but over time this platform could become a way to introduce more transparent, cost-reflective and uniform pricing arrangements across the entire Indian gas market.

To become a successful reference point for price, a trading hub requires a number of enabling conditions, notably an unbundled gas value chain with third-party access to infrastructure and the presence of several buyers and sellers of wholesale gas. It also needs a certain amount of liquidity, meaning that gas might be bought and sold multiple times before being physically delivered and consumed. It must also have depth, meaning that gas has to be available on spot terms, e.g. on a day-ahead basis, and as a futures product, e.g. deliveries agreed for the next month, season or year. Market participants can use these traded products to undertake risk management, for example by hedging their future production or consumption.

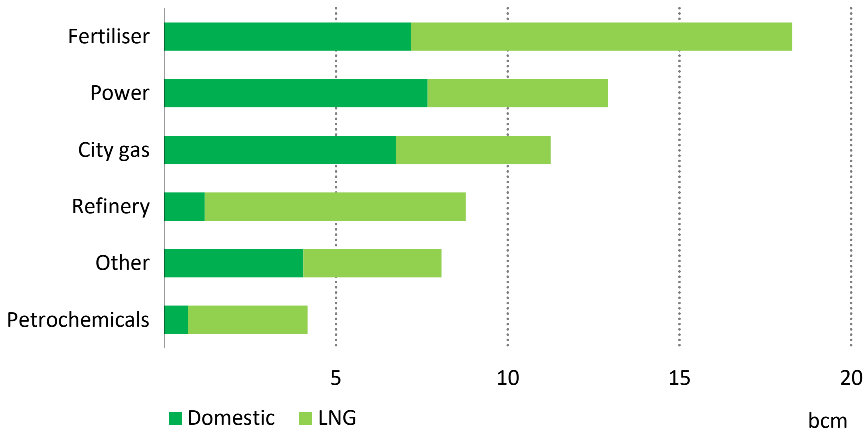
These conditions are not yet met in India. As in many other emerging gas markets, there is only a limited set of gas supply sources in India, while infrastructure (including storage) is still insufficient, and domestic supply is dominated by long-term bilateral contracts, often with strict conditions about delivery and resale. Unbundling the gas value chain, ensuring transparent third-party access and bringing greater competitive pressures to bear on the Indian gas market (thereby curbing the market power of incumbents) is a process that is likely to take time. The most well-known gas hubs in the United States (Henry Hub) and in Europe (the National Balancing Point [NBP] in the United Kingdom and the Title Transfer Facility [TTF] in the Netherlands) all took several years after their inception to reach maturity. The Indian power sector provides a further useful point of comparison: an exchange was created in 2008, and has since seen significant growth in the number of transactions, but the current traded volume still represents only 5% of total power supplied in the country.

3

End-user prices

There are a multitude of gas prices in India, which vary depending on the origin of the gas, the distance it travels and the taxes applicable in the state in which it is consumed. An important factor determining the end-use price of natural gas is the mix between domestic gas and imported LNG. A government-administered allocation policy reserves the cheaper domestically produced volumes of gas for specific consumer categories (Figure 3.15). The order of allocation has undergone frequent revisions over the past several years; power plants, until recently a high priority, have now been removed from the list altogether. Fertiliser plants were also initially given preferential access to reduce the need for more expensive urea imports. However, later revisions gave city gas distribution (CGD) top billing to free up LPG for use in rural areas in place of more polluting fuels, while fertiliser plants transitioned to a "pooled pricing" system to help them to manage the transition to greater imports.

Figure 3.15 ▷ Split of domestically produced gas and LNG consumed by sector, 2019



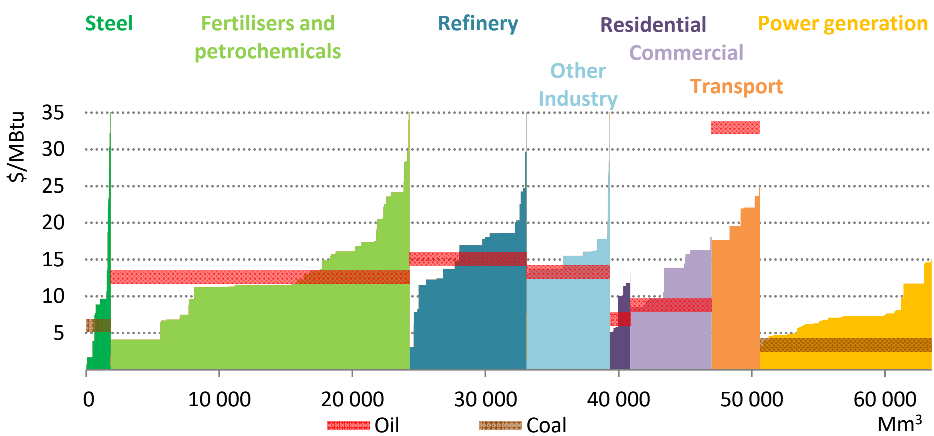
The power sector has received the highest share of cheaper domestically produced gas in recent years, although the most recent rule changes now prioritise CGD.

Notes: IEA analysis based on PPAC (2020).

Commentary about the affordability of gas on India's gas market typically focuses on the sensitivity of consumption to landed LNG costs; a recurring narrative is that LNG prices lying above a $5/MBtu to $6/MBtu range preclude the large-scale adoption of gas in the face of competing fuels. However, pipeline tariffs and taxes are very important elements in the final cost to consumers, and they vary widely in a complex patchwork across the country, depending on the category of consumer and the state in which they reside.[3] In the case of India, tariff reform and a streamlining of applicable taxes are important policy levers that could potentially reduce the prices charged to end consumers and therefore make higher imported gas prices more tolerable.

For this report, we conducted a bottom-up analysis of prices actually paid by different end users, using facility and state-level data in key gas-consuming industries and states. This has yielded a first-of-a-kind estimate of the range of prices paid in different states and sectors in India, making possible a more detailed assessment of the competitiveness of gas compared with competing fuels (Figure 3.16).

Figure 3.16 ▷ Range of natural gas prices paid in selected end-use sectors in India and average price of the main competing fuels, 2019



There is an affordability gap between natural gas and competing fuels in several sectors, although a small subset of consumers benefit from access to lower-cost domestic gas.

Notes: Mm^3 = million cubic metres. Energy sector own use not included. Many industries are not viable for competitive fuel switching, e.g. a relatively small amount of gas is used as process heat in the petrochemicals sector, while 90% of fertiliser production already comes from natural gas. Competing fuels are naphtha and, potentially, coal gasification.

Sources: IEA estimates based on data from GAIL (2020); MPGN (2020); MoSPI (2018); PPAC (2020).

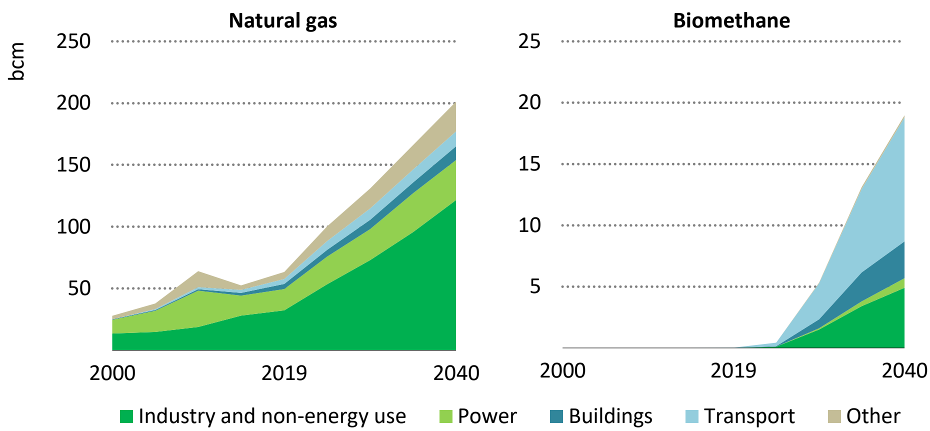
[3] In Ahmedabad, for example, residential consumers pay about 40% less than commercial and industrial consumers for an equivalent amount of natural gas. However, the tax rate in Ahmedabad is double that of Bangalore. The government is now planning to include gas into the GST, which would mean that gas is taxed at a standard rate across India; the implications for the competitiveness of gas would vary, depending on the present arrangements in each state.

As noted above, the weighted average price of domestic and imported gas in India in 2019 was around $6/MBtu. With the additions of different state taxes, transport tariffs and corporate margins, the final cost to consumers is usually considerably higher, however, and the weighted average end user price in 2019 was $12/MBtu. The range is very large, with most gas consumers paying somewhere between $6/MBtu and $18/MBtu. This is comparable in absolute terms to prices paid in Europe, but is much higher after adjusting for relative purchasing power in India. A further difference between end-user prices in India and elsewhere is that most large-scale users of gas in India, such as industrial facilities, pay higher prices than smaller-scale consumers.

As things stand, the main sector where gas is clearly competitive is transport; CNG prices are around 40-50% lower than petrol and diesel prices, which also have a high tax component. Natural gas is also well placed to compete in smaller-scale industries that require consistent levels of adjustable process heat but must, suboptimally, resort to using coal, biomass or furnace oil today. However, in many other parts of the Indian economy – including some key industrial sectors – the case for gas on straight cost grounds is much less compelling. With today's regulatory framework, economics alone do not make the case for gas in India.

3.3.2 Gas demand in the STEPS

Figure 3.17 ▷ Natural gas and biomethane demand by sector in India in the STEPS



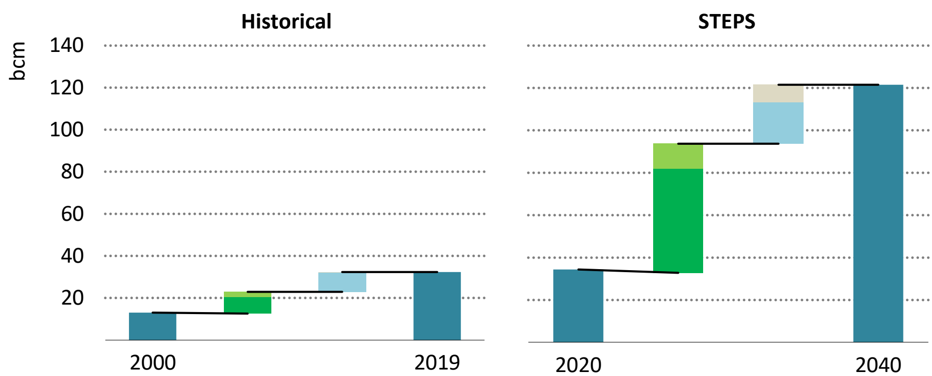
Industry is the key driver of natural gas demand growth, while transport demand underpins the growth of biomethane, which reaches a 10% share of total gas demand by 2040.

Overcoming affordability challenges for natural gas requires a range of supportive policies. The Indian government, as well as some states, has put in place a number of policies promoting gas use, including a wide-scale roll-out of CNG and bio-CNG, and the expansion of gas infrastructure including LNG terminals, long-distance transmission pipelines and CGD networks. These policy ambitions translate into rapid growth of gas demand in the STEPS over the next decade (Figure 3.17). On average, gas grows nearly 7% each year to 2030, more than double the rate of overall energy demand growth. The share of gas in India's energy mix (both natural gas and biomethane) doubles from 6% to 12% by 2040, largely at the expense of coal and traditional solid biomass. However, this share remains the lowest among the countries and regions modelled in the *WEO*.

Gas use in industry

In the STEPS, industrial gas demand – including the use of gas as a feedstock for petrochemical and fertiliser production – is the primary source of demand growth (Figure 3.18), and the share of gas in total industry energy demand nearly doubles to reach 20% by 2040. Most of the growth comes from lighter industrial sectors and small- and medium-scale industrial customers, who gain gas connections as transmission and distribution infrastructure is rolled out. This means that the share in industrial gas demand of energy-intensive industries such as refineries, fertiliser plants and some gas-based steel producers declines from around 40% today to around a fifth in 2040.

Figure 3.18 ▷ Drivers of industrial gas demand in India in the STEPS, 2000-2040



Industrial gas demand is poised to rise rapidly, with infrastructure supporting market growth and encouraging existing end users to switch away from other fuels.

Gas, where it is available, is well suited to the needs of lighter industrial sectors such as textiles, manufacturing, and food and beverages. These tend to be located in or close to large population centres, where air quality becomes an increasingly important consideration; providing policy incentives for such clusters of MSMEs to switch to gas-burning equipment is therefore key to unlocking further growth. For many such industries, the convenience of being able to adjust process heat temperatures and the opportunity to make efficiency gains are added advantages of using gas instead of liquid or solid fuels, although electricity provides competition for some lower-heat applications. For some industries currently using liquid fuels, switching to gas can be commercially attractive, particularly in cases where fuel costs are relatively low in terms of total added value, or where there is a relatively short payback period associated with the upfront investment costs to switch to gas-burning equipment.

Policies will play a critical role in determining the speed and scope of growth in natural gas. Most of the 30 bcm of demand growth attributable to fuel switching in the STEPS is driven by policy-led efforts to reduce the level of coal and oil use in industries which are located near urban areas and contribute to poor air quality. To take one example, the possibility of using CNG in place of coal in India's massive brick industry is attracting interest in some jurisdictions.

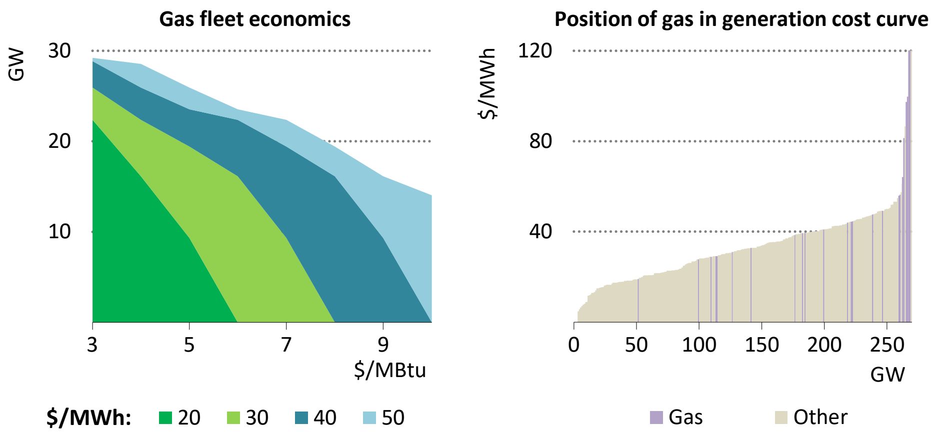
Gas use in power

Natural gas has been facing a perfect storm in India's power sector in recent years. A wave of new power plants was commissioned in the late 2000s in anticipation of a large increase in supply from India's offshore gas resources. However, production from the much-awaited KG-D6 field in the Krishna Godavari Basin off India's east coast did not match expectations and fell away quickly. Gas-fired power plants were left short of gas or became reliant on more expensive LNG. The situation was compounded by revisions to the gas allocation policy, which left power plants lower on the priority list. Lower-than-anticipated electricity demand, along with ample thermal coal capacity, has meanwhile left very little space for gas to contribute to marginal power generation. In 2018, 60% of gas-fired power plants were deemed by the government to have become stranded assets (Ministry of Power, 2018).

Recent market developments have seen mixed fortunes for gas; LNG spot prices in summer 2020 hit record lows of around $2/MBtu, causing an uptick in gas used for power generation. However, a tighter Asian market caused spot prices in December 2020 to surge to multi-year highs, dampening the economics of gas plants. Moreover, supply-side economics are only one determinant of a plant's operations; actual scheduling depends foremost on the level of electricity demand, while the electricity tariffs received by gas are fixed by long-term PPAs, with dispatch determined within a limited contractual pool of generators. Even if this were to change, less than a third of capacity would be competitive at tariffs below $30/MWh (Figure 3.19), given the level of gas import prices reached in *WEO* scenarios ($7/MBtu to $9/MBtu). With cheap solar providing the main competition for the incumbent coal-fired generators, natural gas is looking at a range of walk-on parts in India's power scene rather than a central role.

With plant economics likely to remain challenging, the outlook for gas in India's power sector – as elsewhere – is highly contingent on policy, and on the implications of policy for coal-fired power. Ideas that have been explored to revive stranded gas plants include the possibility of pooling tariffs from gas-based power plants with those of renewable facilities in order to enhance their affordability for consumers. Reforms in the midstream, such as allowing power plants to contract pipeline capacity on a more flexible basis, could reduce operational costs. Using natural gas plants to provide flexibility, and then remunerating their ancillary services to the electricity grid, is another possible option. However, for the moment, most of the tariffs do not reflect the additional costs of meeting peak demand and operating only when renewable energy generation is at seasonal or diurnal lows, and some cash-poor discoms have been reluctant to dispatch relatively expensive gas even when it is required for system reliability.

Figure 3.19 ▷ Gas-fired power generation economics under different delivered gas costs and power tariffs, and generating costs in mid-2020



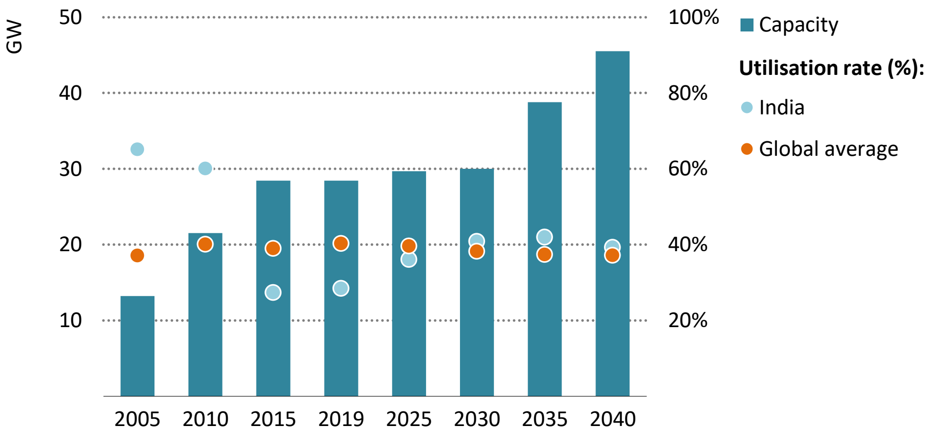
Even with a supportive tariff rate and low delivered gas prices, gas-fired power plants struggle to compete in the Indian power sector.

Notes: Right-hand chart is IEA analysis based on Ministry of Power (2020), covering the period March-August 2020, during which spot gas prices were at record lows. Other refers to generation sources covered by Ministry of Power reporting, primarily thermal coal plants. The delivered cost of gas in the left-hand chart includes the energy component (50-60%) and taxes, tariffs and corporate margins (40-50%).

As discussed in the deep dive on the power sector above, India has an increasing need for flexibility, and this creates some opportunities for natural gas in the future. However, most of India's flexibility needs are relatively short term, even intraday, and these are areas where gas faces some fierce competition from other technology options. Recent auctions for round-the-clock power have primarily been won by renewables linked to utility-scale batteries. In the STEPS, coal plants are the major source of flexibility to balance the growing share of VRE to 2030. In later years gas is used alongside a broad range of other flexibility options, including greater interconnections, battery storage and DSR.

As a result of the difficult environment it faces in the fast-growing power generation sector, only around 10% of additional gas demand to 2040 comes from that sector in the STEPS. Most of that increase over the next decade is due to a revival of existing gas power plants rather than investment in new plant capacity (Figure 3.20). Despite the increase, moreover, the contribution of gas to overall power generation remains static, at around 4%, as solar and wind make up the majority of new generation.

Figure 3.20 ▷ Gas-fired capacity and average utilisation rate in India in the STEPS, 2005-2040



India's gas-based power assets slowly recover from today's low utilisation rates; capacity growth after 2030 is underpinned by flexibility rather than baseload requirements.

One opportunity for new gas-fired power generation is in the captive power sector, i.e. with companies that choose to generate their own power or use diesel as back-up generators. This is a significant element in the Indian power mix, accounting for around 40% of industrial power needs. At present, more than half of India's 75 GW of installed captive capacity is coal-fired, followed by diesel generators with a 20% share. Gas has a 10% share of the captive power sector, and around a quarter of gas-fired generation in 2019 was from captive power units, with petrochemical and fertiliser plants the main users. The scope for growth is linked to two main variables: the roll-out of gas infrastructure and the reliability and affordability of electricity from the centralised grid. We estimate that 1.5 bcm to 4.5 bcm of additional gas demand could arise in the captive power segment, with the upper range depending on industries with existing captive capacity deciding to switch their generation to gas.

City gas distribution

CGD is a category encompassing a number of different uses – gas for residential cooking and hot water, CNG for transport, and a wide variety of commercial and small-scale industrial uses. The rise in gas use in urban households over the last decade has largely been policy-driven, underpinned by efforts to free up LPG for use in rural areas. As of September 2018, 18 states and union territories (covering 96 cities, towns and districts) in India had city gas networks, with the majority of residential gas demand consumed in the urban agglomerations of Delhi, Mumbai and Ahmedabad.

In the transport sector, India is one of the largest CNG markets in the world, with nearly 3 million CNG vehicles and half a million CNG buses on the roads. There are ambitious plans to expand the use of biomethane in transport, with targets to add bio-CNG cylinders to the product line of 5 000 CNG stations by 2025. There are also emerging plans to develop LNG as a heavy-duty transport fuel. This degree of policy ambition translates into an average growth rate of nearly 6% in the STEPS; by 2040, around 5% of total gas demand is used in road transport, more than double the global average.

The uptake of gas by more urban consumers depends on the development of gas infrastructure, especially distribution pipelines and CNG stations. A total of 10 bidding rounds have taken place that awarded tenders to build gas distribution networks, but the scale of the 9th (in 2018) and 10th (in 2019) bidding rounds underlined India's ambitions to extend the gas grid. If all the proposed infrastructure were to be built, this would give potential coverage to 70% of India's population, compared with 2% who are connected today (around 5 million households). GAIL, the main transmission system operator in India, is expanding its gas transmission network by around 80% over the next three years to develop a backbone for this roll-out of distribution infrastructure (PNGRB, 2020). The main trunk line under construction is the Jagdishpur-Haldia-Bokaro-Dhamra Pipeline, nearly 4 000 km in length, to bring gas to the eastern and northeastern parts of the country. There are also plans to develop small-scale LNG supply chains, loading them onto specialised containers for transport through road, rail and barge networks, prior to developing pipeline infrastructure.

A host of permitting and financing challenges remain before these plans can be realised. Moreover, the ambition to scale up urban gas consumption is significantly greater than the projected rise in domestic output, so although the CGD sector as a whole stands to benefit from priority access to cheaper domestic gas resources, it also faces the prospect of increased reliance on imported sources of gas. As the balance of domestic and LNG consumed in CGD tilts towards the latter, prices are likely to increase. The extent to which this might be matched by rising household incomes and industry margins is a key uncertainty.

The affordability of gas also hinges on efforts to reform gas transport tariffs in order to prevent consumers farther away from gas sources from being penalised (while avoiding problems with CGD utilities' cost recovery of the kind experienced by electricity distribution companies in the electricity sector). Unbundling supply from transport and ensuring third-party access are crucial prerequisites for the cost-effective utilisation of the grid. The Petroleum and Natural Gas Regulatory Board has recently enacted a series of supportive regulatory actions aimed at rolling out a uniform transmission tariff, standardising gas purchase agreements and launching an electronic bulletin board.

In the absence of significant winter heating loads, the quantity of gas demanded by CGD consumers does not vary much over the course of the year; seasonal variation is of the order of 10%, compared with over 250% in Northwest Europe. This limits the need to oversize parts of the system, including storage, meaning the marginal investment costs per household connection are relatively lower.

Aggregate demand in the CGD sector is likely to be far lower than in the power generation and industrial sectors, where bulk quantities are contracted by power plants and large-scale industrial users, many of which are directly connected to the high-volume transmission network. As a result, the business model underpinning the expansion of gas distribution networks relies less on securing a few big anchor customers than on building pipelines in conjunction with CNG stations, which are currently the most profitable end users.

3.3.3 Gas supply and security in the STEPS

A key uncertainty in India's movement towards a "gas-based economy" is whether it can take place without a vibrant upstream gas sector. Gas production has fallen since reaching a high point in 2010, and has flattened out at around 32 bcm in recent years. Lower-than-expected domestic production has had several knock-on effects on India's energy sector as a whole, leaving distressed assets in the power sector, increasing the cost of fertiliser subsidies, and reshaping the market distortions that stem from the complex allocation regime of cheap domestic gas. The government wants to revitalise investment in India's own gas resources, but the pandemic and its aftermath weigh heavily on prospects for a durable recovery in regional gas prices, particularly as the LNG market appears well-supplied over the next five years; while this is good news for Indian importers, it does not bode well for the government's ambitions for domestic gas production.

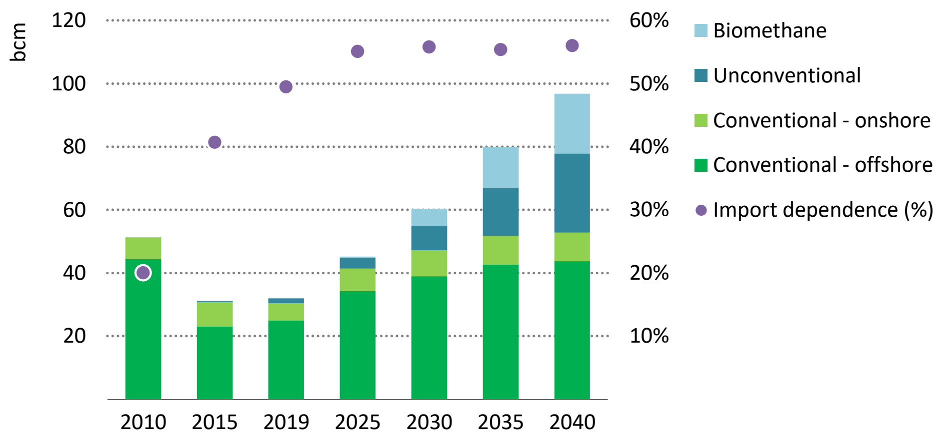
3

Estimates of India's recoverable gas resources stand at around 8 trillion cubic metres (tcm), the majority of which are situated in India's eastern offshore block, Krishna Godavari. The Indian government has taken steps to incentivise development of technically challenging natural gas fields, including deepwater resources, by reforming licensing requirements and allowing companies to market the resulting production at higher prices. This has spurred some new offshore developments by ONGC and Reliance, as well as some spending on smaller fields onshore. The government is also looking to encourage production of coalbed methane, where resources are estimated at some 1.2 tcm and current production is around 1.3 bcm per year. India also has some potential for shale gas, although challenges related to land and water access make large-scale production unlikely.

The major dilemma facing the Indian upstream is the flip side of the "affordability" issue discussed above: prices on the domestic market are at present not adequate to trigger larger investment, especially at a time when company finances are under strain from the pandemic and when there is ample supply of international LNG. In the STEPS, however, the market begins to rebalance in the mid-2020s; domestic natural gas production gradually picks up as prices rise and a hospitable regulatory framework supports additional investment in new offshore fields, and overall output more than doubles to reach 78 bcm by 2040 (Figure 3.21).

An additional, sometimes overlooked, source of domestic gas supply for India is biomethane. India has ample supplies of sustainable feedstock for biogas and biomethane production, mainly from sugar cane, rice and wheat crop residues. Increased urbanisation and improvements in waste management and collection also create significant potential for gas production from municipal solid waste. In an environment where most natural gas is imported, and long-distance pipelines face difficulties with permitting and financing, these local sources of domestic supply represent a potentially attractive option from both a commercial and an environmental perspective. Biomethane production, primarily for use in the transport sector, reaches nearly 20 bcm by 2040 in the STEPS (see section 3.4.2).

Figure 3.21 ▹ Domestic gas production in India in the STEPS, 2010-2040



A revival in offshore gas fields over the next decade helps bring production back to its historic 2010 peak; unconventional gas and biomethane lead growth in the 2030s.

The growing gap between India's domestic output and its projected demand means an increasing reliance on imports. In the STEPS, these are met entirely by LNG; we do not assume any new pipeline connections over the period to 2040. Although the economics could work, the practical and political challenges of bringing gas to India overland from Iran or from Turkmenistan weigh heavily against these options, especially in an environment where LNG is readily available for direct delivery to Indian ports.[4]

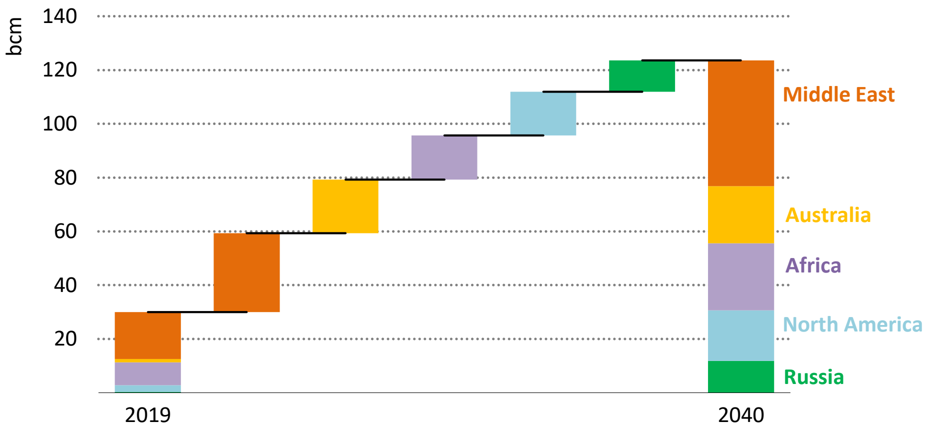
As noted above, India is already a major LNG importer and has several long-term gas contracts in place for around 35 bcm per year of deliveries. The largest source of LNG for the Indian market is Qatar, although its share of the total has declined in recent years as Indian buyers have contracted shipments from a more diverse set of exporters. In 2019, these included African exporters (Nigeria and Angola), other Middle Eastern countries (United Arab Emirates and Oman), the United States and Australia. The range of potential sources of LNG and the increasing flexibility of contractual terms provide some comfort in terms of gas security, although India does face the prospect of a rising bill over time for imported gas.

In the STEPS, India sees a quadrupling of LNG imports from around 30 bcm in 2019 to more than 120 bcm in 2040, and continues to source LNG from a range of international suppliers (Figure 3.22). The annual cost of imported gas rises from $12 billion to $43 billion over this

[4] This represents a change from the previous *India Energy Outlook* (IEA, 2015), in which LNG represented the bulk of India's imports but pipeline imports in the corresponding scenario began in the late 2020s.

period, though this remains relatively small compared with the cost of imported oil ($250 billion in 2040).

Figure 3.22 ▷ Indian LNG imports by exporting region in the STEPS, 2019-2040



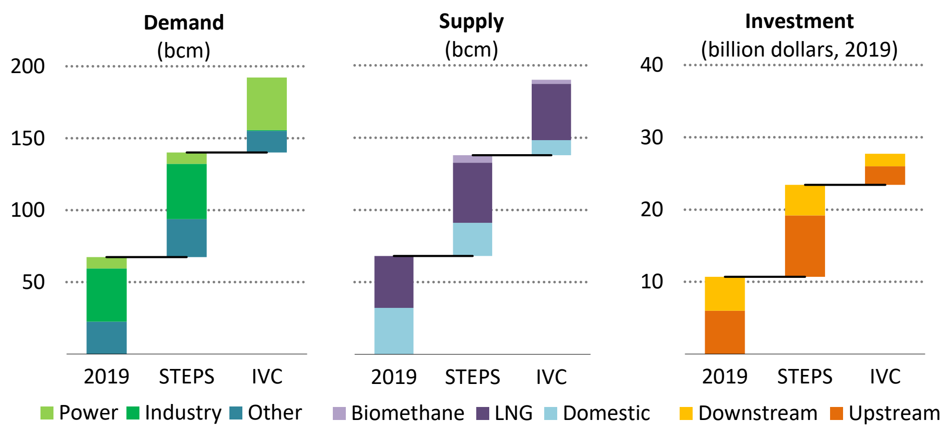
India is a primary market for LNG, accounting for nearly 30% of global growth to 2040 in the STEPS, and is well positioned geographically to develop a balanced portfolio of supply.

Rising LNG imports in the STEPS means that the gap between already-contracted LNG supply and projected LNG demand widens to around 40 bcm by 2030. We assume that this is filled with a mixed portfolio of fixed-term contracts and spot volumes. This does not, as is sometimes assumed, imply a choice between long-term, inflexible, oil-indexed supply and market-responsive spot purchases. While it is true that long-term contracts have "take-or-pay" clauses that oblige buyers to import a minimum contracted quantity of gas, there are several provisions allowing for flexibility. For example, in 2018 GAIL exercised its right to resell US LNG volumes that were uncompetitive in the Indian market by agreeing "swap contracts" with Shell. Moreover, volumes agreed in long-term contracts need not necessarily be oil-indexed, and in recent years sellers have accepted a variety of pricing terms, agreeing to reduced "slopes" dictating the strength of the oil-gas price link, netback to Henry Hub prices or linkages to emerging Asian spot benchmarks. Contracting a spot cargo, by contrast, is by definition "take-or-pay", and short-term contracts underpinning spot deliveries can still be indexed to oil. India's need for reliable baseload supplies of LNG implies that long-term contracts will remain part of the mix, even as the country seeks to benefit from the growing commoditisation of LNG.

3.3.4 Realising the India vision for gas in 2030

The outcomes in the STEPS move India towards the government's aim of becoming a much more gas-based economy, but do not meet its aspirations in full. We explore the additional upside potential for gas in the IVC, in which gas achieves an 11% share in the overall energy mix by 2030 (compared with 9% by the same year in the STEPS). In the IVC, gas use grows at an average annual rate of 8% to 2030, or around eight times the average rate of growth over the last decade. All sectors share in this additional growth, with around 40% coming from industry, especially manufacturing, steel and petrochemicals, and half from the power sector. CNG is also more widely used as a transport fuel (Figure 3.23).

Figure 3.23 ▷ Growth in key indicators for gas in India in the STEPS compared with the IVC, 2019-2030

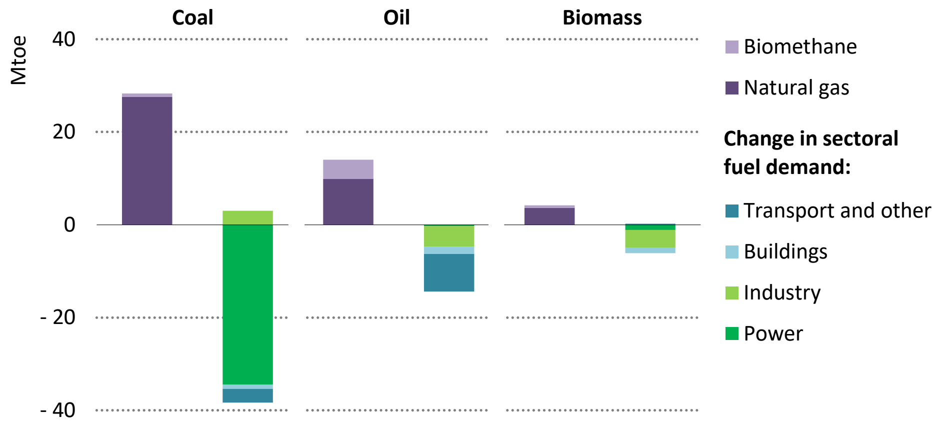


The IVC sees a more than doubling of gas demand in the next decade, sustained by market reforms and policy support.

The IVC is based on higher economic growth than the STEPS, so some of the additional gas demand is due to higher activity levels. But in order to increase substantially its share of overall energy demand, gas needs to *replace* other sources of energy to a much greater extent than is seen in the STEPS. Given its dominance in India's energy system, coal is the main target for substitution, and around 40 Mtoe is displaced in the IVC (or around 10% of total coal demand in 2019) (Figure 3.24).

Part of the switching in the IVC also takes place in the industry sector, where gas displaces some oil, as well as some biomass which is used in traditional industrial furnaces. However, the main change in relation to the STEPS comes in power generation. In the STEPS, installed gas-fired capacity remains roughly level through to 2030 (albeit with a steady rise in utilisation rates); in the IVC, 35 GW of gas-fired capacity is added over this period.

Figure 3.24 ⊳ Change in gas demand in the IVC due to fuel switching from coal, oil and biomass, 2019-2030



To achieve a gas-based economy in the IVC, gas must displace other fuels to a much greater extent than in the STEPS, especially in power.

Non-fossil gases also grow more strongly in the IVC. Some 4 Mtoe of biomethane is deployed as bio-CNG by 2030, decreasing the size of the projected fleet of petrol and diesel vehicles by around 4%, and helping to reduce oil import dependence and import bills. The wider penetration of gas in urban areas in the IVC meanwhile reduces demand in urban areas for LPG; this facilitates greater uptake of LPG in rural areas, aiding in the total displacement of around 50 Mtoe of biomass by 2030.

There is no visible trade-off in the IVC between stronger growth of natural gas and the rise of renewables. Both enjoy robust growth at the expense of incumbent fuels, and the increased share of solar PV in power generation is complemented by the flexibility that natural gas provides.

In order to support the significant level of gas demand growth in the IVC, a number of changes are needed that go beyond those assumed in the STEPS. They can be grouped into four broad categories:

- **Accelerated pace of infrastructure growth.** In the IVC, annual investment in gas infrastructure doubles compared with historical average rates, reaching $5 billion per year on average from 2019-30, or a quarter more than in the STEPS. As a result, the number of CNG stations expands further, resulting in more comprehensive coverage and reduced congestion at stations; LNG terminals, which currently have limited connectivity with potential consumers, are better connected to an expanded grid. The flexibility and reliability of the gas grid is enhanced by more efficient use of capacity, with an independent transmission system operator supporting the roll-out of flexible pipeline nomination schedules, and a balancing code which allows a secondary market for spare pipeline and LNG capacity.

- **Faster transition to a competitive and transparent gas market**. The IVC implies a rapid transition that involves consistent implementation of market-based reforms, a rationalisation of applicable taxes and more robust implementation of existing policies, such as those related to unbundling. This is key to rationalising end-user prices and thereby widening the consumer base.
- **More favourable investment climate for domestic producers of various gases.** In the IVC, annual upstream spending is 60% higher than in the STEPS, and it reaches over $5 billion by 2030, as continued regulatory and licensing reforms generate greater interest in a faster-growing gas market. This spending includes greater investment in waste-to-gas and other biomethane projects, as well as investments that accelerate progress with low-carbon hydrogen (via electrolysis). Higher incomes in the IVC help to support affordability.
- **Stronger policy recognition of positive externalities.** Gases produced and transported in a responsible way can bring environmental benefits when replacing more polluting fuels. The IVC would reduce the carbon intensity of the economy considerably compared with the STEPS. An economy that is 14% larger than in the STEPS in 2040 would be associated with emissions that are 12% lower (see also next section). In addition, more rapid development of biomethane would bring rural co-benefits, reducing stubble burning and methane emissions and underpinning rural business development.

In the IVC, India imports around 90 bcm of gas from international markets by 2030. It takes advantage of today's gas glut, but it also underpins new upstream and midstream developments. India's import requirements in the IVC mean that it becomes a linchpin in the global LNG balance; those requirements open up a global supply gap in the mid-2020s that call for an additional 10 bcm of new projects.

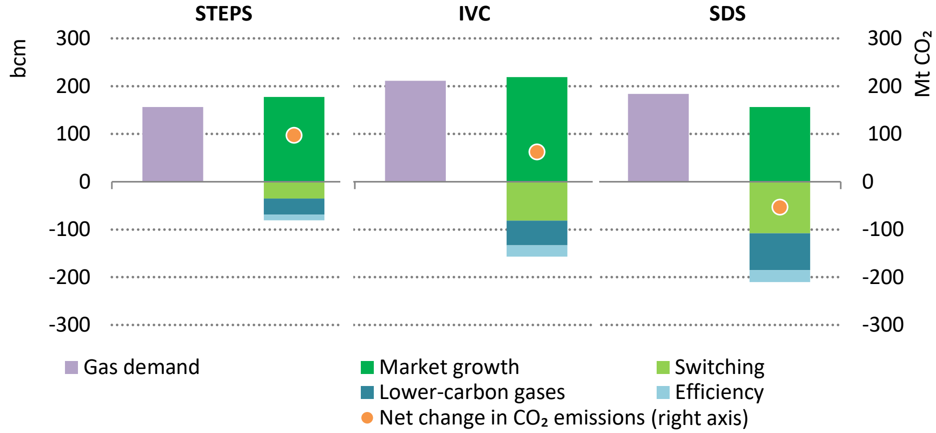
As LNG requirements grow in the IVC, India's importers are able to play a more active role in international gas markets, building a portfolio of supply, shipping and regasification stretching beyond India's own territory. This increases their purchasing power and ability to optimise supply and demand, bringing greater contractual flexibility on volumes as well as the ability to hedge using a diverse set of pricing mechanisms. Regasification capacity reaches 170 bcm by 2030, nearly a quarter more than in the STEPS.

3.3.5 The environmental implications of gas use in India

The contribution of natural gas to reaching environmental goals varies widely across different countries, between sectors and over time. Where it replaces more polluting fuels, it reduces both air pollution and CO_2 emissions. But natural gas is not in itself a solution to climate change: it is a source of emissions in its own right, and new gas infrastructure can lock in these emissions for the future. Our analysis examines these divergent opportunities and risks.

The IVC and the SDS highlight these dynamics in different ways. Gas demand is higher in both cases than in the STEPS, but the effect of that additional gas use is to bring down emissions further than in the STEPS because of the substitution of gas for coal and oil (Figure 3.25). In the IVC, there is a net increase in emissions of around 60 Mt CO_2 by 2040 over 2019 levels from the additional use of gas, compared with a net increase of around 100 Mt CO_2 in the STEPS. So net gas-related emissions still rise from today's levels in the IVC but by less than in the STEPS.

Figure 3.25 ▷ Effect of gas demand growth in India on CO_2 emissions by scenario, 2019-2040



Gas demand growth in the SDS and IVC causes fewer emissions than in the STEPS, owing to greater use of low-carbon gases, and to the use of gas in place of coal and oil.

Note: Lower-carbon gases refer to biomethane and gas-based CCUS in industry, power generation and for hydrogen production. Demand growth includes natural gas and biomethane. Switching includes the net change in emissions from switching to gas (primarily from oil and coal) and switching from gas (primarily to renewables).

In the SDS, India is the only major country worldwide in which natural gas use to 2040 is higher than in the STEPS. The overall expansion of gas demand is associated with a net decrease in emissions of around 50 Mt CO_2 compared with 2019. This is because, in the SDS, natural gas is used to a great extent as a replacement for oil and coal rather than as a means of capturing incremental growth in energy demand (which is covered primarily by renewables and other low-carbon sources of energy). This role as a substitute for more polluting fuels, allied to improvements in end-use efficiency, gives natural gas a place in India's transition to a low-carbon economy in the SDS. Emissions reductions in the SDS also come from much greater deployment of low-carbon gases, as well as investment in carbon capture technologies; at the same time, additional emissions arising from economic growth are reduced in the SDS by more extensive use of gas for non-energy purposes than now (i.e. as feedstock use in industries).

Given a relatively carbon-intensive starting point and the policy imperative to expand industry and infrastructure, the SDS shows that a carefully managed expansion in the role of various gases in India (including low-carbon gases, notably biomethane and hydrogen) could bring significant environmental gains, alongside the rapid growth of renewables. These gains do, however, depend on effective action to minimise leaks all along India's gas value chain, which could quickly negate the climate benefits of natural gas. Moreover, the business model for investing in long-lived natural gas infrastructure would require careful consideration, as the SDS would see India approaching net zero emissions in the mid-2060s.

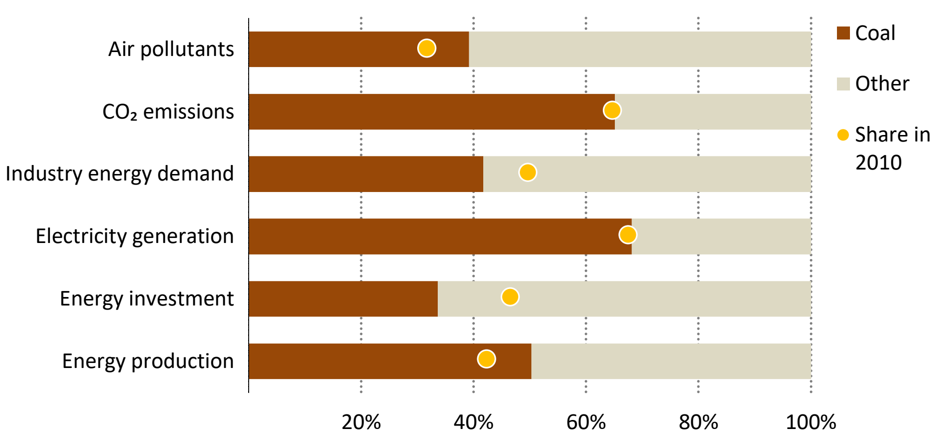
3.4 Transforming traditional fuels: Coal and bioenergy

Traditional solid fuels such as coal and biomass account for almost 60% of India's energy mix, but both of these fuels face significant uncertainties as India modernises its energy system. This section uses the *WEO* scenarios to explore how the outlook for coal and for bioenergy could change in response to the evolving demands of India's energy markets and the growing policy focus on sustainable development.

3.4.1 Coal supply

Coal has been a central part of India's energy system for decades (Figure 3.26). Despite heavy reliance on oil in the transport sector, and growth in demand for other fuels, coal's share in India's energy mix rose from 40% in 2010 to 44% in 2019, and coal continues to be the single largest fuel in this mix. Coal accounts for half of the energy produced in India today, and coal supply and end use attract a third of total annual energy investment.

Figure 3.26 ▷ The share of coal in key energy-related indicators in India, 2019



Coal has maintained a major share in several parts of India's energy sector over the period since 2010 even as energy demand has grown by a third.

The majority of coal in India is used for power generation, where its share has remained constant in a rapidly growing market (India's electricity demand increased by two-thirds between 2010 and 2019). The additional 60 GW of capacity under development could further entrench coal's dominant position in the power generation mix (see section 3.2). Coal also plays a significant role in India's industrial base because it is the main fuel underpinning a sizeable steel manufacturing capability and a growing cement industry.

Domestic production of coal expanded by 100 Mtce over the last decade, reaching nearly 410 Mtce in 2019. Investment in coal supply nearly doubled from 2010-19, spurred by the government's ambition to reduce and eventually eliminate coal imports. However, the goal of raising production to 1.5 billion tonnes (about 800 Mtce), originally set for 2020 (with 1 billion tonnes targeted from CIL), has recently been pushed back.

This push back is partly a consequence of supply-side economic challenges, with the majority of investments made by domestic companies which are increasingly capital-constrained as a result of significant overcapacity in parts of the coal value chain. However, India's production targets are also becoming more difficult to reconcile with the country's evolving energy demands and policy priorities in other areas, particularly in terms of local air pollution and CO_2 emissions: the coal inputs to the Indian power sector are the fifth-largest single category of energy sector CO_2 emissions globally.

There is a sizeable 100 GW pipeline of approved coal-fired power projects (including those under construction), but it is difficult to see many of these being built, given the challenges faced by coal alongside the lower-than-expected electricity demand growth seen in recent years. Fierce competition from renewables, especially solar power, is exacerbating the already low utilisation of existing coal assets caused by the shortfall in expected demand growth, and this is putting several producers under financial strain (see section 3.2.2).

The challenges faced by coal predated the emergence of Covid-19, but the pandemic has served to amplify them. Coal-fired power plants have borne the brunt of the decline in electricity demand in 2020, with solar PV and other renewable sources retaining priority access to the grid, and gas-fired power generation experiencing an uptick on the back of record low LNG prices in the Spring and Summer of 2020. The utilisation of coal-fired power plants fell from over 70% in 2010 to 55% in 2019, and the pandemic caused a further fall to below 55% (with increased cycling testing technical minimum load factors). Annual investment in coal in the power sector has fallen from a peak of $28 billion in 2010 down to $11 billion in 2019, and is projected to fall a further 10% in 2020. The pandemic has led to even greater uncertainty around the outlook for Indian coal demand (Box 3.6).

The coal supply balance in STEPS

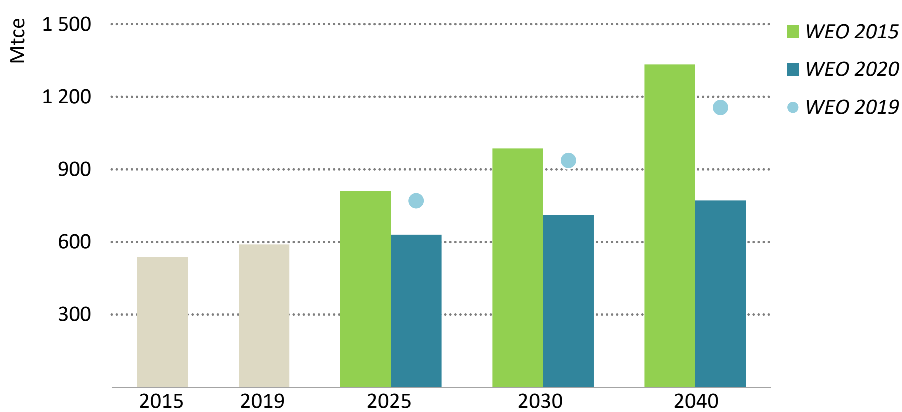
The effects of the pandemic, in the form of reduced macroeconomic growth and a more subdued outlook for electricity demand, are one factor in a major revision of coal consumption projections in the STEPS. A relatively slow recovery from the pandemic sets the tone for the following years, and demand ends up one-third lower in 2040 than projected in *WEO 2019*. An accelerated rate of growth in renewables also starts to push coal out of the mix: solar eventually usurps coal's title as the king of India's generation fleet. The power sector is responsible for nearly 60% of the downward revision in total coal demand in the STEPS to 2040. Net capacity growth is 25 GW, or 10% of India's current installed coal capacity. Meanwhile, solar capacity grows 18-fold, adding 690 GW by 2040.

Box 3.6 ▻ Hard numbers for coal as India's energy policy ambitions evolve

The *WEO 2015* special focus on India projected that coal use would grow at an average annual rate of 3.5% in the New Policies Scenario (the forerunner to the STEPS), underpinned by a large planned expansion of coal-fired power capacity. However, demand in this scenario has been revised down in successive editions of the *World Energy Outlook*. Average annual growth in the STEPS over the period 2019-40 is now just 1.3%, with demand by 2040 ending up more than 40% below what was projected in *WEO 2015*.

Part of the downward revision is attributable to the effects of Covid-19, as a comparison of pre- and post-crisis *WEO* projections makes clear (Figure 3.27). As India's main incumbent fuel, coal's prospects are significantly affected by downward adjustments to the country's macroeconomic growth assumptions, which are a key driver of total energy demand.

Figure 3.27 ▻ Coal demand projections in selected *World Energy Outlooks*



The prospects for coal have worsened markedly since WEO 2015, due to Covid-19 as well as efforts to improve air quality, reduce emissions and diversify the energy mix.

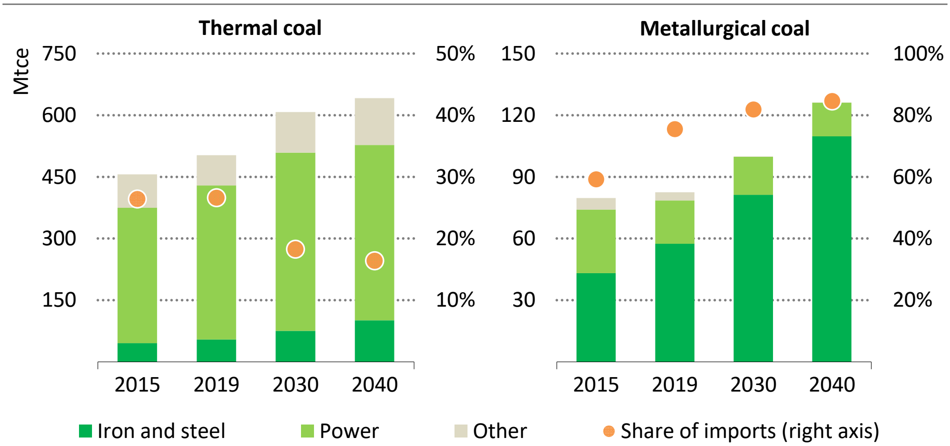
However, this is only part of the story. Most of the downward adjustments have come along gradually in the intervening years since 2015, as a result of improved visibility on India's energy policy priorities and targets. Efforts to improve air quality, enhance energy efficiency and diversify the energy mix – notably by increasing the use of natural gas – have all played a role. India's NDC under the Paris Agreement, committing to a reduction in the emissions intensity of the country's energy supply, has also affected coal's longer-term prospects, as have downward adjustments to India's anticipated future power needs, and the increased competitiveness of solar.

The coal industry now has to find a way to marry government ambitions to increase production with the uncertain demand outlook from coal-fired power plants and industrial users. The task is further complicated by the fact that the type, quality and associated cost of coal produced in India are not a perfect match for the country's evolving demand profile. In particular, the quality of coal produced in India is relatively low, with average calorific value in the range of 4 000 kilocalories/kg; this average has been decreasing over time.

Due to production and quality constraints, as well as the significant distance between coal deposits and demand centres, India has been increasing its level of thermal coal imports. There are around 18 GW of coal power plants located on the coast that are designed to operate using lower-ash imported coal. In recent years, some of these plants have gained a competitive edge over plants relying on domestic coal, as the latter have faced high processing and transportation costs within India. The trend of rising thermal imports has, however, slowed in recent years as a result of lower demand growth and a ramp-up in domestic production. This continues in the STEPS, where the share of imports in India's thermal coal balance drops below 20% by 2040 (Figure 3.28).

3

Figure 3.28 ▷ India thermal and metallurgical coal demand by sector and the share of imports in the STEPS, 2015-2040



A slower pace of demand growth and rising domestic production provide some scope for reducing imports of thermal coal, though this is offset by a rise in coking coal imports.

India's steel industry imports around 80% of its coking coal, in the absence of cost-competitive domestic coal of sufficient quality. It also utilises around 46 Mtce of thermal coal in the production of sponge iron through the direct reduction of iron ore. Nearly 85% of thermal coal used in the sector is bought in from South Africa for cost and quality reasons. In the STEPS, metallurgical coal imports outpace domestic production, reaching 80% by 2040.

Coal does not fare much better in the IVC than it does in the STEPS, reflecting the difficulty of reconciling government ambitions on coal production with other energy policy goals. On the demand side, the policy targets in the IVC to increase the share of gas and renewables have a negative effect on the outlook for coal use. Despite higher economic growth that boosts overall energy demand, and some modest upside from progress towards ambitious coal gasification targets, coal demand growth is limited in the IVC to 85 Mtce by 2040. Coal's overall share in the energy mix drops to around 33%.

What are the options to transform the coal industry?

Where does India's coal industry go from here? It is facing major pressures as a result of a changing market and policy context, as well as near-term challenges related to Covid-19. In the face of these pressures, coal needs to switch to a much leaner, more cost-efficient model for operation and investment. In the remainder of this section, we cover three key aspects of this transition: efficiency and operational performance; the push to attract private investment; and ways to adapt to increased demands for environmental sustainability.

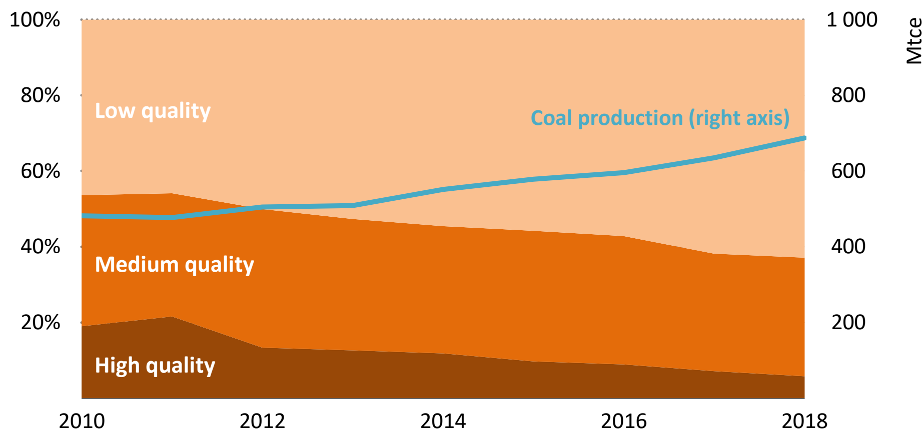
i. Improving efficiency and operational performance

There are several efficiency improvements that can be made across the coal value chain. On the mining side, there is a stark contrast between the labour productivity of large-scale surface mines and small-scale underground mines. Only 10% of underground coal mines in India are mechanised, and the average annual output per miner was less than 1 000 tonnes in 2019. CIL has begun introducing both mechanical and logistical improvements to improve labour and transport margins. As a result, labour productivity has doubled in recent years, though it remains well short of labour productivity global averages. In the STEPS, productivity doubles again by 2040, but this is primarily due to fewer underground mines being required to satisfy production growth, which is mostly captured by more productive open cast surface mines.

There are also numerous efficiency gains possible for coal logistics. Currently, around 60% of coal is transported by rail, providing 40% of revenue for Indian Railways. Coal freight tariffs are among the highest in the world (IEA, 2020), adding up to $10 additional per tonne, as they are designed to help subsidise the cost of passenger rail. Rail transport costs are lower for new coastal plants, given the shorter travel distances from port to plant. As coal demand centres to the west are increasingly supplied from renewables, the revenues from transporting coal from eastern basins will likewise fall. There is little scope to raise tariffs on remaining producers to compensate for these declining volumes, implying that the current revenue models for railways are likely to require reform. An expansion of rail capacity could ease some of the burdens of cross-subsidisation, and a more effective coal allocation policy could make transportation more efficient.

Coal washing is a distinctive additional step in the value chain of India's low-quality domestic coal base (Figure 3.29). Higher-ash coal increases transport costs per unit of energy delivered, decreases boiler efficiency and can also increase emissions if technical equipment to capture particulate emissions is not used when the coal is burned. Rule changes in 2020 removed limitations on the use of high-ash coal, allowing power plants to use coal irrespective of its ash content, and removed the stipulation that high-ash coal could not be transported more than 500 km from the pithead. These changes may reduce reliance on thermal coal imports and may generally be a cost-effective way of utilising domestic resources, but any gains are likely to come at the cost of increased emissions from higher ash content, reduced plant efficiencies and increased transport requirements.

Figure 3.29 ▷ Share of coal production by quality of coal in India, 2010-2018



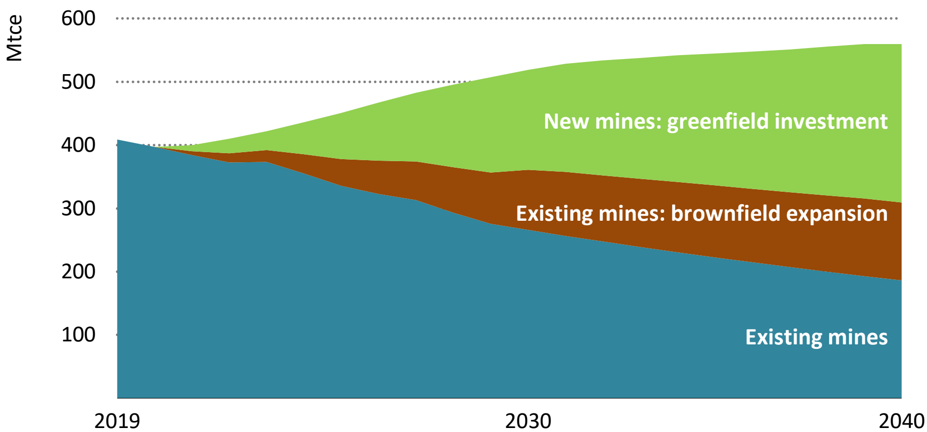
The decline in the quality of India's domestically produced coal has given rise to a number of logistical and cost-related challenges.

On the demand side, three-quarters of India's existing coal power plants are subcritical units which use low-efficiency technology. As a result of new government requirements, around 80% of the coal capacity under construction is in the form of supercritical plants with higher efficiencies, operating with an efficiency of around 36-40%, together with a small number of ultra-supercritical plants. This marginally increases the overall efficiency of the fleet in the STEPS, with the result that around 20 Mtce less coal-fired generation is needed in 2030 than would have been required if the same amount of generation had to be produced at today's efficiency levels. However, there are several countervailing forces in the STEPS that could also reduce plant efficiencies: for example, efforts to move away from imports would allow greater scope for inefficient domestic subcritical coal units to generate power. Moreover, coal plants tend to operate less efficiently when running under lower rates of utilisation or subjected to more frequent ramping, and this is how they have to operate in the STEPS in order to accommodate a growing share of variable renewables.

ii. The push for private investment in coal production

CIL, the world's largest coal producer by tonnage, supplies over 80% of the domestic market for coal in India and employs around two-thirds of the 500 000 workers directly employed by the coal sector (CIL, 2020). Most of CIL's production is sold via long-term fuel supply agreements, with another 10-20% sold via e-auctions, enabling buyers to procure additional quantities of coal on a flexible basis. The remaining supply is mostly produced by smaller, primarily state-owned companies, although a minority of supply (less than 3%) comes from fully private companies. A model by which private companies can be subcontracted as mining developer operators has begun to take root, while the gradual opening of the coal mining and distribution market has encouraged both large public-sector undertakings and smaller private firms, including those owning captive coal power plants, to capture more of the coal value chain.

Figure 3.30 ▷ India coal production by investment type in the STEPS



Government ambitions to increase domestic coal production and stem the increase in imports imply significant investment in existing and new mines.

India recently introduced commercial coal mining, which is the most significant reform undertaken in the coal sector since it was nationalised in the 1970s. The marketing monopoly of CIL has ceased, meaning private companies can develop new mines based on government auctions of unallocated coal mines or blocks, and can sell coal in the market without price or end-user restrictions. To ease the financial burden on new players, the government has reduced upfront payments, relaxed payment schedules and introduced pricing off a new national coal index. In 2020, India announced the public auction of 41 coal blocks to encourage private investment and spur increased efficiencies. So far, only 19 blocks have been awarded, covering 50 Mt of new supply. The prospects are highly uncertain (as highlighted by the variation in coal supply across our scenarios), but in the STEPS there are new investments in mining projects that compensate for the decline in mature coal-producing basins. Around 40% of coal production by 2040 in India comes from greenfield investments in the STEPS (Figure 3.30), compared with 20% globally.

iii. Adapt to growing demands for environmental sustainability

India has to deal with several environmental challenges linked to the production and use of coal, including air pollution, water stress and GHG emissions. Most mines are large-scale surface mines which lead to intense land-use change, necessitating a robust reclamation policy to avoid harmful long-term effects. Coal-fired power plants are significant sources of air pollution, and are also responsible for around 45% of total energy-related CO_2 emissions in India.

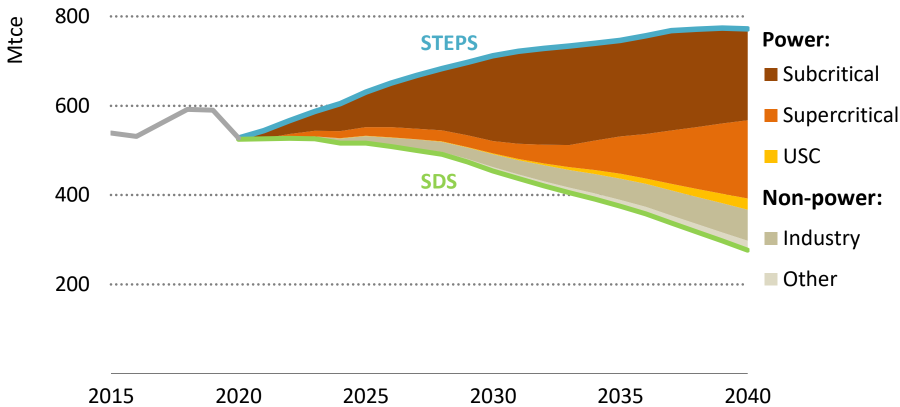
Addressing these environmental effects requires action on a broad number of fronts. In 2015, the Indian government introduced stricter pollutant emissions norms for thermal plants, moving beyond an earlier focus on particulate matter to include restrictions on sulphur dioxide, nitrous oxide, water and mercury pollutants. However, an ambitious deadline has passed with compliance levels remaining low, and an extension of the target date for compliance to 2022 may still fall short as plants have been slow in conducting feasibility studies and tendering for the necessary air pollution control upgrades. This is due, in large part, to a reluctance to incur investment costs to achieve compliance. In the STEPS it is projected that all coal plants will eventually be fully aligned with these rules, meaning sulphur dioxide emissions from coal plants are 90% below today's levels by 2040 (see section 4.2).

Reducing CO_2 emissions from existing coal plants is the single most important way of bending the emissions curve for India. If run at today's levels of utilisation, assuming average technical lifetimes of around 50 years, existing and under-construction plants would emit 25 Gt CO_2 cumulatively between 2019 and 2040, equivalent to 50% of India's total cumulative emissions in the SDS over this period. Avoiding this "locked-in" stock of emissions is both financially and logistically challenging, especially since the average coal plant in India is only around 15 years old, with an efficiency of around 35%, compared with a global average of 42%.

Several routes to transforming the role played by coal-fired power plants appear in the SDS, and they principally involve retrofitting, repurposing or retiring existing coal assets, particularly less-efficient subcritical units. *WEO* analysis has assessed the least-cost pathway to reducing emissions in the coal industry in India along these lines (IEA, 2019). Running coal facilities to focus on providing power system adequacy and flexibility, thereby reducing baseload operations, saves 6 200 Mt CO_2 in the SDS, compared with the STEPS, from 2019 to 2040. A further 3 100 Mt CO_2 is also avoided in the SDS by retiring coal plants early, starting with the oldest, lowest-efficiency and least system-relevant plants. These measures alone would close around 75% of the emissions gap that exists between the STEPS and SDS in the period from 2019 to 2040.

Such measures ultimately lead to a reduction in Indian coal demand in the SDS, with demand falling below 300 Mtce by 2040 (Figure 3.31). The SDS also sees more gains than the STEPS from the use of coal-consuming industrial facilities and plants fitted with CCUS, which provides a route to emissions reductions for sectors consuming both thermal and metallurgical coal.

Figure 3.31 ▷ Difference in coal demand between STEPS and SDS, by sector and technology, 2015-2040



A reduced role for coal-fired power, especially subcritical plants, plays an important part in bringing about change in India's coal demand in the SDS.

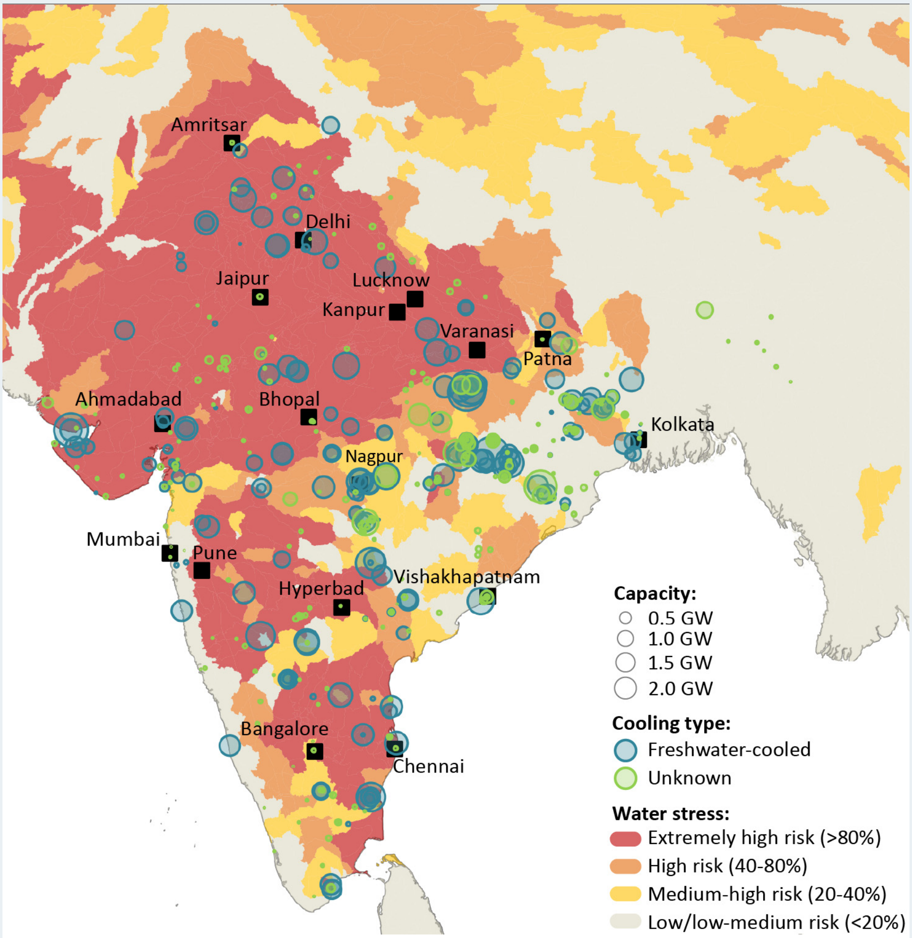
Note: USC = ultra-supercritical.

Box 3.7 ▷ Is India fresh out of coal water?

More than 80% of coal plants today are cooled by freshwater sources. Over 50% of these are in areas experiencing high water stress (Figure 3.32). Almost all fossil fuel capacity under construction is coal-fired, but the share of that capacity being built with dry and non-freshwater cooling is significantly higher than in the past (17% dry and 20% non-freshwater, compared with 2% dry and 6% non-freshwater for existing capacity). As a result, the share of coal capacity that is freshwater-cooled in plants that are under construction is just over 60%.

There are several alternatives to the use of fresh water. India's third-largest coal power plant, Mundra Ultra Mega Power Project, was built in a drought-prone area and uses desalinated seawater for cooling and other end-use applications to avoid aggravating water stress. The use of wastewater for cooling is another alternative, and the government has mandated coal plants to use sewage water if they are located in close proximity to municipal treatment plants. Shifting to dry cooling or air-cooled condenser technology would eliminate the need for water entirely, but this involves significantly more investment and carries a penalty in the form of reduced efficiency, and very few coal plants in India employ these alternative cooling methods. Although low water use approaches are technically viable, a significant shift towards water-saving interventions in Indian power plants is likely to require financial support.

Figure 3.32 ▷ Location of existing coal plants and baseline level of water stress in India



More than 50% of freshwater-cooled capacity lies in areas of high or very high water stress.

Notes: Water stress data are from WRI (2020). "Freshwater-cooled" includes once-through, tower and freshwater pond cooling technologies.

3.4.2 Bioenergy

Bioenergy has a dual identity in India's energy system. A full 12% of India's energy needs today are met through traditional uses of biomass: fuelwood, straw, dung, charcoal burnt in three-stone fire or inefficient cook stoves. These sources are particularly prevalent in rural areas where they are used for cooking and a variety of other household purposes. Bioenergy in India is often thought of in terms of such traditional sources, which have been a focus for reduction on account of their harmful effects on human health. Each year, the air pollutants emitted from combusting traditional biomass indoors cause around 600 000 premature deaths.

There is another side to the bioenergy story in India, and this is focused on modern technologies and supply chains that can put India's substantial level of organic feedstock and waste to productive use. These produce bioenergy that can power vehicles, provide energy services for households, generate local heat and power, and help meet the energy needs of a wide variety of industries. Scaling up the technologies and supply chains that convert organic products into useful energy can help India address core sustainable development goals: ensuring affordable access to modern energy supplies, combating climate change and, if carefully managed, improving air quality as well. The development of local bioenergy supply chains can also address a range of other policy priorities, from reducing the need for imported crude oil to fostering more efficient waste management practices.

Status of bioenergy today

India's bioenergy potential has long been recognised by the government, and several support schemes have been put in place for the development of biogas and biomethane plants, biomass co-generation plants,[5] and industrial and waste-to-energy plants. Different types of bioenergy sources have received different levels of support and attention:

- **Modern solid biomass.** Over the past decade, India has built 11 GW of biomass power and co-generation plants, primarily for the provision of local heat and power, which in 2019 generated around 40 TWh, roughly the same as solar PV. The government has, in particular, incentivised the use of the bagasse as a fuel for co-generation, leading to the commissioning of almost 8 GW of capacity (Ministry of New and Renewable Energy, 2020).
- **Biofuels**. The government has set targets for transport biofuels as a means to reduce the need for imported crude oil. In 2019, India produced around 28 thousand barrels of oil equivalent per day (kboe/d), enough to support a 4% blending rate in gasoline, which displaced less than 1% of crude oil imports. Bioethanol production has varied over the years due to changes in feedstock availability, oil prices and government incentives (a recent example being the removal of excise duty exemptions for bioethanol). India's new biofuels policy, announced in 2018, targets bioethanol blending in gasoline of up to 10% in 2022 and 20% in 2030 and plans for the construction of 12 biorefineries. Negligible quantities of biodiesel are produced today, although there are also targets to achieve blending rates in diesel of 5% by 2030. Efforts are now under way to develop the supply chains necessary to produce biodiesel, especially from used cooking oil.
- **Biogas**. India has long-standing programmes providing support for household-scale bio-digesters as a clean cooking solution in rural areas where LPG access is limited, and for larger-scale projects providing local heat and power generation. Around 5 million household-scale biogas units are currently in operation today. Biogas production also yields "digestate" as a by-product, which can be used as a fertiliser.

[5] *Co-generation* refers to the combined production of heat and power.

- **Biomethane**. A form of biogas that is upgraded to higher quality specifications, biomethane is being targeted for use in the transport sector as a sustainable fuel, for gas-based vehicles. Under the Sustainable Alternative Towards Affordable Transportation (SATAT) scheme, the government has a production target of 15 Mt of bio-CNG by 2023. It has taken action in support of this target, for example by providing off-take guarantees and long-term pricing agreements, and by including bio-CNG facilities in the Reserve Bank of India's priority sector lending.

Many of the existing bioenergy supply chains in India rely on dedicated energy crops – which may compete with food for agricultural land and have adverse sustainability impacts (e.g. CO_2 emissions and other land-use impacts that can be associated with land clearing and cultivation) – or on the collected biomass that is burned in its original place for traditional use in households. These avenues do not do justice to the positive and sustainable role that bioenergy could play in India's energy mix. We consider below the overall potential for bioenergy sources derived *only* from feedstock which can be considered sustainable, before assessing the outlook in the STEPS.

Assessing the potential of sustainable bioenergy feedstock

Due to the size and scale of its agricultural sector, India has vast quantities of organic waste that can be used as feedstock in modern bioenergy supply chains. Currently, only a small fraction of this sustainable potential is utilised.

Around 600 Mt of agricultural waste in India are generated each year, the majority of which are agricultural residues left over after the harvest. This includes around 40 Mt of rice crop residue, known as paddy straw, which is burned annually in Haryana, Punjab, Rajasthan and Uttar Pradesh. The burning of this residue typically occurs over a time frame of six weeks in October and November, and is one of the primary causes of the air pollution crisis every year in northern India, with as much as half of the particulate pollutants in a city like Delhi attributable to this burning. As the world's second-largest producer of sugar cane, India also produces huge quantities of bagasse, an energy-rich by-product of sugarcane processing.

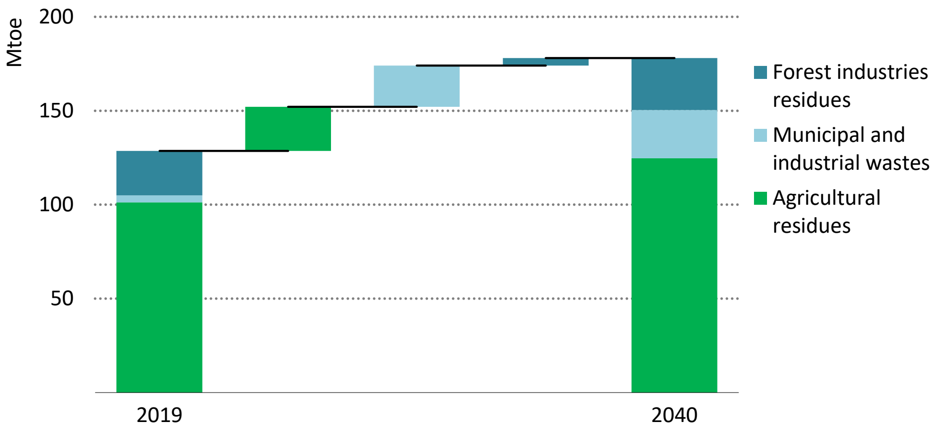
A range of agricultural feedstocks can be used for the production of transport biofuels. A distinction is often made between conventional biofuels, which rely on energy crops and often compete with food supply, and advanced biofuels, which can be derived from organic waste and non-food materials. Bioethanol in India is currently mostly produced from molasses, but some is derived from surplus food grains such as corn and cassava. The new biofuels policy released in 2018 has expanded the list of allowable feedstock sources, which now includes crop residues and industrial and municipal wastes, including used cooking oils. Livestock manure is another amply available feedstock, and is particularly well-suited to the production of biogas.

Organic waste is another source of potential feedstock. It constitutes 40-50% of the 60 Mt of total municipal solid waste generated in urban areas in India each year, and it is likely to total around 100 million tonnes a year by 2040, as cities continue to grow: it can be used in waste-to-energy plants and for the production of various bioenergy sources.

Forest industries also provide potential bioenergy feedstock: residues from wood processing (e.g. produced in sawmills) are relatively cheap and accessible, but residues from logging activities are mostly left on site and would require additional support to be collected.

Along with other forms of organic waste such as wastewater sludge, all of the above sources can be processed with existing technologies. Taking account of the energy content of the various feedstocks, we assess that up to 130 Mtoe of useful energy could be derived from these sustainable organic waste streams (Figure 3.33). There are multiple co-benefits to employing waste in this way, including reduced air pollution, avoided emissions, and rural and agricultural development. Using organic waste also ensures that the nascent bioenergy industry develops in partnership with food production, instead of as a competitor to it.

Figure 3.33 ▷ Bioenergy potential from organic waste in India, 2019-2040



Organic waste could produce 130 Mtoe of useful energy today, equivalent to 15% of India's total energy demand.

There are, however, numerous challenges facing those seeking to scale up modern bioenergy supply chains. These vary depending on the type of bioenergy produced, but there are some common elements:

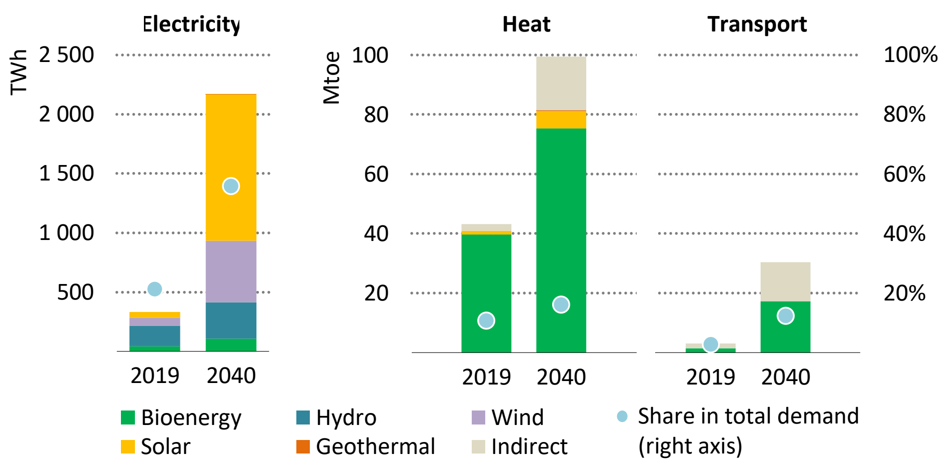
- **Supply chain uncertainties.** Agricultural waste sources are dispersed around the country, sometimes across multiple small landholdings. They differ greatly in terms of their quality and composition, and hence also in their suitability for different conversion technologies. There is also significant uncertainty about the level of availability or reliability of different waste streams. These challenges are compounded by a lack of awareness of the potential uses and technologies.
- **High upfront costs and financing challenges.** Local banks often serve as a first port of call for raising the capital necessary for bioenergy projects, since the loan requirements are too large for individual investors (e.g. farmers) to fund themselves. There is limited knowledge among financial institutions about how to assess the viability of projects, and this adds to the difficulty of securing funding.

- **Competing uses of biomass for non-energy purposes.** The biomass or organic waste with significant potential to be used as modern bioenergy often tends to have competing alternative uses, for example as fodder for animals, manure for fields, or fuel for direct burning in household cooking and industrial processes.
- **A lack of guaranteed off-takers of bioenergy.** Finding reliable outlets can be hard, since procurement prices often do not reflect the co-benefits of employing waste for energy, such as efficient waste management, reduced air pollution and enhanced access to locally produced energy.

The outlook for bioenergy in the STEPS

In the STEPS, a determined policy push brings about a drastic reduction of traditional uses of biomass by 2040. This leads to 270 million people, a population four times the size of France, shifting away from traditional uses, and to a 40% decrease in demand. The changes that take place are the result of greater use of LPG – the main route to clean cooking – and also of biogas and electricity, together with the development and adoption of improved biomass cook stoves.

Figure 3.34 ▷ Renewable energy use for electricity, heat and transport in India in the STEPS, 2019-2040



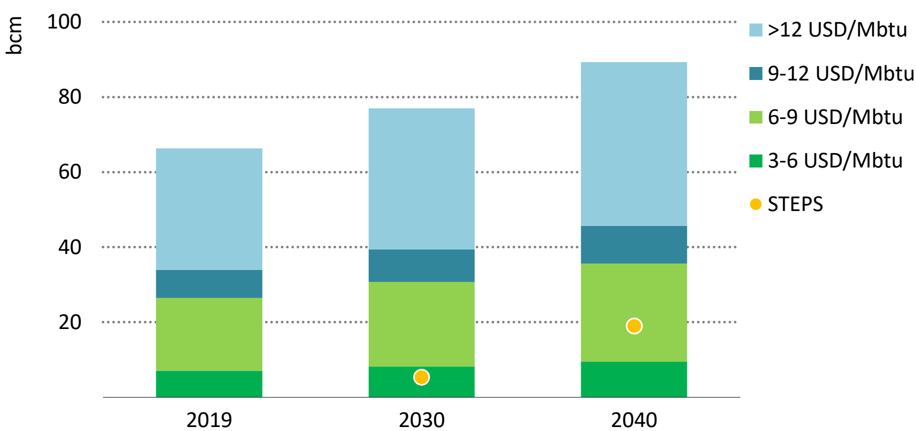
Bioenergy plays a significant role as a renewable heat source for industry and buildings. Biofuels use rises six-fold by 2040, capturing a larger share of overall transport demand.

Note: Heat includes industry, residential and commercial.

Modern bioenergy use goes in the opposite direction, doubling from 2019 to 2040 to reach 140 Mtoe in 2040. Industrial uses, especially in agro industries, account for almost 40% of modern bioenergy growth. Much of the rest of the growth comes from power and commercial heat generation, for which ambitious targets have been set by both the government and some private players.[6] India's biofuel policies also support significant growth in transport demand, and dominate the growth of renewable energy use in the heat sector (Figure 3.34).

There is also growing interest in biomethane as a local and often cheaper alternative to imported natural gas. India is home to 8% of global biomethane production potential, and using all of it would be sufficient to meet India's entire current gas demand (Figure 3.35). Around 2 bcm of biomethane could be developed at a cost below the weighted average gas price in India, making it competitive against conventional CNG for use in the transport sector, and there are already ambitious efforts, through the SATAT scheme, to bring about greater use of gas in the transport sector. In the STEPS, least-cost technologies – landfill gas recovery and agricultural digesters – supply almost 20 bcm of biomethane in 2040 to compete with imported gas. Most of this continues to be used in the transport sector: more than 10% of cars and half of the bus fleet run on gas in 2040 in the STEPS.

Figure 3.35 ▹ Assessment of biomethane potential in India and quantities developed in the STEPS



Biomethane use grows strongly in the STEPS, reaching 20 bcm by 2040, but this is only a small fraction of the total potential.

The key challenge to wider deployment of biomethane relates to costs. Currently, more than half of the biomethane potential would be competitive only with a natural gas price above $9/MBtu, exceeding the gas import prices reached in STEPS in the mid-2020s. There are a number of options to narrow this cost gap, such as crediting both the carbon and methane emissions savings from biomethane, providing tax exemptions in the final sale price, or giving biomethane preferential access to gas infrastructure. For example, a CO_2 price of $25/tonne

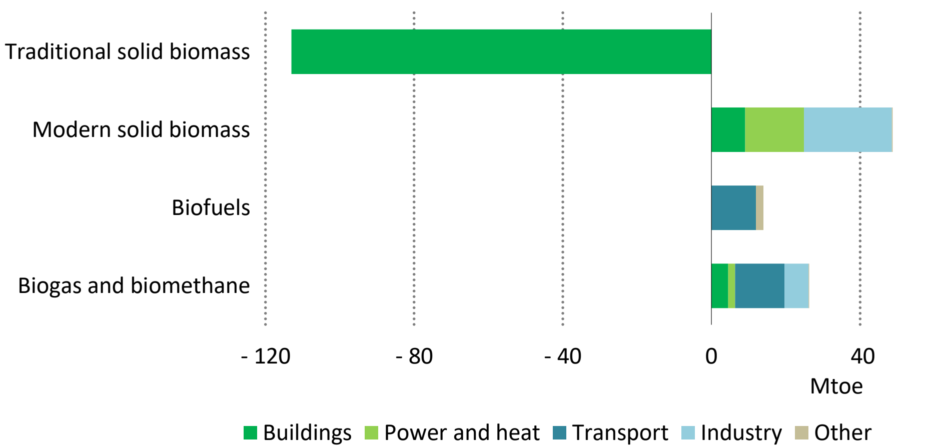
[6] For example, NTPC (the largest thermal power generation corporation in India), has decided to co-fire with coal 6 Mt of pellets from crop residues in its power plants in 2020.

would double the volume of cost-competitive biomethane that could be developed in India by 2040; crediting avoided methane emissions would reduce the CO_2 price required by 20%, taking it down to around $20/tonne. Some biomethane facilities might be able to avoid gas transmission tariffs altogether if they are built close to demand centres, such as CNG facilities or CGD projects. However, scaling up biomethane supply to a significant level would ultimately require a co-ordinated approach involving feedstock-rich states and both local distribution and national transmission gas grids.

The role of bioenergy in the IVC and the SDS

In the IVC, an alignment of agricultural, energy and environmental interests ensures that bioenergy occupies a more prominent place among government policy priorities than in the STEPS (Figure 3.36). At the country level, universal use of clean cooking is achieved by 2030 (see section 4.2). As a consequence, traditional uses of biomass are phased out as nearly 700 million people gain access to clean cooking between 2019 and 2040. Modern bioenergy demand reaches 160 Mtoe as clean cooking policies boost the use of improved biomass cook stoves and biodigesters for household needs, and as the take-up of modern bioenergy in the industry and transport sector rises significantly.

Figure 3.36 ▷ Change in bioenergy use by source in the IVC, 2019-2040



Nationwide access to clean cooking eliminates the need for the traditional use of biomass; the growth of modern bioenergy technologies brings multiple benefits.

The enhanced co-ordination of incentives among central and state governments plays an important role in the IVC in accelerating the implementation of bioenergy production processes, with support schemes tailored to both small- and large-scale producers. Effective regulatory support and wider uptake of the most cost-effective technologies also help to lay the groundwork for growth. India pursues multiple pathways to developing bioenergy, with local, on-site development projects as well as initiatives to collect and transport multiple sources of waste to centralised, larger-scale plants. The majority of the $60 billion cumulative investment from 2019 to 2040 in bioenergy bolsters domestic supply chains and creates local jobs, especially in rural areas.

Supporting policies also lead to a wider development of biomethane plants. In 2040, biomethane use is 40% higher in the IVC than in the STEPS. Most of the increase occurs in the transport sector, with biomethane accounting for 5% of total transport energy demand in 2040 in the IVC, which comes on top of the 5% of demand that is met by liquid biofuels.

In the SDS, the use of modern forms of bioenergy grows much more strongly, and there is also a major increase in the use of alternative feedstocks that minimise or avoid potential sustainability concerns. India manages to exploit more fully its waste crop oils, animal fats, agricultural and forestry residues, and municipal wastes. These feedstocks sustain a more than doubling of modern bioenergy consumption between 2019 and 2040, underpinned by rapid growth in advanced biofuels, biogas and biomethane.

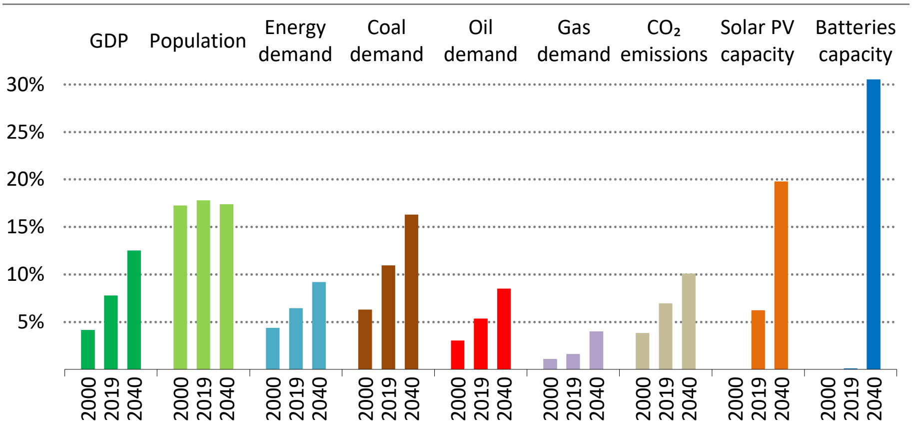
Implications for India and the world

India's change is global change

SUMMARY

- India's energy choices matter. They have direct and far-reaching effects on the lives of a growing population, and major indirect effects on the rest of the world through their impact on energy markets, emissions, and flows of technology and capital.
- In the STEPS, India accounts for nearly one-quarter of global energy demand growth from 2019-40, which is more than any other country. Already a heavyweight in solar PV, India becomes a world leader in battery storage. By 2040, India's power system eclipses the European Union's and becomes the world's third-largest, and it is the second-largest growth market for renewable energy after China.
- India's growing strength in the global industrial economy has important implications for coal and gas markets. India leads global oil demand growth in the STEPS on the back of a fivefold increase in per capita car ownership, and also becomes the fastest-growing market for natural gas. India is in addition one of the very few sources of growth for coal in this scenario, largely for industrial use.

Figure 4.1 ⊳ India's share of selected global indicators in the STEPS



India's influence is felt across all fuels and technologies, as well as in global emissions.

- India already imports around 40% of its primary energy and overall reliance on imports remains at this level to 2040 in the STEPS. However, India's combined import bill for fossil fuels triples over this period, with oil by far the largest component. The SDS sees an oil import bill which is \$1.4 trillion smaller over the period 2019-40 than in the STEPS: these savings offset entirely the additional costs of clean energy investments required in the SDS.
- The rapidly rising requirement for flexibility in the operation of its power system is a potential hazard for electricity security in India. One additional systemic risk comes

from the poor financial health of discoms. Improving billing and collection efficiency and reducing technical and commercial losses are key to reforming the sector. Stepping up investment in renewables also means tackling risks relating to delayed payments to generators, land acquisition, and regulatory and contract certainty.

- In the STEPS, the combined markets in India for solar PV modules, wind turbines, lithium-ion batteries and water electrolysers grow to over $40 billion per year by 2040; in the SDS they grow to twice this size. With a 10-35% market share for some of these products, India has the opportunity to capture more of the value from these supply chains by positioning itself as a hub for innovation and research expertise. In order to support this transformation, India's clean energy workforce grows by 1 million from 2020 to 2030 in the STEPS, and by 1.6 million in the SDS.
- Policies to improve air quality and expand access to clean cooking in the STEPS help to limit pollutant emissions, but a rising urban population means that more people are exposed to air pollution and suffer its ill effects. The IVC and especially the SDS see a lasting reduction in premature deaths from poor air quality, with several related co-benefits for energy security and trade.
- Growth in India's annual CO_2 emissions slows steadily over time in the STEPS, largely because power sector emissions plateau after 2030 due to the rising share of renewables in electricity generation. A cleaner power mix also strengthens the case for the electrification of transport; at present, the carbon intensity of electricity in India means that there is no CO_2 benefit from switching to an electric car.
- Despite a steady slowing in their overall rate of growth, India's total emissions in the STEPS are around 50% higher in 2040 than in 2019, though per capita CO_2 emissions remain low by international standards. Enhanced efforts to cut coal use in power generation and to improve the efficiency and carbon intensity of industrial output bring about lower emissions in the IVC, together with higher GDP. The SDS sees even more far-reaching improvements in efficiency and in the penetration of low-carbon technologies, cutting emissions much further.
- The SDS demonstrates that robust economic expansion is fully compatible with an increasing pace of emissions reductions and the achievement of other sustainable development goals. India's energy-related CO_2 emissions flatten out in this scenario in the 2020s and go into steady decline by the 2030s, on track to reach net-zero by the mid-2060s. This decisive break with historical trends requires tackling emissions from existing infrastructure while also avoiding new sources of emissions wherever possible. In the STEPS, by the late 2030s most of India's annual emissions come from factories, vehicles, buildings and power plants that do not yet exist.
- India's technology choices have to take into account water availability and competing water demands. Thermal power plants are already vulnerable to water stress; without careful planning, some low-carbon energy options – most notably nuclear, bioenergy and concentrating solar power – could be limited by water availability in the future.

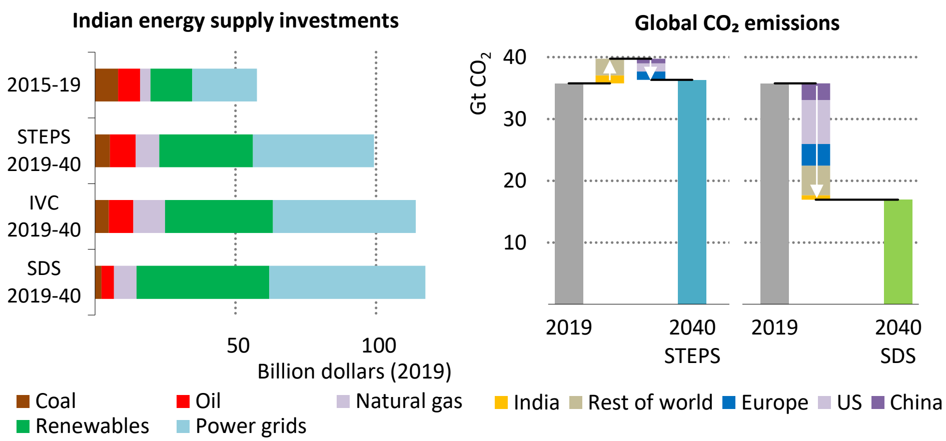
4.1 Overview of energy sustainability and security

4.1.1 Perspectives to 2040

The Covid-19 pandemic has cast a shadow over India's development trajectory. Much uncertainty remains over the duration of the crisis, the shape of the recovery and the nature of further energy-related stimulus measures that may be enacted by the government. Throughout this report, we highlight the range of potential outcomes, distinguishing between temporary dislocations and more durable structural changes. In this chapter, we focus on the implications of those outcomes for energy security and for sustainable development.

In the STEPS, the pandemic is gradually brought under control over the course of 2021. An economic rebound lays the foundation for a return to robust GDP growth for the remainder of the decade, and India is the main source of global growth in energy consumption over the *Outlook* period, making it a pivotal country for market trends across all fuels and technologies. Although India's per capita CO_2 emissions remain well below the global average, total emissions in the STEPS end up 50% higher by 2040, rising almost in tandem with demand growth. The increase in India's emissions offsets the projected decline in emissions in Europe over this period, and makes India the second-largest source of global CO_2 emissions by 2040 (Figure 4.2). India's energy access goals are meanwhile met only in part; around 500 million Indians remain without access to clean cooking in 2030.

Figure 4.2 ▷ Average energy supply investments in India by scenario and global CO_2 emissions by region in the STEPS and the SDS, 2019-40



India's emissions outlook is shaped by the pace at which it scales up renewables, and the infrastructure necessary to integrate them, while transitioning away from coal.

India is one of the few major countries globally that sees a rise in coal demand in the STEPS. This additional coal is primarily for industrial use, and means that its share of global coal demand grows from around 10% in 2019 to more than 15% in 2040. India is already an important market for internationally traded oil and gas, and its requirements increase in the STEPS: its oil import bill rises to over $250 billion by 2040, almost three times higher than in 2019, while imports of LNG cover nearly 70% of gas demand growth, with supplies coming from a diverse set of exporters including Australia, Mozambique, Qatar, the Russian Federation (hereafter, "Russia"), and the United States.

Near-term risks to sustainable development would be heightened in the event of a prolonged pandemic. The DRS sees the initial resilience of clean energy investment eroded over time by weakening government and corporate balance sheets, slowing the pace of structural change in the energy sector. Emissions of CO_2 and of air pollutants are suppressed to some extent in this scenario as a result of diminished economic prospects and lower energy demand, but these emissions reductions come at a very high cost in terms of India's economic and social development. Progress towards a range of sustainable development objectives is set back: improvements in access to clean cooking, for example, slow to less than a third of historical levels, meaning 600 million people remain dependent on traditional use of solid biomass in 2030.

A much more upbeat picture emerges in the IVC, in which muted growth in emissions (400 Mt CO_2 lower than in STEPS in 2040) is associated with substantial progress on renewable energy goals and greater strides towards energy efficiency. Access goals are achieved by 2030, with substantial air quality improvements made as the country moves away from traditional biomass and meets transport efficiency and electrification goals. India becomes a world leader in battery storage and is one of the fastest-growing markets for renewable energy globally. India also remains central to global energy trade, although imports of coal and oil are lower than in the STEPS, and imports of gas higher.

As in the IVC, India in the SDS meets in full its targets to reduce air pollution while ensuring universal energy access to clean cooking. However, energy-related CO_2 emissions follow a very different trajectory. In the SDS, India charts a pathway out of the crisis which focuses on investment in clean energy technologies; whereas in the IVC around 90% of primary energy demand growth is met by fossil fuels over the next decade, in the SDS this falls to around a third and there is significant substitution away from more polluting to less polluting fuels. As a result, emissions peak in the SDS in the mid-2020s, and end up more than a third below 2019 levels by 2040, even though energy demand grows by more than 20%.

There is a huge reallocation of capital in the SDS in favour of low-carbon fuels and technologies, with solar and wind alone attracting an average of $35 billion investment spending per year in the period 2030-40, an almost threefold increase on today's levels. Renewable integration challenges also call for far more spending on electricity networks. The additional investment needed is, however, offset by reduced spending on oil due to transport electrification and tighter efficiency standards: this translates into a 15% fall in India's oil imports, and a consequent saving between 2019 and 2040 of $1.4 trillion compared with the

STEPS. Even though LNG demand is higher than in the STEPS the total import bill for gas is lower, as the greater surplus of global gas supply has a dampening effect on prices.

Table 4.1 ▷ Key energy sustainability and security indicators for India by scenario

			SDS		STEPS		IVC	
	2000	2019	2030	2040	2030	2040	2030	2040
Energy demand (Mtoe)	441	929	994	1 147	1 237	1 573	1 153	1 526
Share of India in global energy demand	4%	6%	7%	9%	8%	9%	7%	9%
Energy intensity (toe/capita)	0.42	0.68	0.66	0.70	0.82	0.99	0.77	0.96
Energy use per capita versus global average	25%	36%	42%	51%	44%	53%	42%	51%
SDG 7: Access (million people)								
Population without access to electricity	602	5.5	0	0	0	0	0	0
Population without access to clean cooking	823	656	0	0	501	375	0	0
Share of global total	28%	25%	-	-	21%	20%	-	-
SDG 13: Energy-related GHG emissions								
CO_2 emissions (Gt)	0.9	2.3	2.1	1.5	2.9	3.4	2.7	3.0
CO_2 captured through CCUS (Mt)	0	0	19	208	0	0	19	138
India share of global CO_2 emissions	4%	7%	9%	10%	9%	10%	8%	9%
Methane (Mt)	1.6	1.7	0.5	0.6	1.4	1.3	0.5	0.6
SDG 3: Air pollution (million people)								
Premature deaths from energy-related ambient air pollution	-	0.6	0.6	0.5	0.7	0.9	0.6	0.5
Premature deaths from energy-related household air pollution	-	0.6	0.1	0.1	0.6	0.5	0.1	0.1
Import dependence								
Oil	64%	76%	91%	92%	90%	92%	90%	91%
Natural gas	0%	50%	64%	69%	58%	61%	59%	61%
Thermal coal	5%	27%	24%	34%	19%	17%	19%	15%
Trade and investment (billion dollars)								
Import bill	**23**	**123**	**153**	**156**	**228**	**326**	**232**	**325**
Oil	22	89	118	106	181	255	180	243
Natural gas	0	12	19	33	26	43	32	56
Coal	1	21	16	18	20	27	20	26
Energy investment	**27**	**84**	**239**	**327**	**176**	**220**	**194**	**241**
Fuel supply	7	25	19	15	27	23	28	27
Power	19	49	128	165	101	127	117	143
Efficiency and end use	-	9	92	147	49	71	67	101

4.2 India and the Sustainable Development Goals

India has made considerable progress in recent years towards achieving the UN SDGs. This section examines recent progress towards the energy-related SDGs, and looks at what policies or measures could help to accelerate action. Progress on the energy-related SDGs offers the prospect of faster progress towards the achievement of other SDGs as well, including those related to health, education, water and sanitation that are often hampered by a lack of reliable electricity access and poor air quality.

4.2.1 Access to affordable, reliable and modern energy services

The UN SDG 7.1 calls for ensuring universal access to affordable, reliable and modern energy services.

Electricity access

India has made great progress on electricity access in recent years through the Saubhagya Scheme, and government data indicate that more than 99% of households were connected to electricity in 2019. There are, however, continuing problems with the quality and reliability of electricity access for connected households, and with access for non-household customers: studies found that less than 80% of institutional customers, 65% of small businesses and 50% of agricultural customers had been connected to the grid in 2018 (Bali, Vermani, & Mishra, 2020; Dayal, 2019).

There is a risk that the Covid-19 pandemic and its economic effects could reverse recent gains and push some connected households back into energy poverty. In India, up to 40 million people with electricity connections could lose the ability to pay for an extended bundle of electricity services (IEA, 2020).[1] Some low-income households are facing the need to make trade-offs between their energy needs and other demands, and this could propel them back to traditional and inefficient fuels.

In the STEPS, near-universal access to electricity is maintained, despite India's population increasing by 130 million people over the next 10 years. Around $35 billion is spent on average each year over the 2021-30 period on the construction and refurbishment of transmission and distribution lines – a substantial increase on today's levels – and subsidy schemes support increased electricity use by poor households. Residential electricity consumption increases from around 1 000 kWh per household in 2019 to 1 500 kWh in 2030 as a result of increased household revenues and improved central grid reliability. This nonetheless remains far below electricity consumption in advanced economies (6 000 kWh per household in 2030), and there are still some reliability and affordability issues, with many households not able to maintain uninterrupted access to electricity.

[1] This extended bundle includes a mobile phone charger, four light bulbs operating four hours per day, a fan six hours per day, a television four hours per day, and a refrigerator, equating to 1 250 kWh per household per year with standard appliances. See part 3.2.1 of the *World Energy Outlook 2020* for more details.

On-grid electrification remains the most economic option for the majority of Indian consumers gaining access to modern energy services, especially with rising household consumption from growing appliance ownership, and it accounts for around 99% of the connections realised within the Saubhagya Scheme. However, in certain cases – especially in remote rural locations – standalone systems and mini-grids offer a viable alternative for ensuring reliable access to electricity services to complement the main grid. Diesel generators are one well-established option, but renewables are expected to play a growing role as the costs of solar PV fall and as solutions emerge which allow electricity to be stored for use in the evenings. India has various policies in place backing solar home systems, solar pumps and mini-grids, such as the Off-Grid and Decentralised Solar PV Programme and the Kusum scheme to replace existing diesel pumps with solar PV pumps. Such measures translate into steady increases in deployment, providing increased access to farmers and other rural consumers.

Both the IVC and the SDS see additional policies and measures to boost the affordability, reliability and use of electricity by households and other customers. Support is also provided for poor households to purchase more efficient appliances, allowing them to increase their access to services without compromising electricity affordability. At the same time, efficiency improvements facilitate improvements to electricity security by reducing the growth in electricity demand, including peak demand. Regulations and incentives further boost the deployment of decentralised systems.

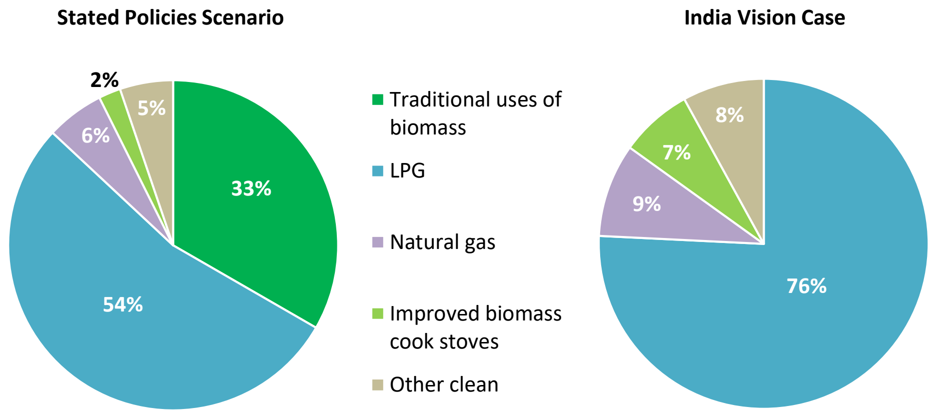
Access to clean cooking

Progress on clean cooking access has been slower than progress on electricity access, hampered in part by affordability and supply issues. As noted in Chapter 1, the government has made huge efforts to expand access to LPG through the PMUY scheme. Even though 97.5% of households today have the ability to access LPG (Indian Ministry of Petroleum & Natural Gas, 2020), we estimate that around 650 million people, just under half of India's population, continue to rely primarily on traditional uses of biomass in households (and so are counted as not having access).[2] This is an issue in rural areas in particular: more than 90% of those without access live in rural areas.

Where LPG connections have been made, they have not always unlocked sustained use due to concerns about supply, as well as cultural factors. A primary difficulty is the need to purchase quantities of LPG in bulk: even with government subsidies, other fuels are often available more cheaply, or in smaller quantities, and are therefore a better fit with the income structure of poor households. In addition, the LPG bottling and distribution infrastructure is not yet ready to sustain the use of LPG by all households, even if they have a connection. Efforts to create new private distributors in rural areas are often hampered by a lack of adequate financial returns (Josey, Sreenivas & Dabadge, 2019).

[2] A full description of the *World Energy Outlook* energy access definition and methodology can be found at www.iea.org/articles/defining-energy-access-2020-methodology.

Figure 4.3 ▷ Share of population relying on different fuels for cooking in the STEPS and the IVC, 2030



In the STEPS, traditional uses of biomass continue to be used by 500 million people as the main way of cooking in 2030; in the IVC, this is replaced by a wide range of alternatives.

Note: Fuel shares in the SDS are similar to the IVC.

In the STEPS, more than 170 million people move from the traditional uses of biomass to alternative clean cooking options over the period to 2030. However, taking into account population growth, this leaves around 500 million people without access. As a result, there are still nearly 0.6 million premature deaths due to indoor air pollution in 2030.

In the IVC and the SDS, full access to and full reliance on clean cooking is achieved by 2030, meaning that close to 670 million people gain access to clean cooking over the next 10 years. LPG is the mainstay of clean cooking access efforts; three-quarters of India's population rely primarily on LPG for cooking by 2030, and LPG demand increases by 50% between 2019 and 2030. Investments and incentives are deployed to expand infrastructure for LPG bottling and distribution and for the repair and replacement of broken stoves. Innovative subsidy schemes play a key role in supporting the sustained use of LPG and eliminate stacking of traditional fuels.[3]

The use of improved biomass cook stoves and biogas also makes an important contribution, providing clean cooking to around 180 million people in 2030. They are especially important in locations where there is more resistance to replacing traditional solutions, or where reliable LPG delivery is more difficult to ensure, and in locations with a ready supply of biogas feedstock. In urban areas, natural gas meets an increasing share of cooking needs in the IVC and the SDS through the development of gas distribution infrastructure in major cities. This

[3] Fuel stacking is when a household uses a number of different fuels for different uses, using a mixture of modern and traditional fuels. For example, a household may have access to LPG, but only use it to boil water, and continue with the traditional use of biomass for other cooking needs.

helps to displace LPG in urban areas and allow its increased use in rural areas where the development of gas distribution infrastructure is more challenging. There is also a role for electricity in providing clean cooking access, especially in urban areas, where 6 million people gain access through electric cook stoves by 2030.

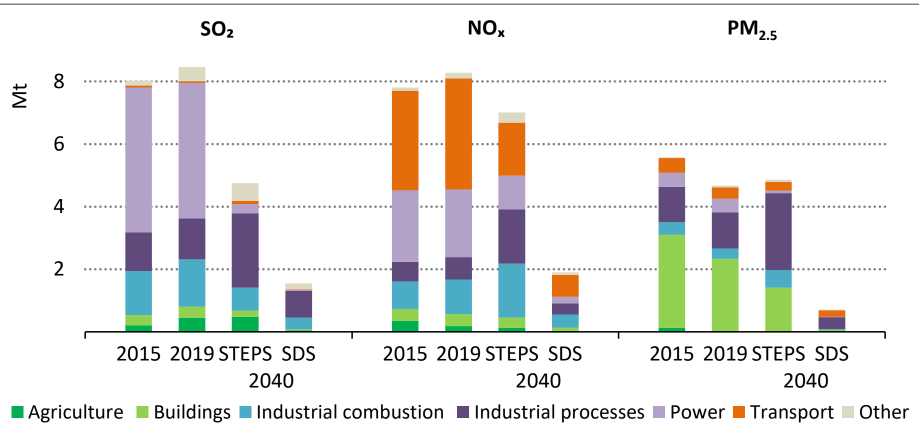
4.2.2 Energy and air pollution

Improvements in air quality are crucial for the achievement of multiple SDGs. Ensuring access to clean energy (SDG 7.1) would reduce household air pollution; increasing the share of renewable energy (SDG 7.2) would permanently reduce power sector air pollution; improving energy efficiency (SDG 7.3) would likewise tackle air pollutant concentrations across the energy economy; enhancing access to sustainable transport (SDG 11.2) would improve the overall air quality in cities (SDG 11.6). Air pollution policies also offer direct co-benefits for GHG emissions reductions (SDG 13).

4

As described in Chapter 1, air pollution has emerged as one of India's most pressing environmental challenges, and the energy sector is the largest source of three of the major air pollutants: nitrogen oxides (NO_X), sulphur dioxide (SO_2) and $PM_{2.5}$. $PM_{2.5}$ is the air pollutant of most concern as concentrations exceed the NAAQS in many monitored locations. NO_X emissions are increasingly problematic in urban areas, while SO_2 concentrations are a particular issue in areas with many thermal power or industrial plants.

Figure 4.4 ▷ Sectoral contributions to air pollution levels in the STEPS and SDS



Air pollutant emissions fall in the power and transport sectors through to 2040 in the STEPS, but only SO_2 emissions fall significantly in overall terms, and industrial emissions grow.

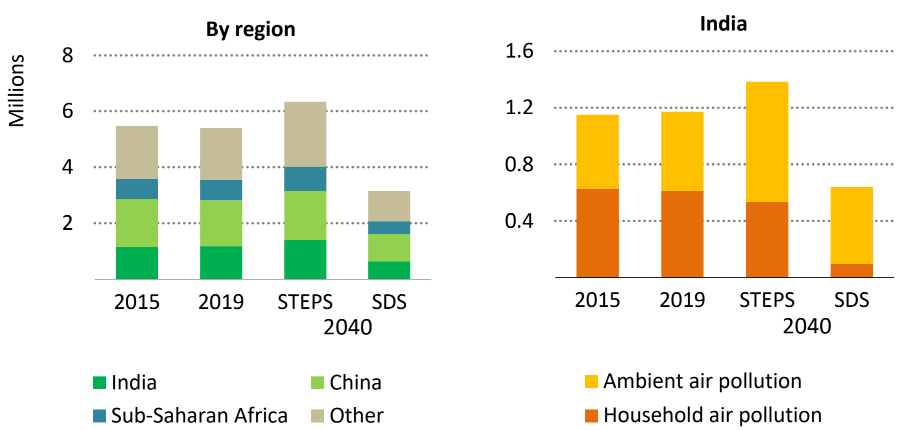
Combustion-related emissions of $PM_{2.5}$ made up more than two-thirds of total household air pollution in 2019. Pollution largely results from the incomplete burning of traditional biomass, such as fuelwood or agricultural residues, used for cooking and heating activities. Policy efforts to promote access to clean cooking led to a 16% decline in emissions between 2015 and 2019 to 4.7 Mt.

The power sector was responsible for half of the 8.5 Mt of total SO_2 emissions in 2019, with industrial activities contributing an additional one-third. Even though India's coal contains relatively little sulphur, coal combustion was the main source of SO_2 emissions. Air pollution control technologies for thermal power plants, such as flue gas desulphurisation, are rarely deployed. The government has recently taken initial steps to rectify this by passing the Environmental Protection Amendment Rules (EPAR) Act.

NO_X emissions have grown slowly in recent years to just over 8 Mt in 2019. About 40% of these emissions stem from road transport, with nearly a further 30% from the power sector. Road transport activity increases with population density, and vehicle tailpipe emissions occur close to the ground, making urban NO_X pollution particularly damaging to health.

In the STEPS, existing policies to curb air pollution are implemented over time, and these limit the level of air pollution despite the rapid rate of population and economic growth over the period to 2040 (Figure 4.4). Increases in urban populations, however, mean that more people are exposed to higher concentration levels of air pollution and so annual premature deaths increase by 0.2 million to nearly 1.4 million in 2040, of which 60% are related to ambient air pollution (Figure 4.5). In the SDS, there is a much more substantial reduction in all air pollutants, meaning that the number of premature deaths in 2040 is more than 50% lower than in the STEPS.

Figure 4.5 ▷ Premature deaths related to air pollution globally and in India



There were nearly 1.2 million premature deaths from air pollution in India in 2019. This number rises by 0.2 million to 2040 in the STEPS but falls by around 0.5 million in the SDS.

There are divergent trends between sectors in air pollution emissions in the STEPS, depending on the stringency of existing and planned regulations.

SO_2 emissions fall by 44% between 2019 and 2040 in the STEPS. A 90% reduction in emissions from the power sector reflects full implementation of the EPAR, which means that the majority of coal-fired capacity is fitted with advanced desulphurisation control technology by 2030. However, neither current nor planned policies adequately monitor and regulate air pollutant emissions from the industry sector, particularly from small and medium enterprises. As a result, emissions of SO_2 from industrial processes, which are only partially covered by existing or planned policies, increase by more than 80% over the 2019-40 period, offsetting a quarter of the reductions in the power sector. NO_X emissions in the STEPS fall by 15% between 2019 and 2040. Conventional vehicles sold after April 2020 are required to meet Bharat Stage VI emission standards, and the number of EVs increases, leading to a fall in road transport NO_X emissions of 60% to 2040. However, NO_X emissions from the industry sector grow by 90% over the same period.

$PM_{2.5}$ emissions in the STEPS increase by 4% through to 2040. Progress in access to clean cooking and heating technologies leads to a 40% reduction in $PM_{2.5}$ emissions from the residential sector, but $PM_{2.5}$ emissions from industrial facilities double over the period to 2040, more than offsetting the reductions elsewhere. While some industrial facilities do use $PM_{2.5}$ air pollution control technologies, there is a lack of effective regulation, and many others do not.

4

In the SDS, air pollution policies are expanded to all sectors, including the combustion of fossil fuels in industry and industrial processes via advanced control technologies. There is also a rapid expansion of low-carbon energy technologies and a sharp reduction in coal-fired power generation. As a result, power sector air pollutant emissions are almost entirely eliminated, and there is a much larger overall reduction in SO_2 and NO_X than in the STEPS. Universal access to clean cooking and heating technologies in the SDS lowers residential $PM_{2.5}$ pollution to a negligible level from 2030.

4.2.3 CO_2 emissions

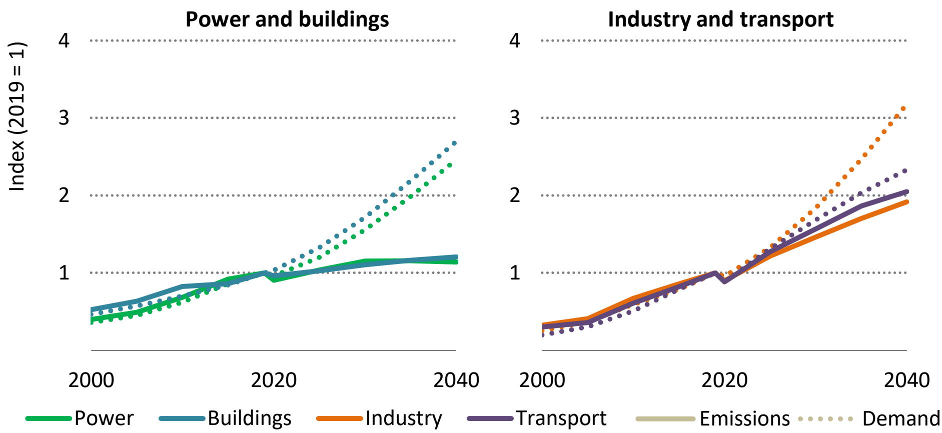
India's large and growing population, its low (but increasing) levels of energy consumption per capita and its high level of projected economic growth could all result in significant levels of future emissions, despite its relatively low per capita emissions today (see Chapter 1). In the STEPS, CO_2 emissions in India rebound quickly from the drop in 2020, and they exceed 2019 levels by 2022. There is a steady slowdown in the pace of growth over the period to 2040: emissions grow by 70 Mt per year between 2019 and 2030, by 60 Mt per year in the first half of the 2030s, and by 45 Mt per year in the second half. Total emissions in 2040 are around 50% greater than 2019 levels, although per capita CO_2 emissions in 2040 (2.4 t CO_2 per capita) are still 40% lower than the global average at that time (4 t CO_2 per capita).

As part of the Paris Agreement, India included in its NDC a target to improve the emissions intensity of its GDP by 33-35% by 2030 compared with 2005 levels and to achieve a 40% share of non-fossil fuels in electricity generation capacity by 2030. Both of these high-level targets are met in the STEPS: the emissions intensity of GDP in 2030 is 40% lower than in 2005, and nearly 60% of India's electricity capacity in 2030 is non-fossil fuel.

The power sector sees an especially large divergence from past CO_2 emissions trends in the STEPS (Figure 4.6). Between 2019 and 2040, electricity demand increases by nearly 150%

while emissions increase by 15%. The share of coal generation drops from just over 70% in 2019 to less than 35% in 2040, while the share of renewables rises from 20% in 2019 to more than 55% in 2040. Power sector emissions grow slightly over the period to 2030 but then remain on a plateau thereafter.

Figure 4.6 ▷ Changes in demand and CO_2 emissions by sector in the STEPS



In the STEPS, activity and emissions diverge significantly in the power sector and the buildings sector to 2040; breaking these links is harder in industry and transport.

Note: Activity variables: Power = electricity demand; buildings = residential floor space; industry = gross value added; transport = vehicle kilometres.

The buildings sector also sees a loosening of the links between emissions and activity in the STEPS. Residential floor space almost triples between 2019 and 2040. There is also a big increase in electricity use in buildings, which expands by a factor of three between 2019 and 2040. Electricity's share of total fuel use in buildings reaches nearly 50%, up from less than 20% today, reflecting an increasing level of appliance ownership. Ownership of air conditioners grows particularly rapidly. Despite this, emissions from residential buildings increase by less than 50%, and a similar pattern is observed in commercial and public buildings. New buildings are built to increasingly efficient designs, and major efforts are made to develop passive cooling systems. Policies that mandate minimum efficiency performance standards for air conditioners also help to curb some the increase in electricity demand that this would otherwise imply, while part of the growth in electricity demand comes at the expense of less efficient traditional biomass.

There is less of a decoupling between activity and emissions in the industry sector. Cement production grows by 150% between 2019 and 2040, and emissions rise by 100%. A similar trend occurs in steelmaking. An increase in the use of natural gas helps keep emissions lower than they would otherwise be by displacing coal: the share of industry energy demand taken by natural gas more than doubles to 20% in 2040. Nevertheless, total CO_2 emissions from industry grow by more than 90% over the 2019-40 period.

The growth in emissions from transport in the STEPS also remains closely linked to increases in activity. Total emissions from heavy-duty trucks nearly triple over this period as a result of increases in freight activity, although they are somewhat lower than they would otherwise be thanks to the average fuel consumption of heavy-duty trucks on the road in 2040 being almost 20% lower than in 2019. There is also a substantial increase in emissions from passenger cars as ownership increases by a factor of five between 2019 and 2040. This is partly offset by a 30% improvement in the average fuel efficiency of passenger cars using internal combustion engines over the period to 2040, and by increasing sales of electric cars. In 2040, around 10% of the passenger cars and more than 50% of two- and three-wheelers on the road are electric. Nonetheless, the growth in emissions from passenger cars accounts for around 40% of the total increase in transport sector emissions.

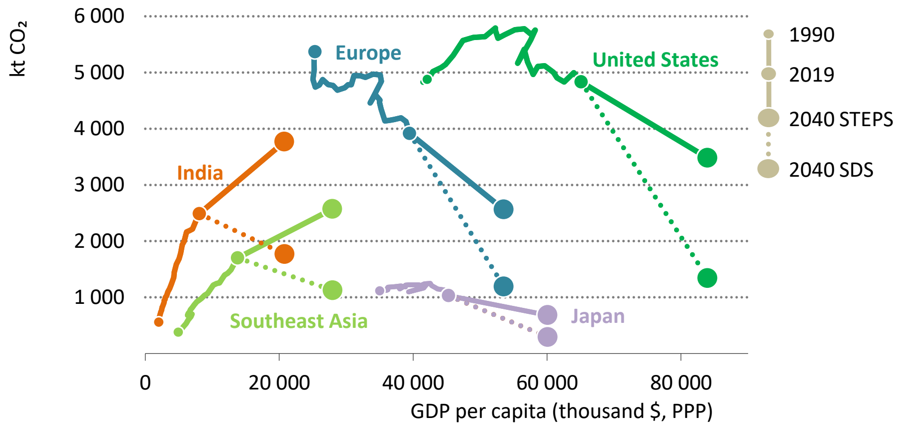
Box 4.1 ▷ How do changes in emissions in India compare with other countries?

Comparisons between the changes in CO_2 emissions in India and in other countries need to be treated with caution. India is at a very different stage of development from many other economies, and it is set to experience rapid population and economic growth for many years to come. India's emissions per capita rank among the lowest in the world today, and it accounts for only about 3% of historic energy sector and industrial process CO_2 emissions since 1850 (compared with around 30% for Europe, 25% the United States and around 15% for China).

In the STEPS, CO_2 emissions in India follow a different trajectory from that in most advanced economies, rising by 50% compared to 2019, to around 3.7 Gt CO_2 over the period to 2040 (Figure 4.7). By 2040, India is the world's second-largest emitting country behind China, although China's emissions (more than 10 Gt CO_2 in 2040) are markedly higher. Nonetheless, India's per capita emissions in 2040 (2.4 t CO_2 per capita) remain far smaller than in most other countries, including the United States (9.5 t CO_2 per capita), China (7.3 t CO_2 per capita), and European countries (3.7 t CO_2 per capita). In the IVC, emissions in India are slightly lower than in the STEPS, despite a higher level of economic growth. In the SDS, emissions in India fall by around 30% over the 2019-40 period.

An increasing number of countries and jurisdictions have announced targets or goals to achieve net-zero CO_2 or GHG emissions. For example, the European Parliament and the European Council have endorsed a target to achieve net-zero GHG emissions in the European Union by 2050, and the Chinese government has announced a target to achieve net-zero CO_2 emissions by 2060. These targets are achieved in full in the SDS. These targets help to spur innovation and provide incentives for consumers and private actors to reduce emissions. They also provide a number of incentives to emissions reductions in India through lower costs for clean energy technologies and a much larger market for low-emissions products and services. In the SDS, India is on track to achieve net-zero emissions around the mid-2060s.

Figure 4.7 ▷ **Energy-related CO_2 emissions and GDP per capita by region in the STEPS**



As with other emerging and developing market economies, there are major differences between the emissions trajectories for India in the STEPS and in the SDS.

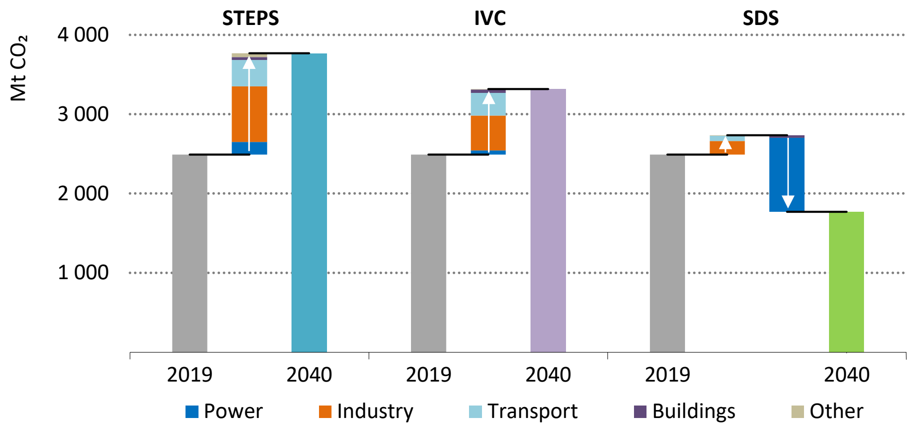
Note: kt = kilotonnes.

Emissions in the IVC rise to a lesser extent than in the STEPS (Figure 4.8). In 2040, CO_2 emissions are around 450 Mt lower in the IVC than in the STEPS, despite stronger economic growth in the IVC and the achievement of universal access to energy. The biggest difference is seen in the industry sector, where CO_2 emissions are around 260 Mt lower in 2040 in the IVC than in the STEPS. This stems mainly from a greater push for the use of more efficient technologies, which slows the increase in coal use, especially in the iron and steel sector. Emissions from the power sector in the IVC in 2040 are also around 100 Mt lower than in the STEPS; much of this is due to the greater growth in the IVC of the use of natural gas in place of coal-fired power, which peaks in the mid-2020s.

The SDS charts a very different course for emissions than the STEPS (Figure 4.8). CO_2 emissions rebound slightly in 2021, but they never return to 2019 levels at any point in the outlook period. By 2030, emissions are around 5% lower than 2019 levels, and in 2040 they are nearly 30% lower. As a result, emissions in India in 2040 are around 1.1 t CO_2 per capita, similar to levels in the mid-2000s. At a sectoral level, the largest differences between the STEPS and the SDS are in the power sector and industry, but there are also much stronger efforts to improve the efficiency of buildings and appliances in the SDS. Nearly 500 million people gain access to clean cooking solutions by 2040 in the SDS through the use of LPG, which leads to a small increase in CO_2 emissions, though this would be more than offset by reductions in other GHGs (methane and nitrous oxide).

In the power sector, emissions from coal-fired power plants fall by 90% between 2019 and 2040 in the SDS. Renewables provide nearly 80% of electricity generation in 2040: generation from solar PV increases by more than 60 TWh every year on average to 2040, while wind generation grows by more than 35 TWh each year. In the SDS, around 40 GW of new solar PV is installed in India on average each year by 2040. To put it in another way, more capacity is added in a single year than was installed up to 2019. Around 15 GW of coal- and gas-fired power plants are also equipped with CCUS in 2040.

Figure 4.8 ▷ Changes in CO_2 emissions in India by scenario, 2019-2040

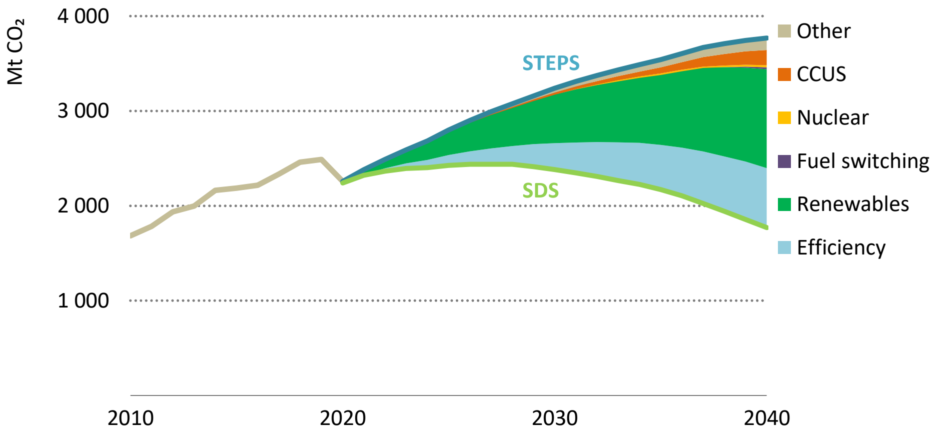


In the STEPS, the industry and transport sectors lead emissions increases; in the SDS, these increases are more muted and there is a marked decline in power sector emissions.

In the industry sector, coal use grows slightly to 2040 in the SDS, but at a much slower pace than in the STEPS. A number of industrial processes are fitted with CCUS to reduce emissions in the SDS, but enhanced efficiency measures play the most important part in curtailing the growth in industrial emissions. In the SDS, fuel use in industry is nearly 25% lower than in the STEPS, despite an identical level of economic output from the industry sector. Electricity also accounts for around one-quarter of total energy use in the industry in 2040, compared with 20% in the STEPS.

In transport, there is much more rapid growth in EVs in the SDS than in the STEPS: by 2040, 60% of passenger cars and 40% of trucks on the road are electric. The use of sustainable biofuels and low-carbon gas and hydrogen-based fuels helps further to reduce the use of petroleum products in trucks, as well as in aviation and maritime shipping. Internal combustion engines are also around 40% more efficient in 2040 than today, reducing emissions from cars and trucks that continue to use them. Transport emissions nonetheless edge up marginally over the period to 2040.

Figure 4.9 ▹ Energy sector CO_2 emissions and reduction levers in the SDS



The enhanced deployment of renewables and efficiency causes CO_2 emissions to peak in India in the SDS by 2030 and to decline steadily thereafter.

4.2.4 Managing potential trade-offs and synergies between the SDGs

Charting a course towards achieving all of the SDGs in India in parallel is an immensely challenging undertaking. The relevant policies align in many respects, and there are a number of areas where synergies mean that progress towards one SDG can boost or support other goals. However, there remains a risk that progress in one area could hamper efforts elsewhere; energy transitions could for example have wider social impacts (Box 4.2). The course described in the SDS seeks to avoid or minimise trade-offs to the extent possible.

Minimising potential trade-offs between the SDGs

One example of potential trade-offs between policy goals comes in the transport sector. Electrification of road transport substantially reduces air pollution from this sector: a conventional car can emit more than 10 times the NO_X produced by an electric car. However, if coal power plants without any pollution controls are used to generate the electricity for these vehicles, this would increase emissions of SO_2. In this case, generating electricity for an electric car using coal would add about 18 times more SO_2 emissions than using a conventional car (Figure 4.10). Implementation of the EPAR measures to reduce SO_2 emissions from power plants would help ensure that transport electrification leads to a reduction in all air pollutants. Conventional cars also produce CO_2, and the emissions intensity of electricity needs to be less than 700 g CO_2/kWh to 750 g CO_2/kWh for new electric cars to result in fewer emissions than existing conventional passenger cars in India. The average emissions intensity of electricity in India is around this level today. In the STEPS, it falls to around 340 g CO_2/kWh in 2040: if all EVs in 2040 were to be powered using electricity with this emissions intensity, this would lead to power sector emissions of around 45 Mt CO_2.

The oil displaced by EVs in the STEPS would avoid around 80 Mt CO_2, meaning that there would be an overall reduction of around 35 Mt CO_2 from the deployment of EVs. The exact level of savings would, however, depend on the precise time of vehicle charging as the emissions intensity of electricity in 2040 in the STEPS varies considerably throughout the day. It would be lowest during the daytime, when there is a large level of generation from solar PV, and highest at night-time, when coal power dominates the generation mix (see Chapter 3). Recharging electric cars during the daytime would therefore reduce the level of emissions coming from the power sector, and so further increase the overall level of savings.

In the SDS, the average emissions intensity of electricity drops to around 60 g CO_2/kWh in 2040. Electric cars would therefore be significantly less emissions-intensive than conventional cars: powering all EVs in 2040 in the SDS with 60 g CO_2/kWh electricity would lead to a net reduction of more than 150 Mt CO_2. Again, savings could be even larger if vehicles were to be charged during the daytime.

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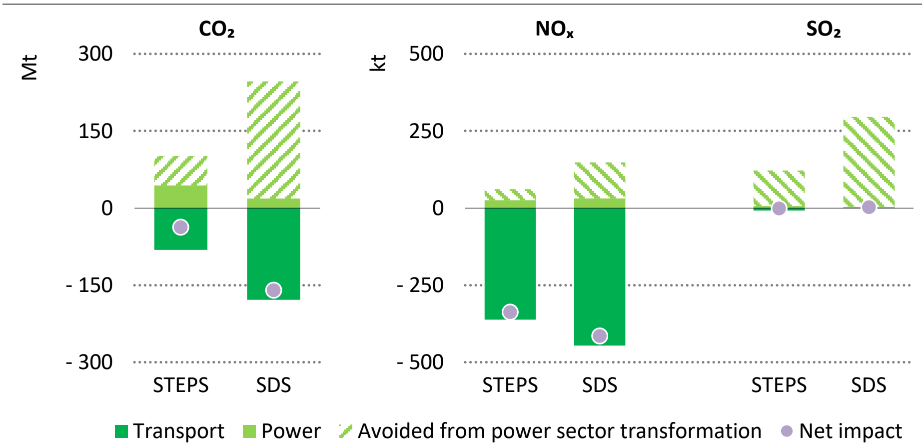
Figure 4.10 ▷ Emissions of CO_2, NO_X and SO_2 from EVs in 2040



Road transport electrification reduces CO_2 and NO_X emissions, but parallel changes in power generation are essential to eliminate potential rises in SO_2 emissions.

Notes: For CO_2, analysis assumes EVs are powered with the average annual emissions intensity of electricity generation. For SO_2, there are measures implemented in the SDS that reduce the sulphur content of gasoline and diesel to very low levels, so EVs displace slightly smaller quantities of SO_2 than in the STEPS.

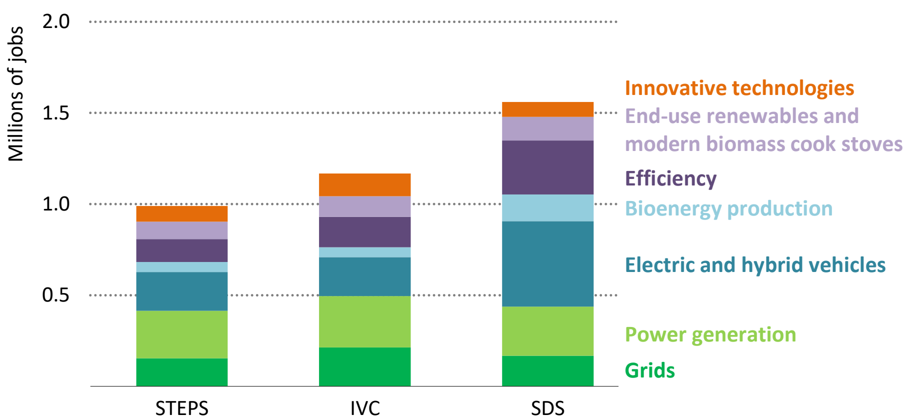
Turning to another part of the energy sector, India has a target to convert around 100 Mt of coal to natural gas using coal gasification by 2030, which points to another potential trade-off between air pollution and CO_2 emissions. The use of natural gas in cities would reduce emissions of SO_X and $PM_{2.5}$, but coal gasification is a very CO_2-emissions intensive way of producing natural gas. Achieving the government's target would lead to an additional 150 Mt CO_2 emissions by 2030, compared with a case where the natural gas was produced from conventional reservoirs. CCUS offers a possible way of avoiding these additional emissions.

Finally, the energy transition envisaged in the SDS requires an increase in investment expenditure compared with the STEPS: a cumulative increase of $1.4 trillion of investments in a wide range of clean energy technologies would be needed over the period 2019-40. To the extent that this relies on direct government expenditure, it would require increases in taxes, possibly including energy taxes, which could in turn increase end-user prices and risk damaging progress on energy access. This could be avoided by mobilising spending from private sources to ensure adequate investment for secure and sustainable energy transitions. As discussed in the next section, such mobilisation depends on improving effective regulatory procedures, reforming energy taxes and reducing risks for private investment.

Box 4.2 ▷ The employment impacts of energy transitions

A transformation of India's energy sector will inevitably have implications for employment as opportunities in cleaner energy and related sectors increase and jobs in traditional parts of the energy economy become scarcer. The changes involved will have a major impact on the lives of many people and communities, and they call for a strategic approach to secure a just transition with a strong focus on training and retraining.

Figure 4.11 ▷ New full-time jobs added in India by 2030 by scenario and investment segment



Clean energy employment grows in all scenarios, especially in the SDS; the scale of the growth underlines the need for training and retraining.

Across all scenarios, employment ramps up rapidly in grids and clean power generation, EV manufacturing, end-use efficiency and renewables, including in appliance manufacturing and the deployment of modern cook stoves (Figure 4.11). In the SDS, employment in these sectors grows notably higher than in the other scenarios, reaching 1.6 million full-time equivalent jobs, largely due to substantial increases in employment in EV manufacturing and in efficiency. In the SDS, strategic decisions taken early to limit growth in conventional manufacturing segments minimise the need for retraining and later retooling of manufacturing lines. The IVC relies heavily on renewable generation and batteries, and employment levels in those areas are comparable to those in SDS.

The location of these jobs is an important factor for managing transitions, especially when directing programmes and funding. Jobs in construction and delivery of retrofits have a relatively even geographic distribution: retrofits can be performed wherever there are buildings. Manufacturing and mining jobs, however, are geographically specific, and are often vitally important to the local area. For example, coal is mostly produced in the poorer states of India today, and coal extraction is the main economic activity in several regions. In the SDS, there is an 85% reduction in coal-fired power generation and a 60% reduction in domestic coal mining between 2019 and 2040. This would inevitably entail large job losses among the roughly 500 000 official workers who depend on the industry, and more among informal workers. Unless carefully managed, this could have major social and economic implications in local economies and communities.

There is much that could be done to support those who would be affected. For example, regions where jobs are lost due to the energy transition could be focal regions for investments in emerging sectors, such as battery production, and funding could be provided for environmental restoration in mining regions, which could provide near-term employment for those approaching retirement as others are retrained. A comprehensive communication strategy, together with well-resourced reskilling and regional revitalisation programmes, would be essential to enable workers in incumbent industries to find alternative livelihoods (IEA, 2020b). Retraining programmes should be informed by a process of mapping skills between displaced and growing occupational segments requiring similar skill sets (ILO, 2011).

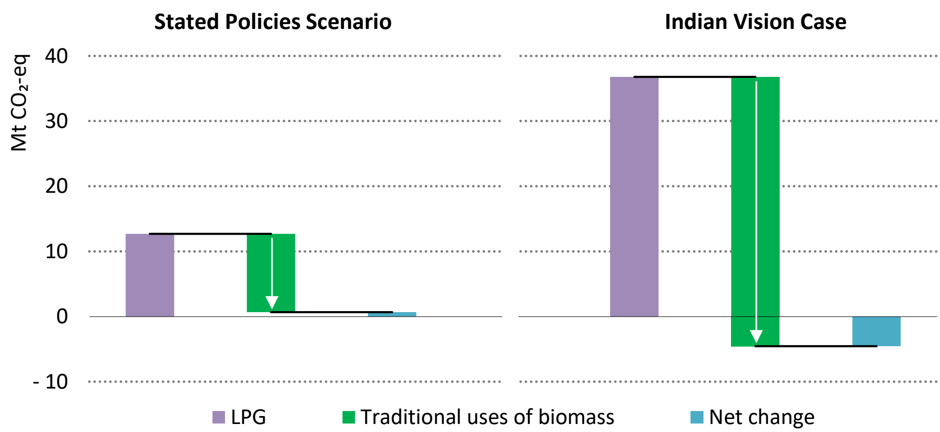
Identifying and maximising synergies

There is a great deal of potential for synergies between improving energy access and reducing air pollution. In 2019, there were around 600 000 premature deaths associated with household air pollution in India, most of which were associated with traditional uses of biomass for cooking. Achieving full access to clean cooking solutions by 2030, as in both the IVC and the SDS, reduces this to fewer than 100 000 deaths in 2030.

Reducing the traditional use of bioenergy for cooking would also reduce GHG emissions. The majority of people gaining access to clean cooking achieve this through the use of LPG. While the achievement of clean cooking for all would lead to an increase in CO_2 emissions, this would be more than offset in terms of overall GHG emissions by a reduction in methane and nitrous oxide emissions arising from the traditional uses of biomass (Figure 4.12). More clean cooking with LPG could also reduce deforestation and other environmental and water stresses that are often associated with the collection of biomass and charcoal.

There is also a great deal of scope for synergies between reducing GHG emissions and achieving other sustainability objectives. For example, greater use of renewables would reduce emissions, and would at the same time reduce water stress (Box 4.3).

Figure 4.12 ▻ Changes in GHG emissions from providing clean cooking by scenario, 2019-2040



Higher CO_2 emissions from increased LPG consumption for access in the IVC are more than offset by a reduction in other GHGs, notably methane, from the traditional use of biomass.

Note: CO_2-eq = carbon dioxide equivalent.

Box 4.3 ▻ Reducing water needs in the power sector

India's power sector withdrew over 20 bcm of water and consumed more than 3 bcm in 2019, almost all of it used for cooling and washing in coal power plants.[4] Yet almost 35% of India's coal power plant capacity that uses freshwater cooling is located in areas that are categorised as extremely water stressed, and a further 16% is in areas experiencing high water stress.[5]

India has put in place a number of measures to reduce levels of water withdrawal. All existing and new thermal power plants are required to switch to tower cooling technologies and to cap their water consumption, and plants located within a 50 km radius of municipal sewage treatment plants are required to use treated sewage water. Nevertheless, just 8% of all coal plants in India have access to treated wastewater and

[4] Water consumption is the volume withdrawn from a source that is not returned (i.e. is evaporated or transported to another location) and is no longer available for other users. Water withdrawals are the volume of water removed from a source and are always greater than or equal to water consumption.

[5] Baseline water stress is taken from the World Resources Institute's Aqueduct database. Stress levels are based on the ratio of water withdrawals to available renewable ground and surface water supplies. For high stress the ratio is 40-80%, and for extremely high it is greater than 80%.

are able to use it completely or partially to meet their cooling water needs; there are also water quality challenges and competition from other uses, such as irrigation.

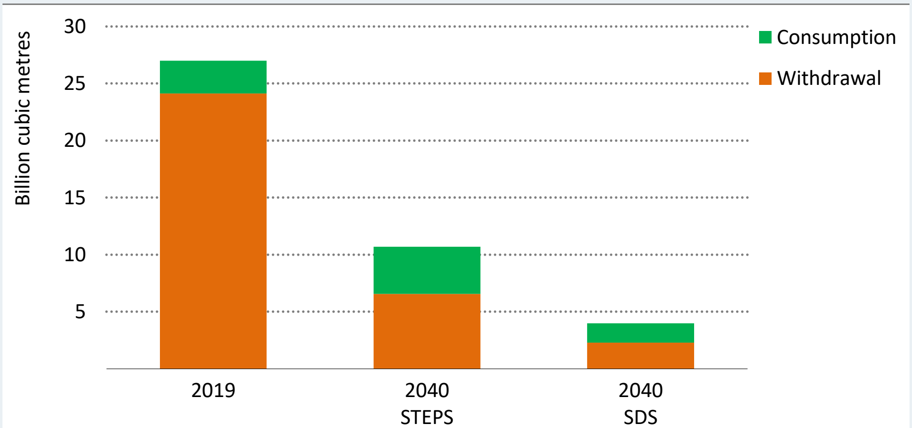
To alleviate water stress further, operators could improve power plant efficiency, deploy dry cooling plants, retrofit existing plants to use dry cooling, and make better use of non-fresh water and water recycling.

A number of low-carbon energy options – most notably nuclear, bioenergy and concentrating solar power – also require access to water and could be limited by water availability in the future. Decisions about plant locations and cooling technology options therefore need to take into account water availability and competing water demands.

The STEPS sees a significant decrease in water withdrawals to 8 bcm in 2040 as a result of increases in the share of electricity coming from use of renewables and regulations on water use in thermal power plants (Figure 4.13). However, water consumption grows by 65% to 2040 as a result of India's policy for all thermal power plants to use tower cooling.

The SDS sees water withdrawals fall to less than 3 bcm in 2040, reflecting a major reduction in coal-fired power generation. The decline in coal-fired generation also means that water consumption falls by around 40% to 2040, although this is offset slightly by increases in consumption from modern forms of biomass, nuclear and concentrating solar power.

Figure 4.13 ▷ Power sector freshwater withdrawals and consumption



Water consumption from coal-fired power generation falls by 90% in the SDS; this is offset to a very limited extent by an uptick from water-intensive low-carbon sources.

4.3 Clean energy investment and finance

India currently devotes nearly 3% of its GDP to energy investment, and an increasing share of this investment is going into clean energy.[6] This clearly represents an investment opportunity, but it is one that comes at a time of increased economic uncertainty and new risks. The pandemic has disrupted supply chains, weakened state discoms, and undermined access to finance, adding new challenges to persistent underlying structural issues. Despite this, interest in investing in India's clean energy transition remains high, as evidenced by a record level of awards of solar PV tenders and by the response of policies, such as Delhi's new EV scheme.

India's investment response to the pandemic has so far focused on short-term measures to ease liquidity and support project development. Efforts to navigate a rapidly changing market situation while addressing longer-term issues will determine how the outlook evolves over the next decade. Mobilising investments will depend on improving the availability of finance from a diverse range of actors and instruments, and that in turn will depend in part on appropriate long-term policy design.

4.3.1 Investment needs under different energy pathways

Under any energy pathway, India's energy system would require a significant amount of investment and a shift towards clean energy and grids. At nearly $160 billion, annual spending in STEPS reaches double the level of the past five years by 2030. Half of this growth comes from power, led by grids, renewables and battery storage. Spending continues for fossil fuel-based power, supported by plants under construction, but the level of expenditure steps down to much lower levels by 2030. Investment in fuel supply grows modestly for oil and gas and biofuels in STEPS, and declines for coal by 2030. There is also a significant rise in support for purchases of EVs, whose sales top 8 million in 2030, as well as for investment in efficiency and renewable heating applications.

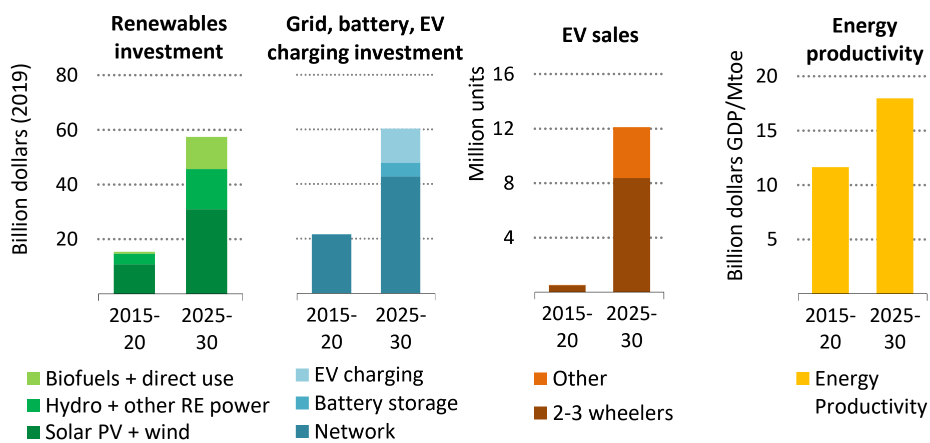
The SDS sees a level of investment by 2030 that is 35% higher than in the STEPS, and three times greater than that during 2015 to 2020 (Figure 4.14). Over 90% of the annual $200 billion in the SDS from 2025-30 goes to clean energy and electricity networks, up from 60% over the past five years. Renewables-based power investment, led by solar PV and wind, triples to almost $50 billion a year, supported by a doubling of spending on electricity grids. System flexibility and emissions reductions are further supported by higher levels of investment in battery storage, as well as by increases in gas-fired power, hydropower and nuclear power.

Investment in the direct use of renewables in buildings, industry and transport, especially bioenergy and biofuels, also rises in the SDS, reaching over $10 billion annually. Spending increases to over $10 billion by 2030 on the electrification of the vehicle fleet too, bringing

[6] Clean energy investment includes low-carbon fuels, renewable power, nuclear power, battery storage, renewables for end use, energy efficiency, EVs and chargers, and CCUS.

about an acceleration of EV sales to 12 million annually on average from 2025 to 2030, 70% of which are two- and three-wheeled vehicles, as well as a rapid roll-out of charging infrastructure. This is all enabled by more stringent consumption measures and investment in energy management systems, more efficient appliances and new industrial motors. Overall energy productivity increases by 55% in the SDS, led by improvements in the energy intensity of commercial buildings and of key industrial sectors such as cement and steel. By 2030, investment in CCUS starts to support emissions reductions in heavy industry and coal power, while investment in new unabated coal power dips to near zero by mid-decade.

Figure 4.14 ▷ Annual average clean energy-related investment and activity indicators by sector in the SDS



To meet sustainability goals, more than 90% of India's energy investment in the SDS goes to clean energy and grids, with sizeable allocations of capital for renewables and efficiency.

Notes: RE = renewable energy. Energy efficiency is shown as gains in energy productivity (economic output per unit of consumption). The 2025-30 time period is used as an indicative post-recovery benchmark.

The role of investment frameworks and the industry and financial landscape

Mobilising capital will depend first on strengthening the enabling frameworks for investment and addressing cross-cutting factors, notably those pertaining to country risks (the macroeconomic situation, particularly currency volatility) and policy and regulatory risks (investors point to issues over "contract certainty" – the combination of contract sanctity and policy certainty – as a key challenge). Other cross-cutting risks include burdensome and slow administrative processes for obtaining project permits, rigid labour regulations, difficulties associated with land acquisition and the relatively low level of availability of long-term, fixed-rate debt (Table 4.2).

The investment outlook also depends on the type of companies developing projects and the way they manage risks and capital budgets. PSUs are the main financiers of electricity grids and are subject to price regulation risk (tariffs revised periodically by the regulator), while investors in utility-scale renewables obtain a price for electricity that is agreed up front and set in a long-term contract. However, India's electricity discoms are subject to cash flow and performance risks that have knock-on effects for the rest of the system, including transmission companies and privately owned generators who remain dependent on reliable dispatching, balancing and payments. Timely investment in any part of the energy system is to a large extent dependent on all parts of the energy system performing at an adequate level.

Table 4.2 ▷ Key factors affecting risks and returns and common types of developers for clean energy-related investments in India

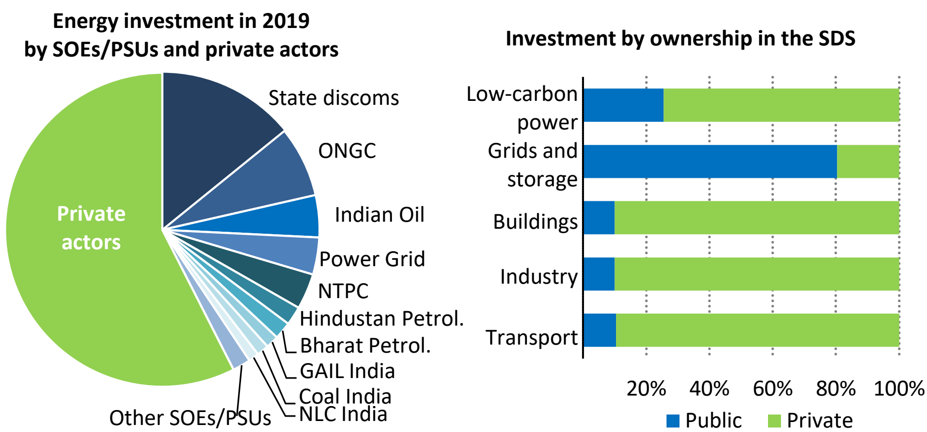
Selected subsector	Key factors affecting risks and returns	Most common developer type
Biofuels and biogases	• Sustainable feedstock supply chains and domestic fuel pricing • Land acquisition	• PSUs and MSMEs
Utility-scale renewable power	• Power purchase and dispatch • Contract certainty • Land acquisition	• Listed and unlisted (i.e. privately held) companies, mainly large, domestic companies
Distributed renewable power	• Retail tariffs and cross-subsidies • Enabling infrastructure • Regulatory risk (access, ownership)	• Corporate consumers, PSUs and households
Electric grids and battery storage	• Regulatory risk (tariff setting) • Volume risk (e.g. line utilisation) • Uncertain business model (storage)	• PSUs, some listed (e.g. Power Grid) and other large companies (inter-state transmission)
Energy efficiency	• Retail tariffs and cross-subsidies • Establishing reliable baseline and measurement/verification of savings • Creditworthiness of small developers	• Large domestic companies, MSMEs, ESCOs, households
Electric mobility	• Enabling infrastructure (e.g. pace of electric charger deployment) • Retail tariffs and cross-subsidies • Performance issues	• State-owned and private transport companies • Corporate consumers and households
Renewable heat applications	• Retail tariffs and cross-subsidies • Creditworthiness of small developers	• Large domestic companies, MSMEs, ESCOs, households

Note: PSUs = public sector undertakings, state-owned enterprises, majority-owned by the central or state governments. MSMEs = micro, small and medium-sized enterprises, ESCOs = energy service companies.

At nearly $85 billion in 2019 (see Chapter 1), energy accounts for around 10% of investment in India. Large, domestically listed energy supply companies play an important role in funding the sector: they account for nearly half of energy investment (Figure 4.15). The other half of energy investment comes from unlisted state-owned companies (e.g. discoms) and private actors, such as MSMEs, individual households and, to a lesser extent, international companies.

PSUs are likely to play a continued important role over the next decade, accounting for around 30% of the ownership of new energy capital over 2025-2030 in the SDS. While 2020 energy investment declined by around 15%, the government is pressing PSUs to meet initial capital budgeting targets in order to sustain employment. Spending is set to decline in the fossil fuel sectors where they are most prominent, but PSUs also account for over 80% of investment in electricity grids over the period. Many PSUs face increased financial strain as a result of the crisis, however, and this is affecting their ability to invest and serve as creditworthy purchasers from private players. Some PSUs are making efforts to diversify: NTPC has signalled a shift towards investing in solar PV to increase its renewable power generation capacity up to 25% by 2032, and Indian Railways – a major consumer – has announced a net-zero emissions target by 2030.

Figure 4.15 ▻ Energy investment by major company in 2019 (left) and ownership of energy capital in the SDS (2025-2030) (right)



Around 70% of clean energy-related investment will be met by private sources; public finance and policy design are critical to mobilise capital to meet diverse financing needs.

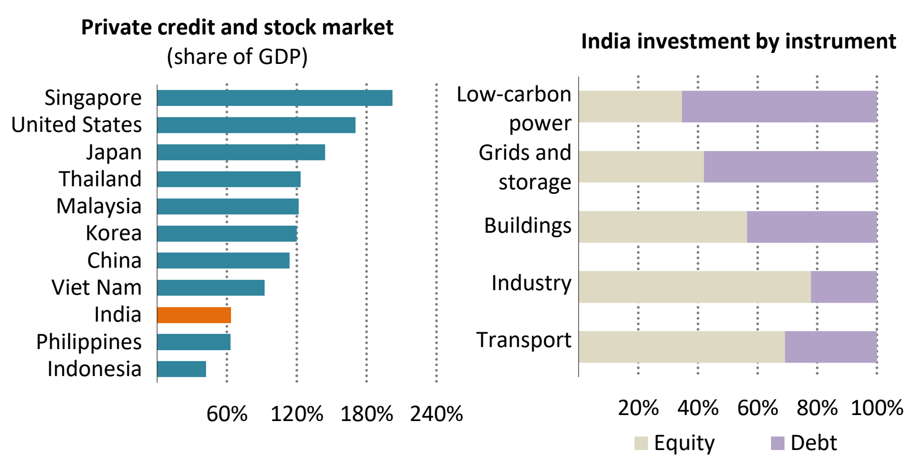
Notes: Petrol. = petroleum; ONGC = Oil and Natural Gas Corporation Limited. The ownership projections are based on estimates of the share of investment that is carried out by state-owned enterprises and government sponsors (public sources) compared with that led by private actors.

Some large private actors have also increased their clean energy ambitions. Reliance Industries has announced a 2035 net-zero target, and other energy supply companies (e.g. Tata Group, Adani Transmission, Suzlon and Essar Oil and Gas) have committed to set emissions reduction goals under the Declaration of the Private Sector on Climate Change, though implementation details are not yet available. Automotive companies in India plan to spend around $500 million in support of EV deployment in the next few years. An increased emphasis on environmental, social and governance (ESG) factors is also starting to influence disclosure and strategies. Among the top listed companies, over half report ESG data, though only around 5% disclose details on how capital expenditure aligns with sustainability goals.

We estimate that 70% of investment over the next decade in sectors critical to meeting the SDS would need to come from privately-owned projects, which are set to play an important part in scaling up renewables, efficiency and new technologies. In recent years, clean energy investments have been carried out more by newer and less well capitalised companies, raising questions over their ability to fund the transition. In some sectors, the industry has become more mature: in utility-scale solar PV and wind, there has been a shift towards fewer large developers with greater risk-taking capacity, which has helped projects to access lower cost funding (IEA/CEEW, 2020). However, clean energy sectors generally still lack scale and diversified access to financing. Some investments in efficiency are carried out by large, established companies, but others are made by MSMEs and smaller ESCOs. Much of the investment in clean energy is also likely to come through unlisted companies that face barriers in raising funding from capital markets. Foreign direct investment and enhancement of domestic sources are both key to meeting financing needs.

Viewed from this perspective, India's financial system development lags behind that in many other emerging market and developing economies, and doubts about the availability of finance puts a question mark against future investment plans (Figure 4.16). In 2020, both debt and equity market risk premiums increased in the first half of the year, reflecting capital outflows amid the pandemic, and offsetting some of the moderating effect from more expansive monetary policy and central bank liquidity support. As a result, the economy-wide cost of capital in India remains high, with risks to the upside in the event of potential further economic fallout.

Figure 4.16 ▷ India's financial system development (left) and clean energy investment in the SDS by financing instrument, 2025-2030 (right)



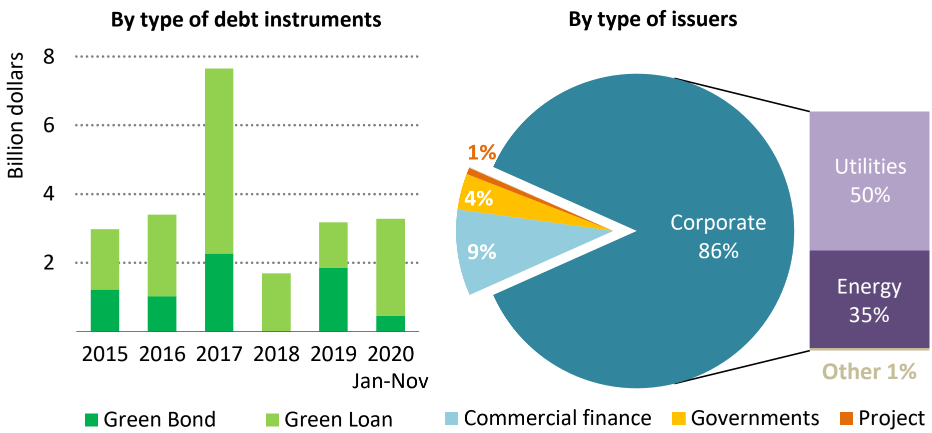
A diverse range of equity and debt instruments is needed to fund clean energy-related investment in the SDS, and access to finance represents a potential barrier to meeting sustainability goals.

Notes: Instruments estimates are based on current observed capital structures by sector, derived from financing data on companies and consumers (for balance sheet financing) and assets (for project finance), applied to SDS investment projections; equity includes grants.

On the equity side, economy-wide required rates of return are generally high, at around 15%, reflecting cross-cutting risks to investing but also the underdevelopment of capital markets. Stock market capitalisation as a share of GDP stands at nearly 65%, compared with the global weighted average of over 100%. India is effective at bringing new companies to market in terms of initial public offerings (IPOs), though relatively few equity market listings have been in the energy sector. Since 2015, industrial sectors have accounted for around 45% of IPOs, and consumer firms such as automotive, retail and textile companies for a further 30%; less than 10% of IPOs were for energy-related companies (mostly renewables companies).

Debt financing largely comes from a mixture of domestic banks and non-banking financial companies, such as the Power Finance Corporation (Figure 4.17). The average of private credit and stock market capitalisation as a share of GDP stands around 60%, compared with a global average of around 100%. While long-tenure debt is generally available for renewable power, regulatory rules on sector lending mean that renewables compete for the same pool of bank capital as thermal power, where an increase in stressed assets has put pressure on bank lending (see below). Debt is more constrained on the consumer side: only around 15% of MSMEs have formal access to credit, and many rely instead on the more expensive and less transparent informal market for lending. While MSMEs are recognised as a priority lending sector, there are no sectoral lending requirements for efficiency.

Figure 4.17 ▷ Sustainable debt issuance and types of issuers in India



India is one of the largest emerging market issuers of sustainable debt. Although issuance has not grown in recent years, it remained resilient in 2020.

Sources: IEA analysis based on data from Bloomberg (2020) and BNEF (2020).

Meeting India's clean energy investment needs over the next decade will require a financial system that can better match the capital needs of energy companies and assets. The closer that India moves towards an SDS pathway, the more investment needs will increase, and the more important the availability of debt finance will become. A shift from investment in fuels to investment in the electricity sector will increase investment requirements; additional investment will also be needed in end-use sectors. Debt shares within these sectors in India are lower than in advanced economies, however, pointing to a need to develop domestic credit markets to support lower-cost financing.

Attracting greater shares of debt depends on addressing the sector-level issues described below, as well as reforming sectoral lending rules, deepening corporate bond markets and fostering markets for new instruments. Better availability of default protection and risk-transfer mechanisms would help enhance corporate borrowing (CPI, 2020). Sustainable debt issuance has surged globally, and India is one of the largest emerging market issuer of green bonds, except for China. Despite the Covid-19 pandemic, sustainable debt issuance in India remained resilient in 2020, supported mostly by energy companies and utilities. Over 90% of proceeds went to renewable power, with a smaller share to low-carbon transport. If it is to scale up, the market is likely to require more integrated frameworks for measurement, verification and reporting, and more diversity in issuers. The creation of a sustainable finance taxonomy, based on a list of green economic activities, could support this. There is also scope for warehousing projects into securities, such as infrastructure and real estate investment trusts (INVITs and REITs), which spread risks and transaction costs.

4.3.2 Key issues and success factors for financing clean energy transitions

Whichever way India's energy sector evolves from here, the scale of the country's energy investment needs is huge, especially in the power and end-use sectors. In the second part of this section, we zoom in on four issues that are critical to the prospects for a more sustainable and secure energy sector:

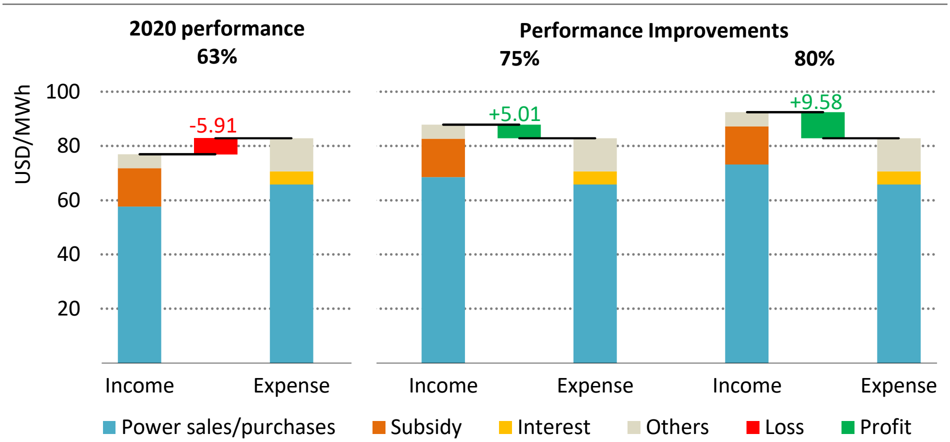
- the financial performance of the state electricity discoms
- the question of how to scale up investment in utility-scale renewable projects
- the different approaches required to finance efficiency improvements, transport electrification and smaller-scale clean energy projects
- the linkages with existing, often poorly performing investments in other parts of India's energy sector.

Improving the financial performance of state distribution companies

State electricity discoms represent the biggest financial uncertainty in the value chain of India's power sector investment. These utilities suffer from persistent revenue shortfalls, in large part due to poor operational performance in billing of power, difficulties in collection of sales from consumers, and high levels of aggregate technical and commercial (AT&C) losses. Performance varies widely by state but overall, outstanding dues to generation companies climbed from nearly $4 billion in September 2017 to over $18 billion in September 2020 (PFC Consulting, 2020). The situation affects the ability of utilities to invest in the expansion and modernisation of grids, honour contracts with renewable and thermal generators, and integrate clean energy technologies, such as distributed resources, that may affect their top-line revenues. As described above, uncertainty over power purchase remains a critical risk for project developers, challenging efforts to manage the cost of energy transitions.

In 2015, the government launched the UDAY initiative in an effort to improve discom finances. This involved state governments writing off up to 75% of their debt and restructuring the remaining loans with a concessional interest rate of only 10 basis points over the central bank's base rate. While UDAY has reduced debt burdens, it has not translated into dramatic improvements in key performance indicators that would denote improved profitability. Recent annual data show the average cost of electricity supply remaining 8% higher than revenues, an imbalance that has only modestly improved over the past three years. The pandemic has not helped: discoms experienced a 15% reduction in demand during March-June compared with the same period in 2019, mostly due to corporate and industrial power users, and this has translated into $3 billion to $4 billion in lost revenues. In March 2020, the central government announced a liquidity scheme of $13 billion to help reduce outstanding dues to generators.

Figure 4.18 ▷ State discom income and impact of enhanced performance in billing, collections and reduction of losses, 2020



Revenue shortfalls for state discoms have led to significant arrears to generators; better performance on key indicators would help enhance profitability.

Notes: Performance is calculated based on billing, collecting and AC&T losses rates. Current value is estimated at 63% (85% billing rate, 93% collection rate and 21% AC&T losses). Improvements in key performance indicators are assumed to benefit each consumer category (domestic, commercial, agricultural, industrial and others) pro rata with its sales.

Sources: IEA analysis based on Power Finance Corporation (2020) and POSOCO (2020).

Narrowing the cost-revenue gap is critical to enhancing financial performance and clearing the backlog of overdue payments. Three-quarters of discom income stems from sales to consumers, 15% from tariff subsidies and 3% from revenue grants under UDAY. Around 80%

of their expenses come from the cost of power purchase and generation, with the remainder from administrative, labour and financing costs. Power costs are determined by the mix of generation, fuel costs and provisions under long-term PPAs, and revenues are influenced by tariff structures and demand.

While larger energy market and policy developments will inevitably have a big impact on the cost-revenue gap, utilities can make important strides towards profitability by focusing efforts on improving billing efficiency, collection efficiency, and reducing AT&C losses. We estimate that discoms were able to monetise only 63% of the electricity they distributed in 2020 due to difficulties in these areas. Raising this to 75% or more would bring them back to profitability (Figure 4.18).

Such improvements may require increased investment and operational measures geared towards metering, billing and collection systems as well as the upgrade and monitoring of distribution grids to reduce losses. However, while distribution companies could improve business profitability by taking such measures, their efforts would be enhanced by better governance and by structural reforms. Such reforms might include government action to improve the cost-reflectiveness of tariffs, increase the share of low-cost renewables, and address the financial implications of existing thermal power assets (see below). They might also extend to opening the distribution segment up to competition, in line with government plans to privatise utilities in union territories.

Mobilising investment for utility-scale renewables projects

Investment in renewable power grew by almost 55% between 2014 and 2019, and interest in investing remains strong, as evidenced by the high level of solar PV bids (15 GW) in the first half of 2020, even if no wind capacity was awarded in the first half of 2020. While this solar PV tendering was influenced by the exercise of a large (8 GW) option awarded under a previous manufacturing-linked tender, the rest of the capacity awarded during the first half of 2020 topped that from the first half of 2019, and was 75% higher than in the first half of 2018.

The impacts of the economic crisis nonetheless add additional layers of risk to the massive scaling-up of investment that would be needed in the IVC or SDS. Meeting the ambitious 2030 target for renewable electricity would require adding more than 30 GW of renewable capacity each year between 2020 and 2030, and this has a much better chance of happening if action is taken to address persistent risks around power purchase, land acquisition and availability of transmission, as well as policy and regulatory uncertainties, such as those related to potential new trade measures for solar PV.

At the same time, financing terms for projects, and the risk and return proposition facing developers, have begun to shift, as illustrated in analysis from IEA and CEEW on tender results over 2019 to mid-2020 (IEA/CEEW, 2020). On the project debt side, availability and pricing have remained stable, with differences mainly due to off-taker risks. Long tenors (16-18 years) and high debt ratios (around 75%) remain the norm. On the equity side, the estimated equity internal rate of return (EIRR; i.e. the minimum return required by equity holders) for solar PV projects stood at around 15% on a weighted average basis (by awarded capacity) over the course of 2019 and the first half of 2020, with differences depending on off-taker risks and type of site.

For example, while expectations of returns for projects with central off-takers and Gujarat distribution companies were similar, they were 80-200 basis points higher where the state utility off-taker presented higher credit risk. Competition in tenders has also been an important determinant of return expectations. In the first half of 2019, bids far outpaced tendered capacity, helping keep EIRRs down around 14%. However, from the second half of the year through mid-2020, returns rose to 16-17% (Figure 4.19), in the face of new policy and market uncertainty—such as potential renegotiation of contracts or the imposition and extension of duties on solar PV imports. The increased interest in the first half of 2020 may have been due to greater innovation in tenders or measures such as granting letters of credit.

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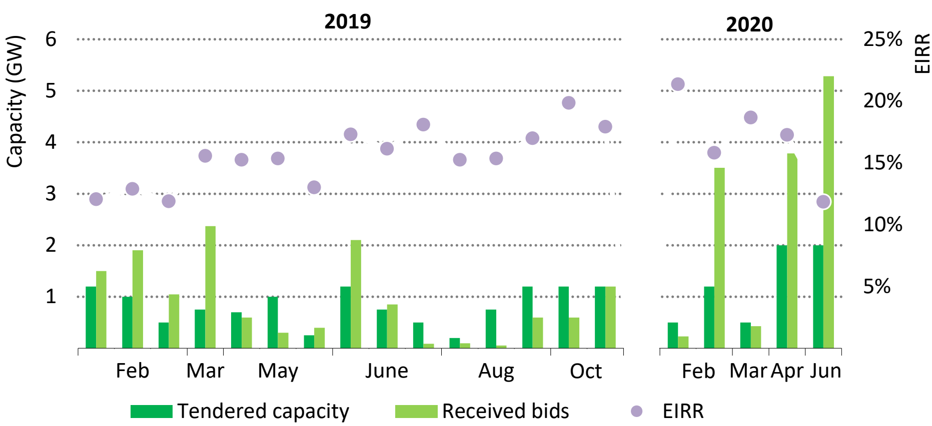
Figure 4.19 ▷ Equity expected returns by level of tender competition for utility-scale solar PV, 2019-H1 2020

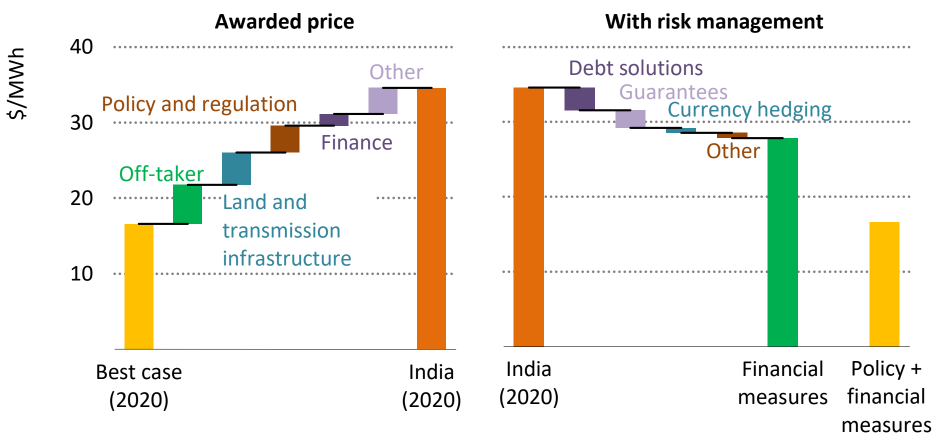


EIRR expectations for solar PV projects stood at around 15% over the course of 2019 and the first half of 2020, with differences depending on off-taker risks and type of site.

While developments over the past few years point to the ongoing maturity and improved competitiveness of the Indian renewables industry, the scaling-up of investment would be materially assisted by efforts to address persistent risks so as to bring generation costs more in line with global best case benchmarks. In the first half of 2020, the average price of tendered solar PV (weighted by capacity) was twice that of the best levels achieved in Europe.

In a survey of key investors, financiers and analysts, the key differences identified related to risks around power purchase (delays in payment by off-takers); contract renegotiation (off-takers seeking to renegotiate PPAs); land acquisition (concerns around availability, pricing, permitting and ownership); finance (limited availability of long-term, fixed-rate debt, and high cost); and regulatory uncertainty (lack of clarity in some laws and regulations, and fear of changes). Power purchase and renegotiation risks – both part of the off-taker risk category – are most prominent when the counterparty is a state discom with a weak financial and operational performance. The availability of grid connections and equipment supply chains are also important factors (Figure 4.20).

Figure 4.20 ▹ Awarded prices in new utility-scale solar PV tenders in India versus benchmark by risks (left) and financial measures (right)



Off-taker risks are the most significant perceived risks for solar PV projects in India today; policy reforms, debt solutions and guarantees could help address these risks.

Note: Awarded prices in India correspond to the average price discovered in solar PV tenders in the first half of 2020 (weighted by capacity). The best case corresponds to average prices discovered in solar PV tenders in Portugal and Spain over the period. Guarantees refer to financial guarantees provided by third parties.

Policy efforts are now being made to address issues around grid integration, land acquisition and the promotion of domestic manufacturing. Reaching the 450 GW target by 2030 will require a much more flexible system, with increased investments in grids and storage, a stronger focus on demand-side measures, and tenders that provide appropriate compensation for flexibility services provided to the system. Around 60% of the projects awarded in the first half of 2020 incorporate new arrangements, for example by allowing hybrid wind and solar PV, or projects bundled with domestic solar PV manufacturing capacity. SECI, a central government counterparty, has also introduced tenders with storage.

New business models and progress in other renewable segments may also improve risk-return propositions, but this too depends on ongoing reforms. Although around 90% of today's power supply is delivered through bilateral long-term contracts (IEA, 2020c), Indian authorities are discussing ways of expanding a wholesale market for trading power across India, including least-cost dispatch of electricity, which could lead to projects taking on a higher degree of merchant risk. Globally, a number of corporations contract power directly from renewable generators, as a way of meeting green purchasing goals and locking in low-cost power supply. Solar PV based on corporate PPAs have, however, reduced considerably in India in 2020 – despite considerable growth in previous years. Reforms could lead to greater utilisation of forward contracts to increase the options for hedging, which are currently not available in India.

Overall, scaling up investment for utility-scale renewable projects will require policy reforms, as well as an expansion of the availability of low-cost financing. Policy and regulatory certainty that allows investors and financiers to price risks effectively remains a key condition. Targeted financial measures, especially those aimed at debt structuring, credit enhancement and guarantees, could further help to address off-taker and finance-related risks. Madhya Pradesh has adopted a three-tier payment security mechanism to address purchase risks, for example, and this kind of mechanism could be adopted more widely. The ability to access loans for longer periods and on more flexible repayment terms that better match project cash flows will become more critical as tenders become more complex. In all these areas, development finance institutions have the potential to play a key financing role, but long lead times and stringent conditions can blunt their effectiveness. Expanding the suite of off-takers through better frameworks for corporate PPAs could also be helpful.

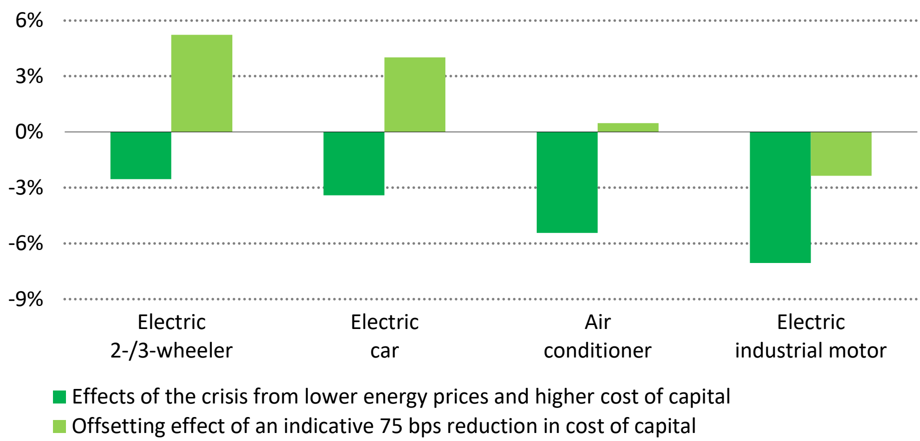
Financing energy efficiency, electrification of transport and small-scale clean energy

Over the next decade, the energy intensity of commercial buildings declines by over one-third in the SDS while the fuel economy of passenger cars improves by 40% compared with the previous five years. These goals are supported by investments in more efficient lighting, cooling and appliances, as well as uptake of EVs and in charging infrastructure. Investment in distributed renewables, including solar PV and solar thermal, tops $14 billion by 2030 compared with $2 billion in 2020.

Much of the investment in the SDS would be for smaller-scale resources, and investment models for such resources differ considerably from those for bulk power assets. They rely to some extent on the balance sheets of consumers, MSMEs, real estate developers and ESCOs, and are often not able to adopt long-term contracts. Remuneration frequently depends on energy savings against retail tariffs, which differ considerably among consumer classes. They also depend to a large extent on equity. Over half of buildings-related investment, and nearly 70% of transport investments, will be financed with equity over 2025-30; investments in utility-scale power and in more developed markets will make more use of debt. Mobilising investment depends on improving returns and financing costs, but changing energy prices and higher market risk premiums are currently extending payback periods and reducing profitability for key efficiency investments. Efforts to improve financing could help (Figure 4.20), but increasing the pipeline of bankable efficiency projects depends on stronger policy frameworks and greater standardisation of financial models with projections of energy savings and monitoring and verification protocols.

Investment in distributed generation, including rooftop solar PV and mini-grids, could help improve electricity services while taking some financial pressure off discoms. Integrating distributed applications with agriculture or other uses could similarly help to relieve subsidy burdens and lower technical losses. The current tariff system does not, however, provide sufficient incentive for utilities to adopt supportive frameworks, in part due to fear that providing such incentives would risk their losing revenues from more profitable industrial consumers. Industry sources point to consumer-owned installations as more common than those leased or made on a PPA basis with third parties, although some investment has been supported by auctions for government off-takers. Captive power users and MSMEs represent a large potential market, but often face credit constraints and lack suitable collateral. Domestic lending capacity has been reinforced by development financing, with preferential lines of credit earmarked by the World Bank and Asian Development Bank in collaboration with local banks, but an acceleration in investment has yet to be seen.

Figure 4.21 ▷ Changes in NPV for key efficiency improvements with changes in energy prices and cost of capital in 2020, compared with 2019



Changing energy prices and a higher cost of capital have reduced profit expectations for efficiency measures; better access to finance would improve the investment case.

Notes: NPV = net present value; bps = basis points. Changes in cost of capital in 2020 reflect movements in the economy-wide risk-free rate and equity- and debt-market risk premiums, weighted by capital structure. Equity share assumptions = air conditioner, 100%; industrial motor, 75%; electric car and two-/three-wheeler, 70%.

For buildings efficiency and distributed generation, bundling assets to achieve scale is one route to securing investment. Construction of green buildings has emerged as another fast-growing mechanism for obtaining investment: in 2020, nearly 1 billion m^2 was certified as green, which is equivalent to 5% of total residential floor space. Efficiency upgrades can increase building valuations, but the benefits are not easy to monetise without independent ratings systems to verify and communicate performance to stakeholders (including current and future owners and tenants). The capital structure of real estate developers mostly relies on relatively costly equity. Access to finance remains a constraint for these developers, particularly those at the smaller end of the scale, and no dedicated finance facility for the sector exists (World Bank, 2018). Incentives to integrate smart energy management systems, government procurement of efficient equipment and appliances, and reduced administrative hurdles for code-compliant investments would all help support the business case for efficiency.

Targeted financial solutions, such as credit enhancement, could better encourage investment in projects serving MSMEs. One study has assessed that the provision of credit guarantees to local banks to support lending to developers could increase private investment in rooftop solar PV by up to 14 times (CPI, 2018). In recent years, domestic lending capacity has been reinforced by development financing, including preferential lines of credit to encourage lower-risk on-lending to distributed sectors. The pooling of real estate assets into marketable securities – through REITs or INVITS – can also support reinvestment by developers and reduce reliance on banks, but action is needed to address regulatory and taxation uncertainties.

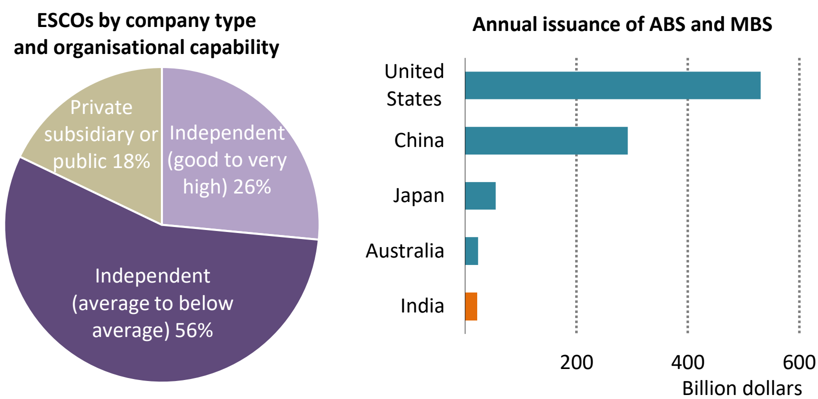
In transport, improving financial options for drivers will be critical. Two-thirds of the increase in EV sales in the SDS comes from two- and three-wheelers. Most three-wheeler (auto-rickshaw) operators lease their vehicle, paying the owners daily from their earnings. Owning an electric auto-rickshaw outright might well make more economic sense for such operators, but it is often hard for them to gain access to finance because of a track record of high default rates on loans for such rickshaws (in part due to the initially unreliable performance of lead-acid batteries), the small size of the loans that are sought and a lack of collateral on the part of the operators (EVreporter, 2020). Incomes for drivers have suffered during the pandemic, making lenders even more cautious about extending finance. Dedicated loan products and buy-back schemes for existing vehicles could help to support investment.

Box 4.4 ▷ Mobilising investment through service models and securitisation

The provision of energy as a service is growing, and this is helping to boost investment in distributed resources and efficiency in India. Some 150 private ESCOs are now accredited by the Bureau of Energy Efficiency, and their numbers have tripled over the past decade. They play particularly important roles in industrial sectors, where their use of performance contracting helps to attract credit from banks. Around 90% of the arrangements made by private ESCOs in industry involve energy performance contracts (EPC) based on shared savings; the remainder take the form of EPCs with guaranteed savings (IEA, 2018). These contracts are reinforced by a Partial Risk Guarantee Fund established by the Bureau of Energy Efficiency, which has mobilised private capital at a rate of over three times the level of public commitment.

The government is also trying to cultivate a market for energy services supported by the state-owned "super ESCO", Energy Efficiency Services Limited (EESL), which has used its balance sheet and development bank funding to become the largest developer of small-scale clean energy, investing nearly $0.2 billion annually over 2017 and 2018 in areas such as lighting, smart meters and buildings. It seeks to increase its spending to over $0.8 billion annually, partly in support of setting up EV charging stations. EESL also aims to bolster bulk procurement programmes, such as the successful UJALA LED initiative, to support lower-cost appliance purchases by consumers.

Figure 4.22 ⊳ India registered ESCOs by type and organisational capability (left) and size of total securitisation market by country (right)



Despite rapid growth, India's energy service market faces organisational and financial constraints, while progress on asset aggregation and securitisation remains limited.

Notes: ABS = asset-backed securities; MBS = mortgage-backed securities. Organisational capability corresponds to ESCO grades assessed by the Bureau of Energy Efficiency.

Sources: IEA analysis based on Bureau of Energy Efficiency (2020) and VKC (2019).

Despite rapid growth, only 5% of the Bureau of Energy Efficiency assessed efficiency market has been tapped by ESCOs. This is due in part to insufficient policy signals and lack of standardisation around savings and contractual frameworks, and in part to constraints in balance sheets, which have deteriorated during the economic crisis. While some ESCOs are part of larger private companies or public entities, most are independent players with limited organisational capability and access to finance (Figure 4.22). Credit-worthy clients have been reluctant to engage, and large industries have yet to show strong interest in performance contracting and energy service models. Banks have nonetheless been willing to lend to projects that are viable, even without the support of guarantee funds (BEE, 2018).

Infusions of both equity and debt are needed in the sector. New business models focused on providing system and end-user services beyond efficiency could help attract risk capital (AEEE, 2017). The promotion of warehousing and securitisation, which aggregate loans, receivables or projects and issue them as listed securities, could support lower-cost refinancing and free up balance sheets for reinvestment. This practice has accelerated globally with the issuance of green MBS and Property Assessed Clean Energy loans in the United States, but the securitisation market has yet to take off properly in India. Better certification, more credit enhancement options for projects and the establishment of a state-backed pooling intermediary could help enhance such a market.

The emissions reductions seen in the SDS compared with the STEPS in industry – including in steel, cement, chemical and manufacturing – require a reduction in energy intensity by around a quarter over the next decade. The investments that would be necessary to make this happen mostly focus on efficiency, but they also include funding for the direct use of renewables, such as bioenergy and solar thermal (the market for which has rapidly expanded to around $1 billion in 2019), as well as for gas and electricity to substitute for coal. These goals come at a time when the government is prioritising domestic manufacturing. Three-quarters of industry investment depends on equity, and there is potential to diversify funding sources and attract more debt to reduce the cost of capital.

The PAT scheme – a market-based mechanism with efficiency targets and tradeable energy savings certificates – provides the main incentive to invest. PAT Cycle 1 resulted in investments of around $4 billion, mostly from large companies, and its targets were met in all sectors except for thermal power. Incentives remain volatile, however, with energy savings certificate pricing varying considerably in recent years, in part owing to an excess of supply. Moreover, the PAT scheme to date has largely excluded the MSME sector. The Atmanirbhar Bharat Scheme is now making available collateral-free debt ($42 billion) and subordinated debt ($6 billion) to businesses and stressed MSMEs. Improving funding options could be enhanced through better domestic corporate bond markets, as well as performance-based financing instruments for use by energy-intensive companies.

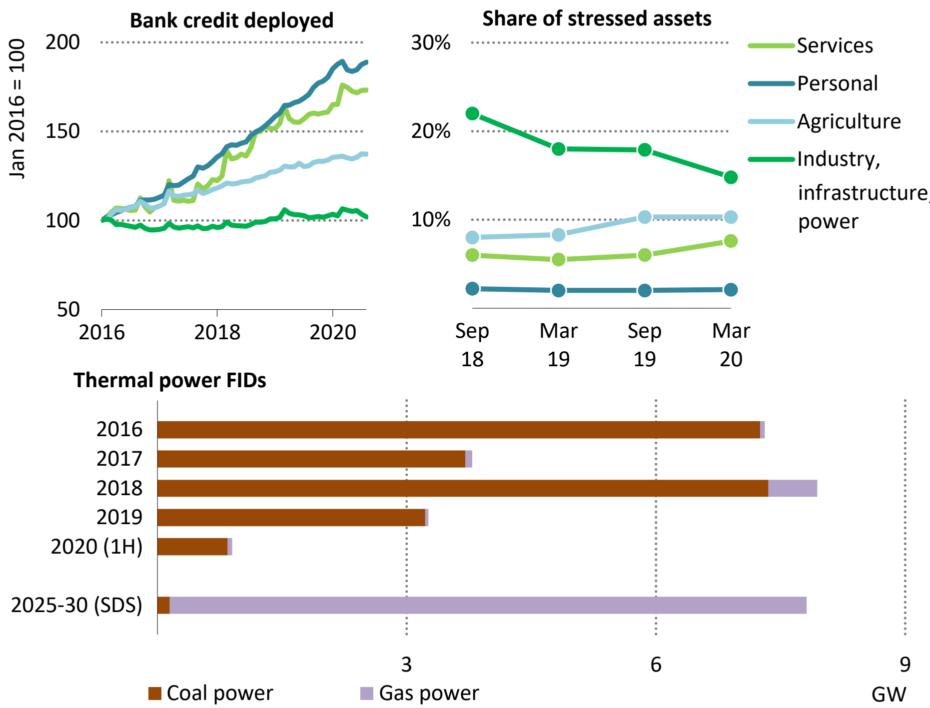
Links with the financial performance of other parts of the energy sector

The financial health of other parts of the energy and industrial sectors has an impact on financing conditions for clean energy investments because there are limits to the capacity of banks to mobilise debt for investments. Industry, infrastructure and power remain the largest recipients of bank credit in absolute terms, but lending has stagnated over the past five years, with most growth occurring in the personal and services sectors. Moreover, while overall bank credit has grown by 40% since the start of 2016, it has stalled with the start of the pandemic.

One reason for the stagnation in recent years is that the RBI has prescribed sector limits to guard against concentration of credit risks, and these limit bank loan portfolios for infrastructure, including power, to 20-25%. Another reason is the high level of stressed assets now in the financial system, which is creating headwinds for overall lending. Nearly 15% of bank portfolios in industry and power remain stressed, and the stressed assets include over 50 GW of existing coal power plants due to a lack of availability of PPAs and coal supply contracts, as well as declining fleet utilisation rates. Exposure to gross non-performing assets in the electricity sector alone stood at over $10 billion in early 2020, with a further $8 billion in metals, $4 billion in construction and $1 billion in mining.

The high level of stressed assets represents an important risk for India's energy transition because it dampens liquidity in the economy and crowds out funds for utility-scale renewables and large-scale investments. While a decline in final investment decisions for thermal power plants in recent years stems from the shifting role of coal and the rise of renewables in India's energy system, it also reflects increased risk aversion by banks. This risk aversion also affects the financing of gas power capacity, which would need to step up in the SDS, and of retrofits and refurbishments of power and industrial plants. For example, banks appear reluctant to fund investment in emissions control equipment of $7 billion for 120 GW of coal power seeking to comply with more stringent environmental rules.

Figure 4.23 ▷ Growth in bank credit deployed by sector (left), share of stressed assets in bank portfolios (middle) and thermal power FIDs (right)



After easing conditions in the past two years, the pandemic and a high level of energy-related stressed assets in the financial system are creating new headwinds for lending.

Notes: FID = final investment decision; 1H = first half. Stressed assets are defined by the RBI as those with delays in the payment of their interest and/or principal by the stipulated date in the loan repayment schedule.

Source: IEA analysis based on Reserve Bank of India (2020) and McCoy Power Reports (2020).

Improving the situation requires a multifaceted approach. In addition to efforts to improve the performance of the distribution sector, and coal supply, enhancements to market design and interconnection to facilitate the more flexible use of the thermal generation fleet could unlock additional value in financially stressed assets and the power system, while the expedited retirement of the oldest, lowest-efficiency and least system-relevant coal power plants could help ease financial strain on newer plants. From a financial standpoint, greater flexibility in the rules and regulations around stressed assets would help matters, as would separate treatment of renewables and other clean energy projects within sectoral lending limits. Greater use of new financial mechanisms, such as off-balance-sheet refinancing through the capital markets, could also help with the management of economic burdens caused by unprofitable assets (IEA, 2020d).

4.4 India in global energy

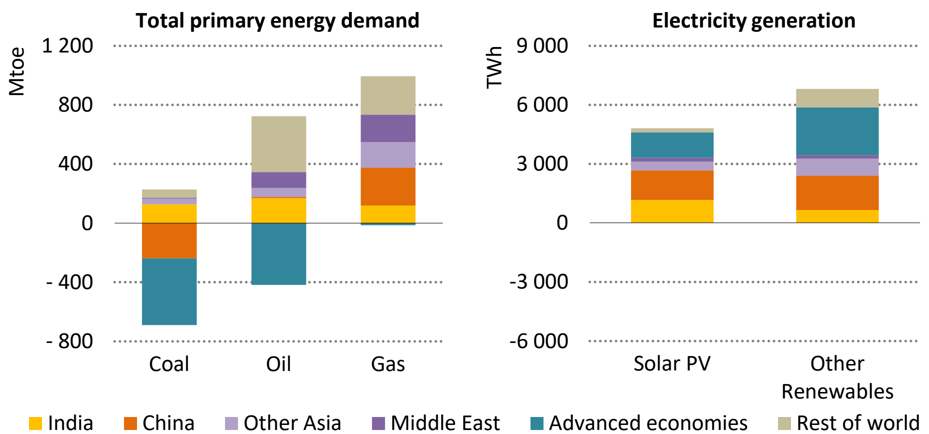
India already has a seat at the top table of international energy affairs, and its role is set to increase in importance in the years ahead. In this section, we consider different aspects of the interactions between India and the global energy economy, ranging from the impacts of Covid-19, market balances and energy security through to clean technology development and emissions.

4

4.4.1 India in global energy markets, trade and security

India is the fourth-largest global energy consumer today, after China, the United States and the European Union, and in the STEPS it overtakes the European Union by 2030 to move up to third position. This is underpinned by a rate of GDP growth that adds the equivalent of another Japan to the world economy by 2040.

Figure 4.24 ▹ Change in total primary energy demand and electricity generation in selected regions in the STEPS, 2019-2040



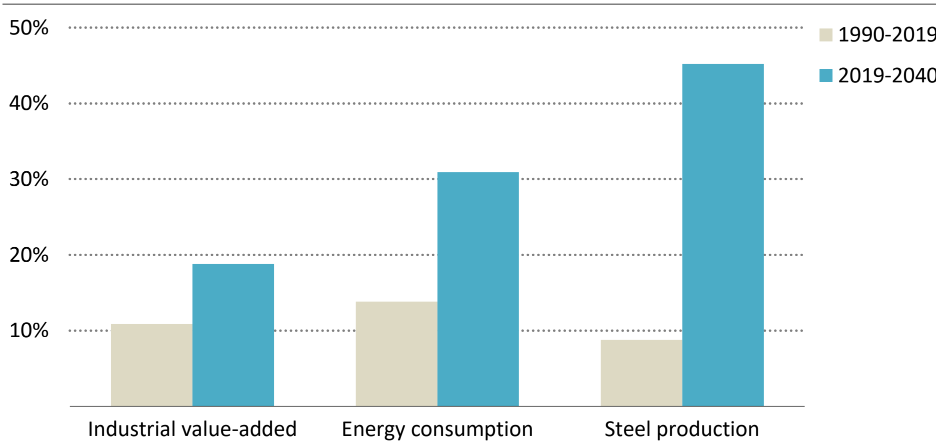
India sees demand grow across the energy sector through to 2040, and its increasing requirements for coal and oil partially offset reductions in advanced economies.

India accounts for nearly one-quarter of global energy demand growth from 2019-40 in the STEPS, the largest of any country. As such, its influence in global energy affairs is felt across all fuels and technologies (Figure 4.24). India's share in the growth in renewable energy in the STEPS is the second-largest in the world, after China. Already a heavyweight in solar PV, India takes on a similar role in battery storage, attracting more than a third of global investment between 2019 and 2040. By 2040, India's power system is bigger than that of the European Union, and is the world's third-largest in terms of electricity generation; it also has 30% more installed renewables capacity than the United States.

India likewise plays an extremely important role in global fuel markets. It leads oil demand growth, which rises over the period on the back of a fivefold increase in per capita car ownership. The country also becomes the fastest-growing market for natural gas, with demand more than tripling to 2040. India is one of the very few growth markets for coal in the STEPS, offsetting just over a quarter of the decrease in coal consumption in advanced economies.

India's continued industrialisation becomes a major driving force for the global energy economy. Over the last three decades, India accounted for about 10% of world growth in industrial value-added (in PPP terms). In the STEPS to 2040, India is set to account for almost 20% of global growth in industrial value-added, and to lead global growth in industrial final energy consumption, especially in steelmaking; India accounts for nearly one-third of global industrial energy demand growth to 2040 (Figure 4.25). This pivot in the global industrial economy towards India has important implications for world energy markets, for example for coking coal and natural gas, but also for global efforts to mitigate CO_2 in the industry sector.

Figure 4.25 ▷ India's share in the growth of global industrial output and energy consumption by time period in the STEPS, 1990-2040



In the STEPS, India becomes a global industrial heavyweight, and by 2040 it is producing almost 15% of the world's steel.

The picture is similar in the IVC, although India's development model is based more heavily on renewables, efficiency and natural gas. India remains the largest source of global energy demand growth in the DRS as well, although an extended pandemic would be extremely damaging to India's development prospects (see Chapter 2).

There is a sharp distinction to be made in the STEPS in terms of India's position in global energy trade between oil and gas, where the volumes and share of imported fuels rise steadily, and coal, where demand for imports is tempered by stagnant demand and relatively strong domestic output. India currently sources around 40% of its primary energy from abroad (360 Mtoe of imports out of a total of 935 Mtoe in 2019), a share that remains roughly constant in the STEPS.

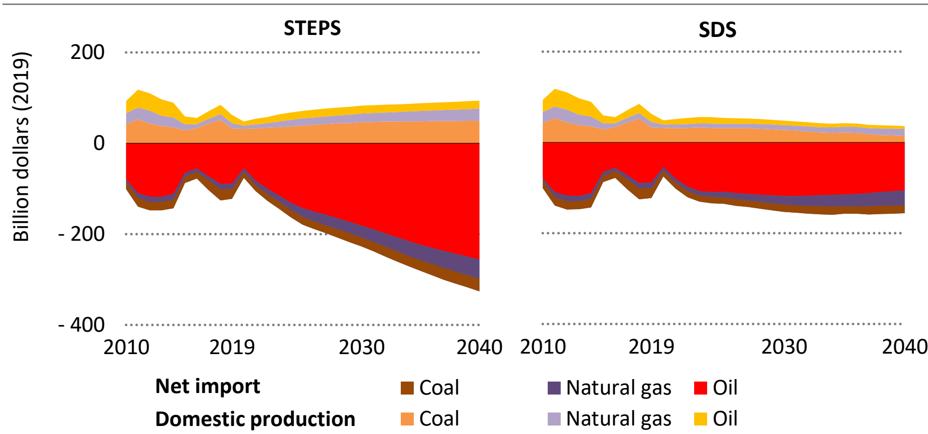
India's net dependence on oil imports – taking into account both the import of crude oil and the export of oil products – is around 75% today; this increases to more than 90% by 2040 in the STEPS, as domestic consumption rises much more than production. Natural gas import dependency increased from 20% in 2010 to almost 50% in 2019, and is set to grow further to more than 60% in 2040 in STEPS. The dynamics look quite different for coal, where India's demand for imported coal barely gets back to pre-crisis levels over the next decade in the STEPS, and this has outsize implications for global trade. India currently accounts for 16% of global coal trade, and many global coal suppliers were counting on growth in India to underpin planned export-oriented mining investments. These expectations are now running up against India's determination to boost domestic production (see section 3.4), leaving relative certainty only over India's requirement to import coking coal for its rising steel production, together with steam coal for those coastal power generation plants that have been designed to receive imported grades.

The combined import bill for fossil fuels triples in India over the next two decades in the STEPS, with oil making up by far the largest component of the total (Figure 4.26). As of 2019, energy accounts for almost one-third of India's total imports by value, and this exposure to global energy prices and market volatility increases in the STEPS. This implies significant vulnerabilities for India, both in terms of import bills and the potential for disruption to supplies.

The first of these vulnerabilities, while significant, has been mitigated to a degree by lower price trajectories in this year's outlook, which have reduced India's cumulative import bill to 2040 by 20% compared with the *WEO 2019*. Lower prices and import bills have already provided a boost to India in 2020, providing much-needed economic relief (and allowing the Indian government to raise duties on transport fuels at the same time). Lower oil and gas prices could also help to accelerate fuel switching from coal to natural gas or from traditional biomass to LPG, although equally they could undermine investment in domestic resources and reduce incentives to improve efficiency, or to switch away from fossil fuels altogether.

However, the shock of lower prices for major hydrocarbon exporters arguably increases the second of these vulnerabilities, the risks of disruptions to supply and market volatility. We estimate that net income from oil and gas in the Middle East, for example, fell by more than half in 2020, and year-on-year declines in net income for African producers on average are likely to be closer to 75%. These have exacerbated the fiscal strains facing many of these producer economies, leaving them with difficult choices on how to allocate scarce financial resources. Investment in new oil and gas supply around the world is expected to fall by around one-third in 2020, much more than the expected 9% drop in global oil demand and 3% fall in gas consumption, and this raises the possibility of new price cycles in the future. Given that India relies heavily on Middle Eastern and African producers to meet its crude oil and natural gas requirements, possible disruption to supplies in these regions could be felt much more in India than in other economies. The risk of a shortfall in investment appears to be higher for oil than for natural gas, which saw record approvals of new LNG export facilities in 2019. This vulnerability is mitigated by a large stock-holding capacity at publicly owned refineries, as well as by the continued build-up of the Indian Strategic Petroleum Reserve, which currently has a capacity of 40 million barrels, roughly equivalent to 10 days' oil consumption.

Figure 4.26 ▷ Value of domestic production and import bills for fossil fuels in India by scenario



The growing import bill for fossil fuels in India implies significant vulnerability to global energy prices and market volatility.

There is a much more profound change in the SDS, in which efficiency and fuel switching reduce the 2040 import bill by more than 50% compared with the STEPS. However, there would still be a need for continued vigilance on traditional aspects of fuel security in this scenario as well, not least because most imports would come from a handful of major low-cost producers whose hydrocarbon-dependent economies would come under immense strain as the global energy economy shifted away from fossil fuels.

Changing global energy dynamics and pathways for India point strongly towards the need for a broader concept of energy security that encompasses new and evolving risks to energy supply. To take one example, changes in India's electricity sector are dramatically increasing the need for flexibility in power system operation, as described in detail in Chapter 3: hour-to-hour ramping requirements are set to more than double in India over the next decade in the STEPS, and the pace of transformation would be even more rapid in the SDS. Like other countries, India needs to ensure that institutional and regulatory changes in the power sector keep pace with the speed of technological change if it is to safeguard the security of its electricity supply.

Another example concerns clean energy technologies. As described in more detail in the next section, India is set to become a major market for these technologies, and the government aims to capture a greater share of this demand through local production, using the leverage that India has as a leader in the deployment of battery storage and other clean energy technologies and as a country with a large and growing domestic market (Box 4.5). But this ambition raises questions about the adequacy of supplies of critical minerals. Managing the risks and geopolitical hazards associated with these increasingly important value chains will be an important task for India's policy makers and one where – as with other aspects of energy security – international collaboration can play a vitally important role.

Box 4.5 ▹ India's oil refining sector: leveraging the large domestic market

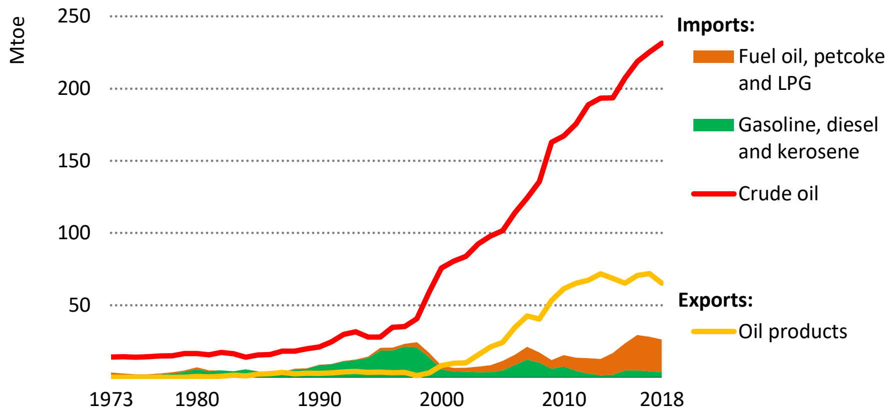
India's natural capital is as diverse as it is vast, but it still relies on imports for some key elements of the energy system. At present, its imports include oil products for transport and industrial applications, and natural gas.

However, limited raw materials do not necessarily lead to a reliance on imports for final product, a point that is exemplified by India's refining industry. With the exception of one refinery processing Assam crude, India's oil product demand was met by imports until the 1950s (Tang, 1994). India then chose to develop a national refining sector and to import crude oil rather than refined oil products, encouraging partnerships between Indian and foreign companies to establish coastal refineries (initially designed to process Iranian crude). In the 25 years to 1982, refining capacity in India grew from around 80 kb/d to more than 750 kb/d.

An initial consequence of this policy was the capture of more value in the supply chain by Indian companies (mostly PSUs). Following the opening of the Jamnagar refinery in 1999 by the private Indian company Reliance Industries, India then became an exporter of oil products and almost eliminated imports of gasoline, diesel and kerosene (Figure 4.27). By 2019, India's oil product exports generated around $3 billion dollars (UN, 2020). In recent years, Indian refineries have been expanding further down the value chain towards petrochemicals to capture additional value. India's ethylene production has almost doubled to 6.6 Mt since 2015 and is set to grow further by two-thirds through to 2030 in the STEPS.

Even without large crude oil resources, India has today developed a mature refining and downstream petroleum industry. In the STEPS, it overtakes Russia in the early 2030s to become the world's third-largest refining centre. The example of oil refining indicates how countries can move up the value chain where there is a strong strategic and economic rationale, especially where – as in this case – it is underpinned by a large and growing domestic market.

Figure 4.27 ▷ India's trade in crude oil and oil products, 1973-2018



Investments in refining have increased imports of crude oil, reduced imports of oil products and moved India up the oil value chain, leading to exports of oil products.

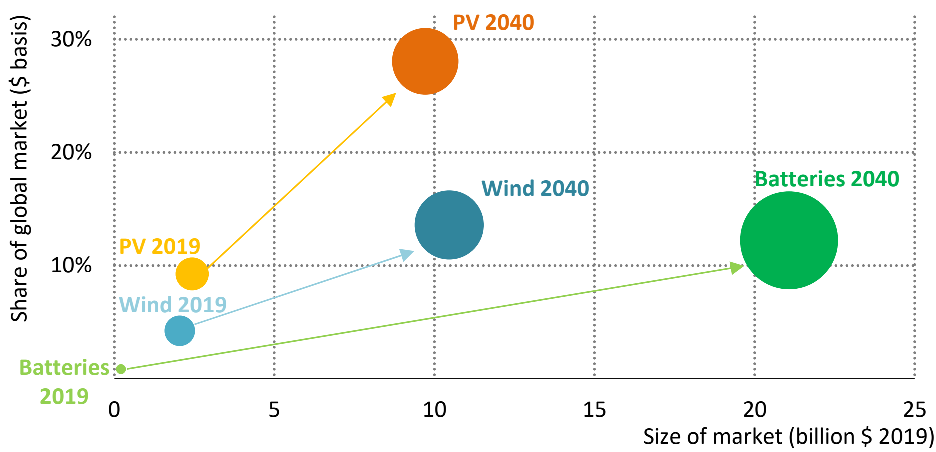
4.4.2 India in global clean energy transitions

India will soon become one of the world's largest markets for a range of clean energy technologies, making it a major target for technology developers looking for sales growth. In the STEPS, the Indian markets for solar PV modules, wind turbines, lithium-ion batteries and water electrolysers together grow to around $40 billion per year by 2040. Lithium-ion batteries alone account for nearly a third of this total, with annual demand in 2040 equal to the output of more than 20 times the capacity of today's largest gigafactory. For each product, India represents a sizeable share of the global market – around 10% for lithium-ion batteries, 15% for wind turbines, and 30% for solar PV (Figure 4.28). In the STEPS, 1 in every 7 dollars spent on these three types of equipment in 2040 is in India, compared with 1 in 20 today.

These trends are accelerated in the SDS, with the combined size of the markets in India almost doubling to around $80 billion in 2040 compared with the STEPS. However, as the faster deployment yields faster cost declines that stem from economies of scale, manufacturing improvements and other innovations, the growth in installed capacity is even larger. This is particularly notable in the case of solar PV: 12% more capacity is added from 2020 to 2040 in the SDS than in the STEPS, but the cost of this is just 6% higher. Faster deployment triggers a virtuous circle of investment, innovation, cost reductions and market growth that lowers the costs of energy transitions based on mass-produced technologies as they proceed.

Currently, India is a net importer of products such as solar PV and batteries, with around \$3 billion of trade per year. India's manufacturing facilities for solar PV cells and modules have so far struggled to operate with high-capacity factors and compete with imports, especially those from China. Local production could potentially meet a greater share of demand in line with the government's policy goal of expanding domestic manufacturing. Some action has already been taken in pursuit of this goal. For example, contracts for 8 GW of solar PV were signed in 2020 under manufacturing-linked tenders that require the winner to undertake both project development and the setting up of new PV manufacturing facilities. In addition, India's first plant producing lithium-ion battery anodes was commissioned in Karnataka in mid-2020, while NITI Aayog's Advanced Chemistry Cell and Battery Gigafactory plan proposes incentives for developers of battery cell factories.

Figure 4.28 ▷ India's market size and global share in clean energy technologies today and in the STEPS, 2040



India's markets for clean energy technologies grow rapidly in the STEPS, led by lithium-ion batteries. India's solar PV market accounts for around 25% of the global total in 2040.

Note: Includes PV modules, wind turbines and battery packs only. Batteries includes both stationary and vehicle markets.

Capturing value in these supply chains will be challenging. The most efficient manufacturers from around the world are likely to increase their focus on India as it takes a higher share of global markets. In addition, clean energy technology markets can be expected to remain highly dynamic and reliant on thin margins. PV cell and module production has been an extremely competitive business in recent years, for example, with many companies going bankrupt after failing to continually innovate or upgrade their assets.

Innovation offers a way to increase the added value of clean technology markets. With 15-30% of the global markets for some of these products, India could position itself as a hub for research expertise and a home for the associated intellectual property. Investments in research and development (R&D) and licensing of technologies could not only contribute to economic growth but also ensure that technologies are adapted to local contexts, taking account of climate, geography, grid requirements and the built environment.

The value of innovation increases dramatically for countries and companies that target net-zero GHG emissions, regardless of the time horizon. IEA analysis shows that around 35% of the cumulative CO_2 emissions reductions needed to shift to a sustainable path come from technologies currently at the prototype or demonstration phase (IEA, 2020e). In addition, many clean energy technologies that are already established in parts of the marketplace need further adaptations to keep reducing costs and expand into new end uses. As a result, there is a great deal of scope for enhanced innovation efforts in areas that are expected to grow rapidly, such as solar PV and battery systems; areas that tap into India's skills, such as digital know-how; and areas critical to tackling future emissions challenges that currently lack solutions (Spotlight). For each area there are opportunities in different parts of the value chain from raw materials processing to component design and installation. Hydrogen is a good example of a technology area where a wide variety of skills will be needed beyond manufacturing, including some that share characteristics with petrochemicals production.

S P O T L I G H T

India's net-zero challenge: addressing emissions, old and new

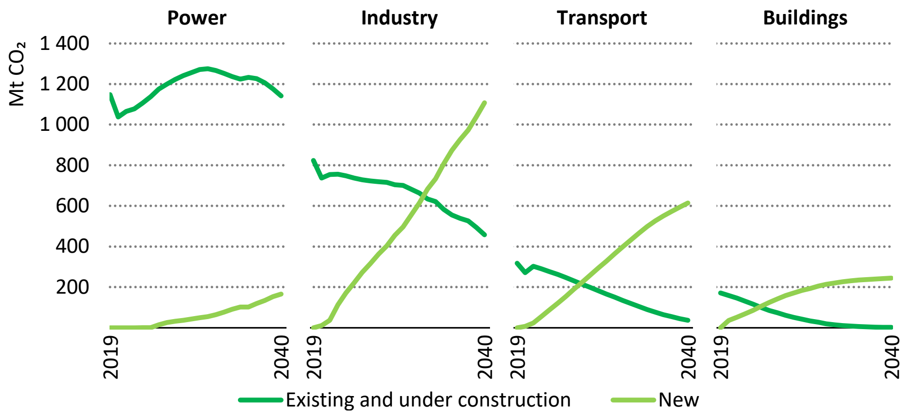
In the SDS, India is on course to reach net-zero emissions in the mid-2060s. In order to do so, India, like other emerging market and developing economies, faces the twin challenge of avoiding emissions from its existing infrastructure, while limiting as much as possible the carbon footprint of new capital stock. These twin challenges call for the deployment of a wide range of different technologies and policy approaches.

Two-thirds of India's total emissions over the period to 2040 in the STEPS come from power plants, factories, vehicles and buildings that exist today. By far the largest share of this comes from India's young and relatively inefficient coal-fired power fleet (Figure 4.29). Emissions will also be strongly influenced in this scenario by industrial facilities commissioned as recently as the 2010s.

If these existing plants and factories operate as planned, then the SDS is out of reach. This highlights the vital role for technologies that can help existing assets run more flexibly and efficiently, switch fuel inputs or capture their emissions. In the SDS, for example, the existing coal-fired fleet is either repurposed to provide system flexibility, co-fired with low-carbon fuels (mainly biomass), retrofitted with carbon capture and storage technology, or retired early.

In the case of industrial facilities, adapting cement plants to enable CO_2 capture is one example of technological efforts to reduce emissions from existing infrastructure, and replacing fossil fuels in steel production and refining with low-carbon hydrogen is another. In both cases, there is huge scope to develop new technologies and skills that are fit for Indian plants, and this has inspired a proposal to install one of the world's largest CO_2 capture systems at a cement plant in Tamil Nadu.

Figure 4.29 ▷ CO_2 emissions from existing and new infrastructure in India in the STEPS, 2019-2040



India faces the need to invest in a range of technologies capable of addressing both existing and new sources of CO_2 emissions.

Source: IEA (2020) and IEA (2020e).

However, much more so than in advanced economies, India's future emissions profile depends heavily on infrastructure that has yet to be built or bought – especially in industry and transport. Because of India's dynamic growth and the twin forces of urbanisation and industrialisation discussed in Chapter 2, already by the late 2030s India's emissions in the STEPS from new factories, vehicles and other equipment overtake those from sources existing today. In the SDS, India keeps these emissions from new sources to a minimum, avoiding higher-carbon infrastructure via early action to prioritise investment in efficient, low-emissions technologies across all parts of the energy sector, alongside a strong focus on sustainable urban design and transport. In doing so, India pioneers a new, low-carbon model of development, with major co-benefits for air quality, reduced energy import bills and increased clean energy jobs and industrial opportunities.

A redoubled effort to promote clean energy innovation in India can play an important role in reaching SDS goals. India is currently drafting a new Science, Technology and Innovation Policy, which will be its first since 2013. Among the stated aims are to double the number of researchers and the level of public and private expenditure on R&D every five years, with energy as a priority topic (DST, 2020). A Science, Technology and Innovation Development Bank is proposed to direct strategic long-term investments, which could help catalyse progress in clean energy technology areas that reflect India's circumstances and needs.

Building on the insights in this report, several clean energy technology areas can be identified as pivotal for reaching net-zero emissions, all of which present opportunities in the near term:

- **Lithium-ion batteries**. India becomes the world's largest market for batteries in the STEPS, IVC and SDS. Supply chains for lithium and cobalt are concentrated outside India, but battery recycling and reuse could be a major opportunity in India, which updated its battery waste management rules in 2020 in recognition of this issue (IEA, 2020b).
- **CCUS**. India's CO_2 storage potential has not yet been properly mapped. Given the important role likely to be played by CCUS in a variety of sectors in India, if CO_2 can be securely stored, there is a strong case for defining the potential and understanding how its geographic distribution might influence future investments in industry and power.
- **Hydrogen**. India has the potential to close the cost gap between hydrogen from electrolysis and natural gas more quickly than many other countries due to its relatively high gas prices and low-cost solar PV potential, but flexible electrolysis and cost-effective hydrogen storage will be essential to integrate hydrogen with variable renewables. Electrolysers share technical attributes with batteries and fuel cells, creating opportunities to co-locate research hubs and exploit synergies.
- **Material efficiency**. Action to minimise the material demands of an expanding stock of vehicles and buildings, including through lightweighting and recycling, has the potential to make a major contribution to India's energy future if it is integrated into planning and design.
- **Digital innovation**. India's information and communications technologies sector is a significant global player and has impressive strengths in digital technologies, which could do much to improve efficiency in energy systems (for example through shaping logistics to reduce diesel demand for freight transport) and to make energy systems smarter, helping to lower bills and integrate variable renewables.
- **Bioenergy**. India's agricultural sector contributes 17% of GDP and around 40% of overall employment. Its biomass resource is large and includes a considerable amount of agricultural waste. There is scope for India to build on its existing leadership in biotechnologies and the demonstration of advanced biofuel technologies, and potential for low-cost biomethane to meet two-thirds of gas demand in India by 2040.

The size of the potential market and the scope for innovation means that what happens in India on clean energy technology will affect the world. India is not currently a major global player in energy R&D. Public spending on energy R&D has increased since India joined the Mission Innovation initiative, rising to around $670 million in 2019, but this remains low as a share of GDP compared with other major economies. Private sector R&D spending is also relatively low, with government funding often favouring public institutions and enterprises. India's innovation and market potential mean that it has nonetheless become a destination for inward investment by multinational energy companies in R&D facilities.

A strategic approach to clean energy innovation in India, aligned with energy and industry objectives, would increase the chances of successful innovation. Where India sits in the value chain for key technologies will determine its trading partners and influence its trade patterns, which will in turn affect the location of its industrial investments. Many governments sought to boost their energy innovation systems in 2020 through the use of economic pandemic recovery plans that seek to improve future competitiveness. India has a range of options available in this context (IEA, 2020c). To take one example, the National Hydrogen Energy Mission proposed by the prime minister in November 2020 represents a near-term opportunity to take a strategic approach to an emerging international technology.

An important step for India will be to review best practice in prioritising technologies and stimulating public and private innovation in the types of technologies needed for energy transitions.[7] Doing this in the context of emerging markets with limited budgets and without a long legacy of energy technology innovation will fill a critical knowledge gap. International co-operation through multilateral initiatives and partnerships with overseas expertise that build local competences are likely to be helpful, while creating new linkages between industry and higher education could improve the exchange of ideas. Finance will also be important, and there is scope to explore how international finance institutions might accommodate pre-commercial energy technology development.

Smaller companies can be more agile than large incumbents when it comes to exploiting emerging market opportunities. However, the level of risk capital required for new energy technologies is often out of the reach of start-ups in the absence of government support. The Clean Energy International Incubation Centre, co-founded by the government as part of its work within Mission Innovation, is relevant in this context: it builds on the existing networks of incubators and investors in India, and also encourages researchers and start-ups to partner with international researchers and incumbent companies to help access costly infrastructure and early-stage customers.

If India were to become more successful at moving clean energy technologies from lab to market, the payback would be economic as well as environmental. In the IVC, for example, more batteries are installed and the industry sector invests in more CO_2 capture because the economy is more dynamic and the technologies are cheaper. By 2040, the IVC is closer to the SDS than STEPS for deployment of these technologies.

[7] This builds on five key recommendations of the IEA *Special Report on Clean Energy Innovation* (IEA, 2020f).

Tables for scenario projections

General note to the tables

This annex includes historical and projected data for the Stated Policies and Sustainable Development scenarios and India Vision Case for energy demand, gross electricity generation and electrical capacity, and CO_2 emissions from fossil fuel combustion for India.

Both in the text of this book and in the tables, rounding may lead to minor differences between totals and the sum of their individual components. Growth rates are calculated on a compound average annual basis and are marked "n.a." when the base year is zero or the value exceeds 200%. Nil values are marked "-".

Data sources

The World Energy Model (WEM) is a very data-intensive model covering the whole global energy system. Detailed references on databases and publications used in the modelling and analysis may be found in Annex E of the World Energy Outlook 2020.

The formal base year for the projections is 2018, as this is the last year for which a complete picture of energy demand and production is in place. However, we have used more recent data wherever available, and we include our 2019 estimates in this annex. Estimates for the year 2019 are based on updates of the IEA's *Global Energy Review* reports which are derived from a number of sources, including the latest monthly data submissions to the IEA's Energy Data Centre, other statistical releases from national administrations, and recent market data from the IEA *Market Report Series* that cover coal, oil, natural gas, renewables and power. Investment estimates include the year 2019, based on the IEA's *World Energy Investment 2020* report.

Historical data for gross electrical capacity are drawn from the S&P Global Market Intelligence World Electric Power Plants Database (March 2020 version) and the International Atomic Energy Agency PRIS database.

Definitional note

Total primary energy demand (TPED) is equivalent to power generation plus "other energy sector" excluding electricity and heat, plus total final consumption (TFC) excluding electricity and heat. TPED does not include ambient heat from heat pumps or electricity trade. Other renewables in TPED include geothermal, solar photovoltaics (PV), concentrating solar power (CSP), wind and marine (tide and wave) energy for electricity and heat generation. Sectors comprising TFC include industry, transport, buildings (residential, services and non-specified other) and other (agriculture and non-energy use). While not itemised separately, hydrogen is included in total final consumption and "other energy sector". Projected gross electrical capacity is the sum of existing capacity and additions, less retirements. While not itemised separately, other sources are included in total electricity generation, and battery storage in total power generation capacity.

Total CO_2 includes carbon dioxide emissions from "other energy sector" in addition to the power and final consumption sectors shown in the tables. Total and power sector CO_2 emissions also account for captured emissions from bioenergy with carbon capture, utilisation and storage (BECCS). CO_2 emissions do not include emissions from industrial waste and non-renewable municipal waste.

Abbreviations used: Mtoe = million tonnes of oil equivalent; CAAGR = compound average annual growth rate; Petrochem. feedstock = petrochemical feedstock.

Energy demand: India

	Stated Policies Scenario Energy demand (Mtoe)						Shares (%)			CAAGR (%)	
	2010	2019	2025	2030	2035	2040	2019	2030	2040	2019-30	2019-40
Total primary demand	**700**	**929**	**1 057**	**1 237**	**1 412**	**1 573**	**100**	**100**	**100**	**2.6**	**2.5**
Coal	279	413	441	498	522	541	44	40	34	1.7	1.3
Oil	162	242	288	335	381	411	26	27	26	3.0	2.5
Natural gas	54	55	86	113	143	173	6	9	11	6.8	5.6
Nuclear	7	10	17	28	44	58	1	2	4	9.6	8.5
Hydro	11	15	15	19	23	26	2	2	2	2.3	2.7
Bioenergy	185	182	183	188	197	204	20	15	13	0.3	0.5
Other renewables	2	11	26	54	102	160	1	4	10	15.6	13.6
Power sector	**237**	**355**	**395**	**475**	**548**	**621**	**100**	**100**	**100**	**2.7**	**2.7**
Coal	177	278	285	317	315	311	78	67	50	1.2	0.5
Oil	7	3	4	3	3	2	1	1	0	2.8	-0.2
Natural gas	25	15	19	22	27	28	4	5	5	3.4	3.1
Nuclear	7	10	17	28	44	58	3	6	9	9.6	8.5
Hydro	11	15	15	19	23	26	4	4	4	2.3	2.7
Bioenergy	8	24	31	34	38	42	7	7	7	3.3	2.8
Other renewables	2	10	24	51	98	154	3	11	25	16.2	14.0
Other energy sector	**69**	**89**	**101**	**120**	**141**	**162**	**100**	**100**	**100**	**2.8**	**2.9**
Electricity	22	32	36	44	53	64	36	36	40	2.7	3.3
Total final consumption	**478**	**621**	**723**	**853**	**992**	**1 123**	**100**	**100**	**100**	**2.9**	**2.9**
Coal	87	111	129	148	168	185	18	17	16	2.6	2.4
Oil	138	216	260	306	349	379	35	36	34	3.2	2.7
Natural gas	19	35	57	78	99	125	6	9	11	7.5	6.3
Electricity	62	103	127	168	216	270	17	20	24	4.5	4.7
Heat	-	-	-	-	-	-	-	-	-	n.a.	n.a.
Bioenergy	172	154	148	150	155	157	25	18	14	-0.2	0.1
Other renewables	0	1	2	3	5	6	0	0	1	9.3	8.1
Industry	**151**	**224**	**277**	**337**	**401**	**465**	**100**	**100**	**100**	**3.8**	**3.5**
Coal	75	99	119	139	159	178	44	41	38	3.2	2.9
Oil	17	31	34	37	39	40	14	11	9	1.6	1.3
Natural gas	2	21	37	53	71	92	9	16	20	8.8	7.3
Electricity	28	41	48	61	77	92	18	18	20	3.6	3.9
Heat	-	-	-	-	-	-	-	-	-	n.a.	n.a.
Bioenergy	29	33	40	47	54	60	15	14	13	3.4	2.9
Other renewables	0	0	0	1	2	2	0	0	0	23.6	16.7
Transport	**65**	**108**	**139**	**177**	**217**	**248**	**100**	**100**	**100**	**4.5**	**4.0**
Oil	62	102	127	157	187	206	94	89	83	4.0	3.4
Electricity	1	2	2	5	9	13	1	3	5	11.1	10.6
Bioenergy	0	1	3	7	12	17	1	4	7	15.4	12.5
Other fuels	1	4	6	8	9	11	3	5	4	7.8	5.5
Buildings	**209**	**218**	**218**	**234**	**257**	**283**	**100**	**100**	**100**	**0.7**	**1.3**
Coal	12	13	10	9	8	7	6	4	2	-3.1	-3.0
Oil	30	38	42	47	51	54	17	20	19	2.0	1.7
Natural gas	1	3	5	6	8	10	2	3	3	5.8	5.1
Electricity	22	42	54	74	99	130	19	31	46	5.2	5.5
Heat	-	-	-	-	-	-	-	-	-	n.a.	n.a.
Bioenergy	143	120	105	95	87	79	55	41	28	-2.1	-2.0
Traditional biomass	136	113	96	85	74	63	52	36	22	-2.6	-2.7
Other renewables	0	1	2	2	3	4	1	1	1	6.7	6.1
Other	**54**	**71**	**89**	**105**	**118**	**128**	**100**	**100**	**100**	**3.6**	**2.9**
Petrochem. Feedstock	24	22	33	41	48	55	31	39	43	5.8	4.5

Energy demand: India

	Sustainable Development Scenario				India Vision Case			
	Energy demand (Mtoe)		Shares (%)	CAAGR (%)	Energy demand (Mtoe)		Shares (%)	CAAGR (%)
	2030	2040	2040	2019-40	2030	2040	2040	2019-40
Total primary demand	**994**	**1 147**	**100**	**1.0**	**1 152**	**1 522**	**100**	**2.4**
Coal	318	209	18	-3.2	463	497	33	0.9
Oil	292	268	23	0.5	325	379	25	2.2
Natural gas	124	181	16	5.9	129	215	14	6.7
Nuclear	28	64	6	9.1	28	58	4	8.5
Hydro	22	31	3	3.5	19	26	2	2.7
Bioenergy	120	169	15	-0.4	116	158	10	-0.7
Other renewables	90	225	20	15.4	72	188	12	14.5
Power sector	**385**	**475**	**100**	**1.4**	**466**	**641**	**100**	**2.9**
Coal	162	42	9	-8.6	261	252	39	-0.5
Oil	3	2	0	-0.5	3	2	0	-0.2
Natural gas	42	52	11	6.2	53	82	13	8.5
Nuclear	28	64	14	9.1	28	58	9	8.5
Hydro	22	31	7	3.5	19	26	4	2.7
Bioenergy	43	72	15	5.4	34	42	7	2.8
Other renewables	84	212	45	15.7	67	177	28	14.7
Other energy sector	**109**	**138**	**100**	**2.1**	**128**	**176**	**100**	**3.3**
Electricity	39	56	40	2.6	45	70	40	3.7
Total final consumption	**703**	**843**	**100**	**1.5**	**782**	**1 071**	**100**	**2.6**
Coal	125	130	15	0.8	154	186	17	2.5
Oil	266	246	29	0.6	297	350	33	2.3
Natural gas	67	103	12	5.3	69	116	11	5.9
Electricity	164	254	30	4.4	179	296	28	5.1
Heat	0	0	0	n.a.	-	-	-	n.a.
Bioenergy	73	93	11	-2.4	77	112	10	-1.5
Other renewables	6	13	2	12.2	5	11	1	11.1
Industry	**290**	**361**	**100**	**2.3**	**328**	**450**	**100**	**3.4**
Coal	118	130	36	1.3	135	168	37	2.6
Oil	28	24	7	-1.1	34	35	8	0.6
Natural gas	43	72	20	6.1	51	92	20	7.3
Electricity	59	85	24	3.5	59	87	19	3.6
Heat	-	-	-	n.a.	-	-	-	n.a.
Bioenergy	39	43	12	1.3	47	62	14	3.1
Other renewables	3	7	2	22.9	3	7	1	22.9
Transport	**161**	**183**	**100**	**2.5**	**179**	**250**	**100**	**4.1**
Oil	129	115	63	0.6	151	192	77	3.1
Electricity	8	26	14	14.3	8	22	9	13.3
Bioenergy	15	26	14	14.8	12	27	11	14.9
Other fuels	10	15	8	7.2	8	10	4	5.0
Buildings	**155**	**190**	**100**	**-0.6**	**170**	**244**	**100**	**0.6**
Coal	7	1	1	-11.6	9	6	3	-3.3
Oil	50	42	22	0.5	54	55	23	1.8
Natural gas	5	6	3	2.8	8	13	5	6.5
Electricity	73	116	61	4.9	79	145	59	6.1
Heat	0	0	0	n.a.	-	-	-	n.a.
Bioenergy	17	19	10	-8.4	18	21	8	-8.0
Traditional biomass	-	-	-	n.a.	-	-	-	n.a.
Other renewables	4	6	3	8.6	3	4	2	6.6
Other	**96**	**110**	**100**	**2.1**	**104**	**126**	**100**	**2.8**
Petrochem. Feedstock	39	49	45	3.9	41	57	45	4.6

Electricity and CO_2 emissions: India

Stated Policies Scenario	Electricity generation (TWh)						Shares (%)			CAAGR (%)	
	2010	2019	2025	2030	2035	2040	2019	2030	2040	2019-30	2019-40
Total generation	**975**	**1 583**	**1 896**	**2 461**	**3 139**	**3 887**	**100**	**100**	**100**	**4.1**	**4.4**
Coal	658	1 135	1 206	1 343	1 344	1 334	72	55	34	1.5	0.8
Oil	18	5	7	7	6	6	0	0	0	4.0	0.6
Natural gas	113	71	94	108	143	157	4	4	4	3.9	3.8
Nuclear	26	40	66	109	168	222	3	4	6	9.6	8.5
Renewables	160	332	523	893	1 477	2 169	21	36	56	9.4	9.3
Hydro	125	175	177	226	268	307	11	9	8	2.3	2.7
Bioenergy	15	42	67	77	91	106	3	3	3	5.7	4.5
Wind	20	66	105	195	374	520	4	8	13	10.3	10.3
Geothermal	-	-	-	0	1	1	-	0	0	n.a.	n.a.
Solar PV	0	48	174	392	736	1 221	3	16	31	20.9	16.6
CSP	-	-	1	3	7	13	-	0	0	n.a.	n.a.
Marine	-	-	-	0	0	1	-	0	0	n.a.	n.a.

Stated Policies Scenario	Electrical capacity (GW)						Shares (%)			CAAGR (%)	
	2010	2019	2025	2030	2035	2040	2019	2030	2040	2019-30	2019-40
Total capacity	**197**	**414**	**573**	**792**	**1 132**	**1 552**	**100**	**100**	**100**	**6.1**	**6.5**
Coal	106	235	269	269	265	260	57	34	17	1.2	0.5
Oil	8	8	8	8	6	5	2	1	0	0.0	-1.6
Natural gas	22	28	30	30	39	46	7	4	3	0.5	2.3
Nuclear	5	7	9	16	25	31	2	2	2	8.2	7.6
Renewables	57	137	247	436	722	1 066	33	55	69	11.1	10.3
Hydro	40	49	60	76	89	101	12	10	6	4.0	3.4
Bioenergy	4	12	13	15	17	20	3	2	1	2.1	2.5
Wind	13	38	57	96	167	217	9	12	14	8.9	8.7
Geothermal	-	-	-	0	0	0	-	0	0	n.a.	n.a.
Solar PV	0	38	117	248	447	724	9	31	47	18.7	15.1
CSP	-	0	0	1	2	4	0	0	0	13.8	15.1
Marine	-	-	-	0	0	0	-	0	0	n.a.	n.a.

Stated Policies Scenario	CO_2 emissions (Mt)						Shares (%)			CAAGR (%)	
	2010	2019	2025	2030	2035	2040	2019	2030	2040	2019-30	2019-40
Total CO_2	**1 572**	**2 319**	**2 576**	**2 948**	**3 188**	**3 359**	**100**	**100**	**100**	**2.2**	**1.8**
Coal	1 089	1 622	1 732	1 951	2 041	2 108	70	66	63	1.7	1.3
Oil	408	612	720	842	956	1 030	26	29	31	2.9	2.5
Natural gas	75	84	125	156	191	220	4	5	7	5.7	4.7
Power sector	**785**	**1 147**	**1 189**	**1 321**	**1 326**	**1 308**	**100**	**100**	**100**	**1.3**	**0.6**
Coal	704	1 104	1 133	1 259	1 253	1 234	96	95	94	1.2	0.5
Oil	23	8	11	11	9	8	1	1	1	2.8	-0.2
Natural gas	58	35	45	51	64	66	3	4	5	3.4	3.1
Final consumption	**752**	**1 110**	**1 316**	**1 544**	**1 768**	**1 949**	**100**	**100**	**100**	**3.0**	**2.7**
Coal	383	514	595	686	782	868	46	44	45	2.7	2.5
Oil	358	564	669	787	899	972	51	51	50	3.1	2.6
Transport	190	309	386	475	568	627	28	31	32	4.0	3.4
Natural gas	12	32	52	70	87	109	3	5	6	7.4	6.0

Electricity and CO_2 emissions: India

	Sustainable Development Scenario				India Vision Case			
	Electricity generation (TWh)		Shares (%)	CAAGR (%)	Electricity generation (TWh)		Shares (%)	CAAGR (%)
	2030	2040	2040	2019-40	2030	2040	2040	2019-40
Total generation	**2 365**	**3 601**	**100**	**4.0**	**2 603**	**4 254**	**100**	**4.8**
Coal	708	181	5	-8.4	1 104	1 073	25	-0.3
Oil	7	5	0	0.1	7	6	0	0.7
Natural gas	240	337	9	7.7	309	509	12	9.8
Nuclear	107	247	7	9.1	109	222	5	8.5
Renewables	1 302	2 832	79	10.7	1 074	2 445	57	10.0
Hydro	258	361	10	3.5	226	307	7	2.7
Bioenergy	105	210	6	7.9	77	106	2	4.5
Wind	343	782	22	12.5	251	695	16	11.8
Geothermal	2	5	0	n.a.	0	1	0	n.a.
Solar PV	584	1 368	38	17.2	517	1 322	31	17.0
CSP	11	104	3	n.a.	3	13	0	n.a.
Marine	0	1	0	n.a.	0	1	0	n.a.

	Sustainable Development Scenario				India Vision Case			
	Electrical capacity (GW)		Shares (%)	CAAGR (%)	Electrical capacity (GW)		Shares (%)	CAAGR (%)
	2030	2040	2040	2019-40	2030	2040	2040	2019-40
Total capacity	**997**	**1 835**	**100**	**7.3**	**931**	**1 764**	**100**	**7.1**
Coal	221	144	8	-2.3	252	231	13	-0.1
Oil	7	5	0	-1.9	8	5	0	-1.6
Natural gas	72	134	7	7.6	64	95	5	5.9
Nuclear	17	36	2	8.2	16	31	2	7.6
Renewables	641	1 334	73	11.5	542	1 206	68	10.9
Hydro	86	117	6	4.2	76	101	6	3.5
Bioenergy	20	39	2	5.8	15	20	1	2.5
Wind	163	334	18	11.0	121	289	16	10.2
Geothermal	0	1	0	n.a.	0	0	0	n.a.
Solar PV	367	806	44	15.7	330	792	45	15.6
CSP	4	36	2	27.1	1	4	0	15.1
Marine	0	0	0	n.a.	0	0	0	n.a.

	Sustainable Development Scenario				India Vision Case			
	CO_2 emissions (Mt)		Shares (%)	CAAGR (%)	CO_2 emissions (Mt)		Shares (%)	CAAGR (%)
	2030	2040	2040	2019-40	2030	2040	2040	2019-40
Total CO_2	**2 126**	**1 460**	**100**	**-2.2**	**2 733**	**2 960**	**100**	**1.2**
Coal	1 226	637	44	-4.4	1 698	1 710	58	0.3
Oil	706	594	41	-0.1	803	898	30	1.8
Natural gas	194	253	17	5.4	233	356	12	7.1
Power sector	**754**	**214**	**100**	**-7.7**	**1 172**	**1 202**	**100**	**0.2**
Coal	645	114	53	-10.3	1 036	1 001	83	-0.5
Oil	10	7	3	-0.5	11	8	1	-0.2
Natural gas	98	113	53	5.8	125	193	16	8.5
Final consumption	**1 298**	**1 173**	**100**	**0.3**	**1 481**	**1 670**	**100**	**2.0**
Coal	576	519	44	0.0	657	703	42	1.5
Oil	660	560	48	-0.0	751	853	51	2.0
Transport	391	350	30	0.6	459	582	35	3.1
Natural gas	63	94	8	5.2	73	114	7	6.2

Definitions

This annex provides general information on terminology used throughout the *WEO-2020* including: units and general conversion factors; definitions of fuels, processes and sectors; regional and country groupings; and abbreviations and acronyms.

Units

Area	m^2	square metre
Coal	Mtce	million tonnes of coal equivalent (equals 0.7 Mtoe)
Distance	km	kilometre
Emissions	g CO_2/kWh	grammes of carbon dioxide per kilowatt-hour
Energy	Mtoe	million tonnes of oil equivalent
	MBtu	million British thermal units
	kWh	kilowatt-hour
	MWh	megawatt-hour
	TWh	terawatt-hour
Gas	bcm	billion cubic metres
	tcm	trillion cubic metres
Mass	kg	kilogramme (1 000 kg = 1 tonne)
	Mt	million tonnes (1 tonne x 10^6)
	Gt	gigatonnes (1 tonne x 10^9)
Monetary	$ million	1 US dollar x 10^6
	$ billion	1 US dollar x 10^9
	$ trillion	1 US dollar x 10^{12}
Oil	kb/d	thousand barrels per day
	mb/d	million barrels per day
Power	GW	gigawatt (1 watt x 10^9)

General conversion factors for energy

Convert to:	TJ	Gcal	Mtoe	MBtu	GWh
From:	multiply by:				
TJ	1	238.8	2.388×10^{-5}	947.8	0.2778
Gcal	4.1868×10^{-3}	1	10^{-7}	3.968	1.163×10^{-3}
Mtoe	4.1868×10^{4}	10^{7}	1	3.968×10^{7}	11 630
MBtu	1.0551×10^{-3}	0.252	2.52×10^{-8}	1	2.931×10^{-4}
GWh	3.6	860	8.6×10^{-5}	3 412	1

Note: There is no generally accepted definition of boe; typically the conversion factors used vary from 7.15 to 7.40 boe per toe.

Currency conversions

***Exchange rates** (2019 annual average)*	**1 US Dollar equals:**
British Pound	0.78
Chinese Yuan Renminbi	6.91
Euro	0.89
Indian Rupee	70.42
Indonesian Rupiah	14 147.67
Japanese Yen	109.01
Russian Ruble	64.74
South African Rand	14.45

Source: OECD National Accounts Statistics: purchasing power parities and exchange rates dataset, July 2020.

Definitions

Advanced biofuels: Sustainable fuels produced from non-food crop feedstocks, which are capable of delivering significant lifecycle greenhouse gas emissions savings compared with fossil fuel alternatives, and which do not directly compete with food and feed crops for agricultural land or cause adverse sustainability impacts. This definition differs from the one used for "advanced biofuels" in the US legislation, which is based on a minimum 50% lifecycle greenhouse gas reduction and which, therefore, includes sugar cane ethanol.

Agriculture: Includes all energy used on farms, in forestry and for fishing.

Aviation: This transport mode includes both domestic and international flights and their use of aviation fuels. Domestic aviation covers flights that depart and land in the same country; flights for military purposes are also included. International aviation includes flights that land in a country other than the departure location.

Back-up generation capacity: Households and businesses connected to the main power grid may also have some form of "back-up" power generation capacity that can, in the event of disruption, provide electricity. Back-up generators are typically fuelled with diesel or gasoline and capacity can be as little as a few kilowatts. Such capacity is distinct from mini-grid and off-grid systems that are not connected to the main power grid.

Biodiesel: Diesel-equivalent, processed fuel made from the transesterification (a chemical process that converts triglycerides in oils) of vegetable oils and animal fats.

Bioenergy: Energy content in solid, liquid and gaseous products derived from biomass feedstocks and biogas. It includes solid biomass, biofuels and biogases.

Biofuels: Liquid fuels derived from biomass or waste feedstocks and include ethanol and biodiesel. They can be classified as conventional and advanced biofuels according to the technologies used to produce them and their respective maturity. Unless otherwise stated, biofuels are expressed in energy-equivalent volumes of gasoline and diesel.

Biogas: A mixture of methane, CO_2 and small quantities of other gases produced by anaerobic digestion of organic matter in an oxygen-free environment.

Biogases: Includes both biogas and biomethane.

Biomethane: Biomethane is a near-pure source of methane produced either by "upgrading" biogas (a process that removes any CO_2 and other contaminants present in the biogas) or through the gasification of solid biomass followed by methanation. It is also known as renewable natural gas.

Buildings: The buildings sector includes energy used in residential, commercial and institutional buildings and non-specified other. Building energy use includes space heating and cooling, water heating, lighting, appliances and cooking equipment.

Bunkers: Includes both international marine bunkers and international aviation bunkers.

Capacity credit: Proportion of the capacity that can be reliably expected to generate electricity during times of peak demand in the grid to which it is connected.

Clean cooking facilities: Cooking facilities that are considered safer, more efficient and more environmentally sustainable than the traditional facilities that make use of solid biomass (such as a three-stone fire). This refers primarily to improved solid biomass cookstoves, biogas systems, liquefied petroleum gas stoves, ethanol and solar stoves.

Coal: Includes both primary coal (including lignite, coking and steam coal) and derived fuels (including patent fuel, brown-coal briquettes, coke-oven coke, gas coke, gas-works gas, coke-oven gas, blast furnace gas and oxygen steel furnace gas). Peat is also included.

Coalbed methane (CBM)**:** Category of unconventional natural gas, which refers to methane found in coal seams.

Coal-to-gas (CTG)**:** Process in which mined coal is first turned into syngas (a mixture of hydrogen and carbon monoxide) and then into "synthetic" methane.

Coal-to-liquids (CTL)**:** Transformation of coal into liquid hydrocarbons. It can be achieved through either coal gasification into syngas (a mixture of hydrogen and carbon monoxide), combined using the Fischer-Tropsch or methanol-to-gasoline synthesis process to produce liquid fuels, or through the less developed direct-coal liquefaction technologies in which coal is directly reacted with hydrogen.

Coking coal: Type of coal that can be used for steel making (as a chemical reductant and source heat), where it produces coke capable of supporting a blast furnace charge. Coal of this quality is also commonly known as metallurgical coal.

Conventional biofuels: Fuels produced from food crop feedstocks. These biofuels are commonly referred to as first generation and include sugar cane ethanol, starch-based ethanol, fatty acid methyl esther (FAME) and straight vegetable oil (SVO).

Decomposition analysis: Statistical approach that decomposes an aggregate indicator to quantify the relative contribution of a set of pre-defined factors leading to a change in the aggregate indicator. The *World Energy Outlook* uses an additive index decomposition of the type Logarithmic Mean Divisia Index (LMDI).

Demand-side integration (DSI): Consists of two types of measures: actions that influence load shape such as energy efficiency and electrification; and actions that manage load such as demand-side response.

Demand-side response (DSR): Describes actions which can influence the load profile such as shifting the load curve in time without affecting the total electricity demand, or load shedding such as interrupting demand for short duration or adjusting the intensity of demand for a certain amount of time.

Dispatchable: Dispatchable generation refers to technologies whose power output can be readily controlled - increased to maximum rated capacity or decreased to zero - in order to match supply with demand.

Electricity demand: Defined as total gross electricity generation less own use generation, plus net trade (imports less exports), less transmissions and distribution losses.

Electricity generation: Defined as the total amount of electricity generated by power only or combined heat and power plants including generation required for own use. This is also referred to as gross generation.

Energy sector CO_2 emissions: Carbon dioxide emissions from fuel combustion (excluding non-renewable waste). Note that this does not include fugitive emissions from fuels, CO_2 from transport, storage emissions or industrial process emissions.

Energy sector GHG emissions: CO_2 emissions from fuel combustion plus fugitive and vented methane, and nitrous dioxide (N_2O) emissions from the energy and industry sectors.

Energy services: See useful energy.

Ethanol: Refers to bio-ethanol only. Ethanol is produced from fermenting any biomass high in carbohydrates. Today, ethanol is made from starches and sugars, but second-generation technologies will allow it to be made from cellulose and hemicellulose, the fibrous material that makes up the bulk of most plant matter.

Gas-to-liquids (GTL): Process featuring reaction of methane with oxygen or steam to produce syngas (a mixture of hydrogen and carbon monoxide) followed by synthesis of liquid products (such as diesel and naphtha) from the syngas using Fischer-Tropsch catalytic synthesis. The process is similar to those used in coal-to-liquids.

Heat (end-use): Can be obtained from the combustion of fossil or renewable fuels, direct geothermal or solar heat systems, exothermic chemical processes and electricity (through resistance heating or heat pumps which can extract it from ambient air and liquids). This category refers to the wide range of end-uses, including space and water heating, and cooking in buildings, desalination and process applications in industry. It does not include cooling applications.

Heat (supply): Obtained from the combustion of fuels, nuclear reactors, geothermal resources and the capture of sunlight. It may be used for heating or cooling, or converted into mechanical energy for transport or electricity generation. Commercial heat sold is reported under total final consumption with the fuel inputs allocated under power generation.

Hydrogen: Hydrogen is an energy carrier that can be burnt or used in fuel cells to generate electricity and heat. Main production pathways are natural gas reforming and electrolysis of water. It is called low-carbon if hydrogen is produced via CCUS-equipped reformers or electrolysers running on low-carbon electricity.

Hydropower: The energy content of the electricity produced in hydropower plants, assuming 100% efficiency. It excludes output from pumped storage and marine (tide and wave) plants.

Industry: The sector includes fuel used within the manufacturing and construction industries. Key industry branches include iron and steel, chemical and petrochemical, cement, and pulp and paper. Use by industries for the transformation of energy into another form or for the production of fuels is excluded and reported separately under other energy sector. Consumption of fuels for the transport of goods is reported as part of the transport sector, while consumption by off-road vehicles is reported under industry.

International aviation bunkers: Includes the deliveries of aviation fuels to aircraft for international aviation. Fuels used by airlines for their road vehicles are excluded. The domestic/international split is determined on the basis of departure and landing locations and not by the nationality of the airline. For many countries this incorrectly excludes fuels used by domestically owned carriers for their international departures.

International marine bunkers: Covers those quantities delivered to ships of all flags that are engaged in international navigation. The international navigation may take place at sea, on inland lakes and waterways, and in coastal waters. Consumption by ships engaged in domestic navigation is excluded. The domestic/international split is determined on the basis of port of departure and port of arrival, and not by the flag or nationality of the ship.

Consumption by fishing vessels and by military forces is also excluded and included in residential, services and agriculture.

Investment: All investment data and projections reflect spending across the lifecycle of a project, i.e. the capital spent is assigned to the year when it is incurred. Investments for oil, gas and coal include production, transformation and transportation; those for the power sector include refurbishments, uprates, new builds and replacements for all fuels and technologies for on-grid, mini-grid and off-grid generation, as well as investment in transmission and distribution, and battery storage. Investment data are presented in real terms in year-2019 US dollars unless otherwise stated.

Lignite: Type of coal that is used in the power sector mostly in regions near lignite mines due to its low energy content and typically high moisture levels, which generally makes long-distance transport uneconomic. Data on lignite in the *World Energy Outlook* includes peat, a solid formed from the partial decomposition of dead vegetation under conditions of high humidity and limited air access.

Liquids: Refers to the combined use of oil and biofuels (expressed in energy-equivalent volumes of gasoline and diesel).

Lower heating value: Heat liberated by the complete combustion of a unit of fuel when the water produced is assumed to remain as a vapour and the heat is not recovered.

Middle distillates: Include jet fuel, diesel and heating oil.

Mini-grids: Small grid systems linking a number of households or other consumers.

Modern energy access: Includes household access to a minimum level of electricity; household access to safer and more sustainable cooking and heating fuels, and stoves; access that enables productive economic activity; and access for public services.

Modern renewables: Includes all uses of renewable energy with the exception of traditional use of solid biomass.

Modern use of solid biomass: Refers to the use of solid biomass in improved cookstoves and modern technologies using processed biomass such as pellets.

Natural gas: Comprises gases occurring in deposits, whether liquefied or gaseous, consisting mainly of methane. It includes both "non-associated" gas originating from fields producing hydrocarbons only in gaseous form, and "associated" gas produced in association with crude oil as well as methane recovered from coal mines (colliery gas). Natural gas liquids (NGLs), manufactured gas (produced from municipal or industrial waste, or sewage) and quantities vented or flared are not included. Gas data in cubic metres are expressed on a "gross" calorific value basis and are measured at 15 °C and at 760 mm Hg ("Standard Conditions"). Gas data expressed in tonnes of oil equivalent, mainly for comparison reasons with other fuels, are on a "net" calorific basis. The difference between the net and the gross calorific value is the latent heat of vaporisation of the water vapour produced during combustion of the fuel (for gas the net calorific value is 10% lower than the gross calorific value).

Natural gas liquids (NGLs)**:** Liquid or liquefied hydrocarbons produced in the manufacture, purification and stabilisation of natural gas. These are those portions of natural gas which are recovered as liquids in separators, field facilities or gas processing plants. NGLs include but are not limited to ethane (when it is removed from the natural gas stream), propane, butane, pentane, natural gasoline and condensates.

Non-energy use: Fuels used for chemical feedstocks and non-energy products. Examples of non-energy products include lubricants, paraffin waxes, asphalt, bitumen, coal tars and oils as timber preservatives.

Nuclear: Refers to the primary energy equivalent of the electricity produced by a nuclear plant, assuming an average conversion efficiency of 33%.

Off-grid systems: Stand-alone systems for individual households or groups of consumers.

Offshore wind: Refers to electricity produced by wind turbines that are installed in open water, usually in the ocean.

Oil: Oil production includes both conventional and unconventional oil. Petroleum products include refinery gas, ethane, liquid petroleum gas, aviation gasoline, motor gasoline, jet fuels, kerosene, gas/diesel oil, heavy fuel oil, naphtha, white spirit, lubricants, bitumen, paraffin, waxes and petroleum coke.

Other energy sector: Covers the use of energy by transformation industries and the energy losses in converting primary energy into a form that can be used in the final consuming sectors. It includes losses by gas works, petroleum refineries, blast furnaces, coke ovens, coal and gas transformation and liquefaction. It also includes energy own use in coal mines, in oil and gas extraction and in electricity and heat production. Transfers and statistical differences are also included in this category.

Peri-urban: Peri-urban areas are zones of transition from rural to urban which often form the urban-rural interface and may evolve into being fully urban.

Power generation: Refers to fuel use in electricity plants, heat plants and combined heat and power (CHP) plants. Both main activity producer plants and small plants that produce fuel for their own use (auto-producers) are included.

Productive uses: Energy used towards an economic purpose: agriculture, industry, services and non-energy use. Some energy demand from the transport sector (e.g. freight) could also be considered as productive, but is treated separately.

Renewables: Includes bioenergy, geothermal, hydropower, solar photovoltaic (PV), concentrating solar power (CSP), wind and marine (tide and wave) energy for electricity and heat generation.

Residential: Energy used by households including space heating and cooling, water heating, lighting, appliances, electronic devices and cooking equipment.

Self-sufficiency: Corresponds to indigenous production divided by total primary energy demand.

Services: Energy used in commercial (e.g. hotels, offices, catering, shops) and institutional buildings (e.g. schools, hospitals, offices). Services energy use includes space heating and cooling, water heating, lighting, equipment, appliances and cooking equipment.

Shale gas: Natural gas contained within a commonly occurring rock classified as shale. Shale formations are characterised by low permeability, with more limited ability of gas to flow through the rock than is the case with a conventional reservoir. Shale gas is generally produced using hydraulic fracturing.

Shipping/navigation: This transport sub-sector includes both domestic and international navigation and their use of marine fuels. Domestic navigation covers the transport of goods or persons on inland waterways and for national sea voyages (starts and ends in the same country without any intermediate foreign port).International navigation includes quantities of fuels delivered to merchant ships (including passenger ships) of any nationality for consumption during international voyages transporting goods or passengers..

Solid biomass: Includes charcoal, fuelwood, dung, agricultural residues, wood waste and other solid wastes.

Steam coal: Type of coal that is mainly used for heat production or steam-raising in power plants and, to a lesser extent, in industry. Typically, steam coal is not of sufficient quality for steel making. Coal of this quality is also commonly known as thermal coal.

Tight oil: Oil produced from shales or other very low permeability formations, using hydraulic fracturing. This is also sometimes referred to as light tight oil. Tight oil includes tight crude oil and condensate production except for the United States, which includes tight crude oil only (US tight condensate volumes are included in natural gas liquids).

Total final consumption (TFC)**:** Is the sum of consumption by the various end-use sectors. TFC is broken down into energy demand in the following sectors: industry (including manufacturing and mining), transport, buildings (including residential and services) and other (including agriculture and non-energy use). It excludes international marine and aviation bunkers, except at world level where it is included in the transport sector.

Total final energy consumption (TFEC)**:** Is a variable defined primarily for tracking progress towards target 7.2 of the Sustainable Development Goals. It incorporates total final consumption (TFC) by end-use sectors but excludes non-energy use. It excludes international marine and aviation bunkers, except at world level. Typically this is used in the context of calculating the renewable energy share in total final energy consumption (Indicator 7.2.1 of the Sustainable Development Goals), where TFEC is the denominator.

Total primary energy demand (TPED)**:** Represents domestic demand only and is broken down into power generation, other energy sector and total final consumption.

Traditional use of solid biomass: Refers to the use of solid biomass with basic technologies, such as a three-stone fire, often with no or poorly operating chimneys.

Transport: Fuels and electricity used in the transport of goods or persons within the national territory irrespective of the economic sector within which the activity occurs. This includes fuel and electricity delivered to vehicles using public roads or for use in rail vehicles; fuel delivered to vessels for domestic navigation; fuel delivered to aircraft for domestic aviation; and energy consumed in the delivery of fuels through pipelines. Fuel delivered to international marine and aviation bunkers is presented only at the world level and is excluded from the transport sector at a domestic level.

Useful energy: Refers to the energy that is available to end-users to satisfy their needs. This is also referred to as energy services demand. As result of transformation losses at the point of use, the amount of useful energy is lower than the corresponding final energy demand for most technologies. Equipment using electricity often has higher conversion efficiency than equipment using other fuels, meaning that for a unit of energy consumed electricity can provide more energy services.

Variable renewable energy (VRE): Refers to technologies whose maximum output at any time depends on the availability of fluctuating renewable energy resources. VRE includes a broad array of technologies such as wind power, solar PV, run-of-river hydro, concentrating solar power (where no thermal storage is included) and marine (tidal and wave).

Regional and country groupings

Advanced economies: OECD regional grouping and Bulgaria, Croatia, Cyprus[1,2], Malta and Romania.

Africa: North Africa and sub-Saharan Africa regional groupings.

Asia Pacific: Southeast Asia regional grouping and Australia, Bangladesh, China, India, Japan, Korea, Democratic People's Republic of Korea, Mongolia, Nepal, New Zealand, Pakistan, Sri Lanka, Chinese Taipei, and other Asia Pacific countries and territories.[3]

Caspian: Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan.

Central and South America: Argentina, Plurinational State of Bolivia (Bolivia), Brazil, Chile, Colombia, Costa Rica, Cuba, Curaçao, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Nicaragua, Panama, Paraguay, Peru, Suriname, Trinidad and Tobago, Uruguay, Bolivarian Republic of Venezuela (Venezuela), and other Central and South American countries and territories.[4]

China: Includes the (People's Republic of) China and Hong Kong, China.

B

Developing Asia: Asia Pacific regional grouping excluding Australia, Japan, Korea and New Zealand.

Emerging market and developing economies: All other countries not included in the advanced economies regional grouping.

Eurasia: Caspian regional grouping and the Russian Federation (Russia).

Europe: European Union regional grouping and Albania, Belarus, Bosnia and Herzegovina, North Macedonia, Gibraltar, Iceland, Israel[5], Kosovo, Montenegro, Norway, Serbia, Switzerland, Republic of Moldova, Turkey, Ukraine and United Kingdom.

European Union: Austria, Belgium, Bulgaria, Croatia, Cyprus[1,2], Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain and Sweden.

IEA (International Energy Agency)**:** OECD regional grouping excluding Chile, Iceland, Israel, Latvia, Lithuania and Slovenia.

Latin America: Central and South America regional grouping and Mexico.

Middle East: Bahrain, Islamic Republic of Iran (Iran), Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic (Syria), United Arab Emirates and Yemen.

Non-OECD: All other countries not included in the OECD regional grouping.

Non-OPEC: All other countries not included in the OPEC regional grouping.

North Africa: Algeria, Egypt, Libya, Morocco and Tunisia.

North America: Canada, Mexico and United States.

OECD (Organisation for Economic Co-operation and Development)**:** Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States. Colombia became a member of the OECD in April 2020, and its membership is not yet reflected in *WEO* projections for the OECD.

OPEC (Organisation of the Petroleum Exporting Countries)**:** Algeria, Angola, Republic of the Congo (Congo), Equatorial Guinea, Gabon, the Islamic Republic of Iran (Iran), Iraq, Kuwait, Libya, Nigeria, Saudi Arabia, United Arab Emirates and Bolivarian Republic of Venezuela (Venezuela), based on membership status as of October 2020.

Southeast Asia: Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic (Lao PDR), Malaysia, Myanmar, Philippines, Singapore, Thailand and Viet Nam. These countries are all members of the Association of Southeast Asian Nations (ASEAN).

Sub-Saharan Africa: Angola, Benin, Botswana, Cameroon, Republic of the Congo (Congo), Côte d'Ivoire, Democratic Republic of the Congo, Eritrea, Ethiopia, Gabon, Ghana, Kenya, Mauritius, Mozambique, Namibia, Niger, Nigeria, Senegal, South Africa, South Sudan, Sudan, United Republic of Tanzania (Tanzania), Togo, Zambia, Zimbabwe and other African countries and territories.[6]

Country notes

[1] Note by Turkey: The information in this document with reference to "Cyprus" relates to the southern part of the island. There is no single authority representing both Turkish and Greek Cypriot people on the island. Turkey recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Turkey shall preserve its position concerning the "Cyprus issue".

[2] Note by all the European Union Member States of the OECD and the European Union: The Republic of Cyprus is recognised by all members of the United Nations with the exception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

[3] Individual data are not available and are estimated in aggregate for: Afghanistan, Bhutan, Cook Islands, Fiji, French Polynesia, Kiribati, Macau (China), Maldives, New Caledonia, Palau, Papua New Guinea, Samoa, Solomon Islands, Timor-Leste and Tonga and Vanuatu.

[4] Individual data are not available and are estimated in aggregate for: Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Bermuda, Bonaire, British Virgin Islands, Cayman Islands, Dominica, Falkland Islands (Malvinas), French Guiana, Grenada, Guadeloupe, Guyana, Martinique, Montserrat, Saba, Saint Eustatius, Saint Kitts and Nevis, Saint Lucia, Saint Pierre and Miquelon, Saint Vincent and Grenadines, Saint Maarten, Turks and Caicos Islands.

[5] The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD and/or the IEA is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

[6] Individual data are not available and are estimated in aggregate for: Burkina Faso, Burundi, Cabo Verde, Central African Republic, Chad, Comoros, Djibouti, Kingdom of Eswatini, Gambia, Guinea, Guinea-Bissau, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Réunion, Rwanda, Sao Tome and Principe, Seychelles, Sierra Leone, Somalia and Uganda.

Abbreviations and Acronyms

AC	air-conditioning (unit); air conditioner
AT&C	aggregate technical and commercial
CCUS	carbon capture, utilisation and storage
CGD	city gas distribution
CIL	Coal India Limited
CNG	compressed natural gas
CO_2	carbon dioxide
CPCB	Central Pollution Control Board
DFC	Dedicated Freight Corridor
discom	electricity distribution company
DRI	direct reduced iron
DRS	Delayed Recovery Scenario
DSR	demand-side response
EESL	Energy Efficiency Services Limited
EIRR	equity internal rate of return
EPAR	Environmental Protection Amendment Rules (Act)
EPC	energy performance contract
ESCO	energy service company
ESG	environmental, social and governance
EU	European Union
EV	electric vehicle
FAME	Faster Adoption and Manufacturing of Electric Vehicles
G20	Group of 20
GDP	gross domestic product
GHG	greenhouse gas
GST	Goods and Services Tax
H_2-DRI	hydrogen-based direct reduced iron
HELP	Hydrocarbon Exploration and Licensing Policy
HPO	hydro purchase obligation
ICAP	India Cooling Action Plan
ICE	internal combustion engine
IEA	International Energy Agency
IGX	Indian Gas Exchange
IMF	International Monetary Fund
INVIT	infrastructure investment trust
IPO	initial public offering
IVC	Indian Vision Case
LCOE	levelised cost of electricity
LED	light-emitting diode

LNG	liquefied natural gas
LPG	liquefied petroleum gas
MBS	mortgage-backed securities
MSME	micro, small and medium-sized enterprises
NAAQS	National Ambient Air Quality Standards
NCAP	National Clean Air Programme
NCEEF	National Clean Energy and Environment Fund
NDC	nationally determined contribution
NO_X	nitrogen oxides
NUTP	National Urban Transport Policy
OECD	Organisation for Economic Co-operation and Development
ONGC	Oil and Natural Gas Corporation Limited
PAHAL	Pratyaksh Hanstantrit Labh
PAT	Perform, Achieve and Trade
PLI	production-linked incentive
PMAY	Pradhan Mantri Awaas Yojana
PMUY	Pradhan Mantri Ujjwala Yojana
PNG	pipeline natural gas
PPA	power purchase agreement
PPP	purchasing power parity
PSU	public sector undertaking
PV	photovoltaics
R&D	research and development
RBI	Reserve Bank of India
REIT	real estate investment trust
RTM	real-time power market
SATAT	Sustainable Alternative Towards Affordable Transportation
SDG	Sustainable Development Goal (United Nations)
SDS	Sustainable Development Scenario
SECI	Solar Energy Corporation of India
SO_2	sulphur dioxide
SPR	strategic petroleum reserve
STEPS	Stated Policies Scenario
TFC	total final consumption
TV	television
UDAY	Ujwal DISCOM Assurance Yojana
UJALA	Unnat Jyoti by Affordable LEDs for All
UN	United Nations
VALCOE	value-adjusted levelised cost of electricity
VRE	variable renewable energy
WEO	*World Energy Outlook*

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India Energy Outlook 2021

World Energy Outlook Special Report

The India Energy Outlook 2021 is a new special report from the International Energy Agency's World Energy Outlook series. The report explores the opportunities and challenges ahead for India as it **seeks to ensure reliable, affordable and sustainable energy to a growing population**. The report examines pathways out of the crisis that emerged from the Covid-19 pandemic, as well as longer-term trends, exploring how India's energy sector might evolve to 2040 under a range of scenarios. The report is presented as a series of 'deep dives' exploring cross-cutting issues, including:

- The effects of economic growth, urbanisation and industrialisation on India's fuel and sector-level demand trends.
- The evolution of mobility, including electrification, in the context of growing urbanisation.
- The prospects for expanding energy access, especially in rural areas.
- Flexibility requirements in the power sector under ambitious renewable capacity targets and a significant rise in electricity demand – especially from air conditioners.
- Challenges and opportunities for clean energy finance, including investments in solar energy and batteries
- The supply and infrastructure required for an expanded role for natural gas, along with a sector-level assessment of its potential.
- Impacts of India's energy policy choices on energy access, air pollution and carbon emissions.
- India's growing importance in global energy issues, and the implications of its development trajectory on international energy supply, trade and investment.

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