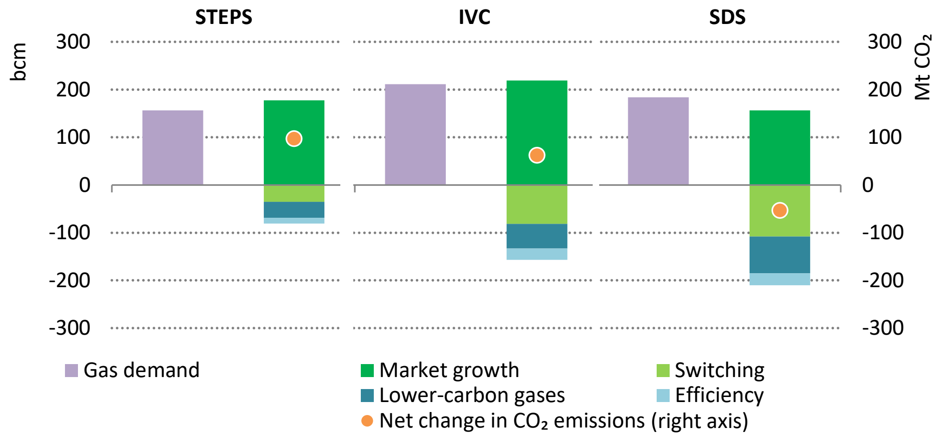
further than in the STEPS because of the substitution of gas for coal and oil (Figure 3.25). In the IVC, there is a net increase in emissions of around 60 Mt CO_2 by 2040 over 2019 levels from the additional use of gas, compared with a net increase of around 100 Mt CO_2 in the STEPS. So net gas-related 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.

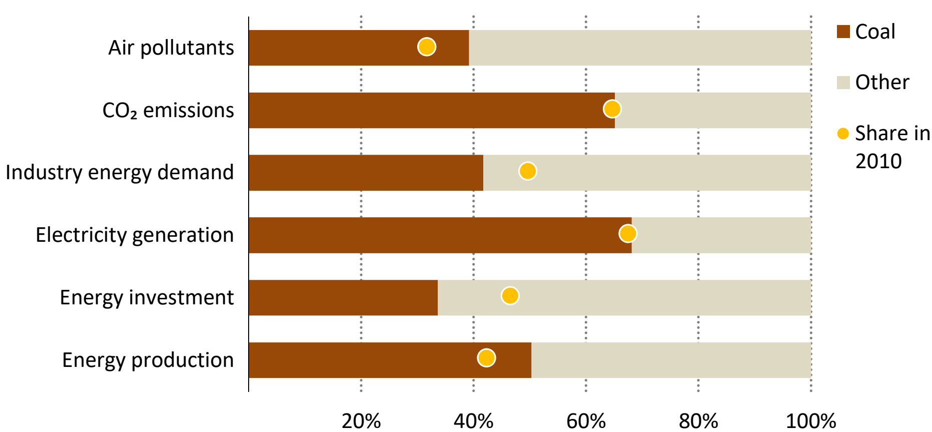
3.4 Transforming traditional fuels: Coal and bioenergy

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

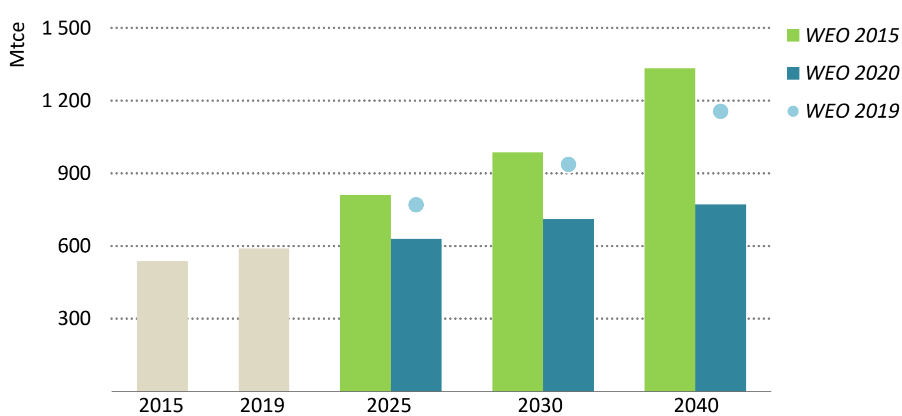
The effects of the pandemic, in the form of reduced macroeconomic growth and a more subdued outlook for electricity demand, are one factor in a major revision of coal consumption projections in the STEPS. A relatively slow recovery from the pandemic sets the tone for the following years, and demand ends 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*



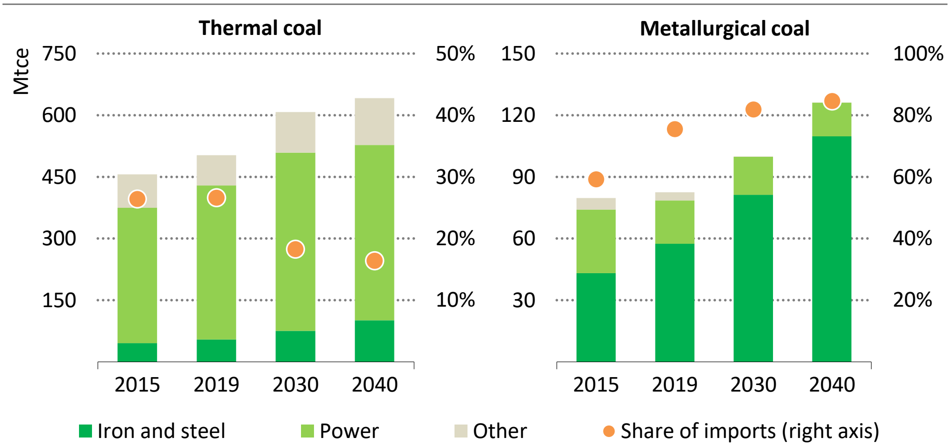
The prospects for coal have worsened markedly since WEO 2015, due to Covid-19 as well as efforts to improve air quality, reduce emissions and diversify the energy mix.

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).

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.

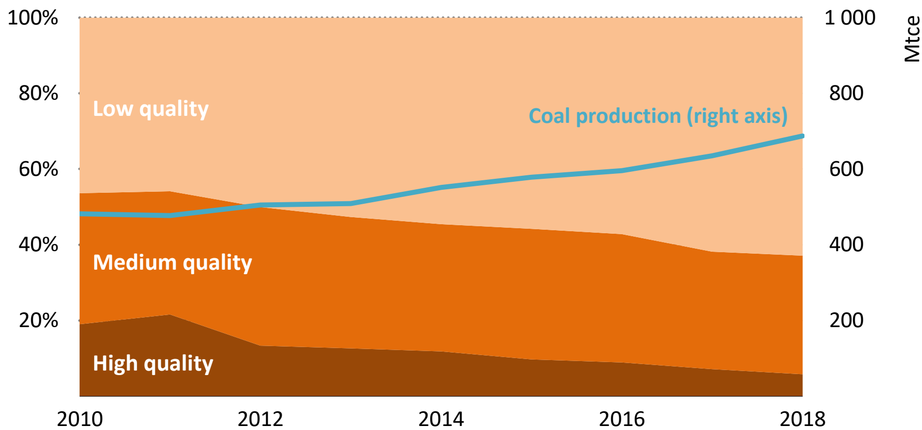
i. Improving efficiency and operational performance

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



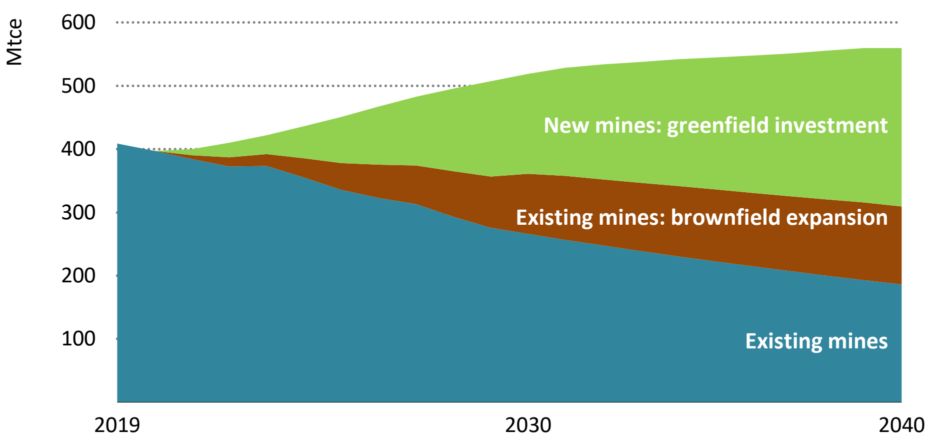
The decline in the quality of India's domestically produced coal has given rise to a number of logistical and cost-related challenges.

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.

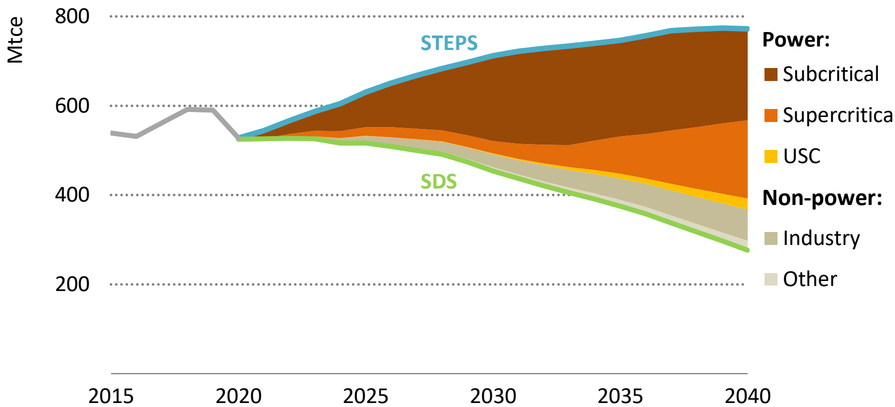
Addressing these environmental effects requires action on a broad number of fronts. In 2015, the Indian government introduced stricter pollutant emissions norms for thermal plants, moving beyond an earlier focus on particulate matter to include restrictions on sulphur dioxide, nitrous oxide, water and 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.

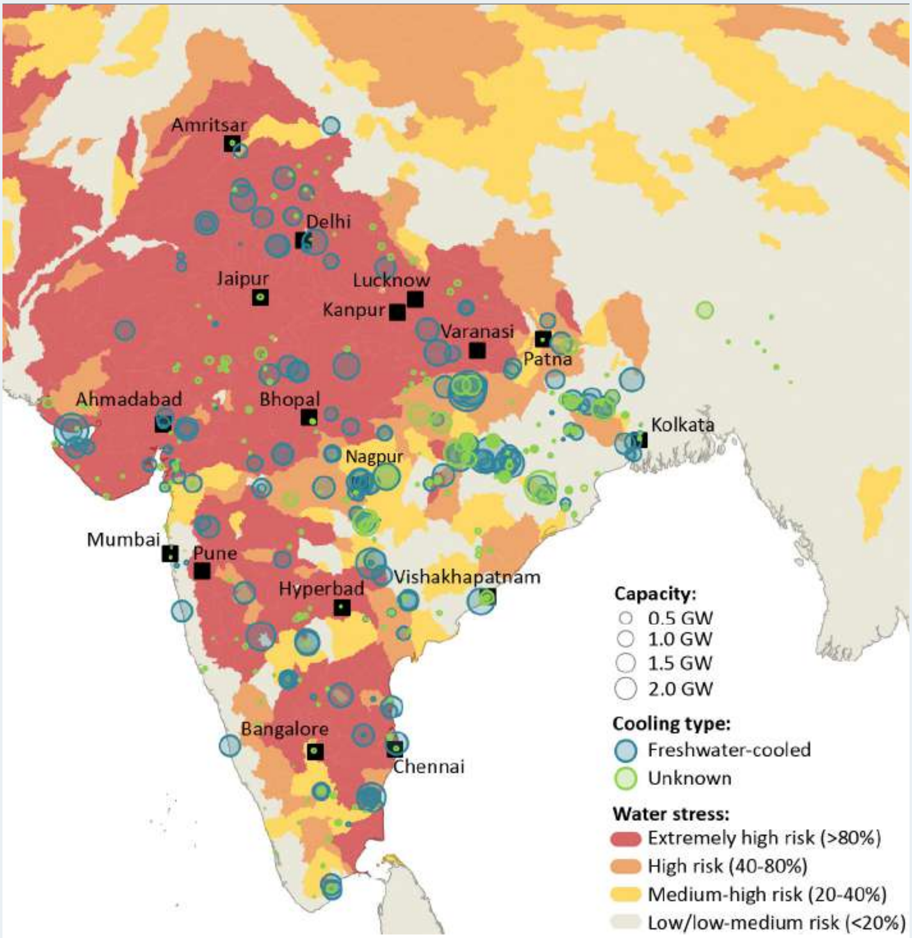
Note: USC = ultra-supercritical.

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.

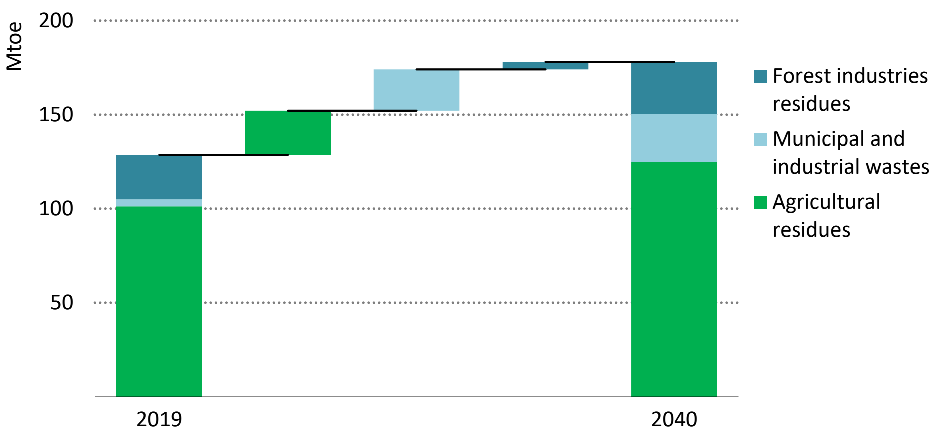
A range of agricultural feedstocks can be used for the production of transport biofuels. A distinction is often made between conventional biofuels, which rely on energy crops and often compete with food supply, and advanced biofuels, which can be derived from organic waste and non-food materials. Bioethanol 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:

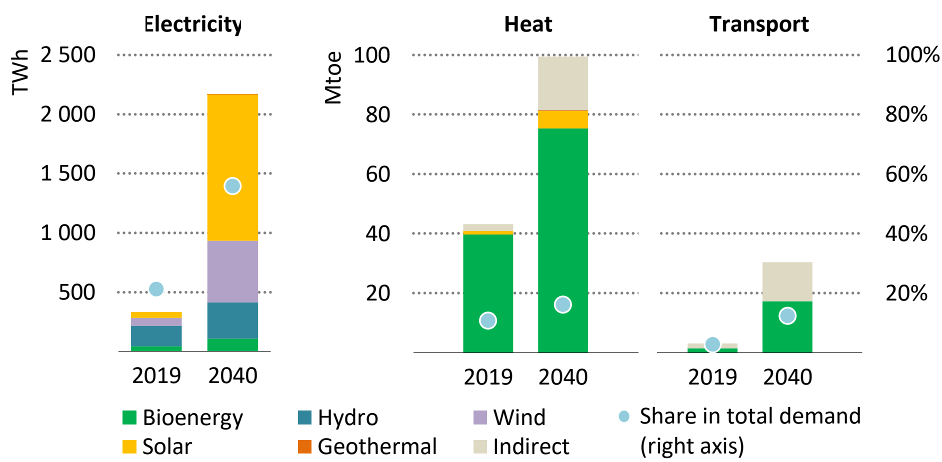
- **Supply chain uncertainties.** Agricultural waste sources are dispersed around the country, sometimes across multiple small landholdings. They differ greatly in terms of their quality and composition, and hence also in their suitability for different conversion technologies. There is also significant 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



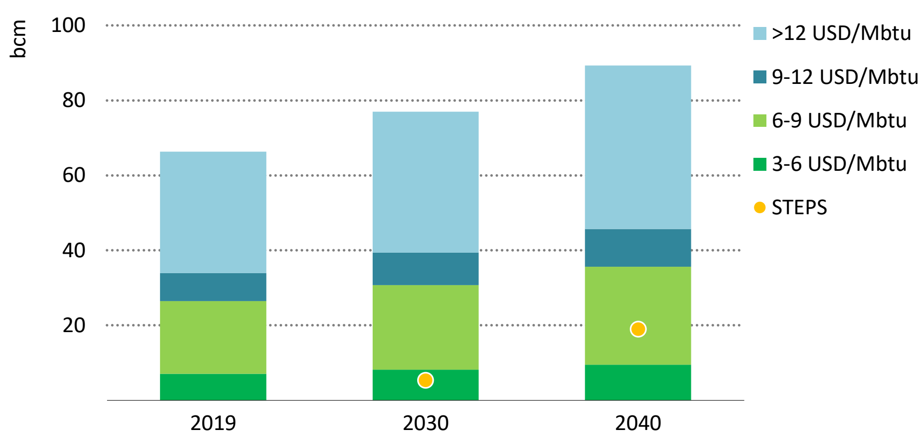
Bioenergy plays a significant role as a renewable heat source for industry and buildings. Biofuels use rises six-fold by 2040, capturing a larger share of overall transport demand.

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

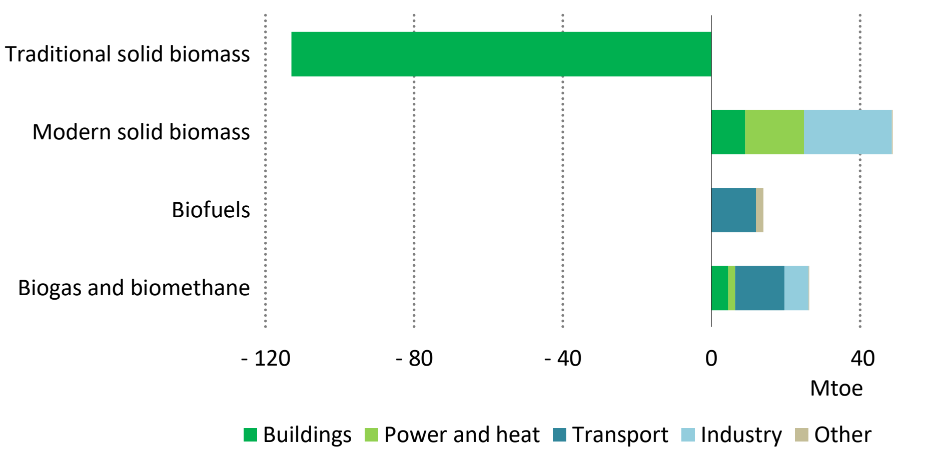
[6] For example, NTPC (the largest thermal power generation corporation in India), has decided to co-fire with coal 6 Mt of pellets from crop residues in its power plants in 2020.

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.

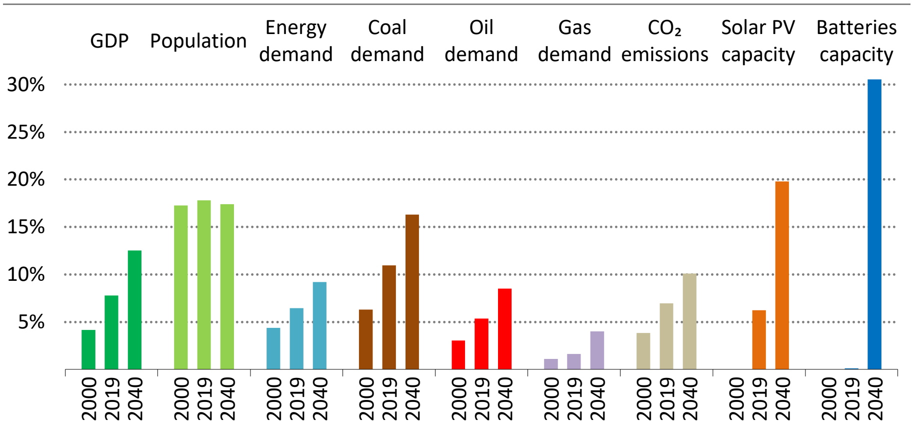
Implications for India and the world

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.

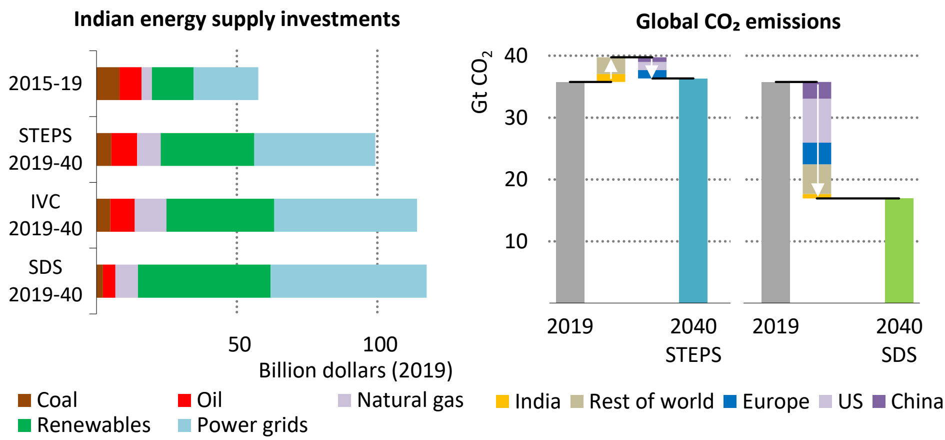
4.1 Overview of energy sustainability and security

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.