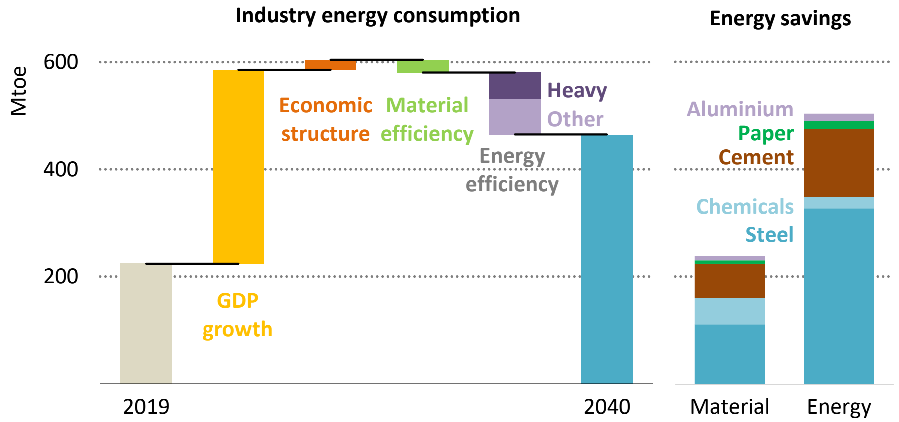
savings from a range of less energy-intensive sectors, such as manufacturing, textiles and food processing, amount to a further 65 Mtoe in 2040 in the STEPS. These sectors include many small and medium-sized firms, underlining the importance of policies to tap the energy savings potential in India's 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.

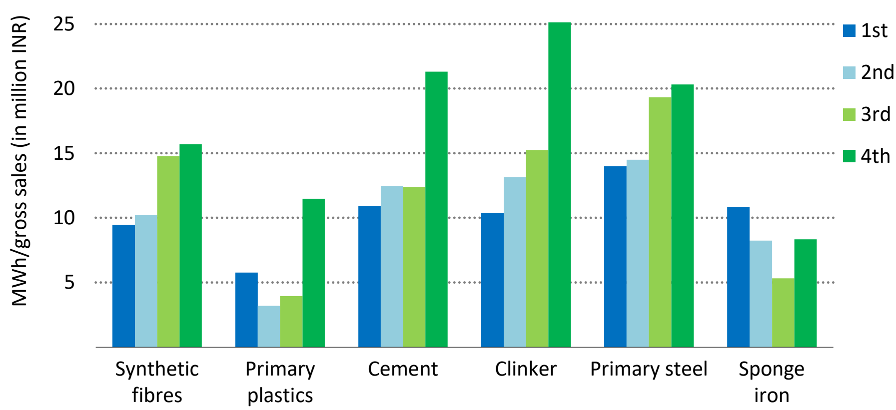
Note: Economic structure represents the impacts of the change in the share of industry value-added in GDP.

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

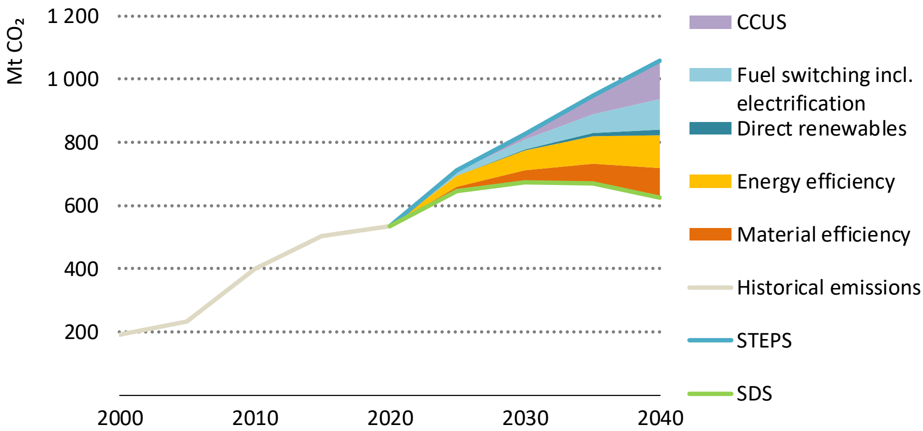
In the STEPS, the industry sector is the largest driver of coal demand and CO_2 emissions in India over the period to 2040. Total direct emissions from the industry sector nearly double, reaching just over 1 Gt CO_2 in 2040. Although coal's market share drops from 44% in 2019 to 38% by 2040, its consumption 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.

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[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.

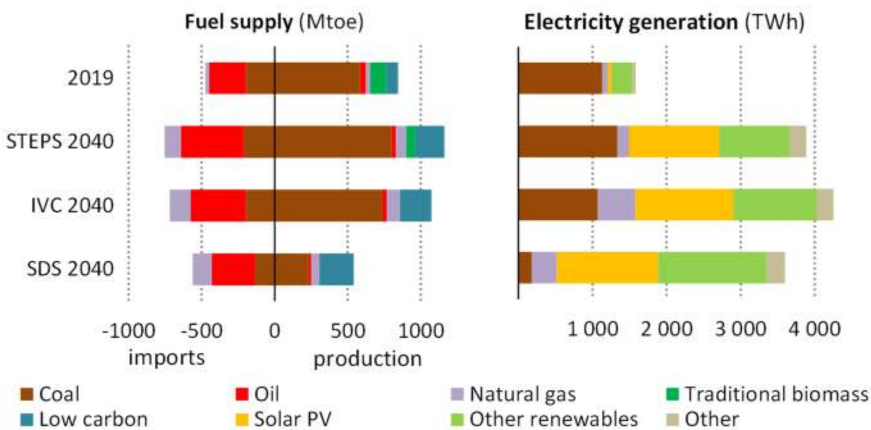
Fuels and electricity in India

Out with the old, in with the new?

SUMMARY

- 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.

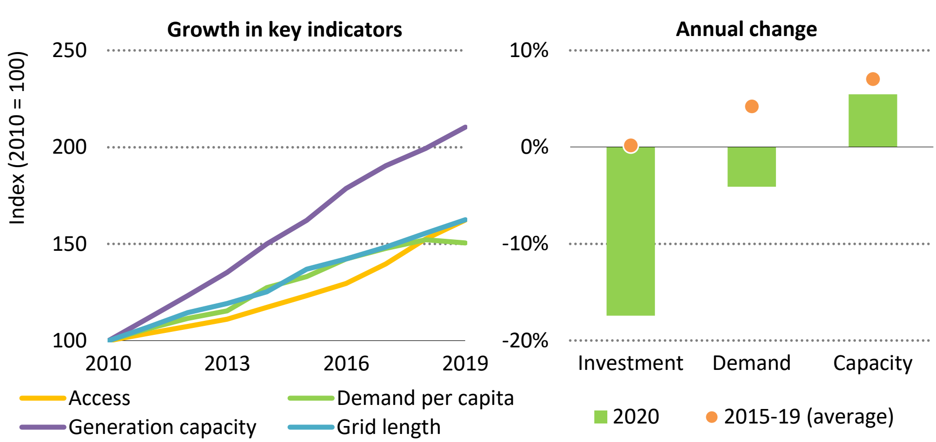
3.2 What's next for India's power sector?

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

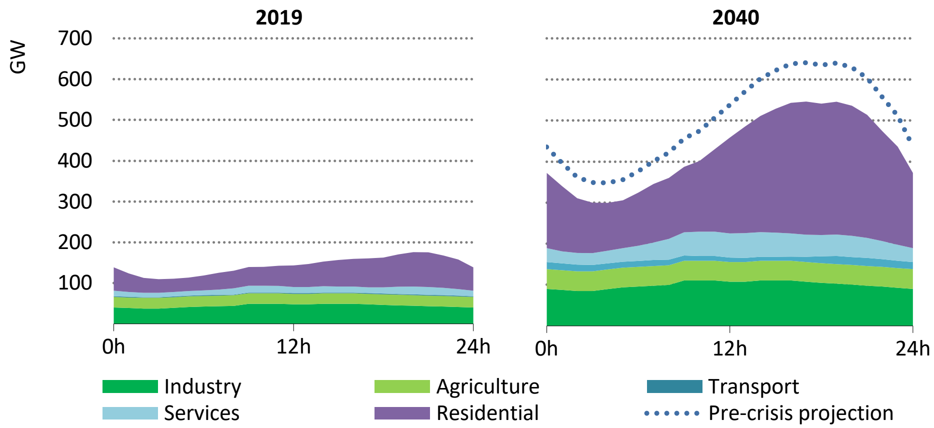
Electricity demand

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.

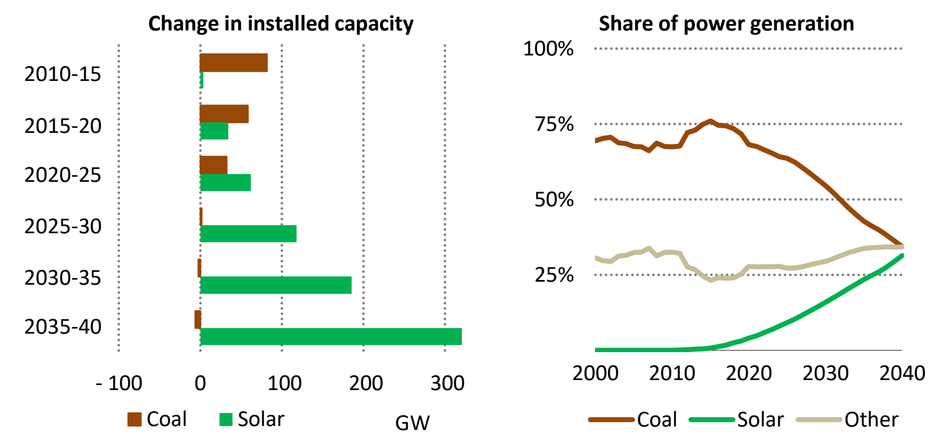
The size of the impact of increased use of cooling systems on the daily peak of electricity demand is subject to several uncertainties. One important factor is how purchases of air conditioners divide between higher- and lower-income households, as higher-income households are more likely to run air 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

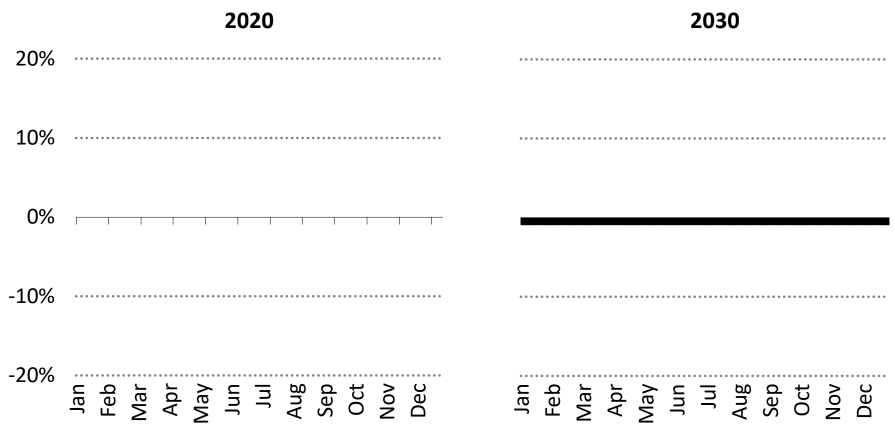
In the STEPS, by 2030 wind and solar PV reach a share of more than 40% in total installed capacity and around a quarter of total generation. The hour-to-hour variation in wind and solar output places increasingly large demands on the rest of the power system to balance supply and demand. *WEO*'s detailed 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).

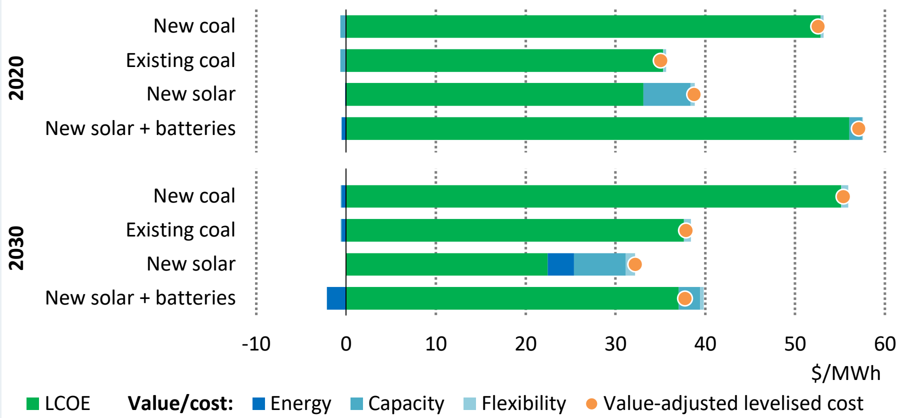
Box 3.2 ▹ Solar PV plus batteries: More competitive than coal?

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.

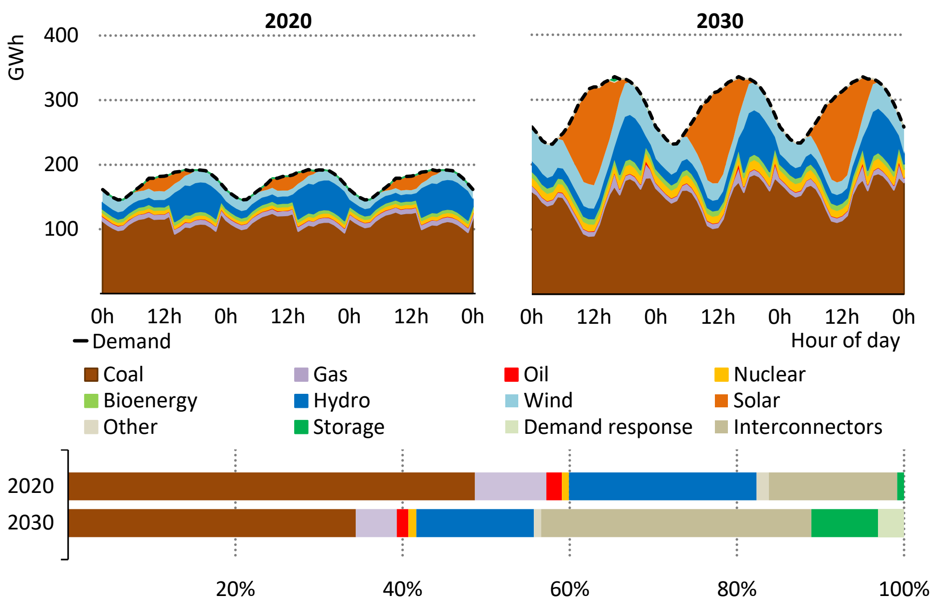
In the STEPS, continuous reductions in the cost of solar PV mean it becomes cost-competitive against most existing coal capacity in India by 2030, even after taking into account the fact that the energy value of solar PV reduces a little as its share of annual electricity generation rises from 3% in 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.

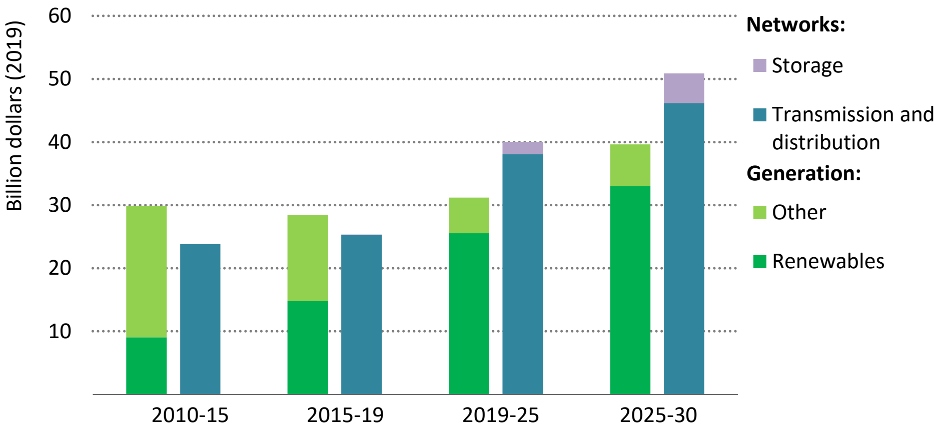
Figure 3.7 ▷ India hourly generation mix and annual share of flexibility by source in the STEPS



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).