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Briefing · November 2024

Renewable energy in India: Manufacturing and recycling require sustained support

Key points:

- China dominates the manufacture of solar PV modules, while India had less than 2% of the global market in 2022
- India's solar PV sector relies heavily on imports, meaning the government must balance its efforts to protect the industry from competition and enable it to compete through access to affordable inputs.
- 70-80% of India's wind turbines are produced domestically, and the country also has a sizeable export market, particularly to the US.
- The need to import cobalt, nickel and lithium, as well as copper and aluminium to a lesser extent, make these critical minerals for India's energy transition.
- Recycling the components of solar and wind technologies will be crucial to creating a supply chain for new manufacturing in the future.

India has high ambitions for renewable energy

At COP26 in 2021, Prime Minister Narendra Modi announced that India would meet 50% of its energy needs from renewable sources by 2030 and that it would have 500 GW of non-fossil[1] electricity capacity by the same date. India's 2022 revision to its Nationally Determined Contribution commits to achieving 50% of electricity (rather than total energy) capacity from non-fossil fuel sources by 2030.[2]

The government claims that these objectives represent the world's largest expansion plan for renewables, and there has been a rapid growth of renewables generation in the last 10 years. However, achieving the targets will require a sustained effort – including building up its domestic manufacturing and recycling capacities to secure India's access to renewable technologies. There is clear evidence that the targets will not be achieved: meeting the 2030 target for 500 GW of renewable electricity capacity has slipped to 2031-32 as the country struggles to drive sufficient deployment of renewables.

How much does India manufacture renewable technologies?

China dominates global manufacturing of clean energy technologies. While India has some profile in solar PV manufacturing, it does not have a significant presence in manufacturing other clean energy technologies (figure 1).

[1] This includes large-scale hydro and nuclear power as well as renewables.
[2] Nationally Determined Contributions (or NDCs) are statements from signatories to the Paris Agreement setting out their national efforts to reduce emissions of greenhouse gases.

The International Energy Agency does not expect the concentration of solar PV manufacturing in China to be reduced over the next decade despite investment plans in India and the US. This is because much of China's existing solar manufacturing capacity is not currently being used. As demand for more solar PV grows, this excess capacity is expected to enter use, diluting the impact of additional capacity elsewhere.

Solar PV production

With 80% of the market, China currently leads global solar PV module manufacturing capacity. In comparison, India had 1.9% of the market in 2022. China also dominates PV cell production, producing 331 GW of solar cells in 2022, around 84% of total global production, while India produced 0.6% of PV modules globally.

China is also responsible for more than 95% of wafer manufacture, with 371 GW of wafers produced in 2022 and an annual production capacity of 673 GW. Indian companies plan to expand wafer production capacity up to 41 GW a year by 2025.[3] However, given that manufacturing costs in India are higher than those in China, the total production capacity might not all be used as there remains significant excess capacity in China.

The excess capacity in the global solar PV market presents India with a dilemma. The government is actively encouraging new manufacturing capacity to be built through its Production-Linked Incentive (PLI) scheme.[4] However there is no guarantee that the capacity will be used in the short term, especially if prices for Indian solar components are higher than for those produced in China.

Currently, India's solar PV industry is heavily dependent on imports, with around 90% of PV modules coming from China. The top three module suppliers in India are also Chinese (Jinko, LONGi and Trina), although their market share might decline as a result of the Indian government's implementation of an approved list of models and manufacturers (ALMM) from April 2024.[5]

India has exempted imports of some solar PV components used in the manufacture of modules from Basic Customs Duty. In effect, India is performing a balancing act: trying to encourage a domestic solar PV industry while also recognising that importing some components for solar modules is necessary and will have to be as cheap as possible to enable the industry to compete with Chinese manufacturers.

Driven by the PLI, large Indian companies are considering building domestic supply chains for solar PV modules to challenge Chinese dominance. For example, Adani Solar hopes to develop a fully vertically integrated supply chain from ingots to modules, as well as building the 648-MW Fatehgarh/Kamuthi solar park.

Wind turbine production

Wind turbines are complex machines. Companies often manufacture one or more components but not necessarily the whole turbine. For example, a company might

[3] The Institute for Energy Economics and Financial Analysis (IEEFA) has a slightly more pessimistic assumption, and estimates that ingots/wafers and polysilicon production facilities could be added by 2026 rather than very rapid growth by 2025.
[4] The Production-Linked Incentive is intended to encourage manufacturing of high-efficiency solar PV modules by reducing investment costs in new manufacturing facilities through payments linked to sales of the modules.
[5] The ALMM sets out which manufacturers are eligible for government subsidy and support and is limited to companies that manufacture PV modules in India.

manufacture turbine blades or assemble nacelles but not be involved in gearbox or tower manufacture. Other companies might assemble components made elsewhere to produce the final turbine.

Overall, India ranks third globally for wind turbine and component production, behind China and Europe, but ahead of the US and Brazil.

India has 7% of global nacelle assembly capacity, with 13 facilities capable of producing 11.5 GW of nacelles a year. There are no offshore wind nacelle facilities in India, and none are planned. In comparison, China has 97 operating nacelle facilities, of which 20 are for offshore wind, with a further 47 planned in the offshore segment.

Around 70-80% of wind turbines deployed in India are made there, whether by domestic companies or global players with a presence in the country. At the moment, however, wind manufacturing capability in India is underutilised because of low demand in the domestic market.

India does have a sizeable export market though, notably to the US. It was the largest wind-related exporter to the US in 2022, with an estimated value of USD 518 million. Generating sets – including nacelles and turbine blades – and hubs made up the bulk of these exports. Overall, the value of global wind exports from India outweighs the value created in the country.

How does India dispose of its renewable energy technology?

Critical minerals

As with other energy technologies, renewable technologies are manufactured using a wide range of minerals.[6] The degree to which individual technologies rely on these minerals varies (table 1).

Table 1: Selected mineral needs for renewable technologies

RE technology	Copper	Cobalt	Nickel	Lithium	Rare Earth Elements	Platinum Group Metals	Chromium	Zinc	Aluminium
Solar PV	high	low	low	low	low	low	low	low	high
Wind	high	low	med	low	high	low	med	high	med
Hydro	med	low	low	low	low	low	med	med	med
CSP	med	low	med	low	low	low	high	med	high
Bioenergy	high	low	low	low	low	low	low	med	med
Geothermal	low	low	med	low	low	low	high	low	low

Source: IEA

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There is no universal definition of 'critical minerals' – the concept is instead related to an individual country's assessment of the importance of any given mineral to its security and economic development, as well as threats to the availability of that mineral. The Indian government conducted an assessment of the importance of minerals to their economy in

[6] Table 1 shows a selection of minerals but others are also relevant, including manganese and silicon.

2023 which categorises copper, cobalt, lithium, Rare Earth Elements and Platinum Group minerals as critical for India (table 2).

Table 2: Critical minerals for renewables in India

	Copper	Cobalt	Nickel	Lithium	Rare Earth Elements	Platinum Group Metals	Chromium	Zinc	Aluminium
Classed as critical in India	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No

Source: IEA, Ministry of Mines

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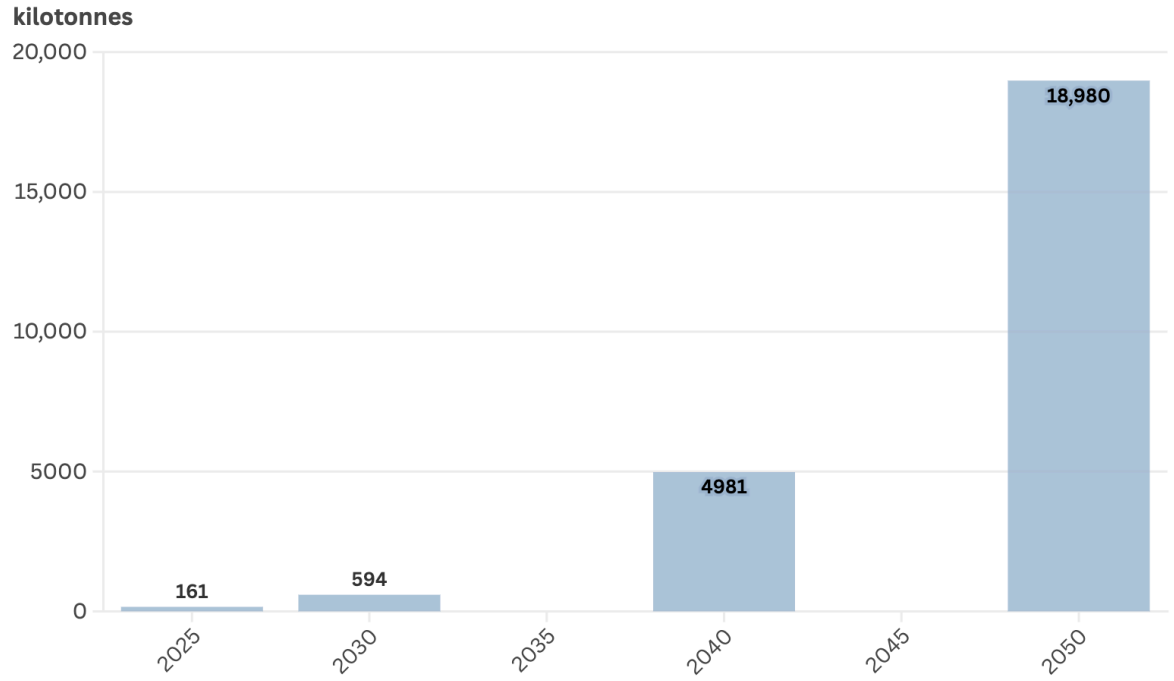
Cobalt, nickel and lithium are not produced domestically, leaving India reliant on imports. While aluminium and copper are produced in India, there are also significant imports of both materials (around 35% and 20%, respectively), meaning that ensuring the international supply chains for these minerals becomes central to developing domestic manufacturing industries in wind and solar.

The IEA states that increasing efforts to recycle critical minerals is essential to mitigate possible supply constraints in future. End-of-life recycling of equipment built using these minerals can help reduce this reliance and therefore boost security of supply and limit vulnerability to price spikes, as well as lowering new resource use and environmental impacts of a net-zero transition.

PV panels

The need to recycle PV panels to recover critical minerals will become an increasingly pressing problem in India as panels reach the end of their operating lives (after around 30 years). The Council on Energy, Environment and Water estimates that meeting India's PV targets will result in cumulative waste of almost 600 kilotonnes (kt) from existing and new PV capacity by 2030 and nearly 19,000 kt by 2050, a 30-fold increase.

Fig. 1: Cumulative waste from solar PV capacity installed up to 2030



Source: Council for Energy, Environment and Water and Ministry of New and Renewable Energy 2024
Note: the report estimates the quantity of waste arising from PV module manufacture and waste 'from the field' which includes modules that are damaged during the construction or operation phases. It also includes the waste generated when modules reach the end of their operational life.

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Up to 95% of the materials used in PV panels can be recovered at the end of their life. Recycling solar panels is increasingly common worldwide and some European countries are recycling or reusing 100% of their PV panels waste.[7]

India has established a system of extended producer responsibility (EPR) for e-waste and set up recycling targets for electronic equipment with a goal of achieving 80% recycling by 2028-29. The rules apply to manufacturers, producers, refurbishers and recyclers of PV modules or panels and require them to register for an EPR certificate. One of the aims of the system is to formalise the e-waste recycling sector and reduce reliance on informal, unmonitored recyclers.

Solar panels were added to the e-waste management rules in 2022. However, the e-waste recycling targets for equipment do not apply to PV wastes.

There is some data on the number of EPR certificates granted by the Central Pollution Control Board (CPCB) and the amount of materials involved on the EPR e-waste portal. However, there is no data on the levels of recycling achieved, whether that is from PV panels or other e-wastes.

The Ministry of Environment, Forest and Climate Change published data on e-waste recycling in February 2024. This shows a significant increase in e-waste recycling between 2016 and 2022 and also provides data per state. There is no information on whether e-waste recycling targets are being achieved, what materials are being recycled or how much PV waste was recycled.

[7] France, Portugal and Spain achieved 100% recycling or reuse in 2021.

Wind turbines

Between 80% and 94% of a wind turbine's mass can be easily recycled. This includes steel, aluminium and copper used in the turbine's tower, gearbox and generators. While nacelles are made of composite materials which are more challenging to recycle, it is increasingly possible to recycle them too.

There is a lack of information on wind turbine recycling in India. The key components would be steel for the towers and components in the nacelles. Recycling steel is a well-established industry in India, using about 32 million tonnes in 2022/23 for new steel production. The government is reported to be aiming to increase the use of recycled steel to 50% of steel production by 2047.