**Table 4**: Sectoral distribution of solar rooftop systems in 2016-2021

| | Until 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|
| Annual Capacity Additions (MW) | 1179 | 1082 | 1645 | 1534 | 719 | 1700 |
| % of Commercial & Industrial Consumers | 63% | 68% | 75% | 81% | 65% | 59% |
| % of Residential Consumers | 24% | 11% | 10% | 12% | 27% | 35% |
| Balance Govt. Buildings & Public Places | 13% | 21% | 15% | 7% | 9% | 6% |

is to apply a brake on the imports over time. To achieve this pivotal objective, a $3.2 billion, five-year subsidy program is in place to stimulate the entire supply chain – comprising indigenous polysilicon, wafer, cell and module production. As per the estimates drawn up by the market experts, the indigenous cell and module production capacity could surge ahead to 18 GW and 36 GW, respectively.

## Laying the Ground For Solar Job Market Assessment

Greenhouse gas (GHG) emissions are a matter of huge concern across the world. India is the third largest emitter of such gases despite having low per capita emissions. The fact is that a bulk quantity of these emissions originates from India's fossil-fuel dependent energy sector. The way forward is an increased deployment of renewable energy sources – more so from solar and wind. These alternatives offer lower life cycle GHG emissions in addition to creating multiple job opportunities. A high number of these directly created jobs is concerned with the construction and operations cum management phases of the projects. Incidentally, the job spread i.e., distribution shows a significant variation at the state and regional levels; it is on account of the variable geographical and socio-political factors. The following section takes a close look at issues like these and much more from the viewpoint of striking a fine balance between the jobs seen at work and jobs lying here, there and everywhere.

### *The magical number of 500 GW*

The 26th session of the Conference of Parties (COP26) convened at the United Nations witnessed a key announcement from India; related to

the targeted installation of 500 GW of non-fossil fuel electricity generation by 2030. As expected, the bulk share of this capacity is to come from RE technologies (like solar and wind) to meet the country's growing energy needs – besides achieving its climate commitments globally. As of July 2022, India attained a total RE installed capacity of 114,437.39 MW, minus the large hydro with full efforts underway to meet the targeted capacity of 175 MW by 2022. These figures represent a big hope forward vis-à-vis the potential for employment and job creation.

### *Dreaming Big With the Solar Jobs Bouquet*

Thousands of jobs exist in the Indian RE sector today. However, it is pertinent to report the findings of a collaborative study undertaken by the trio of NRDC, CEEW and SCGJ in 2019. As per this study, a workforce of 111,400 stands employed by both the wind and solar energy sectors as of FY 21. This factors in a total installed capacity of around 81.3 GW, out of which, wind energy installations account for a capacity of 39.2 GW. The balance capacity is contributed by solar in the ratio of 35.6 GW for utility driven and 6.5 GW for the rooftop segments. By August 2022, the wind and solar energy contributions increased to 40,893.33 GW and 54,849.16 MW, respectively. Indeed, both the large-scale grid-connected wind and solar give immense hope to create more jobs soon. However, the solar rooftop segment is still waiting in the wings to take off on a large scale.

There is yet another interesting dimension in solar application arena. To put this in perspective, the decentralized RE type projects offer a higher job creation potential than the grid-connected power projects or simply the utility scale projects. This is due to the geographical spread, remoteness from the nearest available grid power point, scattered habitations, technology chosen and vulnerability to improper use of the appliances provided, etc. Take for instance the biomass gasifier plant at work in a remote location. Right from raw feedstock identification, collection and its matching characteristics, to the operational specifications and much more – manpower requirements are higher than that for a usual solar PV. Experts believe that DRE solutions have the potential to create up to five times more indirect jobs within the local communities than direct employment.

## Categorizing the Job Groupings in Solar PV

The two broad-based categories of jobs in the solar industry today are of the direct and indirect type. The direct type jobs are primarily related with the design, development, management, construction and operation cum maintenance of the project. In contrast, the indirect jobs are linked with the manufacturing of equipment used for the solar facility. These could very well include the jobs falling in the supply chain or to meet the requirement of raw material feedstock availability and services to the manufacturers. That is not all, as the finance and banking jobs originating from the sector to provide the services for the construction and operation of the facility are also covered under the indirect jobs.

### *Specific categorization of the direct jobs*

Solar PV installations normally progress in three different ways i.e., decentralized system use, setting up of the large capacity grid-connected systems and using the available rooftop spaces for mounting of relatively lower capacity systems. The common power producing component which involves the siting, mounting and interconnections is the solar module. The remaining system components include: the power conditioning unit, i.e., an inverter, together with safety cum protective devices and power evacuation arrangement. Table 5 shows the specific nature of jobs associated with grid-connected solar installations and their market delivery.

Today, a significant number of solar installations (around 88%) fall in the large capacity ground mounted category. The rooftop systems barely account for 12% of the total number of solar installations. Nonetheless, the percentage skill associated with both these skills varies a lot as per Table 6.

### *State-wise Outlook for Solar Jobs*

India has an indigenous availability of technology to produce solar cells and modules right from the early 1980s.

**Table 5**: Types of jobs associated with grid connected solar installations

| Specialized Category | Key Role Fulfilment | Job Titles | Skilled/ Semi-Skilled |
|---|---|---|---|
| System Design & Pre-Construction | System Design | Engineers/Designers/Planners/ Resource Analysts etc. | Skilled |
| Business Development | Customer identification cum order realization etc. | Executives in Sales/Marketing/ Financial/ Regulatory streams | Skilled/ Semi-Skilled |
| Construction and Commissioning | Civil/Electrical/ Mechanical works | Engineers/Planners/Contract Labourers/Supervision Personnel etc. | Skilled/ Unskilled |
| Operation and Maintenance | System upkeep | Engineers/Technicians/Contract Labourers, etc. | Semi-Skilled/ Unskilled |

**Table 6**: Characterization of the available workforce for ground mounted and rooftop solar projects

| Job category | Ground Mounted Solar Project | Rooftop Solar Project |
|---|---|---|
| Design and Construction | 60% Skilled | 72% Skilled + 20% Semi-Skilled |
| Business Development | ~100% Skilled/Semi-Skilled | Uncategorized |
| Construction and Commissioning | 50% Unskilled | Uncategorized (Outsourced) |
| Operations and Maintenance (O&M) | ~100% Unskilled/Semi-Skilled | Uncategorized (Outsourced) |

**Source:** *CEEW-NRDC (2017)*

**Table 7**: State-wise outlook for jobs in the solar power sector

| State | Estimated Solar Potential (GW) | Manufacturing Capacity For Solar Modules (MW) | Present Distribution of Jobs (Manufacturing) | Solar Power (Ground Mounted) MW | Present Distribution of Jobs (Ground Mounted) | Solar Power (Rooftop) MW | Present Distribution of Jobs (Rooftop) |
|---|---|---|---|---|---|---|---|
| Rajasthan | 142.31 | 140 | 364 | 11821.87 | 14186.24 | 814.02 | 5372.53 |
| Gujarat | 35.77 | 5244 | 13634.4 | 5909.27 | 7091.12 | 1923 | 12691.80 |
| Karnataka | 24.70 | 1370 | 3562 | 7280.26 | 8736.31 | 371.99 | 2455.13 |
| Tamil Nadu | 17.67 | 972 | 2527.2 | 5264.95 | 6317.94 | 368.50 | 2432.10 |
| Telangana | 20.41 | 1119 | 2909.4 | 4360.49 | 5232.59 | 255.51 | 1686.36 |
| Andhra Pradesh | 38.44 | - | - | 4240.99 | 5089.19 | 152.85 | 1008.81 |
| Maharashtra | 64.32 | 192 | 499.2 | 1739.10 | 2086.92 | 980.08 | 6468.52 |
| Madhya Pradesh | 61.66 | - | - | 2459.02 | 2950.82 | 205.62 | 1357.09 |
| Uttar Pradesh | 22.83 | 480 | 1248 | 1851.50 | 2221.80 | 258.78 | 1707.94 |
| Punjab | 2.81 | - | - | 828.58 | 994.30 | 222.51 | 1468.56 |
| Haryana | 4.56 | 320 | 832 | 265.80 | 318.96 | 397.40 | 2622.84 |

However, there is no manufacturing of polysilicon/wafer/ingots taking place, even though silicon wafers' specific process know-how had matured in 1986 via a collaborative effort between Metkem Silicon Ltd and IISC, Bangalore. As per the MNRE figures, the per annum solar cell and solar module production capacities are around 3000 MW and 10,000 MW. It is of definite interest to examine which states have the maximum installed solar capacity and the highest solar radiation availability in the country. Likewise, the states having a bulk share of solar manufacturing capacities for solar modules should also be examined. Both these situational contexts shall help to assess the present and upcoming job opportunities in the solar PV arena. Table 7 highlights the first eleven states in terms of the maximum installed solar power capacity in the country as on 30 June 2022.

As seen above, the solar grid power capacity of 57,705.72 MW exists across different geographical regions in the country. There are a selective few estimates available vis-à-vis the state-wise job creation potential through solar grid power systems. These consider 106 GW equivalent of rooftop capacity and 132 GW of ground mounted capacity realization by 2030. A total of 32,66,100 solar jobs alone are worked out through the non-fossil fuel route of power generation. This certainly looks as a distant dream because only about 20% of the target capacity, i.e., 40 GW stands realized as of now. On a similar note, the International Energy Agency (IEA) estimated job availability in 2018. As per this, the total employment generated through a 60:40 mix of ground and rooftop mounted installations shall lead to a cumulative employment generation of around 909,469 jobs.

## The Sunny Job Market Forward

It is beyond doubt that the sun will continue to shine bright on the Indian solar sector due to several key considerations. However, what is of an ultimate significance in the addressed scheme of things is not to lose sight of using quality components, along with the best of installation practices. The sun can surely take under its fold any job aspirant, but skill availability in the requisite measure would remain a huge challenge to fulfill in our drive to march towards the net zero emissions subsequently.

*Dr Suneel Deambi is a solar PV expert and a prolific writer on 'technology in society' issues.*

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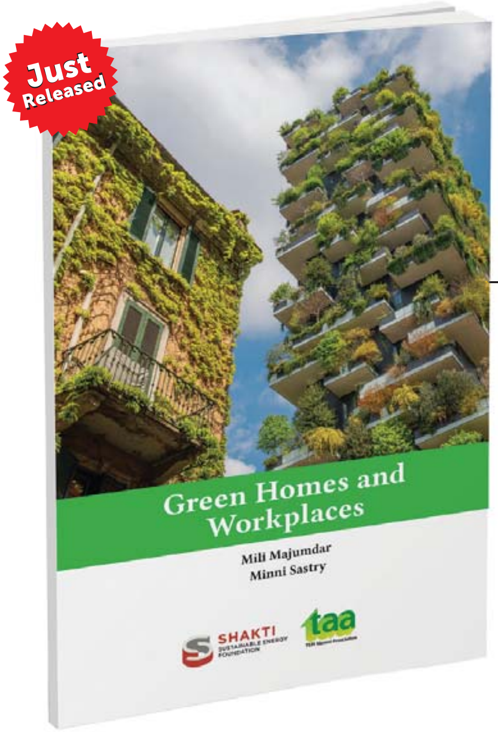

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*Green Homes and Workplaces* is simple and clear explanations of fundamentals and liberal use of illustrations. The authors aim to demystify the concepts and empower everyone to think and live green. For example, are you worried about polluted air indoors? Try a couple of houseplants. Living on the top floor? Try a reflective paint that can lower the inside temperature by at least a couple of degrees.

Although meant to be a guide to the concerned citizen, the book also has a more profound message: as green-buildings practitioners on the frontline of market transformation in India, the authors believe that our homes, buildings, and communities must move from not just doing less harm to becoming truly regenerative.

This book is useful for adults who are concerned about topical issues but lack the understanding to make sense of what they read or watch in the mass media

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Ajay Shankar, Distinguished Fellow, TERI

# ACHIEVING INDIA'S CLIMATE CHANGE GOALS

**India had communicated its Nationally Determined Contributions in 2015. At COP 26, Glasgow, our Hon'ble PM had announced the Panchamrits or nectar elements, four of which were 2030 targets, whereas the fifth element was a long-term target of reaching net-zero by 2070. According to you, what is the significance of short-term goals and how can India achieve these targets?**

The announcements by our Hon'ble Prime Minister at COP 26 last year, in Glasgow, were bold and ambitious: the Panchamrits. These were:

1. India will reach its non-fossil energy capacity to 500 GW by 2030.
2. India will meet 50% of its energy requirements from renewable energy by 2030.
3. India will reduce the total projected carbon emissions by one billion tonne from now till 2030.
4. By 2030, India will reduce the carbon intensity of its economy by 45%.

The fifth was to achieve to net-zero by 2070.

These went way above our Paris commitments and far more than expected. This was probably the largest increase in 2030 goals by any country. This scaling up of India's climate ambition is among the highest in the world. The goal of achieving non-fossil fuel capacity of 500 GW by 2030 has to be seen in relation to India's total capacity being only 157.32 GW, at the time of the announcement.

This is especially noteworthy as action taken within the next few years and in this decade would be critical in determining the fate of humanity. The International Energy Agency (IEA), in its recently released *World Energy Outlook 2022*, has said that as of now, global warming is set to cross 1.7° against the necessity of restricting it to 1.5°. The window of opportunity of staying within 1.5° is closing – unless decarbonization is accelerated very rapidly across the world and especially in the advanced economies.

At TERI, we have prepared a *roadmap for achieving the 500 GW* of fossil fuel free generating capacity by 2030. This would be the key to achieving the other 2030 goals of getting 50% of our energy from renewable sources and reducing 1 billion tonnes of projected carbon emissions. In our Discussion Paper, which can be seen on TERI's website, we concluded that achieving 500 GW of non-fossil energy capacity by 2030 – though very challenging – was achievable. Also, it may well turn out to be the least cost pathway for meeting the growing additional demand for electricity in India. With the rapid decline in the cost of solar and wind power as well as storage costs, there is now a fortunate convergence between what is becoming the least cost option for providing the additional electricity needed for our rapid development on the one hand and what is required for decarbonizing the electricity system on the other.

According to the projections of the Central Electricity Authority (CEA), 500 GW of non-fossil fuel capacity could be achieved by having 430 GW from wind, solar and other RE sources, 60 GW from large hydro and 19 GW from nuclear energy capacity. The CEA and the CERC, both see the need for the creation of grid storage capacity now. This is essential for flexible operation of the power system and for grid stability as the share of RE increases. India needs larger storage capacity as our RE program is driven more by solar power where there is generation only when the sun shines, unlike wind in Europe which generates electricity round the clock. Therefore, India would have to become a global leader in this decade

in the creation of grid-scale storage capacity.

**How do we cater to demand and supply mismatch with increasing share of Variable Renewable Energy (VRE)?**

Renewables generate electricity when the sun shines or the wind blows. This is necessarily variable and intermittent. The grid must be stable with supply meeting demand on a continuing real time basis. The capacity to ramp up supply to meet demand peaks as well as to meet sudden interruptions or decline in RE generation would become more challenging as the share of RE increases in the system. Therefore, in addition to greater flexibility from thermal plants, the need for storage would grow to be able to meet peak demand. Further, as the share of renewables rises and generation becomes higher than demand for some periods in the day, then storage of excess renewables would be essential to prevent loss of generation which has zero marginal cost.

Hence large-scale integration of RE can be achieved only by the adoption of grid-scale electricity storage technologies. According to estimates of the Central Electricity Authority, 27,000 MW/108,000 MWh of grid-scale storage would be required by 2030. In our paper we have suggested the simultaneous deployment of the mature grid storage technologies, of pump storage; river as well as off river, Concentrated Solar Plants with storage using molten salt and battery storage. This should be done through successive competitive bids for price discovery. After a few rounds of bidding and the experience of actual creation and use of different storage technologies it would be easier to take a rational view on life cycle costs and the potential for greater decline in costs of different storage technologies. Accordingly, the optimal share of storage among different technologies would get determined.

SECI has made a good beginning and the results have been very encouraging. In the first tender for round the clock (RTC) supply of RE, two bidders were selected, Greenko and ReNew Power. The tariffs discovered were a flat (off-peak) tariff of INR 2.88/kWh and peak tariffs of INR 6.12/kWh (Greenko) and INR 6.85/kWh (ReNew Power). The recent tender for battery storage has also received a good response.

Pump storage is a mature technology which has been extensively used in the last century across the world for storage to meet peak demand. It has the added advantage that becoming self-reliant and Atmanirbhar is easier. CSP, concentrating the sun's rays through an array of mirrors on to molten salt and using the stored energy to run a conventional steam turbine to generate electricity when needed, is a relatively new technology where costs have now fallen to such an extent that it has become an attractive viable option. The mirrors needed to concentrate solar rays for storing heat in the molten salt can potentially be made in India. Steam turbine production is already taking place in the country. While batteries for small standalone power systems

with solar panels have been in the market for some time, batteries for grid storage are at a nascent stage globally. Different kinds of batteries, such as lithium ion, sodium ion, molten metal, are being developed for large-scale grid storage.

Bids for pump storage and CSP now need to be invited and contracts awarded. These would, however, need sites to be identified. Ideally, the government should quickly prepare a list of feasible pump storage sites, in order of priority. For pump storage sites, technical details would need to be firmed up before inviting bids so that after selection of the developer, work can start quickly. In addition, off river pump storage sites may also be identified and bids from potential developers invited.

For CSP, bids may be invited for specific sites where land is available and details of solar radiation patterns at the site may also be provided to the bidders to get competitive bids. Availability of land and radiation data enables bidders to estimate their costs better and bid more aggressively.

**What are the challenges for the renewable energy sector to scale up in India?**

A very rapid acceleration of the pace of new solar and wind power capacity creation has to take place with private investment. India has been so successful in getting all of its RE capacity creation through private investment. The confidence of the private sector must be sustained.

Markets, domestic as well as international, must not see the risk of delayed payments to RE generators as being serious. The central government needs to give this the highest priority and ensure timely payments to maintain market confidence for the flow of the much higher levels of capital needed for investment for the attainment of the 2030 targets.

A regime of an attractive feed in tariff for decentralized solar power generation in the Kw range in the rural areas would help in accelerating solar power capacity creation. The DISCOMs would gain financially as they would get electricity at a rate lower than their present cost of supplying power in the rural areas. Farmers would get higher incomes from selling solar power to the DISCOMs. The DISCOMs would be able to supply quality power in the daytime for irrigation. This would be welcome to farmers who would be in a better position to use water more efficiently.

Market forces would lead to the development of different sustainable business models to cater to the huge market that would be created. Assuming a potential capacity of 1 MW in a village, India has a potential solar power

capacity of 600 GW in its over six lakh villages.

India also needs to begin the development of offshore wind capacity. A modest program initially would help in capacity creation in project execution as well as cost reduction through competition. Costs which would be higher to begin with could start coming down. The higher cost of wind power has to be seen from the perspective that it does not need storage in the way solar power does.

As we scale up our RE program we need to reduce our dependence on imports and pursue self reliance. This would enhance our energy security and reduce vulnerability. The inclusion of solar panels as well as batteries under the PLI scheme of the government are welcome steps in the right direction.

**How can the Indian industry come forward and contribute to energy transitions of India and do you think India should have sector specific mitigation targets?**

Recently, green energy open access rules have been announced by the Ministry of Power which provides large consumers the option to purchase renewable energy through open access from any developer, purchase renewable energy certificates, or go in for captive generation.

The next step would be for DISCOMs to give Commercial and Industrial (C&I) consumers the choice to buy carbon free electricity on a real time basis with separate tariffs approved by the State Electricity Commissions. This choice may then be extended gradually to all consumers. This would give consumers the ability to accelerate the transition to carbon free electricity without having to find sources of green electricity on their own. This choice would be helpful for Commercial and Industrial (C&I) sectors as well as larger Indian industry to embrace this journey of transition to renewables and become carbon neutral and add to their brand value as a result.

This would create the enabling framework for enterprises as well as individuals to choose to consume carbon free electricity and make their contribution to saving humanity from the impending disaster of global warming. This may gain momentum and India's transition to a fossil fuel free electricity system may take place faster than what may presently be considered feasible.

**What should be India's stand at COP27?**

India is a climate leader having raised its goal for 2030 to having 50% of its energy from renewables.

India can legitimately demand that the advanced countries do much more than they are doing now and decarbonize their economies rapidly. They should aim at achieving net zero by 2040 rather than 2050.

The advanced economies should put in place finance for the developing countries on concessional terms, or at least at the same real interest rates as are available in their countries for RE investments. This finance should be provided on the scale needed for investments into renewable energy for the growing energy needs in the developing countries. EF

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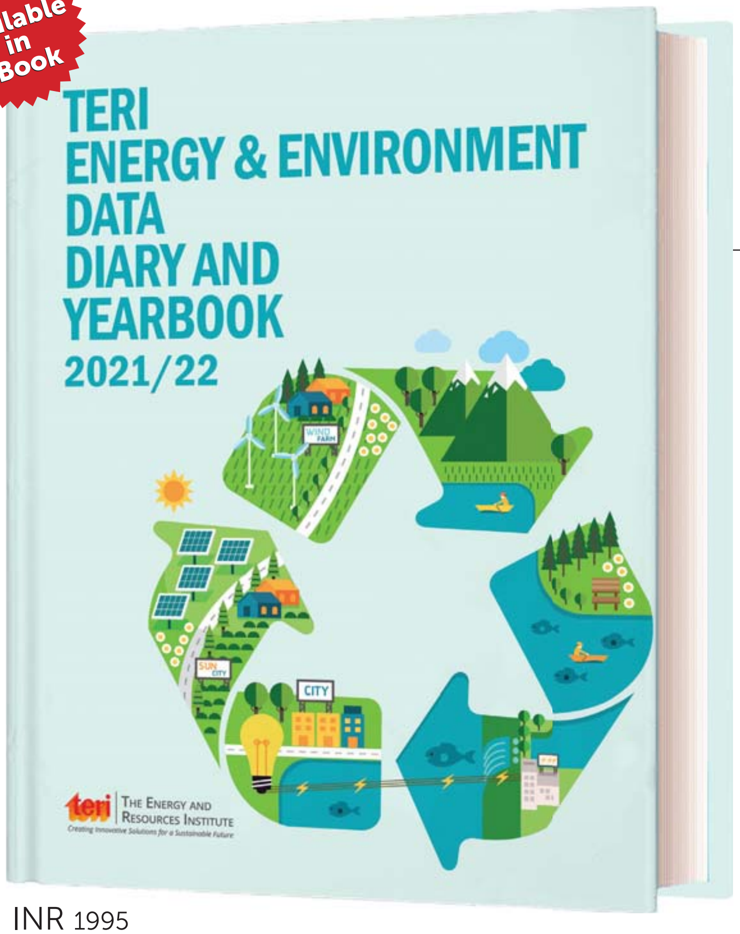

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# CURRENT R&D RENEWABLE

## A net-zero emissions energy system in India by 2050: An exploration

*Journal of Cleaner Production* **352**: 1–12
*Garima Vats, Ritu Mathur*

This study examines whether adequate opportunities exist for full decarbonisation of the Indian energy sector and highlights where enough choices for full decarbonisation by 2050 do not exist. The study suggests transformative levels of electrification, energy efficiency improvements, and a switch towards decarbonised fuels (largely green hydrogen, decarbonised electricity and bioenergy) as the three mainstays of India's decarbonisation strategy that could plausibly shift the energy sector towards a net-zero emissions future. The study also indicates that the heavy freight and industrial sectors face challenges in achieving full decarbonisation because of a lack of adequate technological solutions.

## Energy consumption, greenhouse gas emissions and economic feasibility studies of biodiesel production from Mahua (*Madhuca longifolia*) in India

*Energy* **249**: 1–15
*Jeewan Vachan Tirkey, Ajeet Kumar, Deepak Kumar Singh*

The application of biodiesel plays a substantial role to mitigate fossil fuel consumption and greenhouse gas emissions. Moreover, the major public concerns are about the sustainability of alternate fuel, economic benefit in the production, and adverse environmental impact. Hence, an intensive study of agriculture-associated biodiesel production is required for sustainability. In this study, mass, energy, and market value-based data allocation methods have been adopted for the assessment of Mahua tree cultivation to biodiesel production in terms of energy, economic, and $CO_2$ emission. The results show a positive value for sustainability, in terms of net energy gain (168.68 GJ/ha), energy use efficiency (3.8), energy efficiency ratio (1.498), and specific energy (26.31 MJ/kg). The economic profitability starts from the 14th year of cultivation, where the net present value (NPV) and internal rate of return (IRR) are $402.02 and 12%, respectively.

## Analysing the impact of lockdown due to the COVID-19 pandemic on the Indian electricity sector

*International Journal of Electrical Power and Energy Systems* **141**: 1–19
*Subhadip Bhattacharya, Rangan Banerjee, Ariel Liebman, Roger Dargaville*

This paper aims to understand the responsiveness of the power sector during the lockdown due to the COVID-19 pandemic (beginning from March 25, 2020) and analyses its impact on the demand, operation and supply of electricity in the Indian power system. The role of the C&I load share in reducing the electricity demand of the different states in India has been examined, using multi-sectoral regression analysis. The impact of the pan India lights-off event on the short-term operational flexibility response of the power system has also been analysed using high-temporal resolution data. The results indicate that there has been a reduction of nearly 70 TWh of electricity demand during the lockdown period – an 11% reduction compared to 2019.

## Can economic development and environmental sustainability promote renewable energy consumption in India? Findings from novel dynamic ARDL simulations approach

*Renewable Energy* **189**: 221–230
*Narasingha Das, Pinki Ber, Deepak Panda*

One of the strategies for achieving sustainable development goals  (SDGs) is to close the gap between environmental vulnerability and economic progress. The significance of renewable energy in harmonizing environmental and economic conditions is becoming a touchy subject in current debates. Against this backdrop, the major objective of this paper is to assess whether economic growth and environmental sustainability can promote renewable energy consumption in the Indian economy by using ARDL and Novel Dynamic ARDL estimation techniques. The results obtained from both the methodologies show that rising efficiency in the economic growth coupled with environmental sustainability leads to an increase in renewable energy consumption.

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## Household access to electricity and non-farm business in rural India: A panel data analysis

*Energy for Sustainable Development* **67**: 125–134
*Tanvi Khurana, Seema Sangita*

The role of electricity in formation and performance of rural non-farm entrepreneurial ventures is widely debated. This study aims to understand how, in India, access to household electricity impacts rural households' decisions to take up entrepreneurial activities, operated within household premises. A panel dataset of nearly twenty thousand rural households, carried out in the years 2004–05 and 2011–12, has been used to explore the impact of access to electricity on participation in rural non-farm enterprises, using panel fixed-effects logit models. Further, the role of electricity access on earnings of non-farm enterprises is studied using Heckman two-stage selection models. It is concluded that electricity has a positive effect on the households' decision to establish non-farm enterprises operating within home premises. It is also found that, in the presence of the household electricity access, the income from business increases by 35.2% on an average.

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## Investigation of annual performance of a building shaded by rooftop PV panels in different climate zones of India

*Renewable Energy* **189**: 1337–1357
*Sushant Suresh Bhuvad, Udayraj*

Photovoltaic panels are generally used on rooftop for electricity generation. However, installation of PV on the rooftop also has potential impact on the heating and cooling load of the building. This work studied these indirect benefits of rooftop PV panels by conducting experiments in Raipur, India, and compared the results with the exposed roof. Further, mathematical model is presented to analyse the annual effect of PV shading in terms of thermal load saving and power generation. Annual variation of cooling/heating load, PV power generation and overall energy-saving efficiency index is presented for different climatic zones of India. Average annual reduction in the roof and ceiling temperatures for different cities are in the range of 6.05–10.96 °C and 3.94–7.15 °C, respectively.

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## An analysis of statistical distributions of energy requirement in western part of India

*Renewable Energy Focus* **41**: 198–205
*Balakrishnan Baranitharan, Chandrasekaran Sivapragasam, Krishnasamy Rajesh*

Energy requirement forecast is necessary for arriving at suitable policies for energy management, which is a recognized concern all over the world. This work proposes to examine the energy data from a statistical perspective, before going for detailed analysis such as long-term forecasting. The realities of energy requirements in the western part of India is considered as a case study taking into account the recorded data of the energy requirements of five states for a period of 12 years (2008–2019). We have considered various probability distributions for fitting the energy requirement data. For fitting the distributions, using appropriate statistical software we have used three different statistical tests, namely: the Kolmogorov-Smirnov measure, the Anderson-Darling measure, and the Chi-squared goodness of fit measure.

## A comparative analysis of wind characteristics for distinct terrains of India

*Sustainable Energy Technologies and Assessments* **52 Part A**: 1–21
*Atul Gautam , Vilas Warudkar, J.L. Bhagoria*

The accurate wind potential assessment is the critical and inevitable process before wind farm planning. This paper aims to evaluate and compare the wind potential between the evolutionary algorithms and numerical methods, using the wind measurement data on flat, complex, coastal offshore, and offshore sites, from the mast and remote sensing method. The maximum likelihood method, modified maximum likelihood method, and WAsP (wind atlas analysis and application program) are employed to estimate the optimum Weibull parameters. Furthermore, the Jaya algorithm is compared with particle swarm optimization and genetic algorithms to evaluate Weibull function for different topological terrains of India. The four-performance metrics, root mean square error, normalized root mean square error, normalized error, and root mean square difference are estimated to analyse the accuracy of various methods.

## Performance prediction of the Micro Solar Dome in different climatic regions of India from pilot-scale by Random Forest algorithm

*Sustainable Energy Technologies and Assessments* **52 Part B**: 1–15
*Richik GhoshThakur, Aman Basu, Zinia Haque, Biswarup Bhattacharya, Santipada GonChaudhuri, Srinivasan Balachandran*

As people living in remote areas still lack access to indoor lighting, the intervention of appropriate need-based innovations to improve basic indoor lighting facilities are essential. The present work discusses the development of a hybrid lighting device: Micro Solar Dome that utilizes both the active and passive forms of solar energy to ensure sustainable lighting facilities for rural houses. The work elaborates the design, simulation, and pilot-scale installation of the device in 8 Indian states. Based on the performance, a Principal Component Analysis was done, which indicated that more than 93% variation of the performance of the device was due to Global Horizontal Irradiance and Relative Humidity.

## The development of carbon capture and storage in India: A critical review

*Carbon Capture Science & Technology* **2**: 1–33
*Rohit Shawa, Soumyajit Mukherjee*

Carbon capture and sequestration (CCS) is a three-tier process: carbon capture, transport and storage. The capture consists of pre-combustion, oxy-combustion and post-combustion capture. Transport of $CO_2$ is most viable through pipelines. The biotic $CO_2$ storage occurs through terrestrial or oceanic pathways and can be simulated naturally or artificially. The abiotic/geologic storage is achieved through sequestering $CO_2$ in depleting/depleted hydrocarbon reserves, in deep saline aquifers or through mineral carbonation. At the district level, 64 out of 641 districts (2013 government reports) accounted for 60% of the total $CO_2$ emissions. Controlling $CO_2$ emissions comes with the challenge of sustainable socio-economic growth of the country – a demanding task for the economy.

## A review of piezoelectric energy harvesting tiles: Available designs and future perspective

*Energy Conversion and Management* **254**: 1–14
*Saurav Sharma, Raj Kiran, Puneet Azad, Rahul Vaish*

Piezoelectric energy harvesting has played a vital role in powering several engineering devices and systems, where conventional power supply is either not possible or not desirable. Another perspective for piezoelectric energy is its utilization as a non-conventional clean energy source, harnessing the ambient mechanical vibrations. With the increasing global population and developing infrastructure, the load from human footsteps can be a source of significant amount of freely available mechanical vibration energy. The piezoelectric tiles are aimed at harnessing this otherwise wasted energy with minimum interference to the regular activities. This article aims to provide a comprehensive review of the technologies and methodologies that have been implemented in the literature.

## Projected transition to electric vehicles in India and its impact on stakeholders

*Energy for Sustainable Development* **66**: 189–200
*B.K. Chaturvedi, Atri Nautiyal, T.C. Kandpal, Mohammed Yaqoot*

As electric vehicles share strong linkage with multiple sustainable development goals, India is aiming to achieve 30% electric vehicle (EV) share by year 2030 under the EV30@30 Campaign. The projected transition to EVs would: a) reduce consumption of petroleum fuels currently used for road transportation; b) shift the consumer demand from internal combustion engine-based automobiles to EVs; and c) require additional electricity and network of charging infrastructure for energizing EVs. These changes are going to affect multiple stakeholders in different ways. This paper is a modest attempt to capture the projected transition to EVs in India and its impact on the stakeholders. Impact assessment of stakeholders under various scenarios highlights that the transition is going to be challenging for central and state governments, petroleum sector and automobile industry; whereas for electricity sector, it is expected to open new investment and business opportunities. For smooth transition to EVs, this study proposes synergy between stakeholders, revamping of automobile industry and introduction of green/pollution taxes on additional products and services.

## Dual Fresnel lens and segmented mirrors based efficient solar concentration system without tracking sun for solar thermal energy generation

*Energy for Sustainable Development* **66**: 201–208
*Mayank Gupta, Atyant Bhatnagar, Atul Kumar Dubey, Virendra Kumar, Dalip Singh Mehta*

We propose and experimentally demonstrate a combination of two large Fresnel lenses and six segmented mirrors, for concentrating sunlight efficiently within a common area throughout the day without tracking the sun. The proposed system was used for efficient solar thermal power generation, i.e., efficient heating of water. The angular position of two lenses is designed and mounted in such a way that the lenses are in direct line-of-sight with the sun for efficient sunlight collection during early morning, mid-day and for evening hours. Further, the height gap between Fresnel lenses and receiver unit is sufficient enough such that there is no shadow effect on the receiver unit, hence, the receiver unit is also exposed to direct sunlight rays throughout the day. Due to concentration of sunlight throughout the day, the efficiency of solar thermal system is significantly enhanced.

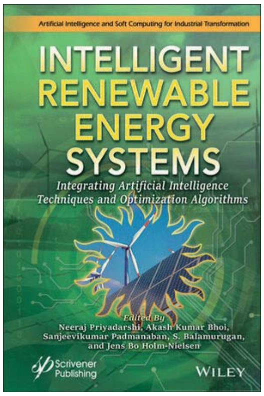
## *Musa acuminata peel*: A bioresource for bio-oil and by-product utilization as a sustainable source of renewable green catalyst for biodiesel production

*Renewable Energy* **187**: 450–462
*Niran Daimary, Pankaj Boruah, Khalifa, S.H. Eldiehy, Tapan Pegua , Pritam Bardhan, Utpal Bora, Manabendra Mandal, Dhanapati Deka*

This study emphasizes the vision of a green, renewably and sustainably integrated route for the catalyst synthesis process and to transform fruit and kitchen wastes into fuel. The alkali and alkaline earth metal-rich biochar, a by-product obtained from banana peel thermochemical conversion (pyrolysis), was calcined and utilized as a catalyst for converting soybean waste cooking oil (SWCO) to biodiesel. The catalyst was characterized by X-ray diffraction (XRD), Transmission Electron Microscopy (TEM), Field Emission Scanning Electron Microscopy (FESEM), Brunauer-Emmett-Teller (BET), Fourier Transform Infrared Spectroscopy (FTIR), Energy-dispersive X-ray spectroscopy (EDX), and Thermo-gravimetric analysis (TGA). The synthesized catalyst showed a high catalytic activity due to the abundance of potassium in oxide and carbonate form.

## Intelligent Renewable Energy Systems: Integrating Artificial Intelligence Techniques and Optimization Algorithms

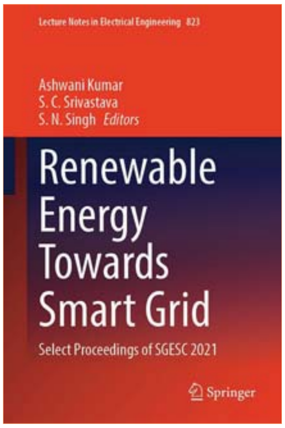
This book illustrates modelling, simulation, design and control of renewable energy systems employed with recent artificial intelligence (AI) and optimization techniques for performance enhancement. Current renewable energy sources have less power conversion efficiency because of its intermittent and fluctuating behavior. Therefore, in this regard, the recent AI and optimization techniques are able to deal with data ambiguity, noise, imprecision, and nonlinear behavior of renewable energy sources more efficiently compared to classical soft computing techniques. This book provides an extensive analysis of recent state-of-the-art AI and optimization techniques applied to green energy systems. Subsequently, researchers, industry persons, undergraduate and graduate students involved in green energy will greatly benefit from this comprehensive volume, a must-have for any library. EF



Authors: Neeraj Priyadarshi, Akash Kumar Bhoi, Sanjeevikumar Padmanaban, S. Balamurugan, Jens Bo Holm-Nielson
Publisher: Wiley, 500p
Year: 2022

## Renewable Energy Towards Smart Grid: Select Proceedings of SGESC 2021

The book contains select proceedings of the International Conference on Smart Grid Energy Systems and Control (SGESC 2021). The proceedings are divided into 3 volumes, and this volume focuses on renewable energy towards the smart grid. It includes papers related to smart grid, renewable energy, its integration, and DERs in the network for better energy management and ancillary services. The book presents cutting-edge research in the emerging fields of micro, nano, and smart devices and systems from experts. Most of the contributors have built devices or systems or developed processes or algorithms in these areas. This book is a unique collection of chapters from different areas with a common theme and will be immensely useful to academic researchers and practitioners in the industry. EF



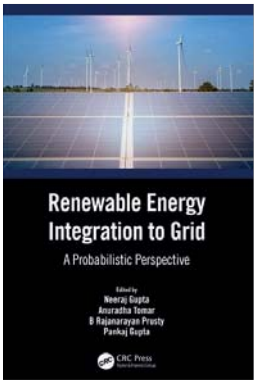
Authors: Ashwani Kumar , S. C. Srivastava , S. N. Singh
Publisher: Springer, 458p
Year: 2022

## Renewable Energy Integration to Grid: A Probabilistic Perspective

This comprehensive reference text discusses uncertainty modeling of renewable energy resources and its steady state analysis. The text discusses challenges related to renewable energy integration to the grid, techniques to mitigate these challenges, problems associated with integration at transmission and distribution voltage level, and protection of power system with large renewable power integration. It covers important concepts including voltage issues in power networks, use of FACTS devices for reactive power management, stochastic optimization, robust optimization, and spatiotemporal dependence modeling.

*Key Features:*

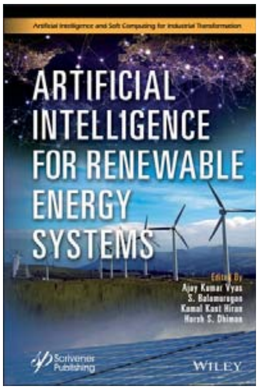
- Presents analysis and modeling of renewable generation uncertainty for planning and operation, beneficial for industry professionals and researchers.
- Discusses dependence modeling of multi-site renewable generations in detail.
- Covers probabilistic analysis, useful for data analysts.
- Discusses various aspects of renewable energy integration i.e. technical, economic, etc. EF



Authors: Neeraj Gupta, Anuradha Tomar, B Rajanarayan Prusty, Pankaj Gupta
Publisher: CRC Press, 262p
Year: 2022

## Artificial Intelligence for Renewable Energy Systems

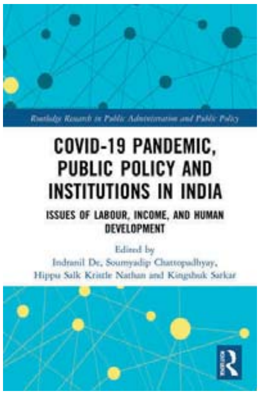
Renewable energy systems, including solar, wind, biodiesel, hybrid energy, and other relevant types, have numerous advantages compared to their conventional counterparts. This book presents the application of machine learning (ML) and deep learning (DL) techniques for renewable energy system modeling, forecasting, and optimization for efficient system design. Due to the importance of renewable energy in today's world, this book was designed to enhance the reader's knowledge based on current developments in the field. For instance, the extraction and selection of machine learning algorithms for renewable energy systems, forecasting of wind and solar radiation are featured in the book. Also highlighted are intelligent data, renewable energy informatics systems based on supervisory control and data acquisition (SCADA); and intelligent condition monitoring of solar and wind energy systems. Moreover, an AI-based system for real-time decision-making for renewable energy systems is presented; and also demonstrated is the prediction of energy consumption in green buildings using machine learning. The chapter authors also provide both experimental and real datasets with great potential in the renewable energy sector, which apply machine learning and deep learning algorithms that will be helpful for economic and environmental forecasting of the renewable energy business.



Authors: S. Balamurugan, Ajay Kumar Vyas, Kamal Kant Hiran, Harsh S. Dhiman
Publisher: Wiley, 272p
Year: 2022

## COVID-19 Pandemic, Public Policy, and Institutions in India: Issues of Labour, Income, and Human Development

The book is split into four parts. Part One outlines the approach of the study, in particular, the examination of policy responses and the effect of the pandemic. Part Two delves into the governance challenges in containing the pandemic while giving the theoretical rationale for institutional responses. Part Three looks at how the pandemic affected economically vulnerable households, workers, and small industries. The effect of pandemic on the informal sector is also detailed. Part Four examines the impacts and responses of Indian public infrastructure and services to the pandemic, in particular, the impact of the COVID-19 outbreak on healthcare and schooling. It also explores the challenges caused by infrastructure inadequacies in Indian cities. The book closes by looking at how businesses in the private sector have responded to the COVID-19 pandemic, with a focus on Corporate Social Responsibility (CSR). The book will be a useful reference to researchers, policymakers, and practitioners who are interested in institutions and development, especially in the context of India.



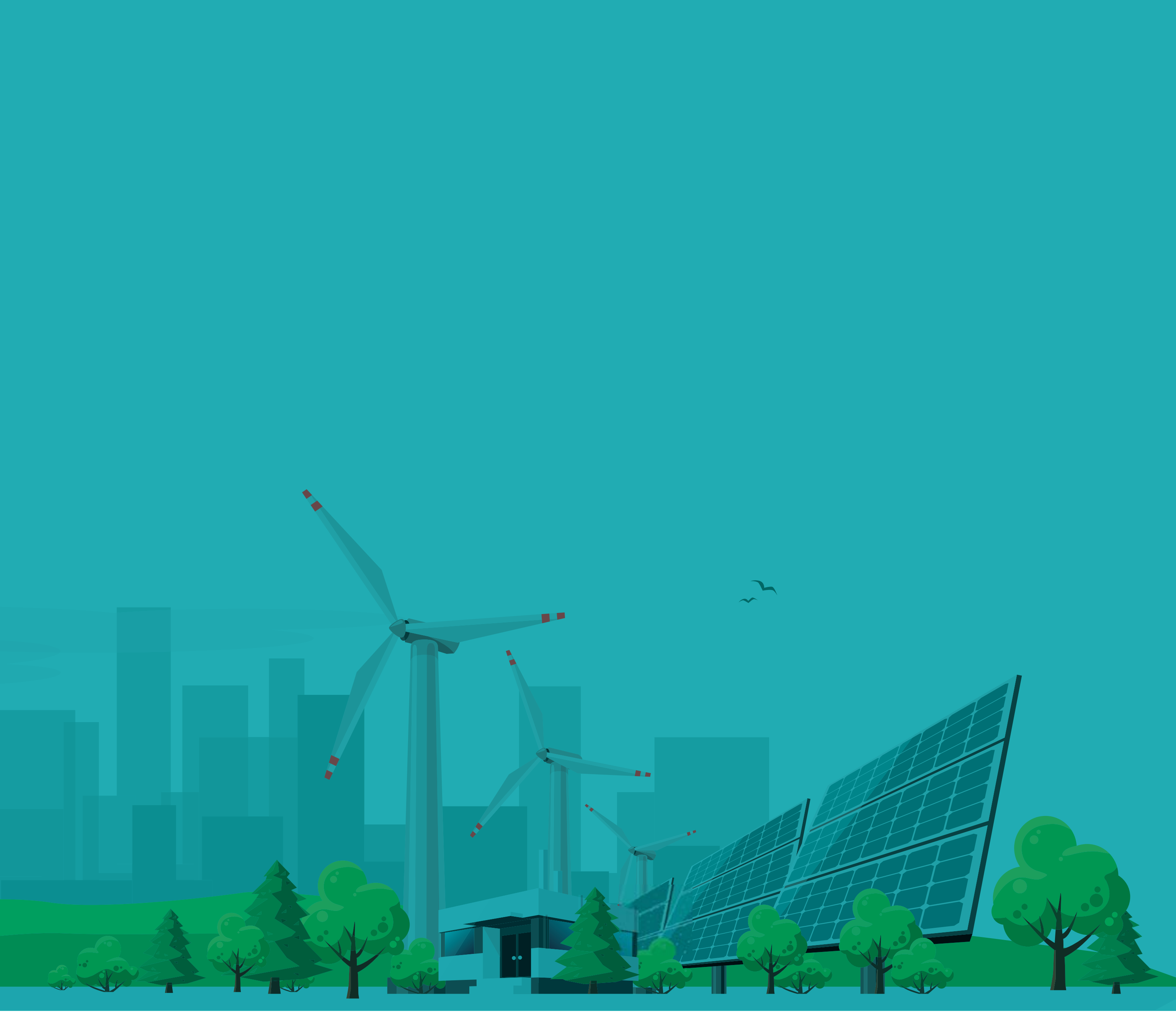
Authors: Indranil De, Soumyadip Chattopadhyay, Hippu Salk Kristle Nathan, Kingshuk Sarkar
Publisher: Routledge: 1st edition, 222p
Year: 2022

# RENEWABLE ENERGY TECHNOLOGY DEVELOPMENT

## Self-healing nanomaterials usable in solar panels and other electronic devices

The field of self-repairing materials is rapidly expanding, and what used to be science fiction might soon become reality, thanks to Technion – Israel Institute of Technology scientists who developed eco-friendly nanocrystal semiconductors capable of self-healing. Their findings, recently published in Advanced Functional Materials, describe the process, in which a group of materials called double perovskites display self-healing properties after being damaged by the radiation of an electron beam. The perovskites, first discovered in 1839, have recently garnered scientists' attention due to unique electro-optical characteristics that make them highly efficient in energy conversion, despite inexpensive production. A special effort has been put into the use of lead-based perovskites in highly efficient solar cells.

The Technion, research group of Professor Yehonadav Bekenstein from the Faculty of Material Sciences and Engineering and the Solid-State Institute, is searching for green alternatives to the toxic lead and engineering lead-free perovskites. The team specializes in the synthesis of nano-scale crystals of new materials. By controlling the crystals' composition, shape, and size, they change the material's physical properties. Nanocrystals are the smallest material particles that remain naturally stable. Their size makes certain properties more pronounced and enables research approaches that would be impossible



on larger crystals, such as imaging using electron microscopy to see how atoms in the materials move. This was, in fact, the method that enabled the discovery of self-repair in the lead-free perovskites.

The perovskite nanoparticles were produced in Prof. Bekenstein's lab using a short, simple process that involves heating the material to 100°C for a few minutes. When Ph.D. students Sasha Khalfin and Noam Veber examined the particles using a transmission electron microscope, they discovered the exciting phenomenon. The high voltage electron beam used by this type of microscope caused faults and holes in the nanocrystals. The researchers were then able to explore how these holes interact with the material surrounding them and move and transform within it.

They found that holes formed on the surface of the nanoparticles, and then moved to energetically stable areas inside. The reason for the holes' movement inwards was hypothesized to be organic molecules coating the nanocrystals' surface. Once these organic molecules were removed, the group discovered the crystal spontaneously ejected the holes to the surface and out, returning to its original pristine structure – in other words, the crystal repaired itself. This discovery is an important step towards understanding the processes that enable perovskite nanoparticles to heal themselves, and paves the way to their incorporation in solar panels and other electronic devices.

*https://www.sciencedaily.com/releases/2022/01/220103104609.htm*

## Carbon-coated nickel enables fuel cell free of precious metals

Cornell University researchers have found a nitrogen-doped carbon-

coated nickel anode that can catalyse an essential reaction in hydrogen fuel cells at a fraction of the cost of the precious metals currently used. The new discovery could accelerate the widespread use of hydrogen fuel cells, which hold great promise as efficient, clean energy sources for vehicles and other applications. "This finding makes progress toward using efficient, clean hydrogen fuel cells in place of fossil fuels", said Héctor D. Abruña, professor in the department of chemistry and chemical biology at Cornell University. The results were published March, 2021 a 'A Completely Precious-Metal-Free Alkaline Fuel Cell With Enhanced Performance Using a Carbon-Coated Nickel Anode', in the Proceedings of the National Academy of Sciences.

Expensive precious metals, such as platinum, are currently required in hydrogen fuel cells to efficiently catalyse the reactions they employ to produce electricity. Although alkaline polymer electrolyte membrane fuel cells (APEMFCs) enable the use of nonprecious metal electrocatalysts, they lack the necessary performance and durability to replace precious metal-based systems. But what about other materials? Recent experiments with nonprecious-metal HOR electrocatalysts needed to overcome two major challenges, the researchers wrote: low intrinsic activity from too strong a hydrogen binding energy, and poor durability due to rapid passivation from metal oxide formation.

To overcome these challenges, the researchers designed a nickel-based electrocatalyst with a 2 nanometer shell made of nitrogen-doped carbon. Their hydrogen fuel cell has an anode (where hydrogen is oxidized) catalyst consisting of a solid nickel core surrounded by the carbon shell. When paired with a cobalt-manganese cathode (where oxygen is reduced), the resulting completely precious-metal-free hydrogen fuel cell outputs more than 200 milliwatts per square centimeter. "The use of this novel anode would dramatically lower prices enabling the application of alkaline fuel cells in a wide variety of areas", Abruña said.

*https://www.sciencedaily.com/releases/2022/03/220324184546.htm#:~:text=Summary%3A,currently%20used%2C%20researchers%20have%20found.*

## Materials scientists finding solutions to biggest hurdle for solar cell technology

Materials scientists at the UCLA Samueli School of Engineering, along with colleagues from five other universities around the world have discovered the major reason why perovskite solar cells – which show great promise for improved energy-conversion efficiency – degrade in sunlight, causing their performance to suffer over time. The team successfully demonstrated a simple manufacturing adjustment to fix the cause of the degradation, clearing the biggest hurdle toward the widespread adoption of thin-film solar cell technology.

A research paper detailing the findings was published in Nature as an early access paper. The research is led by Yang Yang, a UCLA Samueli professor of materials science and engineering and holder of the Carol and Lawrence E. Tannas, Jr., Endowed Chair. The co-first authors are Shaun Tan and Tianyi Huang, both recent UCLA Samueli Ph.D. graduates whom Yang advised.

Perovskites are a group of materials that have the same atomic arrangement or crystal structure as the mineral calcium titanium oxide. A subgroup of perovskites, metal halide perovskites are of great research interest because of their promising application for energy-efficient, thin-film solar cells. Perovskite-based solar cells could be manufactured at much lower costs than their silicon-based counterparts, making solar energy technologies more accessible if the commonly known degradation under long exposure to illumination can be properly addressed.

“Perovskite-based solar cells tend to deteriorate in sunlight much faster than their silicon counterparts, so their effectiveness in converting sunlight to electricity drops over the long term”, said Yang, who is also a member of the California NanoSystems Institute at UCLA. “However, our research shows why this happens and provides a simple fix. This represents a major breakthrough in bringing perovskite technology to commercialization and widespread adoption.”

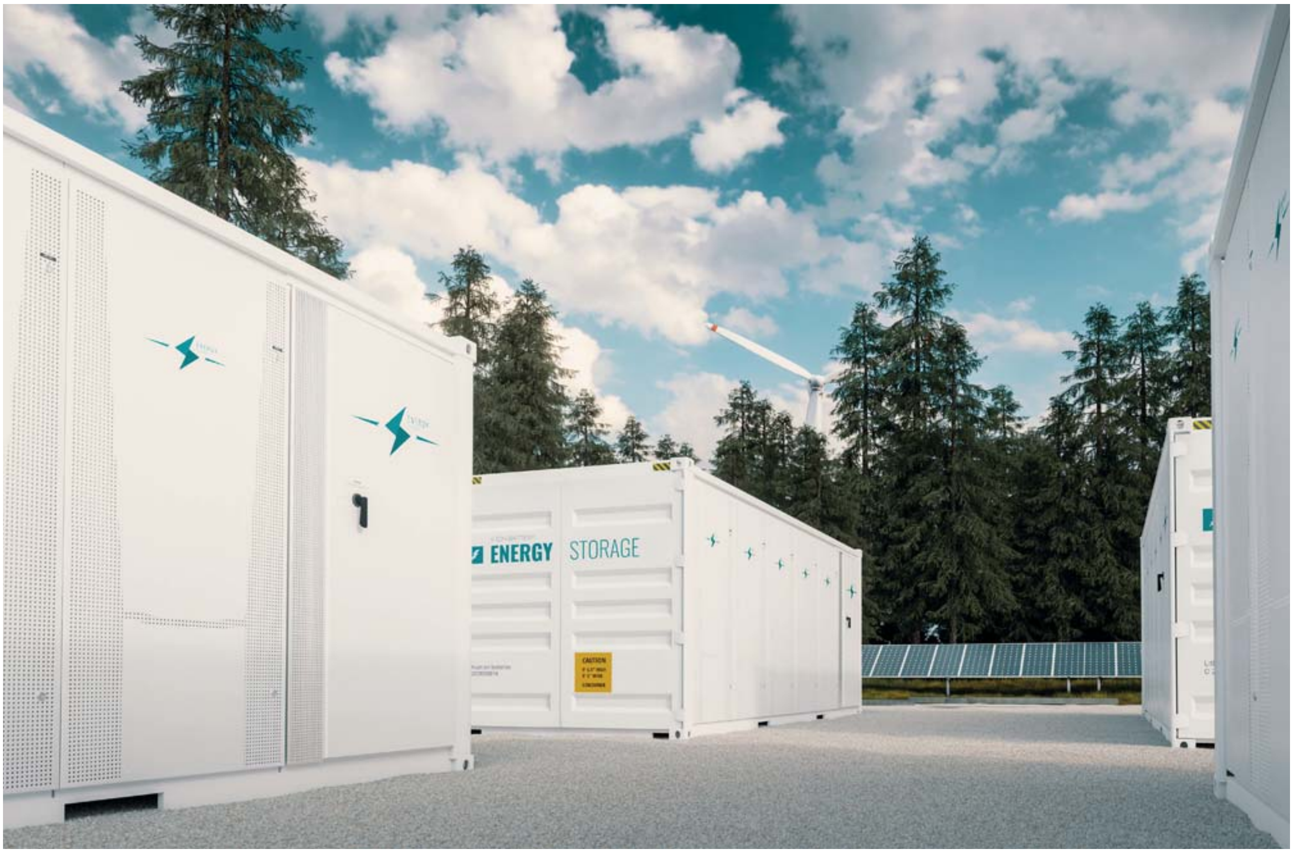
A common surface treatment used to remove solar cell defects involves depositing a layer of organic ions that makes the surface too negatively charged. The UCLA-led team found that while the treatment is intended to improve energy-conversion efficiency during the fabrication process of perovskite solar cells, it also unintentionally creates a more electron-rich surface – a potential trap for energy-carrying electrons. This condition destabilizes the orderly arrangement of atoms, and over time, the perovskite solar cells become increasingly less efficient, ultimately making them unattractive for commercialization.

Armed with this new discovery, the researchers found a way to address the cells' long-term degradation by pairing the positively charged ions with negatively charged ones for surface treatments. The switch enables the surface to be more electron-neutral and stable, while preserving the integrity of the defect-prevention surface treatments.

*https://www.sciencedaily.com/releases/2022/03/220315141803.htm*

## How to clean solar panels without water

Solar power is expected to reach 10% of global power generation by the year 2030, and much of that is likely to be



located in desert areas, where sunlight is abundant. But the accumulation of dust on solar panels or mirrors is already a significant issue – it can reduce the output of photovoltaic panels by as much as 30% in just one month – so regular cleaning is essential for such installations.

But cleaning solar panels currently is estimated to use about 10 billion gallons of water per year, enough to supply drinking water for up to 2 million people. Attempts at waterless cleaning are labour intensive and tend to cause irreversible scratching of the surfaces, which also reduces efficiency. Now, a team of researchers at MIT has devised a way of automatically cleaning solar panels, or the mirrors of solar thermal plants, in a waterless, no-contact system that could significantly reduce the dust problem.

The new system uses electrostatic repulsion to cause dust particles to detach and virtually leap off the panel's surface, without the need for water or brushes. To activate the system, a simple electrode passes just above the solar panel's surface, imparting an electrical charge to the dust particles, which are then repelled by a charge applied to the panel itself. The system can be operated automatically using a simple electric motor and guide rails along the side of the panel. The research is described in the journal Science Advances, in a paper by MIT graduate student Sreedath Panat and professor of mechanical engineering Kripa Varanasi.

Despite concerted efforts worldwide to develop ever more efficient solar panels, Varanasi says, "a mundane problem like dust can actually put a serious dent in the whole thing". Lab tests conducted by Panat and Varanasi showed that the drop-off of energy output from the panels happens steeply at the very beginning of the process of dust accumulation and can easily reach 30% reduction after just one month without cleaning. Even a 1% reduction in power, for a 150-megawatt solar installation, they calculated, could result in a USD 200,000 loss in annual revenue. The researchers say that globally, a 3% to 4% reduction in power output from solar plants would amount to a loss of between USD 3.3 billion and USD 5.5 billion.

*https://www.sciencedaily.com/releases/2022/03/220311141427.htm*

## Fuel from waste wood

Ethanol is usually produced through the fermentation of sugars from starchy raw materials such as corn, or from lignocellulosic biomass, such as wood or straw. It is an established fuel that decarbonizes the transportation sector and can be a building block to reduce emissions of $CO_2$ over the long term. In collaboration with the Lappeenranta-Lahti University of Technology (LUT) in Finland, researchers at the Straubing Campus for Biotechnology and Sustainability of the Technical University of Munich (TUM) have developed a new process for the production of ethanol.

In this context, offcut materials from the area of forestry are used together with hydrogen. The hydrogen is produced by separating water into hydrogen and oxygen with the use of electricity or water electrolysis. In the future, this will allow the excess electricity to be used for the production of ethanol.

"The overall process mainly consists of technically mature sub-processes. However, the composition of the process steps and the final step – the hydrogenation of acetic acid to produce ethanol – are new", explains Daniel Klüh, a doctoral student at the Professorship of Renewable Energy Systems at the TUM Straubing Campus.

The researchers have also assessed the economic feasibility. "The prices we have calculated are based on assumptions for raw materials and energy. We are not using any current market prices. The calculation basis of our prices for the components in the chemical system is the year 2020", explains Klüh. The lowest cost for ethanol in the modelling was 0.65 euros per litre, with biomass costs of 20 euros per megawatt hour, electricity costs of 45 euros per megawatt hour, and a production volume of approximately 42 kilotons of ethanol per year.

"With the current lignocellulosic ethanol production options, the costs are therefore competitive. The price of ethanol is very sensitive to the costs of electricity, and fluctuates between 0.56 and 0.74 euros per litre", explains Assistant Professor Kristian Melin of LUT in Finland. One reason for the high profitability is that the ethanol yield is much higher compared to traditional fermentation based bioethanol process from straw or wood. This process produces 1350 to 1410 litres of ethanol, compared to only 200 to 300 litres of ethanol for the traditional process per dry ton of biomass.

*https://www.sciencedaily.com/releases/2022/03/220329114726.htm*

## Disorder-engineered inorganic nanocrystals set a new efficiency record for ultrathin solar cells

Displayed over roof tops and in solar farms, silicon-based solar cells are, so far, one of the most efficient systems in generating electricity from sunlight, but their fabrication can be expensive and energy demanding, aside from being heavy and bulky. The alternative solution of lower-cost thin film solar cells also brings the caveat of being mainly composed of toxic elements, such as lead or cadmium, or containing scarce elements such as indium or tellurium. In the search for new technologies for thin photovoltaic systems, solar cells based on $AgBiS_2$ nanocrystals have emerged as a star player in the game, consisting of non-toxic, earth-abundant elements, produced in ambient conditions at low temperatures and with low-cost solution-processing techniques. It can be integrated in ultrathin solar cells and has proven to be very stable, avoiding degradation of the cell over long periods of time.

As such, many studies delved into ways to improve their performance and found that the optimal thickness of these semiconductor absorbers is closely linked to the absorption coefficients, thus the goal would be to find an ultrathin solar cell capable of having a high absorption efficiency, quantum efficiency and ultimate performance while reducing cost, weight and manufacturing. But, while aiming for an ultra-thin layered cell, the issue of dealing with light-trapping structures would add cost and complexity to the issue, because the thinner the structure, the more complex it becomes to absorb energy.

To overcome this challenge, ICFO researchers Yongjie Wang, Ignasi Burgues-Ceballos, in collaboration with Prof David Scanlon from University College London, Prof Aron Walsh from Imperial College London and Seán Kavanagh (UCL and Imperial), led by ICREA Prof. at ICFO Gerasimos Konstantatos, have made a considerable leap forward and achieved a ground-breaking result. Published in Nature Photonics, their study reports on a completely new approach towards the fabrication of these solar cells – based on $AgBiS_2$ that enables absorption coefficients higher than any other photovoltaic material used to date.

*https://www.sciencedaily.com/releases/2022/02/220214111751.htm*

# ACHIEVING GREEN STEEL

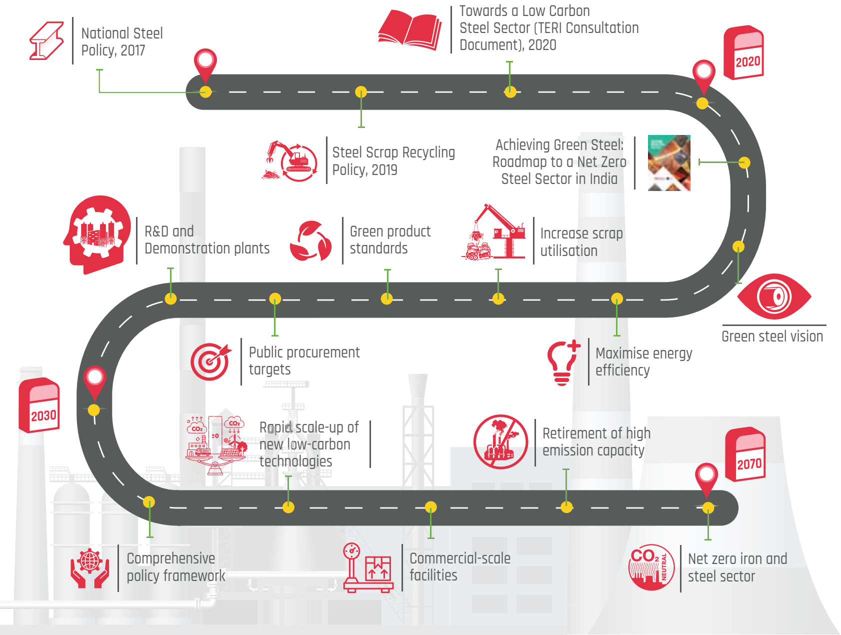
## Roadmap to a net zero steel sector in India

## Introduction

The steel sector plays an important role in the Indian economy; as a critical input for various sectors, steel helps support the infrastructure that facilitates growth, the housing that drives urbanization, and the machinery and tools that power industrialization. Naturally, to satisfy these demands the steel sector in India is expected to grow significantly in the coming decades. However, if India is to continue its leadership on climate change and future-proof its steel industry for a net-zero world, then an ambitious strategy for emissions reduction is required.

In July 2022, The Energy and Resources Institute (TERI) published the "Achieving Green Steel: Roadmap to a Net Zero Steel Sector in India" which sets out such a strategy by detailing the short-term (2020 to 2030) and the long-term (2030 onward) actions required to achieve net-zero emissions for the sector by 2070. It provides a road map that quantifies the scale of the challenge, setting out in clear terms what is required for India to put itself on the path for reaching net-zero by 2070. This includes measures to maximize energy efficiency, increase scrap utilization, set green product standards, develop public and private procurement targets and build commercial-scale demonstration plants in the nearer term. Over the long term, these should inform a more comprehensive policy framework that will assist a mass-market switch to green steel production and use, supported by phase-out policies for older polluting plants, alongside support for new, near zero emission plants. In doing so, India can pioneer a model of 'industrialization without carbonization', setting an example for emerging economies around the world.

This road map is a follow up to the consultation document published by TERI in 2020, titled 'Towards A Low Carbon Steel Sector: An Overview of The Changing Market, Technology and Policy Context For Indian Steel'.



## Background

The global steel industry has continued to grow rapidly over the past few decades, with a significant portion of that growth coming from China, which still produces over half of the world's steel. BF-BOF (Blast Furnace – Basic Oxygen Furnace) and EAF (Electric Arc Furnace) are the dominant routes, currently holding a greater than 99% share for global crude steel production.

Figure 1 sets out a 'business as usual scenario' for steel demand and scrap availability over the coming decades. Currently, the top 5 steel consuming countries are China, India USA, Japan, and South Korea. It is expected that the steel demand in India will increase significantly by 2050, making it challenging to drastically increase scrap usage as a share of overall steel production. However, in countries such as China an increase in scrap availability combined with declining overall demand, will allow for a switch to cleaner secondary production as can already be observed.

In 2018, India overtook Japan as the second largest producer of steel, symptomatic of a broader shift in steel production and demand to developing countries. Currently, India is still the second largest producer and also the

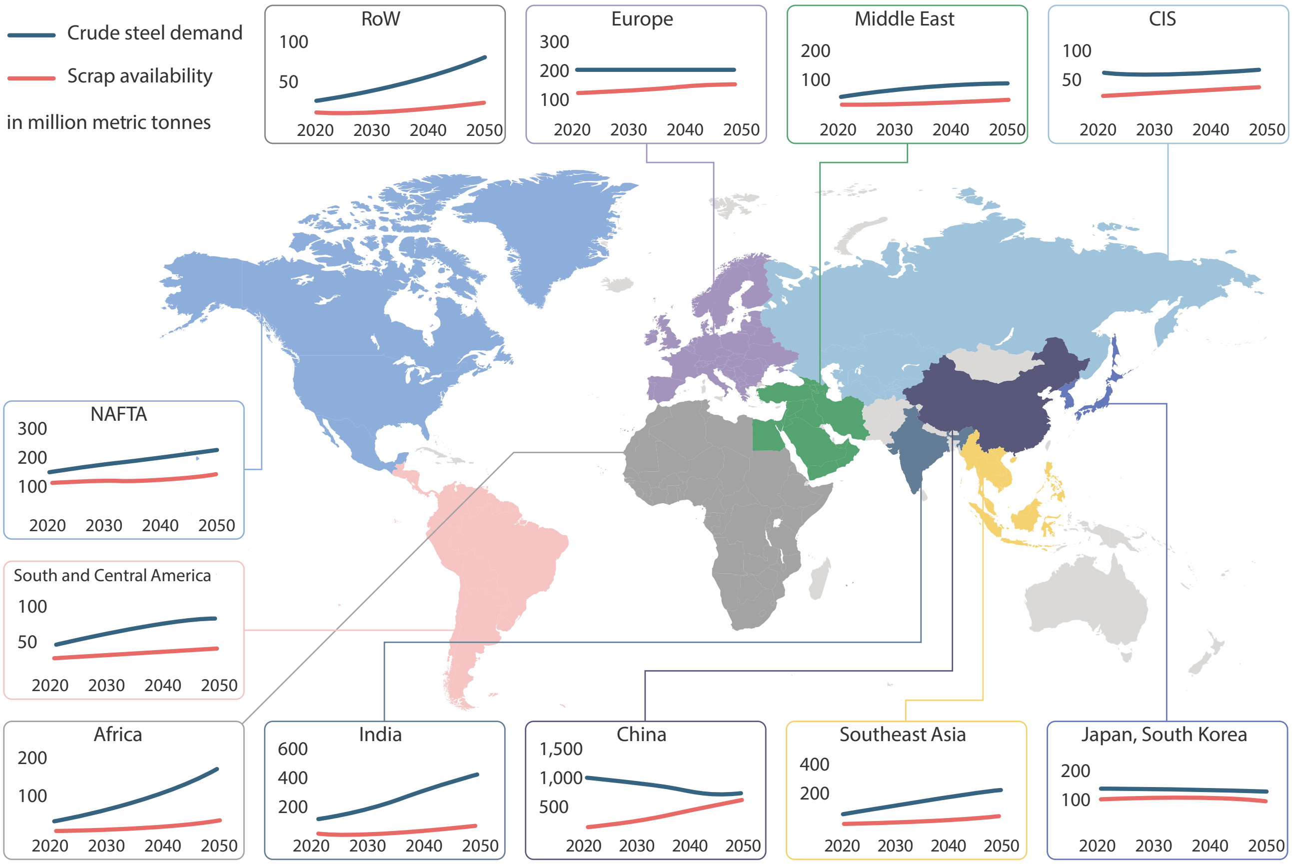


**Figure 1**: BAU demand for crude steel and scrap availability

***Source***: *(MPP, 2021)*

second largest consumer of steel in the world.

The Indian steel industry is relatively heterogeneous. There are a wide range of different-sized facilities in the primary and secondary steel-making sectors. BOF technology dominates a growing share of steel production in India, with EAF and EIF (Electric Induction Furnace) taking an almost equal share of the remainder of the market. Additionally, use of coal-based direct reduction processes is unique to the Indian steel sector and is mainly used in smaller facilities to meet local steel demands. However, use of induction furnaces along with coal-based indirect reduction often results in lower quality steel – as a result of the residual phosphorous. This is one reason because of which a decline in the market share of this route is likely to be seen, with most new steel capacity focused on the BF-BOF and EAF technologies.

As with any industrialising economy, the steel sector is of vital importance to India, contributing around 2% of the country's GDP and employing around 2.5 million people in the steel and related sectors. In terms of production capacity, India reached 144 Mt as of mid-2021. The private sector contributes the majority of this (82%) with 118 Mt currently under operation. There is also significant new capacity in the pipeline, such as, the new 24 Mt Arcelor Mittal/ Nippon Steel facility slated for Odisha, which would be the largest plant in the world. Over 2020-21, utilization rate for this capacity stood at around 70%.

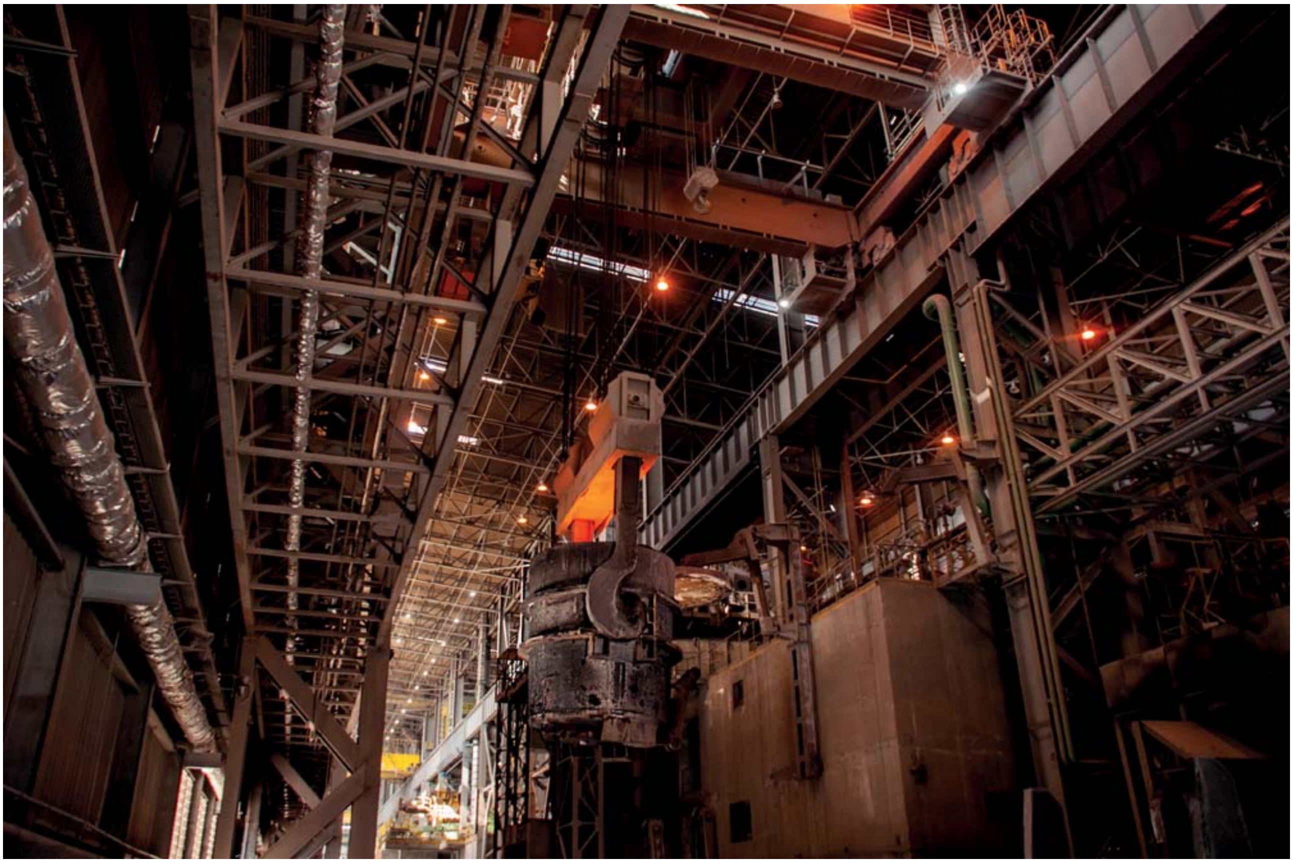
In 2017, the Ministry of Steel (MoS) launched the National Steel Policy (NSP) which included an aim to increase India's steel-making capacity to 300 Mt by 2030. This policy also encompasses targets to reduce energy consumption per tonne of steel, through adopting the latest energy efficiency measures. Alongside energy efficiency, the government has begun efforts to increase material circularity with the MoS launching their Steel Scrap Recycling Policy in 2019, aimed at increasing the availability and use of steel scrap throughout India.

## *Macro Trends*

Macro trends, namely development, digitization, and decarbonization, have the potential to radically change the way steel is produced and consumed.

## Development

Emerging economies like India are likely to become the centre for steel demand growth in the coming decades – as other major economies, such as China, stabilize.



According to the analysis of the historical experiences of many countries, it was found that the most significant determinants of steel demand are income (GDP per capita), the rate of investment (GFCF) and the level of industrialization in the economy (industrial GVA). India is already the world's second largest steel producing country and is expected to increase its annual production volumes by 2050 – by an amount equivalent to twice that of the European Union's total production in 2019. Whilst the pandemic is likely to have a significant short-term impact on the steel sector, the underlying factors that will drive growth over medium and long term (population growth, industrialization growth and income, support for media infrastructure projects such as *Gati Shakti*, etc.), persist.

## Digitalization

As with others, the iron and steel sector will also benefit from the digitalization of production process in supply chains. It will likely have a step-change impact on operational efficiencies.

Emerging technologies that are being considered in the steel industry include augmented reality, virtual reality, blockchain, artificial intelligence, 3D printing, drones and robots. In an era of smart machines, commerce storage systems and production facilities, the above mentioned technologies would be capable of autonomous information exchange, triggering actions and controlling each other independently. This can result in significant cost savings through reduction in labour costs, improvement in efficiency and minimization of error. For example, Jindal Steel and Power Ltd (JSPL) has implemented an IoT framework at its facility in Angul, Odisha, using a network of machines, advanced analytics, and highly skilled IT professionals. As a result, the health and status of machines can be monitored remotely and immediately, greatly improving the efficiency and productivity of the plant.

## Decarbonization

The growing imperative for decarbonization is arguably the trend driving the most significant disruption in the iron and steel sector. This sector is currently both highly energy and emissions-intensive, accounting for 8% of global final energy use and 7% of global direct energy related $CO_2$ emissions (including industrial process emission).

In India, total emissions from the iron and steel sector are around 250 $MtCO_2$ (about 10% of total emissions) and will increase more than three-fold to approximately 800 $MtCO_2$ by 2050 – if no action to decarbonize is taken. For further emissions reduction, introduction of new low-carbon technologies will be required, such as, the use of low carbon hydrogen or carbon capture, utilization and storage (CCUS).

Whilst it is true that some Indian steel companies are already taking significant steps to reduce energy consumption and emissions, the pace and scale of transition taking place in other regions – most notably Europe and China – puts the domestic sector at risk of being left behind.

## Macroeconomic Impacts

The steel sector contributes around 2% of India's GDP and is valued at well over $100bn. The indirect contribution of the sector is significantly higher, given its enabling role in several end-use sectors including construction, infrastructure, industrial machinery and consumer products. For this reason, it is estimated that the investment in the Indian steel sector has an output multiplier effect of nearly 4 times on GDP and employment multiplier factor of 6.8 times, signalling its importance for India's future growth story.

The Indian iron and steel sector is currently relatively financially fragile. As impacts of Covid-19 pandemic have lessened, the global and Indian steel sector has seen an improvement in its condition. However, it is clear that large and risky investments will not be possible without support from public and private players – both domestic and international.

Western states, such as Gujarat, Maharashtra and Karnataka, have already benefitted significantly from good quality renewable resources (wind and solar), which will only continue as the electricity grid further decarbonizes. Interestingly, over 80% of India's iron reserves are in India's eastern states. It will be vital for the success of the energy transition that its benefits are spread more equally across India – a competitive, green steel sector in Eastern India can be an important part of that. Over 80% of India's iron reserves are in India's eastern states (Odisha, Jharkhand, West Bengal, Chhattisgarh, and North Andhra Pradesh). These states also have access to logistics infrastructure including: ports, inland waterways and slurry pipelines. The top states in terms of steel production include Odisha (25 Mt), Jharkhand (20 Mt), Chhattisgarh (19 Mt), Karnataka (15 Mt), Gujarat (13 Mt) and Maharashtra (12 Mt). The Ministry of Steel, under Mission Purvodaya, aims to support the development of an integrated steel hub in Eastern India to improve the competitiveness of the steel sector and facilitate regional development and job creation. This Mission aims to facilitate investments worth $70 billion, supporting new employment (up to 2.5 million jobs) and improvement in living standards among some of India's less wealthy states.

This sector currently employs approximately 2.5 million people throughout the supply chain. This is estimated to increase to around 3.5 million by 2030, depending on the degree of automation. The highest-skilled jobs include engineers and metallurgists, which are vital for the efficient operation of the plants and timely adoption of new technologies. However, the sector is currently facing a significant skill shortage, which is being exacerbated by skilled graduates moving away from the manufacturing

sectors to the service sectors. The shortage is particularly acute for metallurgists, where there could be a shortage of around 15,000 by the mid-2020s. For this reason, the steel sector needs to rapidly improve its offer to young graduates. An ambitious strategy for decarbonizing production and supporting the transition to net zero will be vital for attracting and retaining the best talent.

## Challenges

Cost-competitiveness of production, rapid growth of domestic demand, and the availability of required low emission technologies are some of the key challenges faced by the Indian iron and steel sectors for decarbonization.

While there have been significant improvements in the operational efficiencies of steel production, Indian steel producers are still facing costs around 5 to 10% higher as compared to the global average. The cost premium is driven by a number of factors, the main contributors being cost finance (approximately 12% versus 3% to 5% across the European Union) and the costs of logistics and infrastructure. For the latter, steel producers pay relatively high costs of raw material transport on Indian Railways which requires significant investment to be modernized.

Along with other factors, these place India at a comparative disadvantage, especially in some areas of higher technical sophistication – including stainless steel and alloy steel production. In addition, India’s free trade agreements (FTAs) with South Korea and Japan under the comprehensive economic partnership agreement in 2010 and 2012, respectively have led to a steady reduction in import duties for steel. These have fallen to 0.8% for Japan and 1.25% for South Korea. As a result, combined steel imports from Japan and Korea increased by 71% to 3.8 Mt in 2019-20; to help improve the relative competitiveness of domestic producers, the government has recently approved the production linked incentive scheme for ‘Specialty Steel’.

By 2050, it is expected that steel demand per capita will nearly quadruple to 295 kg per capita (Figure 2). This would make it similar to middle to high income economies today, being equivalent true steel use per capita across the European Union. Whilst the growth rate implied by these projections is high (5% CAGR), this is plausible, given the vast amount of steel that India still requires to develop. The near-term requirements for new steel production place additional pressures on the sector as new green steel production technologies are still not deployed at scale even in developed countries. This puts new capacity additions at risk of being stranded in later life, as the global steel sector decarbonizes and high emitting steel production becomes less competitive.

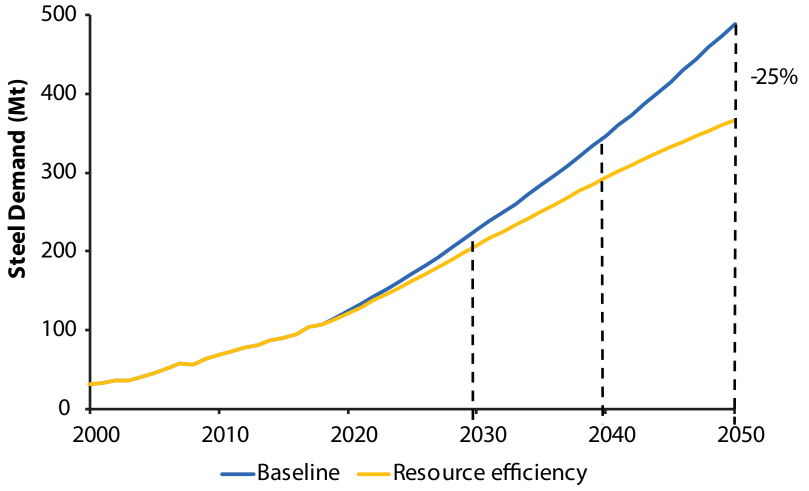


**Figure 2**: Steel demand scenarios including resource efficiency, 2000-50

***Source**: TERI analysis based on data from (MoS, 2017; Cullen, Allwood, & Bambach, 2012)*

To achieve deep decarbonization of the iron and steel sector, new technologies will be required – in particular for the replacement of conventional primary production processes with low emissions alternatives. There are several emerging low emissions technologies to produce steel from iron ore. They broadly fall into three categories:

» Carbon capture, utilization, and storage (CCUS)
» The use of low carbon hydrogen to replace fossil fuels
» Direct electrification through electrolysis of iron ore

An overview is provided in Table 1.

The transition towards a net-zero steel sector will be highly capital intensive. The Indian steel sector relies heavily on FDI, which was estimated to be over $14 billion between April 2000 and June 2020, representing 2.01% of total FDI. To aid in meeting the future capital requirements for the decarbonization of the steel sector, a clear statement of intent will be needed from the government on the future of ‘green steel’ in India. This will provide a clear signal for foreign investment.

Beyond the quantum of finance required for new projects, efforts to lower borrowing rates will also be required; for example, introducing blended finance options that can lower the costs of borrowing.

## Transition Pathways

The current makeup of India's iron and steel-making facilities shows an accelerating trend towards larger integrated steel plants using blast furnace, basic oxygen furnace, and electric arc furnace technologies, as per global trends.

India has seen a relatively steady growth in the blast furnace technology

**Table 1:** Low emissions steel-making technologies

| Technology | TRL | Emissions reduction potential | Suitability for deep decarbonization in India |
|---|---|---|---|
| **Carbon Capture, Utilization, and Storage** | | | |
| BF-BOF with CCUS | 5 | Possibility to reduce $CO_2$ by approximately 60%. Although higher capture rates are possible, costs increase substantially due to multiple $CO_2$ sources (IEA, 2017). | Limited cost-effective $CO_2$ capture will restrict the use of this technology for deep decarbonization, although could play an important role in retrofitting existing plants. |
| Coal-based DRI with CCUS | 4 | There have been no comprehensive studies on applying CCUS technology to coal-based rotary kilns for sponge iron production but similarity to natural gas DRI suggests around 90% reduction may be possible. | Coal-based DRI units tend to have smaller capacities potentially making the fixed and operating costs of CCUS excessively large. Given the early stage of development of the necessary technology, this seems to be unsuitable. |
| Natural gas DRI with CCUS | 9 | Currently, operating plants have shown that around 90% reduction is possible. | Limited availability of natural gas at competitive prices has already restricted the growth of natural gas-based capacity in India. Additional costs of CCUS would make these plants less competitive. |
| Smelting reduction with CCUS | 7 | Smelting reduction processes alone can reduce emissions by approximately 20% versus conventional BF-BOF. The addition of CCUS can potentially reduce emissions by 80% (Tata Steel, 2020). | Tata Steel have developed a pilot smelting reduction plant in the Netherlands (HIsarna) and are considering to install a larger demonstration plant in India. The CAPEX and OPEX savings make such a technology attractive, although the potential of CCUS is uncertain. |
| **Hydrogen** | | | |
| BF with $H_2$ blending | 7 | It is expected that $H_2$ would only be able to replace part of the injected coal, resulting in maximum 20% emissions reduction. | The limited emissions reduction means that $H_2$ injection into BFs can only ever be a transition technology to deeper decarbonisation. |
| $H_2$ DRI | 7 | Emissions reduction potential depends on the share of $H_2$ and whether the $H_2$ is from low carbon sources. Assuming 100% green $H_2$, emissions reduction can be >90%, with residual emissions from carbon sources for steel-making, graphite electrodes and limestone. | Low-cost renewable electricity provides a cost-effective route for green $H_2$ production. Whilst a high $H_2$ blend plant does not currently exist, technology is well understood. |
| H2 plasma reduction | 4 | If produced from low carbon electricity, there is the potential for >90% emissions reduction. | Technology is still at an early stage, although trials have been carried out in both Europe and in India (Institute of Minerals and Materials Technology, IMMT). Timeline for commercial scale is unknown. |
| **Direct electrification** | | | |
| Electrolysis | 4 | If produced from low carbon electricity, there is the potential for >90% emissions reduction. | Current research projects are still at early stages with uncertain timeline for commercial scale. (Siderwin and Boston Metal) |

since the 1960s, with a marked acceleration in deployment since 2000 – from which point two-thirds of the existing blast furnace capacity was added. Based on the largest assessment of blast furnace capacity done to date, it is estimated that the average blast furnace can last around 45 to 50 years, with 2-3 relining campaigns occurring over that timeframe. Relining the blast furnace represents the most significant investment over the lifetime of such a facility and therefore provides a point in time when the producer could choose between prolonging the life of such a plant, retrofitting with new low-emissions technology, or mothballing to be replaced by a new low-emissions technology.

Based on the average reinvestment timeframes, the existing blast furnace capacity in India will all reach the end of their lifetime by 2040 (Figure 3). Much of this capacity from the 2000s will likely only be entering its second campaign, thus limiting the potential of a complete technology switch without significant policy support.

After an assessment of the existing technology make-up, it is necessary to understand how future lower emission technologies could compete – in terms of both costs as well as broader suitability (resource availability, import-export impacts). In the detailed technology assessments undertaken by TERI and ETC for the Indian and global steel sector, it is observed that the costs of steel production from the main conventional routes in India range from

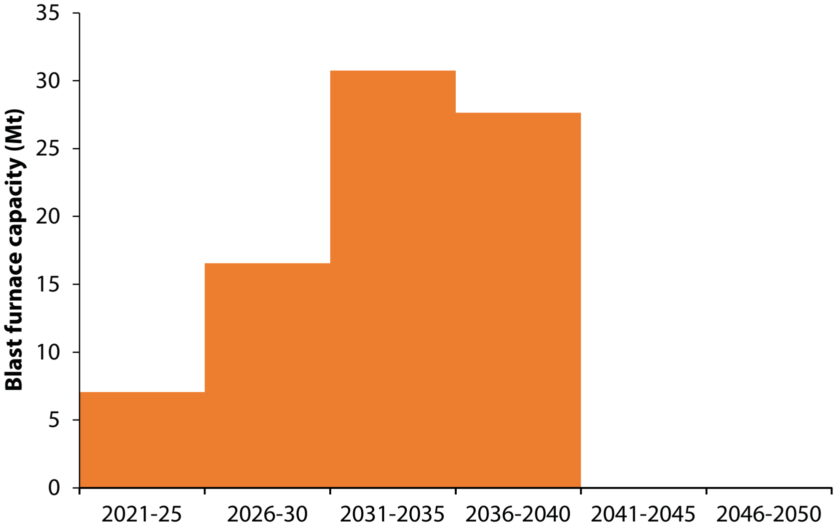


**Figure 3**: Reinvestment timeframe for existing blast furnace capacity in India

***Source**: Agora Industry, 2021*

around \$300/t of crude steel, to just below \$500/t.

Today, the cheapest route is coal-based direct reduction using a rotary kiln, because of lower capital and operational costs and access to cheaper, domestically available fuel. However, many of these plants are highly polluting and the quality of steel produced is not always sufficient for certain specialist applications. Next most competitive is the blast furnace with basic oxygen furnace (BF-BOF), which is the dominant route in India. Natural gas direct reduction is costlier in India due to the higher costs as well as uncertainty around continuous availability of natural gas. The range illustrated assumes delivered costs of \$8/mmbtu to \$12/mmbtu, which represents the historical range of imported natural gas prices – although current prices have been significantly higher. The costs of smelting reduction with CCUS assume that both capital and fixed operating costs are reduced, compared to costs in the BF-BOF plant – due to the removal of coke ovens, sintering plants and pellet factories.

Without CCUS costs, the costs of steel production from a smelting reduction plant would be around 20% cheaper than the conventional BF-BOF route (Figure 4). However, with the addition of CCUS infrastructure at the price of around \$20/t$CO_2$, (a range of \$20-\$80 is shown to reflect uncertainty), costs would be near equivalent to existing BF-BOF. There are also considerable uncertainties with regard to the availability of suitable sites for CCUS near the steel plant locations, as well as the costs of CCUS infrastructure in India, which are reflected in the larger cost range for the SR-BOF CCUS route.

Costs of production from the hydrogen direct reduction route are largely similar to those in the natural gas direct reduction route, with the main difference being the cost of hydrogen as a fuel versus natural gas. In the cost analysis, it is assumed that hydrogen is purchased from a separate producer by the steel plant, as opposed to having the capital costs of the electrolysers included in the capital costs of the steel plant. Costs of electrolytic hydrogen can be as high as \$4/kg; assuming the hydrogen is produced on-site, a range of costs between \$1.5/kg and \$3/kg is provided. Based on these ranges, it would appear that the smelting reduction route with CCUS would be cheaper than the hydrogen direct reduction route (provided there are suitable sites closer to the steel plant locations). However, a key sensitivity to explore is the changing cost of green hydrogen over time. As costs of green hydrogen start to fall over time, potentially reaching \$2/kg in 2030 and \$1/kg in 2050 in the most suitable geographies, hydrogen direct reduction could start to compete. In fact, there have been several key developments in this space. For instance, Reliance Industries, alongside other players, such as NTPC, Ohmium and RenewPower, are taking green hydrogen production very seriously – making it likely that the target of \$1/kg can be hit much sooner than our initial estimate of 2050, thereby making hydrogen direct reduction competitive even earlier than predicted.

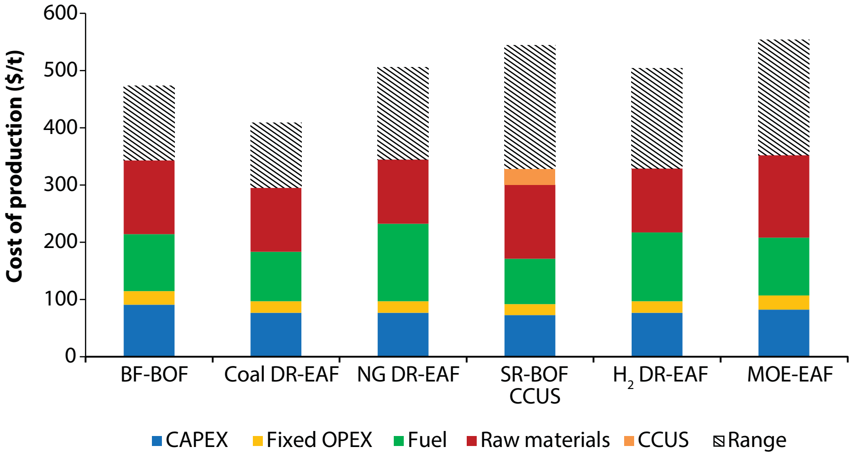


**Figure 4**: Costs of steel production by route

***Source**: TERI analysis based on (IEA, 2019) and (MPP, 2021)*

## Pathways to Net Zero

Understanding these existing assets and future technological trends can help us construct future pathways to achieve a net zero steel sector. The main scenario illustrated here in Figure 5 represents a pathway to net zero by 2070 (NZ2070): in line with the government's economy-wide net zero target announced in 2021.

The primary route to replace the blast furnace is hydrogen direct reduction. This can be scaled rapidly from 2030, at which point it will start to compete directly with the less efficient conventional plants. Thus, in the NZ2070 scenario, new low emission technologies can be introduced rapidly around the same time. From 2040, early Molten Oxide Electrolysis (MOE) plants could be deployed. Scrap-best EAFs will see an ever-increasing role, although this will be limited by the domestic availability of scrap – no import of scrap is assumed. In terms of phasing out existing high emission facilities, a relatively significant role for CCUS can be seen, to help manage the large number of BF-BOF facilities. Whilst relatively expensive to fit these facilities with CCUS versus using alternative low emission routes, it may prove financially viable for those facilities located close to cost-effective $CO_2$ storage and are entering their 2nd or 3rd relining campaign.

An alternate scenario assumes that the steel sector achieves Net Zero by 2050, simultaneously meeting the

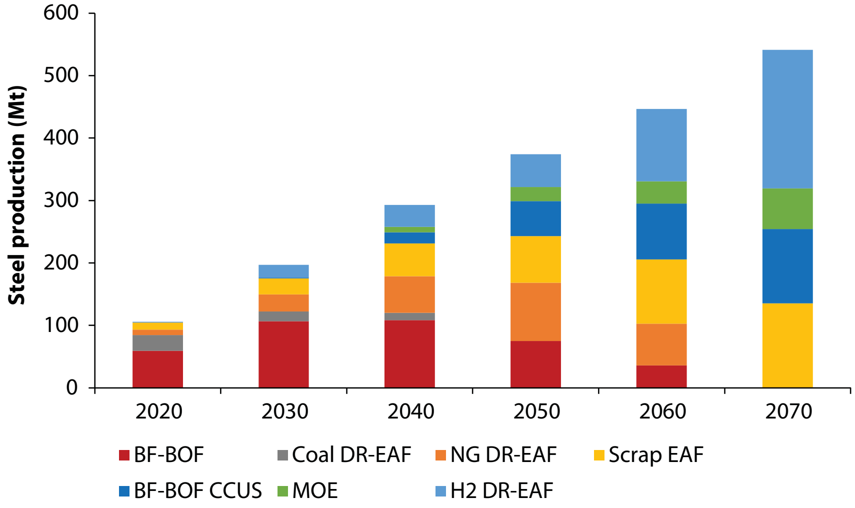


**Figure 5**: Net Zero by 2070 scenario

*Source: TERI analysis*

government's target: 'Atmanirbhar Bharat' by 2047.

In the NZ2050 scenario, low emission technologies are introduced at an even faster rate, with the most significant additions being made by hydrogen direct reduction, followed by MOE. The greater challenge here is phasing out blast furnaces faster, potentially before the end of their useful lifetime. This is largely due to the limits on domestic coking coal of an adequate quality. The National Steel Policy aims to reduce import dependence by 65% by 2030 and Coal India is taking some steps to support this, such as by establishing new washeries. Hence, it can be assumed that domestic coking coal production reaches around 45 Mt by 2050 – reducing import dependence to 0%. Natural gas-based direct reduction facilities are also phased out even faster in the NZ2050 scenario, implying a more rapid transition to 100% hydrogen.

However, one of the major challenges for achieving such a scenario is the rate at which new renewable electricity production needs to be scaled up. These estimates include electricity for scrap EAF, MOE and green hydrogen production[1]. For the NZ2070 scenario, the challenge is already extreme, with production increasing 10-fold to 70 TWh by 2030, nearly 4-fold again to 260 TWh by 2050 and then more than 3-fold again by 2070 to 900 TWh. This represents 65% of India's electricity production today, for just a single sector. The challenge is even more extreme in the NZ2050 scenario as faster ramp-up is required in order to meet the dual targets of net zero and self-reliance.

## Action Plan

It is clear that early action is required to ensure that the sector remains competitive as countries ramp up emissions reduction policies.

**Maximize energy efficiency**: Best available technologies have the potential to reduce energy and emissions by around 15% across the two primary steel-making routes. Moreover, there are a number of older plants in dire need of modernization; these can substantially improve their energy efficiency by applying the existing widely adopted efficiency technologies.

**Increase scrap utilization**: Improving resource efficiency and encouraging greater levels of material circularity is vital for mitigating negative environmental impacts as well. The increasing availability of scrap plays an important role in reducing the amount of energy used for steel-making. Designing steel products so that recycling is made easier, along with building the appropriate recycling infrastructure can be done immediately - the MoS' Steel Scrap Recycling policy is a positive first step. In doing so, scrap use in the BF-BOF route and in EAFs can be increased to reduce energy consumption and GHG emissions. Estimates suggest that scrap use in the BF-BOF route will increase from an average of around 10% today to 20-25% by 2050, which helps increase the efficiency of the process.

**Create procurement alliances**: Groups of corporates who use steel can band together to create clubs for sending clear demand signals to steel producers to start producing green steel. Over time, such clubs could provide guaranteed markets for green steel, helping to de-risk investments for producers. Steel zero is an example of such an initiative in the private sector. Infrastructure accounts for around 27% of steel demand in India most of which is used in public projects. Hence, the Public Works Departments (PWD) could help drive this initial demand, thereby providing a guaranteed market for domestic green steel producers.

**Introduce green product standards**: To help grow the market for green steel as a premium product, green product standards and related product labelling in should be developed and implemented. This will help consumers decide between more or less sustainable products, as they seek to decarbonize their supply chains. For instance, the Confederation of Indian Industry (CII) is working in partnership with producers like Tata Steel to apply its Greenpro

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[1] Electricity consumption assumptions = 650kWh for EAF, 3.4 MWh for MOE and 2.9Mwh for $H_2$DR

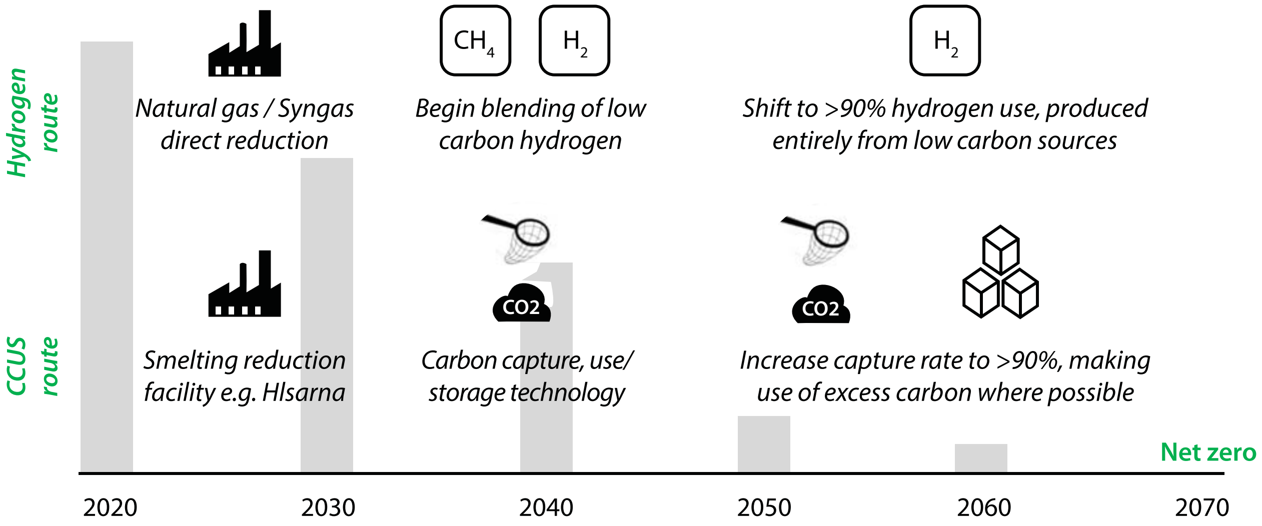

**Figure 6**: Pathways for low carbon primary steel-making

***Source***: *TERI Analysis*

framework to products such as steel rebar. The Ministry of Steel could also work through the Bureau of Indian standards to develop green product–standard similar to the existing process with steel quality controls.

**Promote technical research & development and setup demonstration plants**: While the Indian steel sector has invested some resources into R&D for cleaner production, this is often limited to early-stage laboratory and pilot scale efforts. Given the high risk associated with demonstrating new, more expensive technologies in the steel sector, it will be necessary to establish public-private partnerships. The Government of India, through the 'Promotion of R&D in Iron & Steel Sector' scheme, has been providing financial support to our end projects identified for funding by the Ministry of Steel.

**Future-proof new capacity**: Another important consideration for low carbon steel-making routes in India is the lifetime of the plants and the possibility of retrofit in the coming decades. Figure 6 illustrates two potential transition pathways for the leading technologies discussed earlier. Gas-based capacity could be built in the 2020s, using natural gas or coal-based Syngas; this could then be switched to low carbon hydrogen over time. Alternatively, steel producers could establish smelting reduction facilities, such as HIsarna, over the coming decades, which could then be retrofited with CCUS technology to reduce emissions.

**Lay the groundwork for a domestic carbon trading market**: Taking the necessary steps over the 2020s will put the Indian steel sector in a strong position to start to rapidly decarbonize its production post-2030. India has already achieved much success with the implementation of the Perform, Achieve and Trade (PAT) scheme, which trades energy efficiency certificates between Designated Consumers (DCs). The existing policy can be amended to measure and control carbon emissions, as opposed to energy consumption, operating similar to the EU Emissions Trading Scheme (ETS).

**Support for commercial-scale plants**: As renewable electricity projects become 'self-financing' in India, greater focus should be given to the heavy industry sectors, such as steel. By the 2030s, public and private sectors should have proven joint financing models to facilitate the construction of commercial-scale green steel plants. This will require considerable support, assuming some cost difference between green steel and 'dirty' steel persists. Organizations such as the World Bank, the Asian Development Bank and the Climate Investment Funds should increasingly look to support these heavy industry projects, either through support to reduce costs of capital, or through direct grants. Alongside direct financial support, it will be important to facilitate active technology partnerships (for example, the U.S. - India Climate and Clean Energy Agenda 2030 Partnership).

**Implement a carbon border tariff**: Steel, a carbon-intensive product which is also heavily traded globally, has found a lot of attention in recent years in the trade environment policy discourses. It may be worth exploring policies similar to the EU's Carbon Border Adjustment Mechanism (CBAM), to put restrictions on steel imports to India, originating from countries having higher steel carbon intensity. This may also dissuade Indian steel importers from importing and will help in switching to domestic. Additional revenue that may be collected as import duty can be considered for supporting India's greening of steel.

**Retire older, polluting facilities**: Lastly, for a net zero by 2070 scenario, it is assumed that largely gas-based direct reduction plants are installed during the 2020s, primarily using natural gas. The existing blast furnaces would need to be steadily decommissioned as they reach the end of their economic life. Thus, by 2070, a limited number of blast furnaces would remain, and those that do would be fitted with carbon capture technology.

## Conclusion

India is well positioned to reap many of the benefits associated with a competitive, digital, and decarbonized sector, making use of domestic resources and skills. Nonetheless, there are significant risks of not rising to this challenge. India currently operates one of the highest polluting steel sectors and so has further to go than many others, while growing production at the same time. This report sets out that such a pathway is possible and desirable. Through rapidly scaling-up renewable electricity and green hydrogen production, in particular, the steel sector can shift away from imported fossil fuels, putting the sector on a path to a net zero, self-reliant future. EF

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*Article contributed by Girish Sethi, Senior Fellow and Senior Director, TERI.*

# ECO WAVE POWER TO CONSTRUCT 2MW WAVE ENERGY POWER STATION IN SPAIN

On April 11th, 2022, Eco Wave Power, a leader in the production of clean electricity from ocean and sea waves, announced that it has entered an official agreement with Port Adriano, Spain, for the potential construction of a wave energy power plant of up to 2MW. The agreement expands Eco Wave Power's presence in Europe and will help Spain achieve its aggressive goals for renewable power, leveraging its significant coastline capacity.

According to the terms of the agreement, Port Adriano will assign a potentially suitable location to Eco Wave Power for a period of 20 years; while Eco Wave Power will be responsible for securing all the licenses, constructing, and commissioning the power plant/s and selling the electricity to be generated by the power plant – in accordance with an approved production quota, to be determined for the site.

Port Adriano has been in contact with Ports de les Illes Balears (Ports of the Balearic Islands), which is the public entity responsible for the powers and executive functions of the ports managed by the autonomous community, to inform it about the project. Port Adriano will also proceed to carry out all the legal procedures necessary for the installation of this innovative wave energy power plant - the first application of this technology in Spain.

The power plant is planned to be constructed and commissioned in two stages:

» The first stage is the construction of a plant of up to 1MW.
» The second stage involves the construction, operation and maintenance of the remaining capacity of the plant (2 MWs).

Port Adriano will have a right of first refusal to invest (partially or fully) in both stages of the project, whereas Eco Wave Power will have the right to combine the two stages of the project and execute the whole 2MW from the start.

Inna Braverman, founder and CEO of Eco Wave Power said, "When it comes to renewable energy, Spain foresees a sizeable build-out of new renewables capacity to reach 74% of electricity generation by 2030. Spain also has 8,000 km of coastline. The combination of Spain's ambitious renewable energy goals, along with its significant coastline, makes it an optimal market for Eco Wave Power. We are very excited about the collaboration with Port Adriano and would like to thank them for being true wave energy pioneers."

Antonio Zaforteza, CEO of OCIBAR – the company that owns the Port of Adriano – stated, "We believe that Eco Wave Power is a perfect fit for the innovation and sustainability vision of Port Adriano, creating a new way

of generating renewable energy, that will help our port and our country to meet its ambitious goals to address the climate crisis. We are looking forward to welcoming this innovative project."

As a member of the European Union (EU), Spain is bound by EU targets for energy and climate change as part of the Energy Union. Toward this end, the central strategy document guiding Spain's energy and climate policies over the coming decade is its NECP (National Energy and Climate Plan) for the period 2021-2030. It outlines several policy actions in various sectors that will support the country's climate targets, including in the areas of energy efficiency, renewables, and transport. Its 2030 objectives include:

» a 23% reduction in greenhouse gas emissions from 1990 levels;
» a 42% share of renewables in energy end use;
» a 39.5% improvement in energy efficiency;
» and a 74% share of renewables in electricity generation.

Policies include increasing renewable power installations and boosting the use of renewable gases in the power sector, modal shifts and electrification in the transport sector, refurbishments and increasing the use of renewable heating in the residential and commercial sectors, promoting energy efficiency and fuel switching in the industry sector, and energy efficiency improvements in the agricultural sector. The Spanish government anticipates that investments of EUR 241 billion will be needed to enact the measures outlined in the NECP, out of which 80% is estimated to come from the private sector.

Spain's commitment to renewable energy is evident from the fact that the share of renewables (including non-renewable waste) in the national electricity mix grew from 24% in 2009 to 38% in 2019. Spain further emphasized its focus on renewable energy by planning to phase out both coal and nuclear power generation. The coal phase-out appears well on track, with coal only providing around 5% of electricity generation in 2019 and even less in 2020. Nuclear power, which accounted for 22% of power generation in 2019, will begin shutting down from 2027. Four of Spain's seven nuclear reactors are scheduled to close by the end of 2030, representing around 4 GW of capacity.

As such, Eco Wave Power believes that there is a significant opportunity to contribute towards Spain's transition to renewable energy, by making wave energy an important part in Spain's renewable energy mix.

## About Eco Wave Power Global AB

Eco Wave Power is a leading onshore wave energy technology company that developed a patented, smart and cost efficient technology for turning ocean and sea waves into green electricity. Eco Wave Power's mission is to assist in the fight against climate change by enabling commercial power production from the ocean and sea waves.

Eco Wave Power is recognized as a 'Pioneering Technology' by the Israeli Ministry of Energy and was labeled as an 'Efficient Solution' by the Solar Impulse Foundation. Eco Wave Power's project in Gibraltar has received funding from the European Union Regional Development Fund and the European Commission's Horizon 2020 framework program. The company has also received the ***Global Climate Action Award*** from the United Nations.

*Read more about Eco Wave Power at: www.ecowavepower.com*

## About OCIBAR / Port Adriano

Port Adriano is a marina belonging to Ocibar, a Spanish company specialized in the construction and management of marinas and refit areas. Ocibar operates a network of marinas in four strategic locations in the Mediterranean: Port Tarraco (Tarragona), Port Adriano (Mallorca), Botafoc (Ibiza) and Marina Santa Eulalia (Ibiza). Situated in a privileged setting in the south-west of the bay of Palma de Mallorca, near the best sailing areas of the Balearic Islands, Port Adriano is a reference port in the Mediterranean. It has a total of 488 moorings between six and 80 meters and a modern shopping area designed by the prestigious Philippe Starck. EF

*Read more about Port Adriano at: www.portadriano.com*

# RENEWABLE ENERGY AT A GLANCE

| Ministry of New & Renewable Energy | | |
|---|---|---|
| Programme/Scheme wise Cumulative Physical Progress as on Sept, 2022 | | |
| **Sector** | | |
| | **Achievements (April -Sept 2022)** | **Cumulative Achievements (as on 30.09.2022)** |
| **I. INSTALLED RE CAPACITY (CAPACITIES IN MW)** | | |
| Wind Power | 1308.50 | 41666.08 |
| Solar Power* | 6817.39 | 60813.91 |
| Small Hydro Power | 50.60 | 4899.50 |
| Biomass (Bagasse) Cogeneration | 0.00 | 9433.56 |
| Biomass(non-bagasse)Cogeneration | 0.00 | 772.05 |
| Waste to Power | 0.00 | 223.14 |
| Waste to Energy (off-grid) | 18.48 | 272.09 |
| Total | 8194.97 | 118080.33 |

*Source: https://mnre.gov.in/the-ministry/physical-progress*

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# ENERGY FUTURE

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