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ENERGY, WHAT WE NEED AND WHAT WE CAN

Energy transitions amid an economic transformation

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Abstract

Countries undergoing traditional transformations witness economic prosperity before undergoing an energy transition. However, this trajectory looks much different for emerging markets and developing economies like India, where multiple energy transitions are occurring simultaneously with rapid economic growth. Emerging markets are key to the global energy transition and the locomotives for global growth. If they do not shift, or "leapfrog", to clean energy sources, there will be no global energy transition. As an example of the transitions underway in emerging markets and developing economies worldwide, this paper discusses India's four central energy transitions—traditional to modern energy sources, rapid urbanization, growth of sustainable energy infrastructure, and deeper integration into global energy markets—which impact the sustainable development goals. This paper then delves into the challenges associated with the energy transition for emerging markets like India. Financing for clean energy continues to be a high cost for emerging markets; clean energy supply chains are highly concentrated, impacting materials, minerals and intermediate and finished products; and new markets for the fuels of the future are limited by a lack of common standards across jurisdictions. For the rapid growth of renewables in the decade of leapfrog, the more structural problems in the energy transition must be resolved through innovative solutions and international cooperation.

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1 Introduction | Markets are emerging yet submerging

Emerging markets are key to the global energy transition. With 99 percent of developed countries having already peaked their energy demand, about 88 percent of the new growth in electricity demand between 2019 and 2040 is expected to come from emerging markets and developing economies (EMDEs). If emerging markets do not shift, or "leapfrog", to renewables and other clean energy sources, there will be no global transition to a cleaner energy future. This decade has been termed 'the leapfrog decade', with emerging markets such as India shifting to cleaner energy at a rapid pace. But this decade is also critical to achieve the first energy transition (from no access to getting access to electricity or clean cooking energy). This double energy transition is fundamental to achieve the sustainable development goals (SDGs), drive economic growth in EMDEs, and combat the climate crisis.

Bond et al. (2024) have demonstrated that emerging markets will not follow the same path to renewables as developed markets. Countries undergoing traditional transformations have witnessed economic prosperity before undergoing an energy transition—a linear path. However, this trajectory looks much different for emerging economies, where we can already observe signs of a leapfrog from fossil to non-fossil fuel sources of electrification, as well as multiple energy transitions occurring simultaneously with rapid economic growth.

This essay outlines these trends using India's example while highlighting opportunities and concerns for EMDEs more generally. India is currently one of the fastest-growing major economies, ranking fifth globally in terms of current gross domestic product (GDP) and fourth in terms of GDP in purchasing power parity.[1] India is also poised to be the third-largest economy by 2030, driven by a year-on-year growth rate of six to seven percent.[2]

However, India's economy and its potential growth stand threatened by the accelerating impacts of climate change. The country remains vulnerable to climate hazards, such as

[1] Data, The World Bank (2024).

[2] European Commission (2024).

floods, droughts, and cyclones. Over 75 percent of Indian districts are extreme event hotspots with multiple, overlapping hazards. This makes 80 percent of India's population highly vulnerable to extreme hydro-meteorological disasters. Since 1970, not only has there been an increase in the frequency of disasters, such as floods and cyclones (by 20 and 12 times, respectively), but more than 40 percent of Indian districts are witnessing swapping trends, that is, traditionally flood-prone areas are witnessing more frequent and intense droughts and vice-versa.[3] The country is also experiencing severe heat stress as well as changing precipitation patterns.[45]

2 Not one, but many energy transitions

Emerging markets are undergoing multiple, simultaneous energy transitions, which is unlike the traditional pathways and binary transitions that are discussed more often.[6] India is undergoing four such energy transitions—traditional to modern sources of energy, rapid urbanization, growth of sustainable energy infrastructure, and deeper integration into global energy markets.

These transitions are a result of India's evolving climate action story, which began with the National Action Plan on Climate Change (NAPCC) launched in 2008, involving eight national missions. Later, India's Nationally Determined Contributions (NDC) under the Paris Agreement was followed closely by an updated version, specifying its net-zero ambition for 2070 and accompanying targets related to total non-fossil energy capacity, reduction in emissions intensity, additional carbon sink, and renewed investment focus through the development of new programs.

The success of these four transitions will determine whether India can balance the energy trilemma of energy affordability, security and sustainability, in furtherance of the SDGs. These energy transitions impact other SDGs too, from gender equity to new jobs to sustainable cities to responsible production and consumption to reduction in poverty via clean energy-driven livelihoods.

2.1 Traditional to modern sources of energy

First, the quantum of energy demand is substantially rising, with a focus on ensuring access and affordability. In the Indian context, millions of Indians are gaining access to modern energy sources. In 2015, when the SDGs were announced, the Council on Energy, Environment and Water (CEEW) published the results from the world's largest survey on energy access.[7] India had the dubious distinction of having the largest number of people without access to electricity.

In 2017, a national program was launched to connect households to electricity, resulting in 28 million households being electrified within 18 months—this effectively translates into 11,000 Indians getting electricity every hour. The world still has about 700 million people without access to electricity, which means that we will need to electrify 11,500 human beings per hour, all the way to 2030!

2.2 Rural to urban

Second, the patterns of energy demand are shifting with a large population moving from rural to urban areas. Therefore, what is primarily agricultural demand for energy then moves toward heating and cooling for homes and commercial buildings, transportation systems, data centers and so forth, keeping urban needs in mind. Urban India is already the world's third-largest country by population. By 2047, half of India's projected 1.64 billion people will live in its urban centers,[8] increasing pre-existing pressure on already strained public transport systems, resource needs, and energy infrastructure. Integrating energy production with urban homes, industries, and infrastructure can help cities independently meet future energy demand. For instance, grid-integrated rooftop solar alone has the technical potential to generate 637 gigawatts (GW) of renewable energy in India through over 250 million households across the country.[9] The future of power markets will involve not just cleaner energy sources but more decentralized infrastructure and more digitalization to enable peer-to-peer trading of clean electrons.

2.3 Growth to sustainable growth

Third, the shift within the energy system itself is apparent in the transition from dirty to cleaner sources (or from dirtier growth toward more sustainable growth). India has a short time horizon from peaking fossil fuels by 2040 to reaching its net-zero target by 2070. For this, all of India's energy vectors must grow to meet rising energy demand, conventional fuels need to be secured before phasing down, and newer fuels need nurturing and support to scale up.

India's electricity system has shifted rapidly toward a cleaner electricity system and is progressing toward being as clean as it is required to be. When India's National Solar Mission was launched in 2010, India had less than

[3] Mohanty et al. (2021).

[4] Prabhu et al. (2024).

[5] TMC and CEEW (2024).

[6] Bery et al. (2017).

[7] Agrawal et al. (2020).

[8] Shree et al. (2023).

[9] Tyagi et al. (2023).

20 megawatts (MW) of solar energy installed. As of 2024, India has become the world's fifth-largest market for solar by installed capacity and the fourth-largest installed capacity for wind energy.[10] In January 2024, India's total non-fossil installed capacity stood at 189.52 GW, making up 44.07 percent of India's total installed capacity for all sources.[11] By the end of the year (December 2024), India had 217.62 GW, making up 47 percent of the total installed capacity.[12]

The pace of deployment of clean electricity in India—in absolute and relative terms—can rapidly edge out fossil fuels in the electricity mix. Overall, India houses the fourth-largest renewable energy installed capacity globally and is on track to be the world's third-largest market for renewable energy by 2030. India's expansion trajectory so far makes this a likely reality. Over the last decade, power capacity has grown in India by 82 percent, coal-based capacity has grown by 50 percent, and renewable energy-based capacity has grown by 388 percent.

Concerning overall emissions reduction, analysis by CEEW suggests that India's current climate policies for emission reduction across the power, residential, and transport sectors have already saved 440 million tons of CO_2 ($MtCO_2$) from 2015 to 2020. Further projections suggest that these policies will save 3,950 $MtCO_2$ from 2020 to 2030, 22,670 $MtCO_2$ from 2030 to 2050, and 44,070 $MtCO_2$ from 2050 to 2070. This translates to a 23 percent reduction in cumulative emissions between 2015 and 2070.[13]

As per Bond et al. (2024), cleantech costs are on the decline and will continue to fall at around 20 percent for every doubling of deployment due to technology improvements and widespread adoption. Given these falling costs, new opportunities to leapfrog are opening up to other EMDEs as well. For example, in Namibia, falling costs of solar have led to it making up almost 40 percent of total generation. Wind is seeing a similar rise in Uruguay, and almost 30 percent of Vietnam's final energy supply is from electricity. All three of these examples surpass the United States significantly in terms of utilization of solar, wind and electricity for their total energy supply.[14]

2.4 Deeper integration into global energy markets

Fourth, developing countries and their energy demands are integrating deeper into global energy markets, impacting how they operate. For example, nearly a quarter of global energy consumption will come from India by 2040,[15] reshaping global energy supply chains.

India is also promoting global multilateral initiatives, such as the International Solar Alliance and the Global Biofuels Alliance. The former, co-founded by India and France, already has more than 120 member countries, demonstrating the desire of many EMDEs to chart their unique pathways toward a clean energy transition. The latter—launched in 2023 by the top three biofuel producers, India, the United States, and Brazil—seeks to balance energy needs with food security by developing and deploying the next generation of biofuel technologies.

3 Vulnerabilities persist in finance, supply chains, technology, and standards

At the same time, three challenges persist. Financing for clean energy continues to be expensive for emerging markets. Clean energy supply chains are highly concentrated, impacting materials, minerals, intermediates, and finished products. Further, new markets for decarbonized hydrogen are also limited by a lack of common standards across jurisdictions. The more structural problems in the energy transition must be resolved for the rapid growth of renewables in the leapfrog decade.

These problems are often interlinked in many ways. For example, cleantech at early levels of technology readiness (TRLs), especially in emerging markets, tends to attract lesser financing for the research and development and demonstration stages, exacerbating a country's supply chain insecurities due to higher imports of these technologies. A lack of global standards for decarbonized hydrogen also impedes the level of financing that such hydrogen projects will bring when countries unilaterally build their hydrogen value chains at the cost of cross-border partnerships.

3.1 Challenges associated with investment and low-cost financing

In 2024, global energy investment was set to go beyond USD 3 trillion for the first time, with USD 2 trillion going toward clean energy.[16] However, as per the latest climate finance data, most of this money does not flow to where the sun shines most. Climate finance is severely lacking for developing countries, both in absolute as well as incremental terms, with only around 15 percent of global clean energy investments directed toward the Global South (excluding China), a percentage growing at a significantly lower pace

10 MNRE (2024).

11 Central Electricity Authority (2024a)

12 Central Electricity Authority (2024b).

13 Chaturvedi et al. (2024).

14 Bond et al. (2024).

15 IEA (2021).

16 IEA (2024).

for emerging markets. This is despite global investments in clean energy being double that of investments in fossil fuels.[17]

To effectively channel climate finance, the three 'I's stand to be important—incentives, instruments and institutions. Financing incentives, such as feed-in tariffs and tax credits, will programmatically de-risk investments by reducing financial uncertainties and increasing project attractiveness. Innovative financing instruments, such as green bonds and climate derivatives, will offer new mechanisms that attract a diverse range of investors, improve returns and address further risks. Finally, strong, redesigned national and multilateral institutions will play a key role in mobilizing, structuring, and deploying climate finance.

3.2 Concentration of cleantech supply chains, critical minerals, and intellectual property rights

The number of countries with concentrated imports of solar photovoltaic (PV), that is, with high reliance on very few countries for the bulk of their solar PV imports, rose from 38 in 2012 to over 71 in 2021.[18] Similarly, the numbers for lithium-ion batteries jumped from 19 to 49.[19] Therefore, even as countries are doubling down (in some cases, even tripling down) on their renewable energy targets, they are reliant on fewer countries and sources for these products. For high-income countries, dependence on concentrated imports is about 60 percent, but this trend is particularly problematic for lower–middle-income and upper–middle-income countries, where there is nearly 100 percent dependence in many cases.[20]

India is trying to become a leading supplier of clean energy technologies—but with a different approach. As of 2021, India had 8 GW of effective solar module production capacity.[21] Due to the government's Production-Linked Incentive (PLI) scheme's two tranches, there has been a total allocation of around USD 3.2 billion for establishing a combined manufacturing capacity of about 48.3 GW.[22]

In future, India can potentially indigenize the manufacturing of 82–85 percent of the components of three select electrolyzer technologies, namely proton exchange membrane (PEM), alkaline electrolyzer, and solid oxide electrolyzer (SOE).[23] As for other cleantech supply chains, India can achieve export competitiveness in select components of solar (solar wafer, polysilicon, EVA, diamond wire saw), lithium-ion batteries (synthetic graphite, aluminum foil), and already has a comparative advantage with select components for wind (wind turbine gearbox, hub castings, wind turbines).[24]

This approach—of component-wise green comparative advantage—can support green industrial development in India and also position it as a critical node in interdependent global value chains for cleantech. Such a pathway is more amenable to building secure, reliable and resilient cleantech supply chains in contrast to the current concentration of manufacturing in China or the protectionist policies in the European Union or the United States.

Similarly, for innovation, just five G20 countries account for 85 percent of the patents applied for and for patents granted under the Patent Cooperation Treaty (PCT) for environmental technology between 2000 and 2021.[25]

This concentration of cleantech intellectual property calls for a new paradigm of technology co-development. This can involve pooling of financial resources as well as technical and human resources, for the development of cleantech oriented toward the hot tropics.[26]

A similar challenge exists for critical minerals as well. Fifteen countries are home to at least 55 percent of the identified critical minerals for the cleantech transition. Within them, even fewer account for 70 percent (sometimes rising to 90 percent) of the mine production of these minerals.

Four opportunities can be identified for both suppliers and demanders of critical minerals to tackle the current challenges. The first is in data transparency for countries and companies, with standardization of exploration data to improve consistency and collect granular data. The second is collaborating on exploration, exploration technologies and finding alternative sources through various potential approaches. Conscious effort in technology cooperation is key to diversifying sources. A related third opportunity is the co-development of mineral processing technologies between countries with mutual interests—those home to large mineral deposits and mining companies with interest to develop, deploy and transfer advanced technologies for exploration and production. Finally, mineral recycling and circularity can create local and resilient supply chains which could significantly reduce import dependence.[27]

3.3 A rules-based architecture for the fuels of the future

Decarbonized hydrogen stands to be a key fuel to decarbonize heavy industries, such as steel, aluminum, and fertilizers,

[17] *Ibid.*

[18] CEEW (2023).

[19] *Ibid.*

[20] CEEW analysis (2024).

[21] Gupta (2022).

[22] Ministry of Power (2023).

[23] Patidar et al. (2024).

[24] Warrior et al. (2024).

[25] Gupta et al. (2023).

[26] Ghosh et al. (2022a).

[27] Ghosh (2025).

as well as long-distance freight transport and energy storage, and become integral to novel applications such as sustainable aviation fuels.

Currently, there is no energy security architecture to protect countries that will drive the world's future energy demand or secure the necessary fuels of the future, such as decarbonized hydrogen. Due to a lack of global consensus on common standards, countries are trying to unilaterally secure access to these value chains. Such a race could then intensify prevalent resource conflicts, exacerbate global energy insecurity, and decelerate the decarbonization efforts of developing economies.[28]

A robust rules-based architecture will secure the supply and demand of this critical fuel by increasing transparency, governing technology development, supporting diversified production and value chains, trade and transport, and safe storage and use. By making green hydrogen more equitably accessible to all markets—affordable for retail and industrial consumers and available at scale—there would be a chance to bridge the emissions gap without deindustrializing fast-growing EMDEs.[29]

4 Conclusion

The energy leapfrog is already ongoing in EMDEs across the globe. In some countries like India, the scale of such a transition will have a large impact on the global energy transition. There will be multiple energy priorities through this decade (and beyond)—access, sustainability, and security—that will develop a new political economy for EMDEs as compared to developed countries. These energy transitions are part of an economic transformation. EMDEs, as the locomotives of the global economy, are likely to invest more in the clean energy transition as it becomes a part of their broader green industrialization strategy, giving them multiple opportunities to become a part of the global supply chains in the clean economy of the future.

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Declarations

Conflict of Interest The authors declare no competing interests.

[28] Ghosh et al. (2022b).

[29] *Ibid.*

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