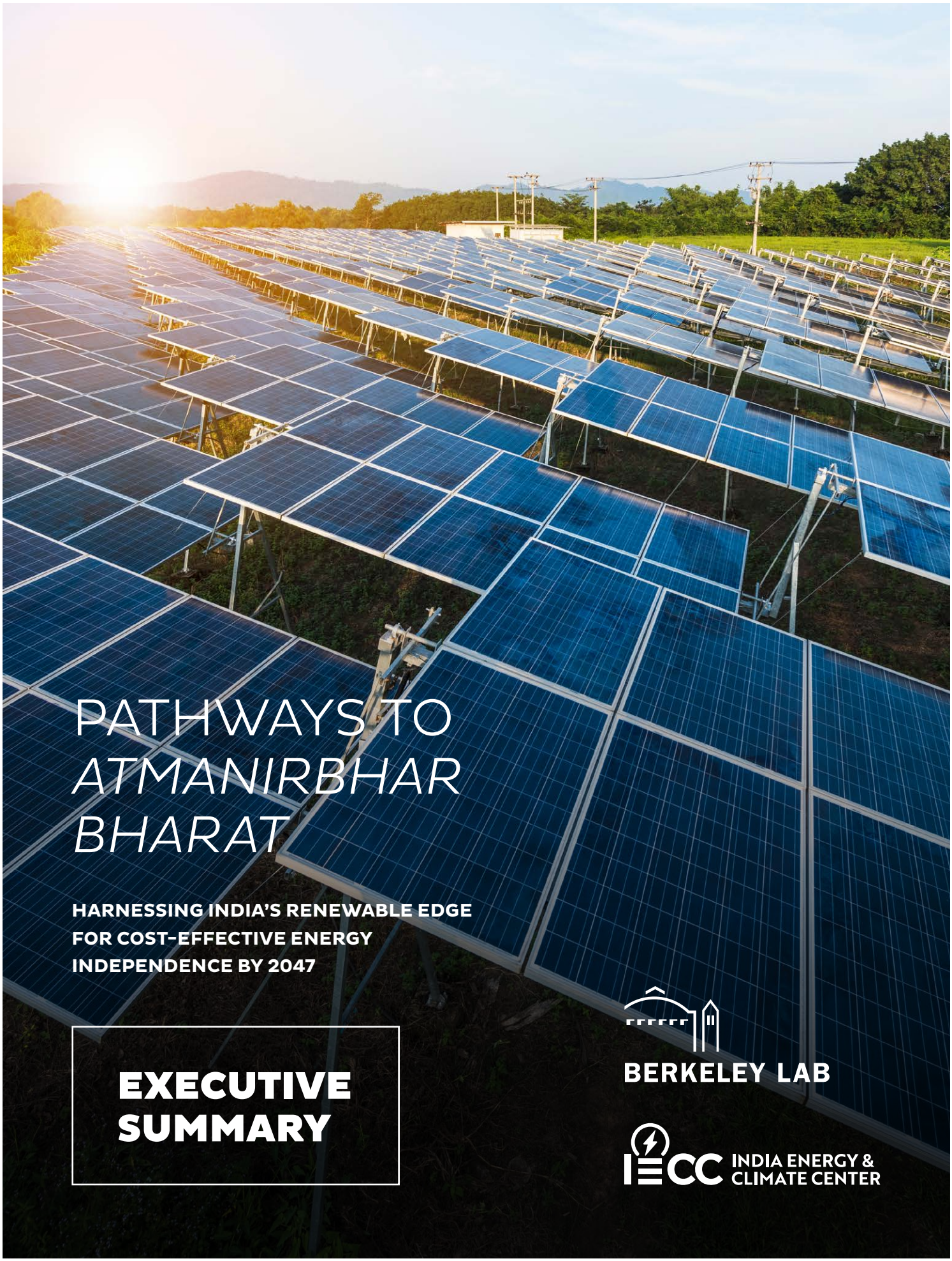

PATHWAYS TO *ATMANIRBHAR BHARAT*

HARNESSING INDIA'S RENEWABLE EDGE FOR COST-EFFECTIVE ENERGY INDEPENDENCE BY 2047

EXECUTIVE SUMMARY

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IECC INDIA ENERGY & CLIMATE CENTER

Oil, gas, and coal prices have shown significant volatility in the past few years due to geopolitical tensions, supply chain shocks, and a demand rebound following the COVID-19 pandemic. India currently imports 90% of its oil consumption, 40% of its gas consumption, 20% of its coal consumption, making it vulnerable to fluctuations in global energy prices and supply disruptions (MOSPI, 2022). This leads to a strain on the country's balance of payments and economy-wide inflation.

As the fifth largest economy in the world, with rapidly growing incomes, urbanization, and industrialization, India's energy demand is expected to nearly quadruple in the coming decades (IEA, 2021). This study aims to assess a pathway for India to meet its growing energy needs and achieve near-complete energy independence by 2047, a goal set by Prime Minister Narendra Modi. We believe that recent technological advances and deep cost reductions in clean technology, as well as excellent quality renewable resource potential, offer a cost-effective opportunity for India to attain this goal. Since much of the energy infrastructure in the country is yet to be built, we focus primarily on how most of the new investments will be clean in three largest energy consuming sectors in India –power, transport, and industry — which collectively account for more than 80% of the country's energy consumption and energy-related CO_2 emissions. We run detailed energy-emissions models, including hourly grid simulations, for these three sectors, from 2020 through 2050 for the following two scenarios:

(a) Reference: The reference scenario models historical and recent trends in clean energy deployment, assuming that there is progress on existing targets and commitments at the current pace. This pathway includes renewable energy deployment that achieves 37% clean generation by 2030 (>350 GW non-fossil capacity) and 60% by 2047. In the transport sector, the scenario assumes 45% electrified new vehicle sales by 2035 for two-wheelers, 24% for passenger cars and 12% for medium and heavy duty vehicles. . Industrial production continues to be dominated by fossil fuels.

(b) CLEAN-India (Clean Energy for AtmaNirbhar India): CLEAN-India scenario incorporates the potential for rapid and cost effective clean energy deployment that is already commercially available today. It models a pathway for renewable energy deployment that achieves the current 2030 targets (>500 GW non-fossil capacity), 80% clean generation by 2040 and 90% by 2047; nearly 100% electrified new vehicle sales by 2035 in all vehicle categories; and a shift to green hydrogen and electrification in industrial production as a replacement for coking coal, natural gas, and oil. It is important to understand that the CLEAN-India pathway is not a projection; rather, it is intended to illustrate a potential pathway for achieving energy independence by accelerating the clean energy transition in India.

KEY FINDINGS

CLEAN ENERGY CAN ENABLE INDIA'S ENERGY INDEPENDENCE BY 2047

The CLEAN-India pathway can achieve energy independence by 2047 by significantly decreasing the amount of oil imported for road transportation and coal imported for industry and power sectors. In the Reference scenario, total primary energy consumption is expected to double from 652 mtoe in 2022 to ~1181mtoe by 2047. This would require roughly 39% of primary energy supply in 2047 to be imported, including over 90% of oil consumption (299 mtoe) and 70% of coking coal consumption (175 mtoe), costing $275 billion (INR 2.1 million crores). In contrast, the CLEAN-India scenario would reduce fossil fuel imports to $15 billion (INR 112,500 crores) by 2047, with oil imports decreasing to 27 mtoe and industrial coking coal imports decreasing to below 5 mtoe (Figure ES-1-2).

CLEAN-India pathway avoids fossil fuel imports, but it also involves a multi-fold increase in the deployment of solar panels, wind turbines, electrolyzers for producing green hydrogen, and lithium-ion batteries for grid-scale storage and electric vehicles. While India has made significant progress in domestic manufacturing of clean technologies, there are concerns about the availability and supply security of lithium and other critical minerals used in them, especially in batteries. Our analysis finds that total cumulative lithium requirements between 2022 and 2040 would be roughly 1.9 million tons;1.7 million tons of that lithium will be used for electric vehicles. India's recent lithium discovery is estimated to be 5.9 million tons, substantially larger than the cumulative lithium requirement over the next 20 or so years (Figure ES-3). Studies have shown that large portions of lithium in spent car batteries can be recycled and reused in new batteries. We estimate that if the lithium in retiring EV batteries is recycled (up to 95%), it could meet between a quarter and a half of the annual lithium demand in the 2040s in the CLEAN-India case (Figure ES-4).

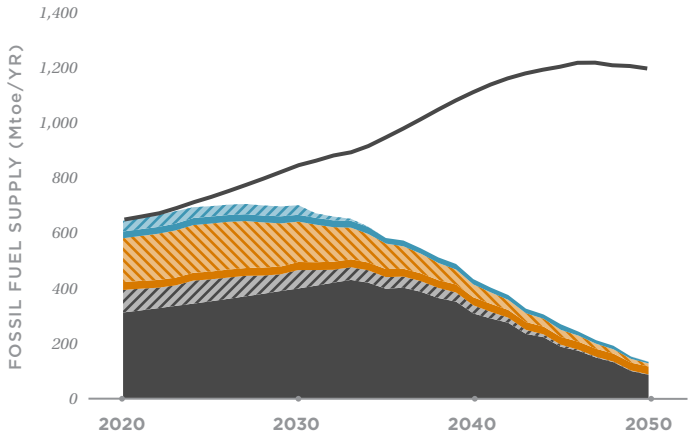

FIGURE ES-1.
Fossil Fuel Supply, Reference vs. CLEAN-India Scenarios

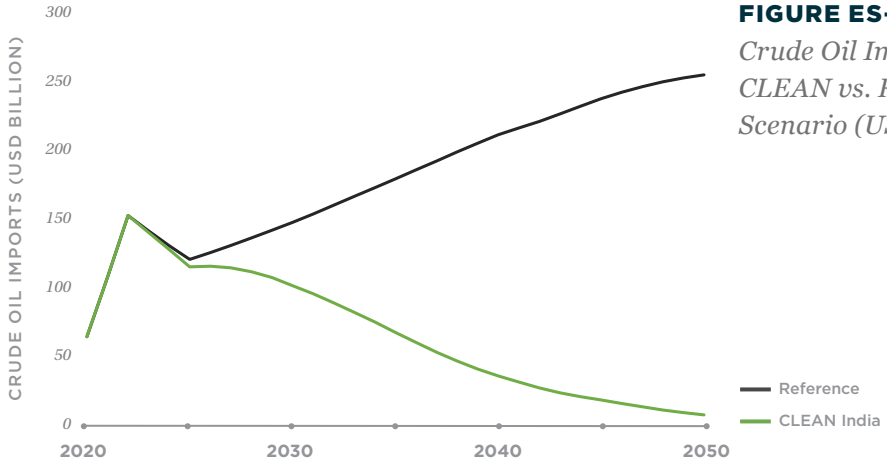

FIGURE ES-2.
Crude Oil Import Costs, CLEAN vs. Reference Scenario (USD billions)

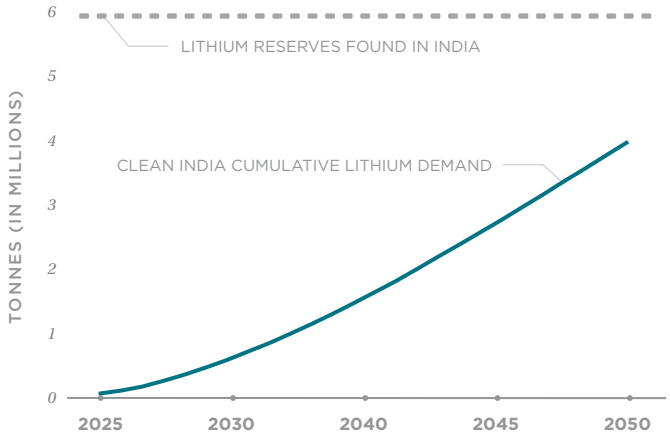

FIGURE ES-3.
Cumulative Lithium Demand vs. Estimated Lithium Reserves in India

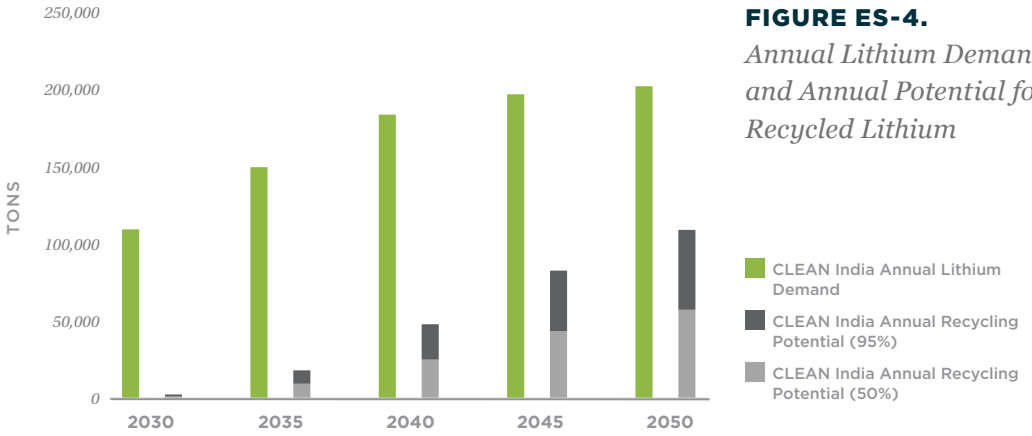

FIGURE ES-4.
Annual Lithium Demand and Annual Potential for Recycled Lithium

While the CLEAN-India pathway can avoid expensive fossil fuel imports in the transport and industrial sectors, one could envision a domestic coal dominant energy independence pathway for the power sector. However, such a pathway may not be cost-effective due to the declining costs of RE and energy storage. For example, the levelized cost of solar energy co-located with energy storage, which would provide a combined capacity factor of around 60%, is expected to be around INR 3.5/kWh by 2030, which is cheaper than building new coal power plants (Abhyankar et.al, 2021).

SWITCHING TO CLEAN ENERGY WOULD ENHANCE INDUSTRIAL COMPETITIVENESS

India's heavy reliance on imported fuels makes the industrial energy and freight movement costs vulnerable to global energy price fluctuations and supply disruptions, leading to economy-wide inflation as well as straining the country's balance of payments. For example, just in the financial year 2021-22, average crude oil import price in India fluctuated from $40 to $120 per barrel. It is estimated that every $10 increase in crude oil prices adds $12.5 billion to India's current account deficit, leading to rising inflation (Ghosh and Tomar, 2019).

The CLEAN-India scenario offers an opportunity to reduce and inflation-proof India's energy costs because renewables, storage, EV batteries, electrolyzers, and hydrogen infrastructure are capital assets. Additionally, Indian industry, to remain globally competitive, must transition to clean technologies such as EV manufacturing and green steel manufacturing. For instance, the Indian auto industry is the fourth largest producer of passenger vehicles in the world and exports nearly a quarter of its production. Some of their largest export markets are EU countries including Italy, Germany, and the Netherlands, all of which have committed to phasing out internal combustion engine vehicles by the 2030s. Similarly, India is one of the largest steel exporters, with its largest markets in EU countries that have committed to carbon neutrality by 2050, including imported goods.

ELECTRIC VEHICLES AND A CLEAN GRID WOULD SAVE CONSUMERS TRILLIONS, WITH MANAGEABLE IMPACTS ON TAX REVENUES

This study finds that transitioning from a coal-dominated power grid to a 90% clean grid in the CLEAN-India scenario is technically feasible and economically viable. As clean technology prices continue to fall, the average cost of electricity generation is expected to drop by about 10% in real terms between 2020 and 2050. Similarly, in the transportation sector, for most vehicle classes, EVs are already on par with internal combustion engine (ICE) vehicles in terms of the total cost of ownership (TCO). With a steep reduction in upfront prices expected in the coming years, EVs will have a 34-53% lower TCO than ICE vehicles by 2030. As a result, a shift to electric transportation is estimated to create $2.5 trillion (INR 19 million crores) in net consumer savings by 2050 from reduced fuel and maintenance costs, even after accounting for the high upfront costs of EVs. In the industrial sector, the cost-effectiveness of clean energy transition, in particular green hydrogen based steel manufacturing or electrified cement production etc, is still a decade away.

Fossil fuel taxes, duties, and royalties, as well as electricity duties, contribute significantly to state and central government revenues (Figure ES-5), totaling

around $80 billion (INR 600,000 crore) per year, or 12% of total government revenue. Under the CLEAN India scenario, despite an aggressive clean energy transition, the fossil fuel consumption and associated tax revenues will not drop below 2020 levels until 2035, assuming the current tax regime continues. By 2047, total energy tax revenue would drop to about half of the 2020 levels, with electricity duties (mostly collected by the state governments) making up for a part of the lost tax revenue from reduced fossil fuel consumption. Because of India's rapid economic growth and expanding tax base, we believe that there will be several opportunities to offset this modest loss (i.e. 2-3% of the total government tax and non-tax revenue by 2047) in the coming decades. Note that a more nuanced analysis will be needed to assess this issue in more detail. For instance, our analysis aggregates the total tax revenue irrespective of where the tax is collected and how it is shared between the state and the central governments.

Indian Railways (IR) transport most of the coal consumed in the country and there will be a major revenue loss for them due to decreased coal consumption, but this will potentially open up the rail network for industrial freight that currently relies on road transport, making up for the lost coal revenue.

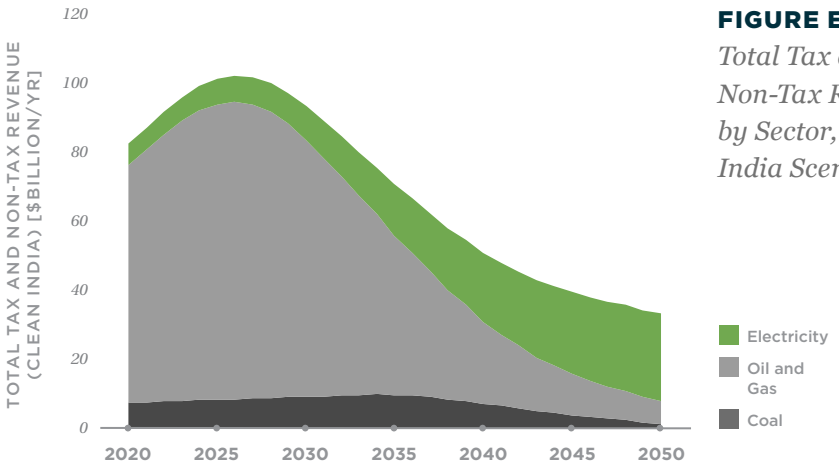

FIGURE ES-5.
Total Tax and Non-Tax Revenue by Sector, CLEAN India Scenario

A RAPID EXPANSION OF CLEAN ENERGY INFRASTRUCTURE WILL BE CRITICAL IN THE COMING DECADES

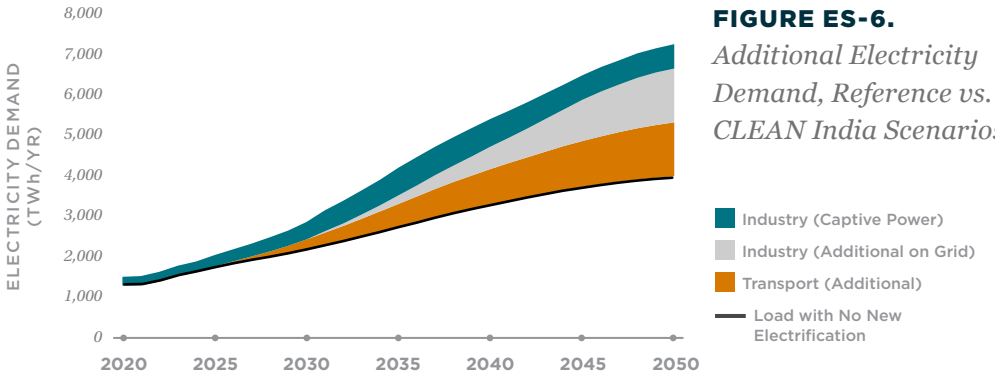

FIGURE ES-6.
Additional Electricity Demand, Reference vs. CLEAN India Scenarios

Because of the transport and industrial electrification and green hydrogen production, the electricity demand increases drastically in the CLEAN-India scenario — from 1300 TWh/yr (bus-bar) to over 6600 TWh/yr by 2050 (Figure ES-6). This demand is 70% higher than a scenario with no new electrification policies and 50% higher than the Reference case, which also includes significant transport sector electrification. Note that this is only utility-supplied electricity. If industrial captive power is included (as seen in the graph), electricity demand jumps to roughly 7200 TWh/year by 2050. The CLEAN-India scenario includes several energy, process, and material efficiency policies resulting in a significant reduction in the overall load. In absence of such policies, the additional electricity demand from the industrial sector could be 40% higher.

In the CLEAN-India scenario, the power sector achieves carbon free electricity generation of 90% by 2047. This entails 1236 GW of solar capacity, 909 GW of onshore wind and 375 GW of offshore wind capacity, and 452 GW / 2500 GWh of energy storage. The pace of required renewable capacity additions is around 40 GW/year through 2030, ramping up to about 100 GW/year between 2030 and 2050.

In the transport sector, over 22.5 million electric 2-W, 7.5 million electric cars and 330,000 heavy duty electric trucks will be sold each year by 2035. By 2047, over 95% of all on-road vehicles will be electric.

In industry, the pathway primarily focuses on electrification and green hydrogen across the iron and steel, cement, and fertilizer, chemical and petrochemical sectors. 255 MT/yr of steel (60%) will be manufactured using green hydrogen and 42 MT/yr (10%) with electrification by 2050. In the cement sector, 480 MT

of cement production (65%) will be manufactured using electrification and 184 MT (25%) will be manufactured using green hydrogen by 2050. 67 MT (100%) of fertilizer production will be green hydrogen based by 2050, and 82 MT (100%) of chemical and petrochemical production will be green hydrogen based by 2050.

The CLEAN-India pathway will be more capital-intensive and will change the cost structure of the energy sector to one dominated by capital assets/fixed costs. We find that the total investment required for building new clean energy infrastructure between 2020 and 2047 will be $3.5-4 trillion (INR 26-33 million crores), including $2.6 trillion for power generation, $60 billion for charging infrastructure, and over $1-1.5 trillion for the heavy industry. It should be noted that even in the Reference case scenario, India will need to invest over $2 trillion from 2020-2050, including approximately $1.5 trillion in power generation, $20 billion in charging infrastructure for electric vehicles, and $500 billion in heavy industry. The net additional investment required for the CLEAN pathway would be $1.5-2 trillion (INR 11-15 million crores). These estimates are high-level and require further analysis, but they are also consistent with other recent studies (McKinsey, 2022). While the scale of the additional investments is significant, they are manageable given the rapid growth of the Indian economy (annual GDP increasing from approximately $3 trillion in 2020 to $15-20 trillion/year by 2050) and the availability of global capital (PwC, 2017).

CLEAN ENERGY OFFERS ENVIRONMENTAL AND PUBLIC HEALTH BENEFITS WITHOUT COMPROMISING ECONOMIC GROWTH

In the Reference case scenario, energy-related carbon dioxide (CO_2) emissions from power, transport, and industry sectors will continue to grow until the late 2040s, peaking a little above 4 gigatons/year (nearly double current levels). In the

CLEAN India scenario, emissions will peak in the early 2030s, before dropping to under 500 million tons/year by 2047 and near-zero by 2050 (Figure ES-7). The majority of emission reductions (41%) will be achieved through clean electricity generation, followed by electrified industrial processes and hydrogen-based iron/steel and fertilizer production (29%), and electrified transport, particularly electric heavy-duty vehicles(16%). Additionally, due to the significant reduction in fossil fuel consumption, over 4 million premature deaths related to air pollution could be avoided between 2022 and 2047.

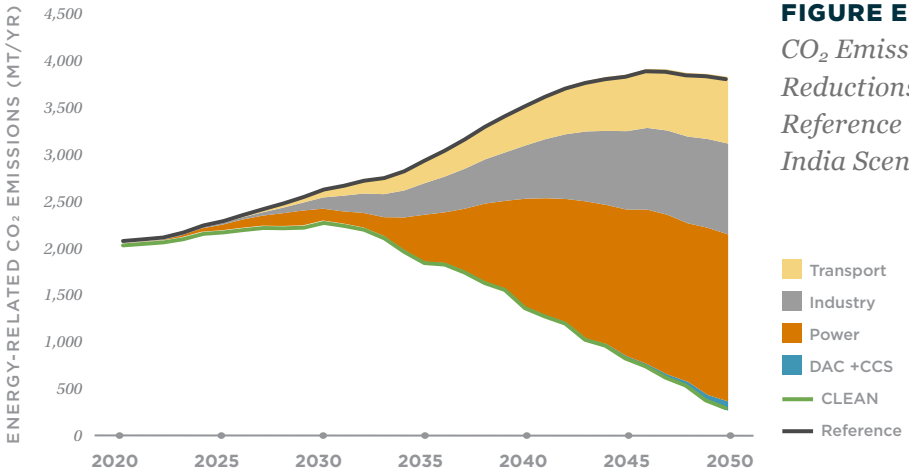

FIGURE ES-7.
CO_2 Emissions Reductions by Sector, Reference vs. CLEAN India Scenarios

MANAGING THE CLEAN ENERGY TRANSITION WOULD REQUIRE SIGNIFICANT POLICY SUPPORT

Given the scale and pace of the clean energy transition needed to attain energy independence by 2047, creating an enabling policy and regulatory ecosystem will be critical.. This will be also essential to manage this transition in an equitable and just manner. Due to India's rapidly growing energy demand , we find that there is a lead time of 10-15 years to make this transition and it will be important to do so in concert with the most affected communities.

The policy ecosystem needs to have five pillars: deployment mandates for commercial / cost-effective clean technologies that creates a virtuous cycle of economies of scale and cost reduction, financial support for emerging technologies, long-term infrastructure planning, accelerating and scaling domestic manufacturing, and planning for a just transition as summarized in Table ES-1.

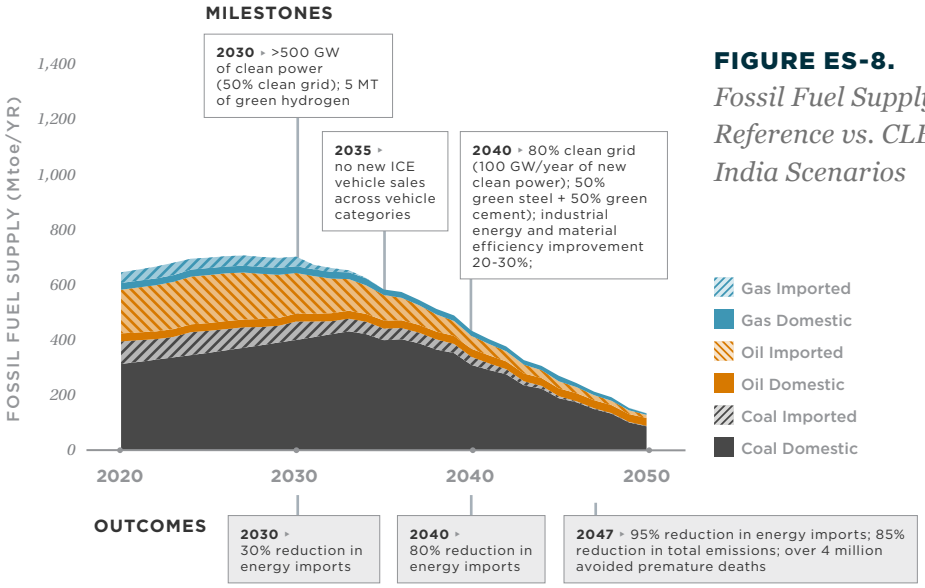

FIGURE ES-8. *Fossil Fuel Supply, Reference vs. CLEAN India Scenarios*

TABLE ES-1. *Policy Ecosystem Needed for Achieving Energy Independence*

SECTOR	MANDATES	INCENTIVES	DOMESTIC MANUFACTURING	INFRASTRUCTURE PLANNING	UPFRONT CONSIDERATION OF A JUST TRANSITION
Power	Renewable Purchase Obligation / Storage Purchase Obligation	Long duration storage, offshore wind	Production Linked Incentive + Strategic Alliances for manufacturing solar panels, batteries, electrolyzers etc	Cross-sectoral least-cost investment planning	Safety Nets Worker Retraining Social Dialogue Economic Diversification
Transport	Zero Emissions Vehicle Sales Mandate	Public EV Procurement (e.g. buses)		Public Fast Charging + Low-Cost Solar Charging	
Industry	Clean Mandate on new Industrial Facilities and Hydrogen Production, energy and material efficiency standards (e.g. expand PAT)	Green hydrogen pilots, RD&D		Hydrogen Infrastructure and Low-Cost Solar PPAs	