Innovation and India's Energy Future

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ReNew POWER

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ABOUT THIS REPORT

The Precourt Institute for Energy leads Stanford University's efforts in energy research and education. The institute funds an extensive portfolio of energy research, and it has launched Stanford research initiatives on energy storage, sustainable finance, electric grid modernization and natural gas, as well as on environment and energy policy.

The Precourt Institute also is a major contributor to building the energy transition ecosystem on campus and around the world. Thought leaders gather at events like Global Energy Forum, Global Energy Dialogues, StorageX International Symposium Series, as well as many smaller meetings and workshops. As part of this, the institute examines regional issues of energy development.

In that spirit, the Precourt Institute partnered with ReNew Power to explore India's needs and opportunities for innovation in building a sustainable energy system.

ReNew Power is the largest independent producer of renewable energy in India in terms of total commissioned capacity. Since its founding by chairman Sumant Sinha in 2011, it has built a renewable asset base of 10.3 gigawatts. ReNew Power develops, builds, owns and operates utility scale wind and solar energy projects, as well as distributed solar energy projects that generate energy for commercial and industrial customers.

ReNew and the Precourt Institute assembled a group of experts from their two organizations, as well as from other Indian companies, research institutes and government (See page 19). This report is the initial product of the group's work. It is based primarily on a workshop at ReNew Power's headquarters in Gurugram, India in February 2020, as well as the research in preparation for that workshop and interactions since. The report is intended to inform policy makers, businesses and academia on the most promising areas to benefit from innovation in the Indian energy sector.

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FOREWORD BY ARUN MAJUMDAR

Director, Precourt Institute for Energy, Jay Precourt Professor, Professor of Mechanical Engineering and of Photon Science and, by courtesy, of Materials Science & Engineering, Stanford University

India is in a unique position in the on-going global energy transition. India's large and growing population and the increasing economic prosperity will lead to a dramatic increase in its energy demand in the next three decades. Energy is the mother of all infrastructures in any modern economy. As opposed to China and OECD countries, India's energy infrastructure is yet to be fully built. This offers the opportunity to shape it in a way that addresses the energy needs for all Indians in a sustainable manner that reduces pollution and greenhouse gas emissions. The large scale of this endeavor could provide a much needed example of how to transition for both developing and developed countries.

Today, India depends largely on coal for electricity generation and is not blessed with natural gas resources. Much of its road and air transport uses imported oil, exposing India to geopolitical security and economic risks. India is blessed with an abundance of renewable energy through solar, wind, hydroelectric and biomass. It has nuclear resources and know-how. Much of its transportation needs are met by small light-duty vehicles and rail. Given these initial and boundary conditions, India has significant incentives to innovate and change course. How rapidly can India transition to a low-carbon economy that is domestically sourced? The answer to this question is relevant for India's economic, environmental and national security, and for the world to address climate change. Extreme weather conditions caused by climate change can, in turn, have devastating consequences on the Indian economy and its people.

Undeniably, India needs to align its innovations in technology, finance, business, governance, policy and public acceptance. With this goal in mind, we have initiated the Stanford-India Roundtables, thanks to the tremendous help of Varun Sivaram, Stanford alumnus and former chief technology officer at ReNew Power. The purpose is to host a series of discussions among domain experts and policy makers to better understand the key factors, barriers and opportunities that impact India's energy landscape. These discussions must lead to actions. The eventual goal of these roundtables is to identify a set of actions or collaborative projects where Stanford University and the Silicon Valley innovation ecosystem can partner with stakeholders in India to play a positive and enabling role for India to achieve its goals and aspirations at speed and scale.

FOREWORD BY SUMANT SINHA

Founder, Chairman and Managing Director, ReNew Power

These are exciting times for the Indian power sector as it undergoes a fundamental transition. The sector is at an inflection point with renewable energy gradually emerging as the dominant and preferred source of power supply, vis-a-vis coal-fired power plants. Renewables have been gaining currency ever since the Indian government realized the seriousness of the climate crisis and the urgency to move away from fossil fuels. It focused on developing a vibrant renewables sector to help meet global commitments around reducing carbon emissions. A steady drop in the cost of generation of renewables thanks to technological advances has also accelerated its adoption. Today, renewables account for around 24% of the total power capacity in India (372 gigawatts), while coal's share is 62%.

Thankfully, the sector has been impacted very little by the pandemic and India's energy transition looks firmly on track. The future looks bright for renewables in India given the huge market potential and the aggressive targets set by the government. While we produce 1.2 trillion units of electricity, our per-capita electricity consumption is quite paltry, only one-third the global average and a quarter that of China. This is poised to double by 2030 but this next doubling will be markedly different in that it will have a much higher contribution from renewables versus coal; we are looking at potentially 360GW from renewables to meet the fresh demand. While coal will continue to meet a fair chunk of the demand, there are clear signs of the electricity mix shifting in favour of renewables. This is great news given that there is global consensus on a "green" recovery strategy as we build back post Covid. There is a huge opportunity for India to expand its clean energy sector and lead the developing world's decarbonization efforts.

The road to this transformation is not without its share of challenges. Firstly, an incremental 360GW from renewables is a mammoth number. Effectively we need to add as much renewables capacity in 10 years as generated so far from all sources to date. This will take some doing given the huge requirements of land, machinery and skilled manpower. This will also need some reforms in the power distribution sector aimed at improving the operational and financial health of the mostly state-owned distribution companies. This is critical to avoid any liquidity crunch across the sector value chain. We also need a smarter, modern grid that can handle variability enabling us to inject more renewables.

Innovations and disruptive technologies hold the key to renewables maintaining its ascendancy. Technological advances should boost efficiency of wind turbines and solar modules. As batteries become more affordable, we should have effective storage solutions that will neutralize the solitary weakness of renewables: intermittency. Hybrid renewable projects in conjunction with storage systems can lead to firm, forecastable, round-the-clock green power. The electric vehicle market is also poised for steep growth as the government is working on policies and incentives to boost this sector. Given how vehicular emissions are a key driver of poor air quality, the government is keen to shift to less carbon intensive alternatives, and we can expect the two and three wheelers and public transport fleet to be electrified in the first round. Going forward, if we can ensure all these EVs are charged by renewables, that would generate significant demand for clean energy.

Presently, India does not have a robust research and innovation culture. Particularly the private sector is guilty of not investing enough in R&D. Research efforts are mostly fragmented and lack coordination. This is where industry–academia collaboration can play a pivotal role by jointly working on targeted research, yielding critical solutions to propel the sector ahead. Institutions like Stanford are driving cutting-edge research in clean energy and cleantech and Indian renewables sector stands to benefit by collaborating with such institutions. This is the rationale behind ReNew Power partnering with Stanford's Precourt Institute for Energy to initiate a series of roundtables featuring multiple stakeholders to better gauge the energy landscape in India, opportunities, barriers and decide on core areas of strategic and collaborative research. The Indian renewable energy sector can gain a lot from exchange of the latest knowledge, research trends and best practices through such partnerships. I am hopeful that this partnership can provide real impetus to the pace of energy transition in India.

Executive Summary

India is in the midst of an unprecedented energy transition. Driven by economic progress, the country's growing energy demand is projected to double by 2030. India has made significant strides toward meeting this demand through increased generation capacity from both existing and new sources of energy. It has expanded electricity service to millions of its citizens. Simultaneously, India is pursuing ambitious clean energy and climate change mitigation goals. The transition has been enabled by the deployment of many inventive technologies and policies. India's energy future will rely on continued innovation and capitalizing on new opportunities in the sector.

In February 2020, Stanford University's Precourt Institute for Energy in partnership with ReNew Power held a day-long roundtable discussion on the key opportunities and challenges for innovation in India's energy future in four areas: power sector transformation, clean energy finance, vehicle electrification, and energy research and development. The roundtable brought together Indian experts on energy, environment, transportation and R&D from the public, private and non-profit sectors. This report reviews the key themes and takeaways that emerged. By identifying critical innovation needs, this report could be a road map for continued work on India's energy future and help identify opportunities for collaboration between stakeholders.

However, this report is not a comprehensive review of all energy-relevant topics in India. The roundtable did not explicitly address industrial emissions, for example, or energy use in buildings. It is also not a consensus document.

The panel topics provide much room for debate, especially on uncertainty around future directions. Instead, based on the discussions and the summary of key themes from the panel moderators, this report identifies a basket of opportunities for innovation within each topic area.

Section 1 offers a brief overview of the landscape of India's energy transition. Section 2 dives deeper into power sector transformation and clean energy finance. Section 3 explores the electrification of India's transportation sector. Section 4 takes stock of efforts in research and development relevant to the energy sector.

THE KEY TAKEAWAYS FROM THE ROUNDTABLE IN SUMMARY:

India's energy future depends on how the country addresses an interwoven set of challenges, some of them unique to the Indian context and others more representative of the global energy transition:

- Choosing energy technologies to balance growth and capacity
- Overcoming physical infrastructure constraints
- Reimagining energy policy, governance and finance
- Bolstering a clean energy R&D agenda integrated into national policy

With the increase in renewable generation and the continued reliance on coal, India's power sector grapples with creating a more responsive, flexible, and resilient system. As private companies deploy more renewable energy, especially solar and wind generation, clean energy finance has begun to take center stage. For the power sector and clean energy finance, key opportunities include:

- Address transmission and distribution bottlenecks to enable renewable integration in the short term
- Strengthen and/or reimagine institutional structures at the central, state and local levels to support India's envisioned energy future
- Identify innovative finance mechanisms to help clean energy finance scale up
- Integrate energy, economic, and climate considerations in policy

India's transportation sector has seen the rise of motorized transport and the decline of public and non-motorized transport modes in recent years. Only 14% of vehicles are cars. The roads are dominated by two- and three-wheeler vehicles powered by fossil fuel. The electrification of India's transportation must cater to this distinctive context. The following are key opportunities for vehicle electrification:

- Envision electric mobility not as a stand-alone set of technologies and policies, but as part of a sustainable transportation framework for the Indian context centered on accessibility for all citizens
- Resolve the disconnect between transportation planning and electricity planning to enable their simultaneous transformation
- Strengthen the connections between transportation and urban planning
- Create granular and reliable data on transportation for the entire country

India's central government has allocated USD 110 million to clean energy research for a range of strategic funding and research initiatives. These cover technology-specific national missions:

- To accelerate the development and deployment of clean energy solutions
- To develop standards and facilitation through several government agencies created to foster renewable energy
- To learn from successful global examples through India's membership in the Mission Innovation group of countries

However, clean energy R&D is still very new in India and has significant gaps. Key opportunities in clean energy research include:

- Enable interdisciplinary energy research and education in India
- Scale up digital innovation in energy beyond pilot projects
- Integrate clean energy R&D into national energy and climate policy

The landscape of India's clean energy transition

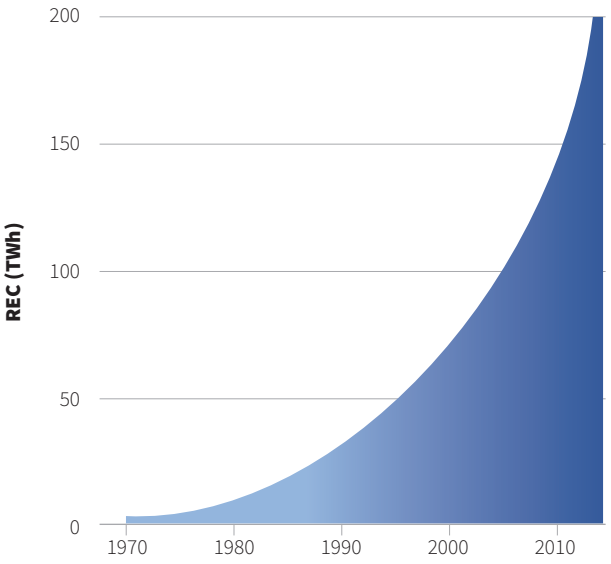
WHY INDIA NEEDS A CLEAN ENERGY TRANSITION

India's energy demand has grown by leaps and bounds in recent decades due to rising income, increased electrification and population growth. Figure 1 shows the exponential increase in total residential electricity consumption from 1970 to 2017.[1] And yet, as Figure 2 demonstrates, India's annual per capita electricity consumption of 1.1 MWh is just one-third of the global average of 3.2 MWh per capita.[2,3]

From the supply perspective, India has a generation surplus. India's total installed electric generation capacity is 367GW while peak demand is 140GW as of December 2019.[4] Despite the surplus, there are still frequent power shortages, brownouts and blackouts due to persistent transmission and distribution issues. While the grid-connected section of India's population experiences intermittent access, nearly 200 million people (18.8% of the country's population or close to 1 in 5 Indians) still lacked access to the grid in 2017. In the past few years, India's central government aggressively pursued the goal of 100% household electrification and also achieved 100% village electrification in 2018[5], although a connection currently does not guarantee reliable 24x7 supply.

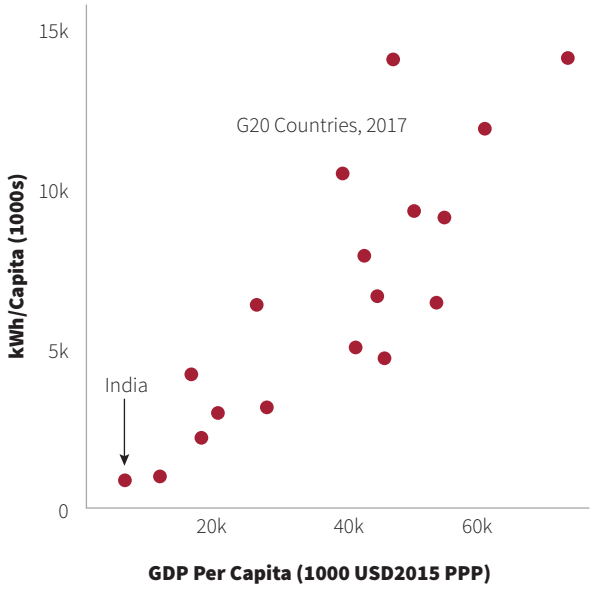
From the demand side, India's energy demand will only continue to increase as this populous economy of 1.36 billion people grows and modernizes. This makes an energy transition focused on a reliable, clean, and affordable supply of energy critical to not only India's economic development, but also to the global economy and the environment. Going beyond supply and demand, India's energy transition will deeply influence the environmental impacts of its energy system. Nearly 50% of India's current commercial primary energy supply comes from coal.[6] Since the energy sector accounts for more than 80% of the country's emissions, India's energy transition is tied intimately to its emission reduction and climate action goals. In recognition of this challenge, in its Intended Nationally Determined Contributions under the Paris Agreement, India committed to aggressively increase the share of electric power from non-fossil resources to 40% by 2030, starting from a baseline of 14% in 2016.[7] It is worth noting that currently, factors such as the economic competitiveness of renewables, the need for expanded energy access, the need for improved energy security, and the reduction of severe health impacts of air pollution are more important drivers of clean energy in India than emissions targets.[8]

FIGURE 1: TOTAL RESIDENTIAL ELECTRICITY CONSUMPTION (TWH) IN INDIA, 1970-2017.
Source: Chunekar et al, 2016



India's energy sector is also intimately tied to public health. Air pollution from the burning of fossil fuels continues to be a grave problem, especially in India's cities. Fourteen Indian cities are among the top 15 most polluted cities in the world. [9] Air pollutants, including particulate matter (PM), sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), and ozone (O_3) often exceed the National Ambient Air Quality Standards (NAAQS) in Indian cities.[10] This matters because high levels of long-term exposure to ambient particulate matter (PM2.5) is associated with the loss of 21.3 million disability-adjusted life years (DALYs) in India.[11] So, a clean energy transition will enable the country to transform not just the energy system, but also its environmental and pollution impacts.

FIGURE 2: GDP VS ELECTRICITY CONSUMPTION (BOTH PER CAPITA) FOR INDIA AND G20 COUNTRIES, 2017.
Source: TERI, based on IEA and World Bank data



TAKING STOCK – WHERE INDIA IS RIGHT NOW

The production perspective. India does not have severe energy deficit (unmet demand) issues. The energy deficit has reduced significantly since 2010 and is less than 1% currently. The current challenge lies in integrating the growing share of renewable power generation into the grid. A combination of factors is driving the growth of renewables, including:

- **Conducive federal policy initiatives** – India set an aggressive national target in 2015 of 175GW of renewable energy capacity by 2022, including 100GW of solar and 75GW of wind. In 2020, these targets were enhanced to 450GW of renewable energy capacity by 2030. Through a range of policies from tax incentives to enabling 100% foreign direct investment, the central government has worked to create a conducive and stable policy environment for renewables.

- **Economic competitiveness of renewables** – India relies on a competitive auction system that has resulted in INR 2.5-3/kWh ($0.035-$0.042/kWh) solar and wind tariffs, which are lower than coal. In fact, renewables are now cheaper than new coal as well as the short-run marginal cost of parts for existing coal generation.[12]

- **Abundance of untapped potential** – The total renewable energy potential is estimated at 10,000GW for solar and 2,000GW for wind.[13]

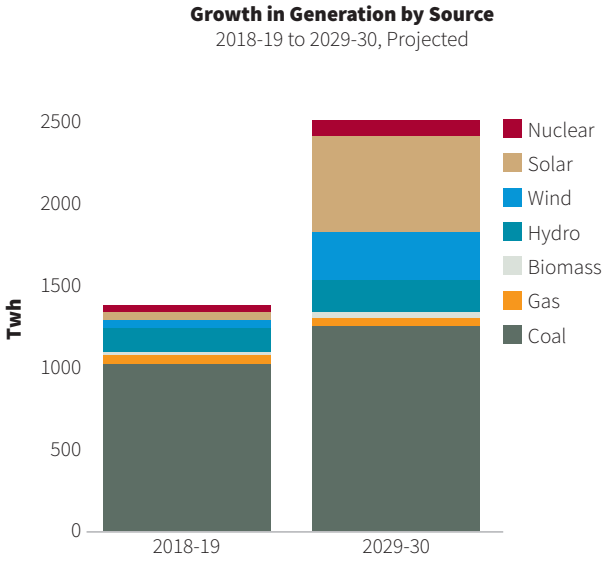
Renewable power generation has grown at an impressive average annual rate of 17.5% from 2015-19, putting India on a path to a rapid energy transition. Figure 3 from TERI shows the historical and projected trajectories for generation by different fuel sources for India. Renewables also accounted for more than 50% of all new capacity in 2019.

Given the prevalence and economic viability of renewable energy, the current challenge is thus not in further cost reduction but in equipping the power system to intake this growing supply and in dealing with the challenges of variability and demand-response.

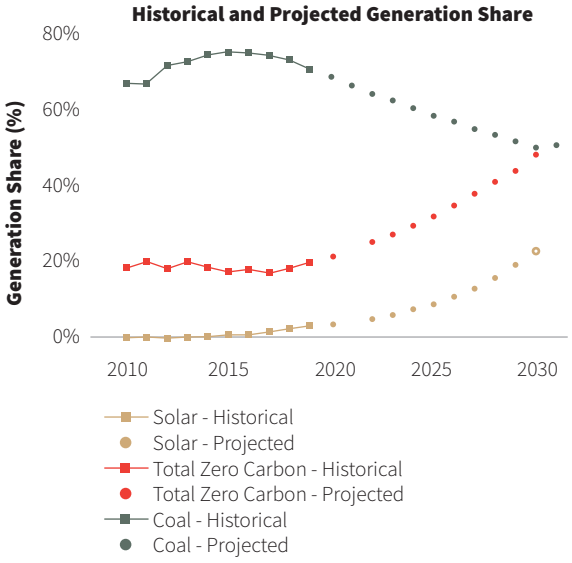
The transmission and distribution (T&D) perspective. Despite the energy surplus, persistent blackouts and brownouts affect all regions of the country due to T&D bottlenecks. Rural areas in particular are severely affected, facing 20-30 interruptions per month on average.[14] The average duration of these disruptions can range from less than an hour in major cities like Delhi to several hours in rural parts of states like Bihar and Orissa. Despite policy aimed at reducing the Aggregate Technical and Commercial (AT&C) losses, they are still estimated to be about 18.7%[15], which is quite high compared to other countries.

The consumption perspective. India's total electricity demand is projected to double to 2,040 TWh by 2030, with an annual growth rate of 6%. India's energy transition is strongly linked to its urban transformation, with a majority of the population projected to live in urban areas by 2030.[16] This makes the urban end-uses of building and transportation energy critical to the energy transition. Air-conditioning in buildings will account for a large share of the growth in building energy demand in coming years in India.[17] In the buildings sector, a cross-subsidy exists from industrial and commercial customers who pay higher tariffs to residential and agricultural customers, who pay lower tariffs. In the transportation sector, personal motorized transport in the form of two-wheelers dominates the vehicular mix, but there is an aggressive policy push towards electrifying the country's vehicle fleet.

FIGURE 3: HISTORICAL AND PROJECTED GENERATION BY SOURCE, TWH (LEFT) AND SHARE (RIGHT)
Source: TERI report on Transition to Renewables



Source: TERI, based on data from (CEA, 2019)



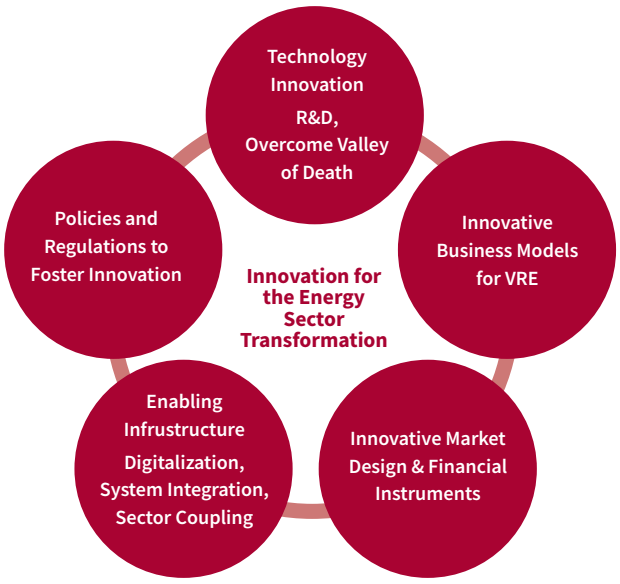
Source: TERI, based on data from (CEA, 2019; IEA, 2019)

INDIA'S ENERGY FUTURE – CRITICAL CHALLENGES

The International Renewable Energy Agency (IRENA) lays out a broad four-pronged framework for governments around the world to enable a clean energy transition, which is particularly relevant to the Indian context:

- Nurture innovation through policy incentives that prioritize a long-term perspective
- Pursue power-system integration for renewable energy sources
- Decarbonize end-use sectors through enhanced energy efficiency in buildings, transportation and other end uses
- Expand innovation beyond R&D to include policy frameworks, business models and financing mechanisms

FIGURE 4: COMPONENTS OF INNOVATION FOR ENERGY SECTOR TRANSFORMATION
Source: IRENA



This framework recognizes the role of innovation in accelerating the clean energy transition and transforming the power sector. As Figure 4 shows, innovation for the energy transition in India needs not just research and development, but also the requisite balance between technology push and market pull for the accelerated and equitable deployment of renewable generation. India's energy future depends on how the country addresses an interwoven set of challenges, some of them unique to the Indian context and others more representative of the global energy transition:

1. **Choosing energy technologies to balance growth and capacity.** Unlike many developed countries where older fossil-fuel driven generation capacity has to be substituted with clean energy sources, the challenge for India lies in creating entirely new generation capacity. Therein lies the opportunity as well – this new capacity can be from clean energy sources. However, while the rapid deployment of renewables will play a central role in building India's generation capacity, there is a lot of uncertainty around equipping the grid to handle their variability. At the same time coal, will likely continue to be a dominant fuel for power production in the next decade.[6]

2. **Overcoming physical infrastructure constraints.** Ramping up from 87GW today to 450GW of renewable capacity by 2030 requires massive investments and construction of physical infrastructures assets. Even with 450GW built out, it still can only account for half of increased demand by 2030. If left unaddressed, persistent constraints in terms of land acquisition and grid expansion to connect new capacity can severely impact clean energy development.

3. **Reimagining energy policy, governance and finance.** In a nutshell, India's energy sector is faced with three monumental challenges – (1) a patchwork of central and state government energy policies that are often not in sync; (2) Distribution companies (Discoms) facing persistent financial issues and misaligned incentives for both producers and consumers; and (3) a disconnect between energy policy on one hand and economic and climate policy on the other.

4. **Bolstering a clean energy research and development agenda that is integrated into national energy policy.** While the central government in India has certainly taken many positive strides towards developing an Indian pipeline of research initiatives and funding, much remains to be done in scaling up R&D and aligning it with the tapestry of national, state and local energy policies.

The central role of power sector transformation and clean energy finance

POWER SECTOR TRANSFORMATION

The power sector plays a central role in India's energy transition. The country's electricity grid is primarily managed at the national and state levels. Nationally, the NTPC Limited (formerly National Thermal Power Corporation Limited) is responsible for power generation and the Power Grid Corporation (commonly, Power Grid) handles transmission and distribution. There are also state-level electricity generation, transmission and distribution boards.

Since the mid-2000s, the Indian power sector has taken important steps towards capacity addition and grid access, aided by federal policy initiatives.[15] Electricity generation was opened up to the private sector under the Electricity Act of 2003, leading to a spur of investments in generation capacity. Significant coal-fired generation capacity was added from 2010 to 2015, reducing the total and peak annual energy deficits (unmet demand) to less than 1%. This was an important step because the total and peak energy deficits were nearly 10% and 15-20% respectively in prior decades. From the grid access perspective, the power sector has also prioritized rural electrification as part of the central government's Saubhagya initiative, aimed at 100% rural electrification by 2019.

Major policy challenges. Amidst these positive efforts and progress, important challenges remain:

- **Troubled financial health of distribution companies (Discoms):** Discoms in India rely heavily on subsidies from state governments, and still face heavy losses. Many Discoms supply power at tariffs below cost of supply, and their financial health is further jeopardized by T&D losses, power theft, and political pushback against increased tariffs. Several rounds of regulatory reforms have attempted to improve Discom finances. Most recently, in 2015, the central government launched the Ujwal Discom Assurance Yojana (UDAY) to financially stabilize Discoms by converting debt into state government bonds. State governments would take over three-fourths of the debt of their state Discoms and issue bonds to raise money and pay off loans. The remaining one-fourth would come from low-interest loans and state-backed Discom bonds. The total estimated UDAY bailout was about INR 2.32 trillion (1.3% of GDP). The Discoms were also required to reduce T&D losses and theft, install smart metering and gradually raise tariffs. Post-UDAY, the aggregate Discom debt fell from INR 2.7 trillion (USD 37 billion) in 2015 to INR 1.5 trillion (USD 27 billion) in 2017 but returned to pre-UDAY levels in 2019.
- **Improper price signals:** Due to the cross-subsidy from industrial and commercial customers to agricultural and residential customers in most Indian electricity markets, the tariffs charged for electricity often do not reflect the true cost of supply, with an average gap of INR 0.26/ kWh (USD 0.37¢/ kWh).[18]
- **Persistent technical T&D problems:** Having a grid connection does not always translate to reliable 24x7 power supply. Reliability of supply continues to be an issue, with 20-30 interruptions per month on average.

Given the current state of the power sector, the transition to increased renewable power generation poses additional challenges and could exacerbate existing issues:

- **Grid flexibility:** The variability of solar and wind generation will necessitate increased flexibility of the grid for renewable integration as well as the on-demand curtailment of other generation capacity.
- **Integration of storage:** Integrating more solar and wind power into the grid will likely necessitate rapid deployment of battery storage capacity.
- **Price signals:** When it comes to rooftop PV for the built environment, the economics only make sense for commercial and industrial customers in India who pay higher electricity tariffs and have ease of access to capital. The residential rooftop PV sector is not as viable currently.[19]

FACILITATING INVESTMENTS IN CLEAN ENERGY

The addition of substantial capacity to meet India's growing energy needs will require proportionate scaling up of investment. The total investment requirement for generation capacity addition is estimated to be INR 10.3 trillion (USD 144 billion) during the period 2017-2022 (includes renewable energy capacity addition and advance action on upcoming projects).[20] To meet this need, the central government has taken a number of positive steps to increase both domestic and foreign direct investments in clean energy through fiscal policy measures and continued support from tax incentives. Recent investment trends in renewables have been characterized by higher market concentration of developers, reduced risk, improved bankability, and the ability to negotiate better financing terms.[21] Renewable energy investments are currently more lucrative and less risky than fossil fuel power in India, with solar power seen as less risky than wind power.[20]

Despite these steps forward, much remains to be done. Annual investment in clean energy markets in India has stagnated at about INR 714 billion (USD 10 billion) for several years.[22] A majority of the current investment flows towards utility-scale solar and wind power projects. Higher risk perception by investors of three primary types - counterparty risk, grid risk and financial risk - continue to pose barriers to investments in renewable energy.[20] In addition, international investors face currency risks as well. Constraints in obtaining long-term debt, problematic land acquisition processes, and infrastructure bottlenecks pose additional financial obstacles. For instance, the average cost of debt in India is among the most expensive in Asian countries, at around 9-11%.

KEY OPPORTUNITIES FOR INNOVATION:

The above challenges point to clear opportunities for innovation:

In the short term, address bottlenecks to enable renewable integration

This particular opportunity has been studied in great detail in research by both academic and non-profit organizations in India.[13,17,20] Increasing grid flexibility in response to renewable integration and identifying specific T&D bottlenecks will be critical in the short term.

In the medium to long term, strengthen or reimagine institutional structures to enable the transition

India's energy sector has a range of different actors with differing priorities, leading to three monumental challenges: 1) a patchwork of central and state government energy policies that are often not in sync; 2) distribution companies (Discoms) facing persistent financial issues and misaligned incentives for both producers and consumers; 3) a disconnect between energy policy on one hand and economic and climate policy on the other. These are often facilitated by continued reliance on a least-cost framework for project deployment that makes no room for economic and climate concerns. In order to address these challenges, there is a need to take a step back and ask - what are the institutions that can enable the envisioned future of India's energy system? Where does current technical capacity and expertise lie and where will it need to be reimagined or enhanced India moves from a top-down centralized power generation model to a more decentralized and distributed generation model? There is a need for a road map of what distribution companies will look like in 20 years in the Indian context.

Mainstream clean energy finance at scale

The learning curve for scaling up of capital has been and will continue to be very rapid for renewable deployment in India. Banks and finance corporations continue to be dominant sources of domestic debt, and high risk perception and policy uncertainty pose barriers to the entry of new investors and lenders. At the same time, continued reliance on public funding can impede the mainstreaming of clean energy finance at scale. There is thus much room to think about innovative finance mechanisms to address barriers to clean energy finance in India.

Integrate energy, economic and climate considerations

Energy is not electricity. Having targets for the electricity sector transition is not the same as having a narrative for India's energy systems and their connections to other economic and climate considerations as a whole. India can benefit from international examples of integrated national energy and climate plans, such as the 10-year plans required by the EU for each member country.[23]

Electrifying India's transportation sector

INDIA'S UNIQUE MOBILITY CONTEXT

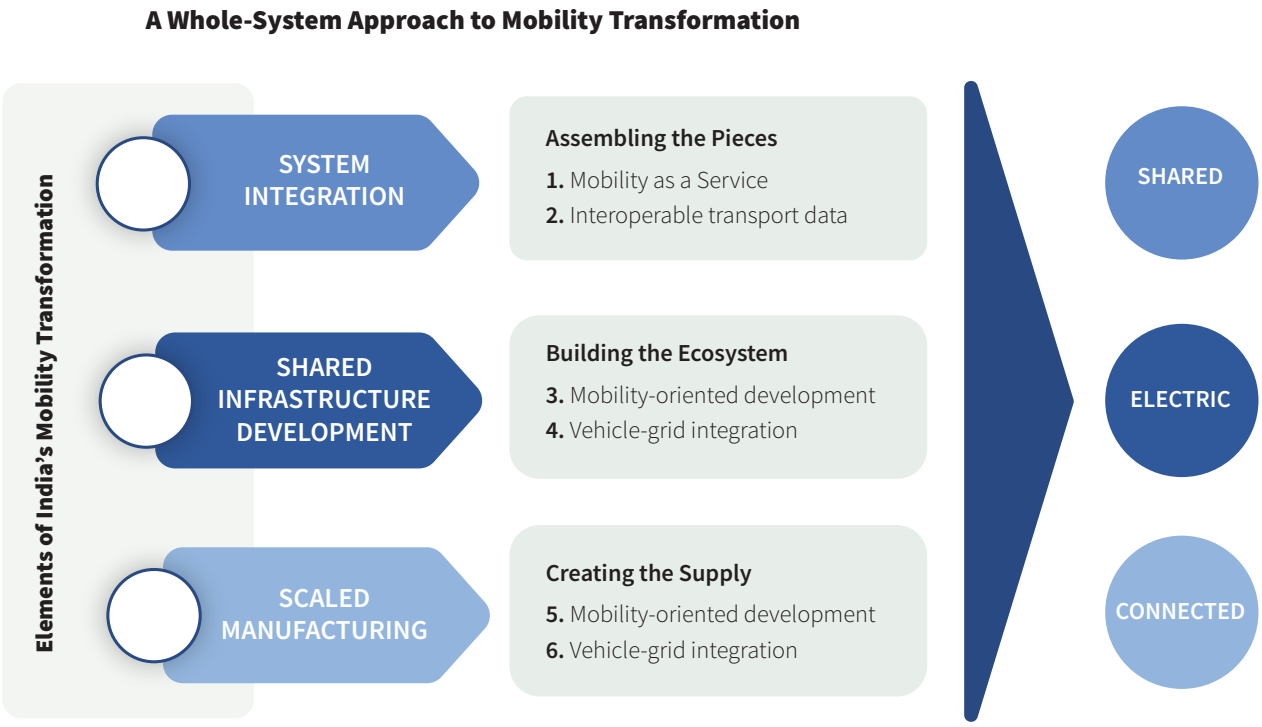
People in India's numerous cities, towns and villages move around using a variety of public, motorized and non-motorized modes of transport. In particular, recent decades have seen a decline in the use of public and non-motorized transport and a multi-fold increase in motorized transport.[24] For instance , the number of registered vehicles in India grew from 5.3 million to 230 million in 1981-2016.[25] Not surprisingly, urban areas are home to a large share of the vehicles - 31% of vehicles are registered in cities of 1 million people or more. Personal motorized vehicles dominate India's unique mix of vehicle types. Two-wheelers account for 79% of all registered vehicles, three-wheelers (such as auto rickshaws) account for about 4%, and cars account for just 14% of the mix.[26] Large commercial vehicles (buses and goods vehicles) make up the remaining 3% of registered vehicles. Despite their small share of the fleet, these commercial vehicles account for about 80% of total PM2.5 emissions from vehicles.[25]

In keeping with global trends and the growing share of personal motorized vehicles, India's transportation sector is grappling with the electrification of motorized transport. India's vehicle electrification experience will likely be quite different from the European and North American trajectories given the relatively small share of cars. This is reflected in the Electric Vehicle (EV) adoption targets for different vehicle types set by the central government. The current goals specify that all three-wheelers are to become battery electric vehicles (BEVs) by 2023, and all 2-wheelers (<150-cc engines) by 2025. In addition, there are state and local government targets. For instance, the Delhi government has set a target of 25% EV share of all new vehicles by 2024.[27]

These ambitious vehicle electrification targets have challenged manufacturing priorities in India as well. India's large auto industry has made substantial capital investments in internal combustion engine (ICE) manufacturing. The transition to manufacturing EVs in the country will likely lead to heavy losses for the industry. India's limited capability and technical expertise in EV manufacturing could disrupt vehicle electrification and limit indigenization of the supply chain.[25]

From the policy perspective, the National Urban Transport Policy formulated by the Ministry of Urban Development (MoUD) (2014 and 2006) guides transportation sector policy in India. In 2017, a strategic road map (Figure 5) was developed by the National Institution for Transforming India (NITI Aayog), which serves as the policy think tank for the Government of India, in collaboration with the Rocky Mountain Institute. The road map emphasizes the pursuit of a "shared, electric and connected mobility future" to reduce energy demand from oil as well as carbon emissions.[28] Key elements of this road map include system integration, shared infrastructure development and scaled manufacturing. More recently, the National Mission on Transformative Mobility and Battery Storage was set up in 2019 to guide India's mobility transition.

FIGURE 5: A WHOLE-SYSTEM APPROACH TO MOBILITY TRANSFORMATION
Source: Niti Aayog and Rocky Mountain Institute (2017)



KEY OPPORTUNITIES FOR INNOVATION:

The above challenges point to clear opportunities for innovation:

Envisioning electric mobility as part of a sustainable transportation framework for the Indian context

Despite the growing share of motorized transport in India, it is important to recognize that electric mobility is not a silver bullet for existing issues such as congestion and transport safety or larger goals such as decarbonization. It can function effectively only as a key part of a broader sustainable and equitable transportation framework. India's National Urban Transport policy clearly recognizes that the goal is "moving people rather than vehicles".[29] In other words, the ideal goal of a transportation network is to deliver inclusive access to people who wish to reach places of work, recreation and vital services.[30] This means that there is a need to:

- Identify the suite of decarbonization pathways for India's transportation sector and the specific role that different types of electric mobility play in these pathways. There are opportunities to more readily address some specific types of mobility, such as electrifying car fleets and modernizing the highly polluting commercial vehicle fleet in India.
- Address the complex interactions between mobility and other systems. For instance, electrifying the three-wheeler fleet will need to address the syncing of regulation across governmental levels, credit access for rickshaw drivers for vehicle purchase, and coordination with driver unions.

Addressing the disconnect between transportation planning and electricity planning

Vehicle electrification is so challenging because it hinges on the simultaneous transformation of two juggernauts in India: the electric grid and the transportation network. Vehicle electrification can only be possible through the large-scale and uniform expansion of both captive and public charging infrastructure integrated with the electric grid.[31] This infrastructure is currently being driven by a patchwork of small private sector enterprises or through pilot initiatives by Discoms in a fairly ad-hoc manner. At the same time, the technical and economic viability of battery swapping (wherein discharged batteries from vehicles are simply swapped out with charged batteries instead of plugging the vehicle into a charging point) is currently unclear for different vehicle types, and there are no existing standards for the handling of batteries in such a model. Both plug-in charging and battery swapping rely on the increased availability of expensive battery technology and the safe disposal of depleted batteries, both of which continue to remain challenges across the world.

- There is thus a clear need for policy coordination between transportation planning and electricity planning at central, state and local levels in India in ways that simply have not existed before. Beyond the grid, the electrification of motorized transport has implications for India's energy sector at large. It has strong ties to energy security due to the country's heavy dependence on imported coal and oil. For instance, India imported 80.9% of its oil in 2015-16. Reciprocally, volatility in global oil prices can also influence the economic viability of electric vehicle adoption.

Strengthening the connections between transportation planning and urban planning

- Urban design and planning can play a critical role in vehicle electrification in particular and sustainable transportation in general, offering ways to shorten trips and increase the modal share of non-motorized transport through compact and well-planned cities. There is a need to jointly plan for electric mobility needs and land use in the Indian context, particularly in light of existing challenges around urban governance.[32] Environmental impacts, particularly in urban areas, are strongly tied to transportation. Air pollution and public health implications are critical, particularly in urban areas with heavy health burdens from pollution, such as Delhi. While transportation contributes less than 10% of total national emissions, this will likely change as the share of motorized transport continues to grow.

Creating granular and reliable transportation data

This is a common thread that affects all the three issues identified above. There is a surprising dearth of granular and regularly updated data on how people move around in Indian cities.[33] While several central government policies have outlined the setting up of a regularly updated and comprehensive transportation data repository for the country, there is now an opportunity to use data streams from mobile data and remote sensing to create and manage transportation data without personally identifiable information.

Bolstering clean energy research and development

INDIA'S ENERGY R&D CONTEXT

Historically, research and development (R&D) efforts in India started out on par with other Asian countries. In the 1980s, for instance, India invested 0.6% to 0.9% share of GDP in research, which was similar to or higher than Singapore, South Korea and China.[34] But that share has stagnated over time at 0.9%, while other countries now invest 2-4% of their GDP in research. While the private sector contributes a majority share of investment towards R&D in these other countries, corporations in India account for only 35% of R&D investments and public research institutes take on nearly 60% of the investment burden.[34] This general trend extends to India's energy sector as well. Enabling India's energy transition will require more consistent and scaled up incentivization of R&D.

The central government has taken on a leading role in India's clean energy research, providing funding and launching strategic R&D initiatives. Central government funding for clean energy R&D in 2017-18 stood at about USD 110.6 million, a significant share of the USD 650 million spent on all energy R&D across all governmental levels.[35] In addition to funding, the central government has initiated technology-specific "national missions" to accelerate the development and deployment of clean energy solutions, such as the National Solar Mission (2010), the National Electric Mobility Mission (2012) and the National Smart Grid Mission (2015).[35] The Ministry of New and Renewable Energy (MNRE) is developing initiatives for testing, standards and facilitation through the National Institutes of Solar Energy, Wind Energy and Renewable Energy, as well as the Indian Renewable Energy Development Agency (IREDA) and the Solar Energy Corporation of India (SECI).

From an international perspective, India has developed collaborative research partnerships such as the Partnership to Advance Clean Energy-Research (PACE-R) and the Partnership to Advance Clean Energy - Deployment (PACE-D) between the U.S. and India. With the goals of learning from global experiences and harnessing external expertise, India is now part of the Mission Innovation group of countries and has committed to doubling its public investment in clean energy R&D. India's Ministry of Science and Technology, the Mission Innovation India unit in the Department of Biotechnology, and the International Energy Agency (IEA) signed a Memorandum of Understanding (MoU) in 2018 aimed at enhancing innovation for the clean energy transition.[36]

More recently, with an eye on early stage research investment, India's Department of Science and Technology (DST) launched the Clean Energy Research Initiative in January 2020[37]. They also have joint CES Fellowships with the India Energy Storage Alliance (IESA) for energy storage technology and application development. With these new initiatives, the DST is transitioning from a more siloed and subject-specific focus to an interdisciplinary focus on energy systems research as a whole.

KEY OPPORTUNITIES FOR INNOVATION:

Clean energy R&D is in its nascency in India and there are still significant R&D gaps to be filled. At the same time, there is an opportunity for targeted policy to create an environment conducive to energy innovation. India could benefit from lessons learned in experiments in other countries such as the United States' Advanced Research Projects Agency–Energy (ARPA-E), which supports and funds research and development of advanced energy technologies.

Enabling interdisciplinary energy research and education in India

A common theme that emerged in the roundtable was the need to address silos in clean energy research in India, especially in academia. Without consistent platforms for interaction or data on ongoing work, it can be difficult to foster collaboration across disciplines and organizations when it is not clear which institutes are doing what research. Further, there is an educational imperative to create a pipeline of qualified professionals who understand both the technology and policy sides of clean energy and are able to bridge them with societal needs. There are ongoing efforts through initiatives such as the School of Public Policy at the Indian Institute of Technology (IIT) Delhi, but more are needed.

Scaling digital innovation in energy beyond pilot projects

Digital innovation can play a critical role in both the deployment of renewable technologies and also in enhancing the efficiency of energy networks, particularly in buildings and transportation sectors in India. One such innovation is that of Advanced Metering Infrastructure (AMI), which is yet to find widespread adoption in India. A majority of existing projects focus only on small scale pilots. Currently, regular meters record consumption in each building and agents from the utility physically travel to each meter location, take a reading, then generate a bill. The central government's Uday policy scheme aimed to replace all conventional meters in India by December 2019. However, less than 5% of meters are currently smart and the new replacement target is March 2022.[38]

The federal Ministry of Power has 14 ongoing smart grid pilot projects in different cities, and individual cities are considering smart metering through the Smart Cities Mission. For instance, the Chennai Smart City Limited has a pilot project for the deployment of 120,000 smart meters in the southern city of Chennai. The Energy and Efficiency Services (EESL), a state-run company, is leading efforts to deploy smart meters in a few regions and has pilots in Delhi and the state of Bihar. A few Discoms have begun to harness smart meter technology in parts of their distributional networks, presenting a step towards demand response and net metering, as well. For instance, Tata Power in Delhi has currently installed 35,000 meters in its service area in Delhi. However, there is a need to scale these efforts to generate more consistent data that is actually employed in operation and management of the grid.

Integrating clean energy R&D into energy and climate policy

While existing R&D efforts in India are making the right strides, the patchwork of national-level efforts can be organized into a more consistent clean energy R&D framework that is aligned with energy and climate policy and goals.[39] For instance, opportunities in the short term within such a framework could include exploring performance-driven efficiency targets for demand-side management for building energy use, and developing business models for clean energy technology that is ready to be deployed. Opportunities in the long term include identifying and developing over-the-horizon technologies for the Indian context, such as cooling technologies.

AFTERWORD BY SALLY BENSON

Jay Precourt Family Professor, Professor of Energy Resources Engineering, Stanford University

India's energy landscape is changing quickly on many fronts and the pace of these changes is likely to only accelerate over the next several decades. There are many stakeholders and the stakes are high. Increasing access to high quality electricity and cleaner transportation services are essential for sustained growth of the economy and wellbeing of India's more than 1.3 billion citizens. Navigating this complex landscape requires simultaneously dealing with the here and now, while supporting R&D and new policies for encouraging innovation to provide cleaner and more efficient ways of producing and using energy. Indeed, this is a tremendous challenge, but also a tremendous opportunity.

With its vast natural resources, talented engineers, and entrepreneurial spirit, India has the potential to build a truly modern 21st century electric grid and transportation system from the ground up. Integrating renewable generation, energy storage technologies, and clean, firm power energy technologies – such as nuclear generation and fossil fuels with carbon capture and storage – can provide the lowest cost pathway to a reliable and clean energy system. India can provide a blueprint and lead the world in how to "do this right."

We are deeply appreciative of having the opportunity to learn first-hand about challenges and opportunities of achieving India's ambitious goals for growing the energy system, integrating vast amounts of renewable generation and energy storage, and reducing emissions from the transportation system. Leaders from research programs at Stanford – Bits & Watts Initiative, StorageX Initiative and the Sustainable Finance Initiative – learned much about how they and companies in Silicon Valley might contribute to India's energy transition. In addition, Stanford is in the process of creating a new school focused on sustainability. This, too, could help India policy makers and businesses consider the energy transition holistically and consider other issues, such as clean water, other environment and health impacts, and land use. Shortly after the first roundtable, COVID-19 spread throughout the world and changed everything. The pandemic's effects will change how the energy transition will be achieved in India and around the world, but the mechanisms of change remain the same. We are excited about the opportunity to collaborate and learn together.

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ABOUT RENEW POWER AND STANFORD PRECOURT INSTITUTE FOR ENERGY

ReNew Power is the largest independent producer of renewable energy in India in terms of total commissioned capacity. Since its founding by chairman Sumant Sinha in 2011, it has built a renewable asset base of 10.3 gigawatts. ReNew Power develops, builds, owns and operates utility scale wind and solar energy projects, as well as distributed solar energy projects that generate energy for commercial and industrial customers. Today it operates more than 110 utility scale projects spread across 8 states in India. In 10 years of its operation, ReNew projects have generated almost 85,000 jobs, directly and indirectly.

The Precourt Institute for Energy leads Stanford University's broad and deep efforts to help create a future of sustainable, affordable and secure energy for all people. The Precourt Institute funds an extensive portfolio of energy research. It has launched Stanford research initiatives on energy storage, sustainable finance, electric grid modernization and natural gas, as well as on environmental and energy policy. The institute supports courses and internships for students and contributes to energy literacy. It also is a major contributor to building the energy transition ecosystem on campus and around the world.

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