What would India need for moving to a 100% renewable energy scenario by 2050?

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Background

The Fifth Assessment Reports released by the IPCC indicates that increase in global temperatures is proportional to the build-up of long-lasting greenhouse gases in the atmosphere, especially carbon dioxide. Various models have estimated 680—1200 billion tonnes of CO_2 as being the maximum volume of CO_2 that could be emitted till 2100 into the atmosphere to still stay within the 2 °C limit. However, few countries have made efforts to move towards any major deviations from their past emission trajectories. Various studies such as the Emissions Gap report brought out by the UNEP indicate that the emission gap (defined as difference between what existing pledges can achieve and what is required over different time frames) is not becoming any smaller but more and more difficult to achieve.

Pursuing an energy trajectory alternate to the historical fossil fuel dominant trajectory is widely regarded as the preferred policy option to rapidly reduce the emission gap without compromising with the imperatives of reducing development deficit. Renewable technologies not only provide a low carbon enhancement of energy security, but also have other crucial benefits like improving access to energy services, increasing the standard of living and levels of employment of the local population, reducing pollution, improving health, ensuring sustainable development of the remote regions in a country and so on. Moreover, renewables are amenable to adoption at various scales – ranging from a few kilowatts to hundreds of megawatts, and can therefore be adopted in modular standardized designs across a variety of end-use applications and in a decentralized mode. Renewables can also provide greater resilience to volatility in market prices of energy than conventional energy fuels. In addition to promoting renewable energy, improving energy efficiency across various sectors offers an excellent opportunity for linking sustainable development with climate mitigation. Improvements in energy efficiency in fact can bring with it a wide range of positive social impacts such as reduced air pollution and the consequent health benefits. Various studies indicate that several thousand premature deaths related to air pollution could be avoided

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annually by 2030 through energy efficiency measures in the transport, buildings and industrial sectors[1].

Contextualising India's need for examining alternative energy paths

India ranks at a low 136 among 186 countries in terms of its human development index, indicating that India's development needs are still huge. Much of the infrastructure growth across sectors, whether it is in built-up infrastructure, power generation and transmission capacity, mobility provision, education or health related infrastructure, still needs to happen. With a large and increasing population, and the Government's plans to maintain GDP growth at around 8% - so as to improve per capita incomes and bring about inclusive growth - an increase in the country's energy requirements is imminent. Various studies have indicated that India's primary energy requirements could increase at least 4-5 folds over the next 2 decades in order to fulfil the country's development aspirations[2].

India thus faces a huge challenge in meeting its growing energy demands in a sustainable manner. It is important for the country to examine the scope for deviations from its current energy path and explore various alternatives. While India's current energy mix remains largely dominated by coal and oil based energy forms, continuing this trend would increase its import dependencies enormously while creating a high carbon path dependency. On the other hand, India is blessed with a large renewable energy resource base and should explore the realisation of the opportunity to enhance and accelerate the deployment of renewables and pursue a more sustainable and energy secure development path. Accordingly, we seek to explore the choices, constraints and barriers for India in moving towards a 100% renewable energy scenario, with the intent of not only examining whether a 100% renewable energy scenario is indeed theoretically possible, but also assessing what such a transformational scenario would imply in terms the requisite technology, policy, behaviour, institutional and infrastructural changes that would be required.

Broad Approach and Assumptions

A scenario based approach is used to examine the possibility of a 100% (or near 100%) renewable scenario for India by 2051. The MARKAL model set up to represent India's energy system using TERI's country-level database has been in this study to examine the choices available to the country over a 50-year period. The model represents a detailed set of fuel and technology choices across all of the energy demand and supply sectors as depicted in Figure 1, and is set up as a bottom-up engineering linear programming modelling framework.

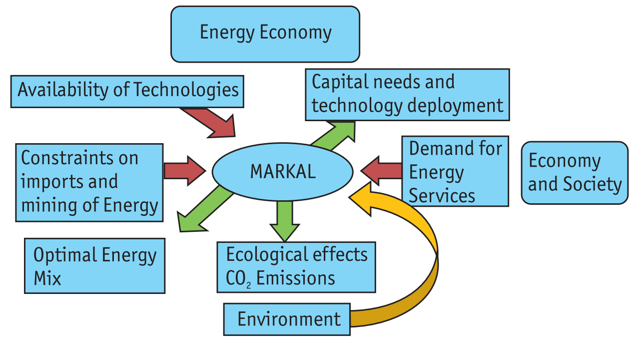

Figure 1: MARKAL framework overview
Source: IEA, ETSAP

For the purpose of comparison with the reference energy scenario, a 100% renewable scenario is explored to identify technical potential and areas of focussed intervention:

1. **Reference Energy Scenario (REF):** Considers current trends and policies, including any autonomous energy efficiency improvements and structural/lifestyle changes taking place, and projects these into the future as determinants of energy demand and supply. Energy choices and imports are unhindered, driven purely by economics.
2. **100% Renewable Scenarios (REN):** Examines the possibility as well as the energy mix of a scenario approaching 100% renewable energy in primary commercial energy. Fossil fuels and nuclear based technologies are phased out and no new capacity additions in either of these are considered except for the ones that are already under construction.

All other macro assumptions such as those regarding assumptions on GDP, population growth rates and energy prices etc. remain the same across both the scenarios.

The REN scenario assumes that the technological limits of several renewable technologies and fuels can be stretched in an accelerated manner, exploiting them to their maximum technical potentials by the end of the modelling period. For example, on-shore wind and solar

[1] UNEP, 2014. The Emissions Gap Report
[2] Planning Commission, GoI, 2006, Report of the Expert Committee on Integrated Energy Policy

would need to be exploited to a very large extent by 2051. Concentrator solar thermal plants with storage and solar power towers are also considered in this scenario and assumed to be able to act as base load plants. Moreover, industrial process heating requirements are assumed to be met to a large extent through concentrator solar thermal technology. In addition, other renewable technologies such as Geothermal, Ocean, and Waste to Energy are also considered to be able to achieve 100% of their technical potential by 2051. Solar power technologies like solar PV have been considered as per the potential available from 1% of country's land area with insolation of more than 5kWh/m2/day. Solar thermal technologies like concentrator solar thermal technologies (CST) are also assumed to be able to meet end-use heat demand to the maximum extent possible.

Further, it is assumed that renewable resources will replace conventional sources of energy almost completely by 2051. Nuclear and fossil fuels are phased out gradually by 2051. The most efficient fossil based technologies such as advanced gas-based power generation (e.g. H-frame combined-cycle gas turbine) with 60% efficiency are assumed to be commercially available by 2016/17. Bio-fuels are also assumed to be available as replacement of petroleum fuels in the transport sector. While all of the potential area delineated for Jatropha plantation is taken up, second generation bio-fuels like cellulosic ethanol and advanced biodiesel (FT-Biodiesel) bio-fuels are also assumed to be produced from crop residue and fuel wood for energy purposes from the year 2026. Additionally third generation (algae) biofuels also need to play a major beyond 2031.

Key transformations required for a 100% renewable scenario for India

In a Reference (REF) scenario, India's primary energy supply could increase from 738 mtoe in 2011 to 3613 mtoe in 2051 (an increase of 6 times). Coal and oil continue to dominate the energy mix in this scenario. While renewables increase significantly in magnitude terms, their share could continue to remain small at around 4% even in 2051. As much as 90% of the commercial energy is likely to be based on coal and oil. The fuel import dependency under such a scenario is estimated to rise to over 97% for oil, around 75% for coal and more than 80% for gas by 2051. This undoubtedly raises concerns with regard to energy security as well as increasing pressure on the country's energy import bills and the vulnerability to global price fluctuations and regional fuel supply disruptions apart from the environmental implications of such an energy mix both at the global and local levels. Examining and addressing the energy issues that may arise in the near future is therefore a fundamental requirement from various relevant perspectives. In this scenario, India's final energy demand is estimated to increase from around 560 Mtoe in 2011 to around 2545 Mtoe in 2051, largely fuelled with fossil based energy forms.

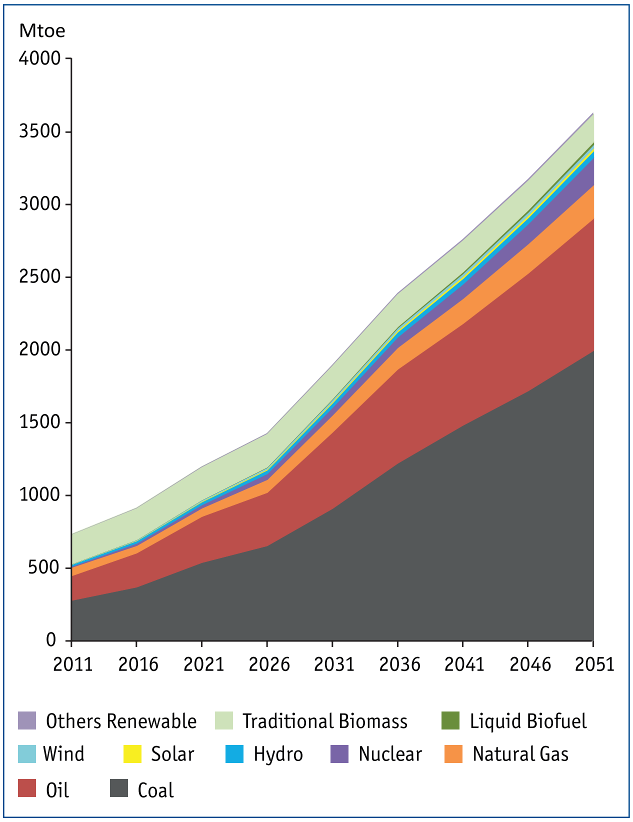

Figure 2: Resource wise Primary Energy Supply in REF Scenario

In the REF scenario, electricity generation (centralized and decentralized) grows by 8 times the 2011 level of 1151 TWh in 2051, with the share of renewables in electricity decreasing from the 2011 level of 18% to 13% in 2051. The rest of the energy comes from fossil fuels (79%) and nuclear power (8%). The installed capacity for power generation increases to 829 GW in 2031 and 1917 GW in 2051 in the REF scenario.

In order to achieve the REN scenario, energy efficiency needs to play a key role in terms of reducing the primary commercial energy requirement significantly based on adoption of not only more efficient options across the various end use sectors, but also switching to more efficient

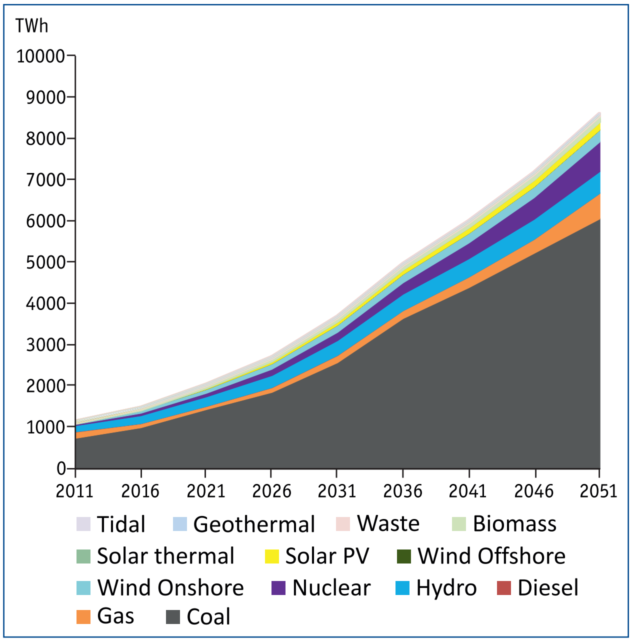

Figure 3: Resource wise Electricity Generation in the REF Scenario

conversion processes, fuels and technologies. Accordingly, primary commercial energy supply increases by only around three times the 2011 level to 1478 mtoe in 2051. Coal consumption increases to 4310 MT in the REF scenario in 2051 while in the REN scenario, it could reduce to a mere 94 MT. In case of natural gas, annual consumption increases

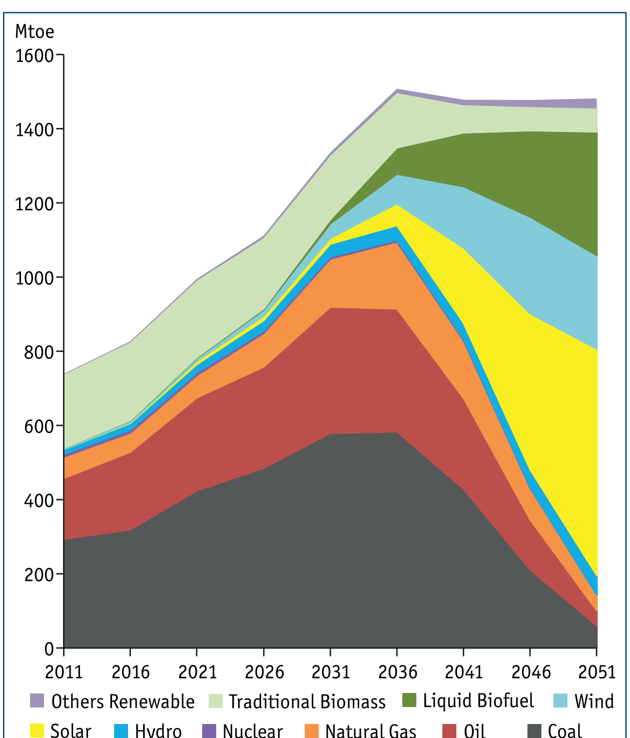

Figure 4: Resource wise Primary Energy Supply in REF Scenario

to 261 BCM in 2051 for the REF scenario, while it rises to only 48 BCM in the REN scenario.

With determined and aggressive efficiency improvements as well as electrification across sectors, the total final energy demand of the country increases only to 1461 mtoe in 2051 in the REN scenario, as compared to a level of 2489 mtoe in the REF scenario (a reduction of about 41%). The scope for transformations and energy saving varies across sectors, with the largest potential being reflected in the transport and industry sectors, in terms of both energy levels and energy mix. These two sectors, together, account for around 72% and 76% of the total final energy consumption in 2051 in the REF and REN scenario respectively.

Efficiency improvements in the transport sector include not only policy induced shifts that encourage modal shifts to more efficient options such as mass rapid systems and other public transport, higher shares of rail based passenger and freight movement etc., but also efficiency improvements in vehicle technology.

Water heating is assumed to be met entirely through solar heating by 2051 in the REN scenario. 100% of the cooking requirement is met through improved cook stoves in rural areas, which frees up more biomass for bio-fuels production, while urban cooking is envisaged to be able to move completely towards electrification by 2051. The REN scenario therefore assumes several lifestyle changes that allow for greater electrification of end-use demands, as in case of urban cooking and transport related demands which are assumed to be met through electricity.

In both, REF and REN scenarios, electricity generation increases by 8 times the 2011 level. Although electricity consumption in the REN scenario reduces significantly as a result of efficiency improvement, increased electrification in the transport sector, residential cooking and thermal applications in industries leads to compensating this reduction and resulting in similar levels of electricity requirement as in the REF scenario (Figure 5).

The power generation capacity rises to 833 GW in 2031 and 2870 GW in 2051 due to lower capacity factor of renewable technologies. In the REN scenario, close to 100% (90%) of the primary commercial energy supply is from renewable sources by 2051. Of this, liquid bio-fuels constitute 22.5% of the total energy supply, and serve to replace petroleum fuels requirements mainly for the transport sector.

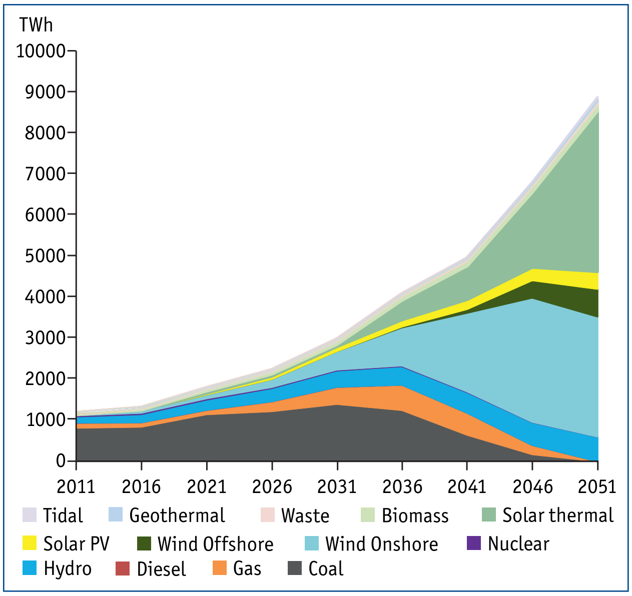

Figure 5: Resource wise Electricity Generation in the REF Scenario

Sectors such as the iron and steel sector would need to switch to recycled scrap based process to the extent of about 80% in the REN scenario and assumes the possibility of major behavioural shifts such as the ability to move completely to electricity based cooking in urban areas and improved cook stoves in rural areas. Also some fossil fuel and nuclear plants would need to be decommissioned well before their normal operational life. Despite such aggressive movements towards renewable sources, efficiency improvements as well as lifestyle changes that bring in transformational shifts away from the use of the conventional fuels, a small amount of coal (4% of total primary energy supply) still needs to be used as non-replaceable fossil fuel (reducing agent) in the iron and steel industry. Similarly, there is a limited use of natural gas (~3% of total primary commercial energy supply) as a feed stock in industry.

Overall, the study suggests that a sustainable, renewable energy based economy could theoretically be achieved, where as much as 90% of India's total primary commercial energy supply could technically be based on renewable sources. The remaining 10% would still need to be fueled by fossil based sources that are required as feedstock, and where a substitution by renewable energy forms is not possible. In the REF scenario the economy is likely to remain primarily based on coal, oil and gas, while in the REN scenario, solar, wind and hydro are considered to be the main fuels for electricity generation while 2nd generation and algae bio-fuels contribute to meet the demand from the transport sector.

Emission Implications of REN Scenario

In the REF scenario, CO_2 emissions increase by 7 times the 2011 level of 1.7 Giga tonnes per annum to 11.2 Giga tonnes per annum in 2051. If at all India is able to achieve the energy mix as defined in the REN scenario by 2051, India's emission story changes completely. The model suggests that the total CO_2 emissions from energy system associated with the REN scenario in 2051 will a mere 0.40 Giga tonnes. This is substantially less than the current level of India's CO_2 emissions (Figure 6).

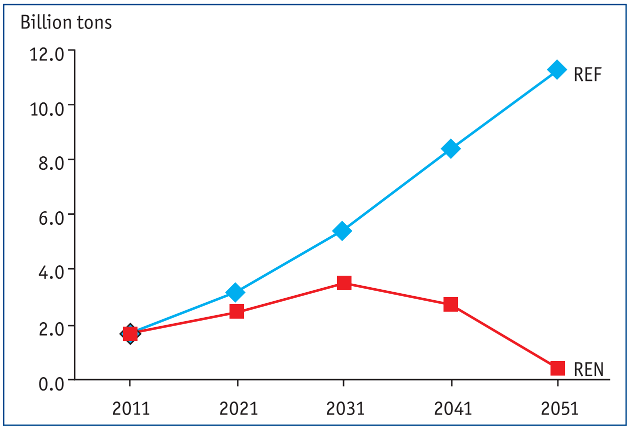

Figure 6: Total CO_2 emissions from energy system

India's challenges in realising a 100% renewable energy scenario

The REN scenario is clearly desirable both from an environmental as well as from an energy security perspective, but achieving such a scenario poses considerable challenges at this point in time, and would require several transformational changes to be undertaken across sectors with a sense of urgency. These include not only the timely availability of alternative commercially viable and affordable technological solutions across sectors, but also a rapid scaling-up of these options together with accelerated build-up of supporting infrastructure, appropriate skill-sets, regulatory and institutional frameworks, and adequate renewable manufacturing capacities. The availability of land for installation of wind and solar power in desired areas is likely to be another key challenge.

The REN scenario also assumes increased use of scrap based inputs in the steel production to reduce the use of coal. In view of low per capita steel consumption, domestic availability of steel scrap in the future is expected to be very low in the country and such a scenario may imply increasing imports of scrap. At present, in India scrap steel is obtained from domestic old steel, ship breaking and import of the scrap from other countries. However, due to increasing environmental concerns associated with ship breaking and import of scrap, availability of large quantity of scrap steel is questionable.

In the REN scenario, 77% of the final energy demand of the residential sector is met through electricity and rest via traditional biomass and solar energy. Such an energy mix requires that all of the urban cooking demand in 2051 be met through electricity. Here again, the shift to electricity from LPG to meet cooking needs involves lifestyle changes and is not likely to be easily adopted by people due to individual preferences and cultural factors.

Even if the country were to make all efforts in pushing domestic policy and institutions, availability of appropriate and commercially viable technologies and adequacy of finance are likely to remain the 2 big challenges.

Technological challenges

- The REN scenario involves meeting all industrial heating requirements upto 7000C through Concentrated Solar Technologies (CST) by 2051. This implies that CST technologies need to be a commercially viable option even for small to medium manufacturers by 2041 in order to gain popularity and become the prevalent option in the next two decades.
- For the industry sector, solar thermal appears as a new and major energy source, comprising of 36% of total end use demand by 2051 for meeting the process heat requirement to a large extent through concentrator solar thermal technologies (CST). It is worthwhile to highlight that CST also requires a separate set up and a large land area within the premises, which a lot of small and medium enterprises may not have. Furthermore, the huge initial capital expenditure required would prove to be a challenge for many industries until the technology becomes commercially viable.
- The REN scenario is designed to move away from usage of petroleum products. In this scenario electricity and biofuels comprise 32% and 68% of the transport sector energy demand respectively in 2051. REN scenario considers 100% electrification of cars, two wheelers and three wheelers. Buses, HCVs LCVs, aircrafts and ships are considered to run on biofuels like 2nd generation (FT- biodiesel), 3rd generation (algae) biofuels. Transforming the transport sector towards a 100% renewable pathway would necessitate a large part of the sector's energy demand to be met through 3rd generation biofuels. In reality, this technology is still in the R&D phase, and in order to be available as a major fuel option by 2051 as in the REN scenario, this technology would have to become commercially viable within the next two decades.
- Nearly 170 GW of off-shore wind capacity installation also needs to feature by 2051 in India's REN scenario with its initiation in 2031. At present, there is no credible estimate of offshore wind potential for India. Accordingly, this implies that within the next two decades offshore wind potential would not only be estimated in detail, but its detailed techno-economic analysis would be conducted and commercial deployment would be successfully initiated.
- Given the large share of renewables in the electricity mix, apart from development of storage technology, improved grid integration and load management systems would be required with immediate effect.
- A large renewable base would also need to be complemented by large energy storage facilities as well as smart grid design as renewable sources are largely intermittent. This would require additional costs which are not as yet incorporated in the model.

Financial Challenges

The total undiscounted investment in technology for the next 40 years is estimated at US$ 22 trillion for the REF scenario, and US$ 31 trillion for the REN scenario. The investment cost for REN scenario is 42% higher than the REF scenario. Consequently, REN scenario requires an additional investment between 2011 and 2051 of US$ 9 trillion over and above the investment in the REF scenario which is around 4% of the cumulative GDP during this period.

In terms of total undiscounted system costs, the REN scenario is only 10% higher than the REF scenario. This however, includes only technology level substitutions and does not entail costs that may need to be undertaken for supporting infrastructure, RD&D or improvements in regulatory and institutional setups. Accordingly, when compared on a technology-to-technology basis over the 50 year period under consideration, many of the alternative options are likely to be attractive, but the ability to garner adequate finance to implement the alternative options in a scaled up manner is likely to be constrained.

For example, in the transport sector, around US$ 50 billion needs to be spent on the dedicated freight corridors planned thus far, as against the approved loan of around US$ 10 billion from bilateral and multilateral organisations, needing to scale this up by 5 times. Similarly, India would need to be able to invest around US $ 150 billion in metro rail systems in 60 cities within a span of 20 years, and around US$ 100 billion for high speed rail network along 12 proposed routes . Also in case of renewable based power, India would require an investment of US$ 55 trillion between 2011-2051. These levels of investment are clearly much above the levels that are expected to be garnered at this point in time.

Conclusion

The REN scenario is clearly desirable for India from various perspectives. However, the ability to move towards such a transformational pathway depends crucially on availability of commercially viable technologies and adequate financing. Renewables have the technical potential to theoretically meet most of India's energy requirements. However, since the REN scenario involves introduction of many technologies that are currently in the R&D phase by 2031, accelerated technological progress at a global level would be needed before India can envisage such a scenario by 2051. Adequate availability of commercially viable technological solutions is the main problem along with very high initial investment requirements. Higher levels of international cooperation can play a key role in accelerating the pace and spread of renewable energy development and deployment. Hence, this study calls out to the global community to come together and focus on accelerating technological advancement and ensuring that adequate finance for clean technologies is made available, so that countries are facilitated in being able to adopt clean energy choices at a transformative level.

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TERI also publishes Policy Briefs based on its research work in specific areas. These briefs are made available to Members of Parliament, policy-makers, regulators, sectoral experts, civil society, and the media. The briefs are accessible at http://www.teriin.org/policybrief/. The purpose is to focus on key issues and list out policy recommendations to encourage wider discussion and debate. We would very much value your comments and suggestions.

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