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Supporting Climate Moonshot Technology Development for Innovation

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Abstract

India has set ambitious goals following COP26, including a 2070 net-zero target and installation of 500 GW of non-fossil fuel electricity capacity by 2030. In conjunction with its climate targets, it remains committed to national priorities on poverty alleviation, strong economic growth, gainful employment and attainment of various other SDGs. This necessitates a new growth paradigm that examines the energy transition challenge as an opportunity for transforming India from a labour-intensive, middle income, developing market economy to a smart economy. This paper examines climate frontier moon-shot technology solutions in light of India's transitional challenges and developmental ambitions.

For smooth transitioning, technology solutions would need to be developed and integrated across power, industry and transport sector on priority. India's transitional challenges can therefore be grouped under three broad categories – scaling green energy generation capacity; effective storage; and industrial decarbonisation. Despite rapid development of solar and wind capacity, scaling up non-fossil fuel electricity capacity to 500GW in 2030 and upto 2500 GW by 2050 through large-scale solar and wind power plants could be impacted critically due to vast requirement of land in business as usual scenario. Going forward, competing land requirements for food security, nature conservation and housing needs of a growing population, would further contribute to scarcity of available land. To mitigate this, alternate technology solutions such as offshore wind could be explored. Fungibilities with development of green hydrogen production capacity offers increased decarbonisation potential within hard-to-abate sectors such as steel, chemical and cement but would require policies for market creation, demand aggregation, and scale economies. Installed renewable capacity would additionally need to be complemented with development of battery storage technology capacity to achieve India's 2030 and 2070 targets, in the face of limitations posed by geographic availability of climate and mineral reserves along with incipient infrastructural setup. Together, these solutions hold the key to unlocking energy transition in India. However, technology deployment in these segments exists at a very nascent stage in the country.

This paper therefore examines the abovementioned priority technologies within the three categories by studying the estimated financing requirements, ecosystem barriers and existing technology maturity. It begins by examining the role of state in facilitating the respective technology development and deployment within the country. Different technology solutions would require varying degrees of state action - ranging from infrastructural support, R&D investments, geo-political alliances for raw material supply, market formation and promotion of market proliferation. We refer to past instances of frontier technology development in the country, using space research and biopharmaceutical research as case studies, to draw inferences on successful innovation governance models and associated institutional capabilities. The paper concludes with recommendations for indigenous development of high-potential moonshot technologies within the new growth paradigm, wherein India could position itself as an emergent leader in climate research and high-value technology exports.

I. Introduction

Global economy stands to lose up to 18% of its total economic value by mid-century due to climate change (Swiss Re, 2021). Recognising the increasingly dangerous and irreversible impacts of climate change, low-carbon and resilient transition as outlined in the Paris Climate Agreement (2015), sets the ambition of a carbon-neutral society in the second half of the 21st century to limit the rise in global temperatures to +2°C by 2100 as compared to the pre-industrial era. While countries, companies and investors around the world have committed to achieving this collective goal, climate action is lagging in comparison to the required scale and urgency.

An analysis by World Resources Institute (2022) on forty indicators of action required by 2030 and 2050 show that *none* of the indicators are on track to achieve 2030 targets. Notably, the share of electricity in Industry sector's final energy demand must grow by 1.7 times while the share of zero-carbon sources in electricity generation must grow by sixfold. In parallel, the share of battery electric vehicles and fuel cell electric vehicles in light-duty vehicles and bus sales must increase by fivefold and tenfold respectively.

Global climate commitments would thus require unprecedented effort at a massive scale and pace to disrupt current trajectory while stimulating innovation and action around the world. This is nothing short of a moonshot. It advocates for promotion of climate moonshot technologies, requiring focused attention and resources for technology innovation and application. Complemented by changing regulatory landscapes and increased diversion of global investment flows towards climate-aligned projects and technology, the shape of global economy is slowly but surely changing. In the new low-carbon economy, an early 'green' transition along with development of climate technologies can have profound impact on future trade competitiveness and global positioning.

As a key contributor to global low-carbon transition, India finds itself at the forefront of the new climate-aligned economy. From a national perspective, India's net-zero commitment will require urgent energy transition in its power and transport sector at the very outset. While it has developed impressive scale in solar and wind energy in the past two decades, the share of clean energy must grow exponentially to meet the growing energy demand. Keeping this in mind, the paper sets out to explore game-changing climate moonshot technologies to decarbonise the Indian power and transport sector, namely offshore wind, green hydrogen and battery storage. We seek to study this through a lens of industry creation and economic development, looking specifically at the role of state in climate moonshot technology development and innovation.

The rest of the paper is structured as such: First, we examine innovation theory and study two case studies on successful sectoral innovation and associated industry creation in the country. The insights from these case studies will inform the role of state in facilitating technology innovation and indigenous research capability. In the next section, we conduct a deep-dive on the three abovementioned climate moonshot technologies to understand current status-quo along with the required governmental support to aid technology development. We conclude, finally, with key recommendations on fostering climate moonshot technologies for innovation.

II. Literature review

Innovation theory finds its roots in Friedrich List's (1856) contribution towards its early definition, wherein he defined innovation and knowledge as key drivers of differential economic growth among countries. This was further emphasised by Schumpeter (1912) in his analysis of the uneven diffusion of innovations, between regions and industries. Schumpeter broadly identifies six factors influencing the rate and direction of innovation – these being prevailing economic structure, institutional set-up, internal organisation of firms, inter-firm relationships, role of the public sector, Research and Development (R&D) intensity and R&D organisation. Over the past few decades, the study of innovation has expanded into systems of innovation thinking, thereby focusing on systems design thinking within national innovation systems, regional innovation systems and more recently, into sectoral innovation systems.

Following pioneering work by Freeman (1987), in which organisational structure was posited as a key differentiator in being conducive to development and efficient use of technology, Lundvall (1992) and Nelson (1993) provided seminal contribution in the systems of innovation approach and framework. Nelson's analysis provided a link between innovation and economic development through differences in national innovation systems. Porter (1990) indicated four factors affecting competitiveness of national industry, including firm strategy, factor conditions, demand conditions and supporting industries. Despite different definitions among these authors on composition of institutions, organisations and relationships between firms, (national) systems of innovation is widely recognised as an important contributor to understanding differences in innovation performance between nations and consequently, on economic development. It has since been codified into science and technology policy by nations around the world.

Mazzucato (2021) follows a different approach in mission economy framework, although familiar factors for innovation emerge. Clear, ambitious, measurable and time-bound goal (the mission) along with a dynamic and nimble governmental structure, consistent narrative building and citizen engagement, cross-sectoral innovation, industrial collaboration, dedicated research and bottom-up experimentation are some of the parameters emphasised for technological innovation.

Despite vast existing literature on factors of innovation and economic growth, studies focusing on India are fairly limited. Herstatt et al (2008) attempted to categorize various strengths and weaknesses of the Indian Innovation system. Availability of skilled labour and perhaps more uniquely, India's growing market potential contributed to emerging innovation and R&D in the country. At the same time, challenges related to infrastructure, quality of education and bureaucratic hurdles hampered innovation. Kale and Rath (2018) find a positive relationship between innovation and total factor productivity. Barring some sector and firm-specific studies, few empirical studies explore the role of state and industrial policy in technological innovation within the Indian context.

The innovation ecosystem in India is impeded by persistent low investment. India lags in R&D expenditure, at 0.68% of its GDP between 2014-18, as compared to other countries such as China and Singapore at 2% or Japan and Israel at 3% of its GDP. Nath, Sengupta and Chattopadhyay (2022) examined a cross-panel of emerging and developed countries, with a specific focus on India and found that higher aggregate R&D expenditures were positively associated with existing quality of institutions (relating to 'ease of innovation'), quantum of exports, per-capital GDP and Foreign Direct Investment (FDI) inflows. Higher R&D spending by businesses, in particular, was found to be significantly associated with degree of downstream commercialisation.

Nonetheless, it is worth highlighting that despite a lagging innovation index, India shows a promising positive trajectory. Patent and trademark filings in India have grown by 9.8% and 8.5% on an average, in 2007 and 2019 respectively; much faster than its developed counterparts (ibid). However, these growth patterns are fragmented, often sector-specific and largely influenced by governmental support during initial industry formation through policy and fiscal interventions. The paper therefore seeks to draw from innovation theory, contextualised to India's ecosystem, by examining factors of innovation in two sectoral case studies.

The objective is to examine various initiatives undertaken by the Indian government that led to technological innovation and industrial growth in the sector, while isolating the sectoral nuances. We seek to relate this to climate moonshot technology innovation by holistically positioning it as a new sectoral entry within the Indian economy and understanding the role of state in boosting such sectoral growth.

2.1. Case study: Indian space research

India has demonstrated several impressive feats in indigenous space research and development. As the sixth largest space agency in the world, the Indian Space Research Organisation (ISRO) houses one of the largest fleets of communication, remote- sensing and navigation satellites. ISRO has gained the reputation of delivering highly cost-efficient and reliable launch systems at one-tenth the cost as compared to its peers (). The research and technologies developed by ISRO have found numerous applications in broadcasting, disaster management, GIS, navigation, automobiles, and telemedicine, among others. The impact delivered by Indian space research has far-reaching significance, not just for national security, but also in terms of commercial and socio-economic development within the country. The evolution of the Indian space industry can therefore offer pertinent insights on the role of state in developing indigenous research and technological capabilities.

Recognising the early potential of rocket technology and satellites in a demographically vast, newly independent country, India's political leadership gave strategic importance to the development of space research. Originally placed under the Department of Atomic Energy (DAE), the space programme led to the creation of ISRO in 1969 (Sankalp India Foundation, n.d.); (ISRO, n.d.). Given the nature of its complexity and size, the space programme was expanded and brought under the Space Commission, shortly thereafter leading to its own government department, Department of Space (DOS). The commission directly oversaw and formulated its policy, while functioning directly under the Prime Minister.

It could be argued that this allowed for a clear political directive and formulation of mission objectives, cutting through layers of otherwise prevalent bureaucracy. The establishment of space systems and their applications are guided by national level planning, coordination and advisory committees, while programme offices at ISRO coordinate the various programmes (ISRO, n.d.). A nimble organisational setup could thus enable vertical integration between policymakers and institutions such as ISRO, leading to achievement of set objectives.

In addition to directed organisational structure, the application of space science and technology in India has benefited from collaborative structures, both domestically and internationally. The Department of Space implements its programmes through ISRO and its network of Grant-in-Aid institutions[1]. ISRO activities are integrated across modular units and centres of excellence, specialising in various components such as Launch Vehicles, Satellite development and design etc, through time-bound projects and academic research.

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[1] These include Physical Research Laboratory (PRL), National Atmospheric Research Laboratory (NARL), North Eastern-Space Applications Centre (NE-SAC), SemiConductor Laboratory (SCL) and Indian Institute of Space Science and Technology (IIST).

The advancement of indigenous space research capabilities was further enabled through public partnerships with academia and universities. ISRO started its flagship programme, RESPOND in the 1970s, providing necessary financial and technical support to academia in India for conducting research and development activities related to Space Science, Space Technology and Space Applications. ISRO has also set up dedicated Space Technology Cells (STC) at premier Indian academic institutions and universities[2]. Through its RESPOND programme and university tie-ups, dedicated research is also channelled into national missions like IMPRINT (IMPacting Research INnovation and Technology) programme and Uchhatar Avishkar Yojana (UAY) (ISRO, n.d.) . Complementing its domestic network, DOS and ISRO have collaborated with the international scientific community since inception --whether this be the establishment of Thumba Equatorial Rocket Launching Station in ISRO's early days or the recent joint agreement between ISRO and National Aeronautics and Space Administration (NASA) to work on future joint mission to Mars.

While the early visionary government funding, policy and infrastructural support along with its governance structure laid the foundation for development of intellectual capital within space research, there exists a vast scope of market expansion and capital formation in Indian space industry. ISRO's state-owned commercial arm, Antrix Corporation, has steadily increased its revenue over time, clocking over USD 919 million (INR 6,298 crore) from launching 239 satellites between 2016-19 (The Hindu, 2020). However, despite increasing revenues, the Indian space industry captures only over 2% of the global space industry (PWC, 2020). The missing piece points towards enhanced commercialisation and participation of private industrial sector.

Legacy policies often unwittingly created multiple entry barriers for the private sector; case in point is the Satellite Communication Policy (SATCOM) which granted GoI the exclusive ownership of data received from Indian remote sensing satellites. Lack of private sector participation has in-part propagated smaller budgets for ISRO, given near-exclusive dependence on government spending[3]. The limited availability of patient capital necessitated shorter mission durations, which in turn had adverse implications on data collection, observation, and development of indigenous disruptive technologies. Having recognised the need for increased private participation in Indian space industry, the government announced the intent to open up the sector in 2020, with subsequent changes in policy for low-orbit space. Entry of private players such as Skyroot, Digantara, Dhruva Space etc. show a promising trend in boosting India's space economy.

The advancement of Indian space industry offers interesting insights for indigenous development of climate moonshot technologies, summarised in section 2.3 below.

2.2. Case study: The Indian pharmaceutical industry and vaccine research

India's domestic pharmaceutical market stood at USD 42 billion in 2021 accounting for over 50% of global demand for various vaccines. It includes a network of 3,000 pharma companies and approximately 10,500 manufacturing units, stimulating Indian economy and job creation (India Brand Equity Foundation, 2021). Globally, India ranks third in terms of pharmaceutical production and fourteenth in terms of market value, thereby enjoying an important position in the global pharmaceutical sector (Gupta, 2022).

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[2] Dedicated STCs are present within Indian Institutes of Technology (IITs) - Bombay, Kanpur, Kharagpur, Madras, Roorkee, Guwahati and Delhi, Indian Institute of Science (IISc), Bengaluru along with Joint Research Programme with Savitribai Phule Pune University (SPPU, Pune)

[3] NASA's annual spending, for instance, is almost 12-13 times higher than INSRO.

Vaccination efforts began during the beginning of twentieth century in the country, primarily driven by need as opposed to indigenous research capability. The outbreak of cholera and plague in India, followed by the First World War and the Influenza Pandemic prioritised vaccination efforts by the government. This led to the initial setup of institutes for immunisation and smallpox vaccine in the country. Post-independence, immunisation received additional importance through the Prime Minister's 20-point programme wherein it was recognised as one of the five National Technology Missions launched in 1986 (Lahariya, 2014). The Universal Immunisation Program (UIP) went on to become the largest public health program to cover all districts in India.

The same year witnessed the formation of Department of Biotechnology (DBT). The necessary infrastructure and capacity building programmes were coordinated through DBT, in line with the identified long-term priorities. India's first autonomous institute, the National Institute of Immunology, was brought under the wings of DBT. The next two decades saw additional institutional capacity through establishment of various institutes focused on research and development[4].

The National Technology Mission on immunisation helped in modernisation and upgradation of vaccine facilities and by 1990-1991, the country became self-sufficient for nearly all vaccines covered in the UIP. Following this, India established a National Technical Advisory Group for Immunisation (NTAGI) in 2001, which sought to advise and support the government in taking informed decisions regarding strengthening the UIP and inclusion of new vaccines. The NTAGI was composed of inter-disciplinary independent experts, chaired by DBT and Department of Health Research (DHR), thus creating a strong governance structure around immunisation and pharmaceutical development in the country.

In addition to academic research, DBT established various initiatives towards stimulating private sector and advancing biotechnology industry in India. This included establishment of biotech clusters, incubation centres and innovation parks along with funding support to Small and Medium Enterprises (SMEs). The state also enabled international research collaborations and industry academia partnerships for accelerated product development. The latter was facilitated through the state interface agency, Biotechnology Industry Research Assistance Council (BIRAC), that provided access to risk capital through targeted funding, technology transfer, intellectual property management and handholding schemes.

This was complemented by concurrent policy and legal developments. Prior to 1970, the Patent Act 1911 prevented indigenous firms from manufacturing patented drugs. However, the Indian Patent Act 1970 changed the landscape by encouraging procedure patent, rather than product patent (Sood, 2019). This allowed domestic companies to adopt innovative methods to manufacture drugs with limited-to-no royalty fees. However, indigenous research for new drugs and vaccines was not incentivised and remained fairly limited until the 1990s.

Post liberalisation in 1991, many Indian companies entered foreign markets with cost-effective products. The amendment to the Patent Act in 2005, following World Trade Organisation membership, allowed product patents in India up to 20 years. This led to changes in the production frameworks and increased the level of competition. Indian pharmaceutical companies began to

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[4] This included the National Facility for Animal Tissue and Cell Culture of Pune, later christened as the National Centre for Cell Science. In the late 1990s and early 2000s, institutions such as The National Institute for Plant Genome Research (NIPGR), the National Brain Research Centre (NBRC), the Centre for DNA Fingerprinting & Diagnostics, Institute of Bioresources and Sustainable Development and the Institute of Life Sciences were formed.

change production patterns from reprocessing and ‘reverse engineering’ drugs to fundamental research and development.

The private pharmaceutical industry therefore received substantial State patronage for its growth through process patent laws, subsidised bulk drugs from public sector companies and protection from multinational companies in the initial stages, followed by open trade. Several incentives were built in the decade following 2000s, such as special tax rebates and 100% foreign direct investments for pharmaceutical and medical industry. State foresight and support played a pivotal role in creation of a thriving biopharmaceutical industry in the country.

2.3. Learnings for development of indigenous technological and industry capability

Both case studies underline the criticality of state support in establishing new technological capabilities within the country. The development of space research was driven by political buy-in from the Prime Minister’s office, while immunisation and biopharmaceutical research derived their political backing from being one of the national technology missions. Political buy-in from the highest level along with a nimble organisational structure and limited bureaucratic roadblocks allowed for a clear direction of travel and vertical integration with policy.

In its nascency, both sectors benefitted greatly from Public-Private Partnerships (PPP) and setup of autonomous research capabilities in collaboration with Indian academic institutes. An industry-academia interface greatly helped align capacity building efforts with long-term policy vision. While this enabled the initial policy and technological infrastructure in the country, state support was equally essential in enabling the right conditions for subsequent growth of the industry.

As seen in the case of biopharmaceutical sector, targeted infrastructure funding and international collaborations were complemented with policy, legal and trade guardrails. The sector saw substantial state patronage through fiscal incentives and process patent laws during its growth stage. This incentivised private sector to ‘reverse engineer’ but provided little stimulation for fundamental research and product innovations. Regardless, it allowed for development of industry capabilities in its infancy. Post liberalisation, open markets and trade further stimulated private sector to invest in fundamental research and development, leading to a thriving biopharmaceutical sector. The Indian space industry, on the other hand, discouraged private participation through legacy laws and policy bottlenecks.

In conjunction with innovation theory, these case studies signal specific parameters that are relevant to industry development and innovation. We have attempted to isolate parameters where direct relevance of state support can be drawn (as opposed to innovation literature focused on firm behaviour and governance) and categorize them under the type of support required. The parameters that came up most exhaustively across different theoretical frameworks and our case studies included R&D expenditure and infrastructure, political directive, institutional quality, governance, legal frameworks (signalling ‘ease of business and innovation’), educational quality, industry-academia and international collaborations, trade (protection) laws, fiscal incentives and subsidies. For the purpose of this paper, we have categorized state support with regard to these parameters under - **Governance and Oversight**, **Policy and Technology Infrastructure**, **Research and Development Capabilities**, **Incentives** and **Commercialisation.** We propose to study the role of state in the development of climate moonshot technologies across these innovation dimensions.

III. Developing climate moonshot technologies

Post the landmark Paris Agreement, governments around the world, including India, have drawn up their climate objectives to transition to a low-carbon economy. In COP 26, the Honourable Prime Minister of India has committed to a 2070 net-zero target along with a 500GW non-fossil fuel-based capacity target by 2030. Akin to biopharmaceutical industry and space research in India, development of indigenous climate moonshot technologies could not only aid industrial growth and economy but also contribute towards its development objectives in the new low-carbon paradigm.

India's climate commitments would potentially require integration of utility scale renewable energy along with deep decarbonisation across its industrial sectors. However, deep decarbonisation across hard-to-abate sectors such as iron, steel and cement etc is at a nascent stage and may require fuel substitution along with electrification. India's intermediate target of 175GW alone would require 55,000 to 125,000 km2 of land, impacting approximately 6700–11,900 km2 of forest land and 24,100–55,700 km2 of agricultural land (Negandhi, 2019), thereby posing significant challenges for land use. These challenges could be targeted through development of climate moonshot technologies such as offshore wind, green hydrogen, and energy storage systems.

Indigenous development of climate moonshot technologies will require deep technological and industrial innovation. The national innovation system in India is arguably segmented with differing pace of innovation among various sectors and suffers from a paucity of data. This restricts the development of basic research in entirely new sectors, given limited availability of research labs, infrastructure, and limited participation by the private sector. The latter is primarily driven by challenges in commercialisation, ease of doing business and fewer industry-academia collaborations, resulting in limited applied industrial research and fewer incentives to build inhouse capacities. As observed in section II, the government of India played a major role in providing specific impetus to drive the innovation ecosystem *within* a particular sector.

The state typically plays a crucial role in the development of the energy sector. This is even more pronounced as compared to other sectors and could perhaps be best compared with creation of new industrial capability within a country. Several parallels can be drawn for boosting indigenous innovation in these energy technologies with the previously discussed case studies, particularly due to the below characteristics:

- **Energy technologies are highly capital intensive**: The energy industry is one of the most capital-intensive industries. For example, for renewable energy, upfront capital costs contribute at least 85% of the total levelized cost of energy (Kraemer-Mbula, 2021). Given the scale of upfront capital costs and other cost barriers such as special equipment needs, uncertain payback and access to raw materials, the State often plays a role in either undertaking these investments directly (traditionally via public sector enterprises in India like the National Thermal Power Corporation) or via reduction in risk-quotient for the private sector through policy support. Take, for example, incentives for solar and wind over the last decade in India, such as generation-based inventives, feed-in tariffs, accelerated depreciation, viability gap funding schemes (Shrimali, Renewable Energy in India: Solutions to the Financing Challenge, 2018), which largely led to increased local deployment and cost parity with conventional energy sources.
- **Energy technology development entails a strong (usually state supported) R&D component**: Development of new energy technologies entails a strong innovation and R&D component, which the state typically has a role in funding or facilitating (via public investment in education, patent laws, international partnerships for tech transfer etc.). According to the IEA (2022), Governments have a major role to play in shaping energy innovation priorities, with

public energy R&D spending rising to USD 38 billion globally in 2021 – a 7% average annual increase from 2016-2020. This is especially relevant in the case of moonshot technologies, which are not (yet) commercial.

- **Energy technology deployment is strongly influenced by the regulatory environment**: The energy sector is typically highly regulated, with regulatory frameworks exerting a strong influence on the development of the sector. In India, for example, both electricity production and sale (markets) are highly regulated (Dibyanshu, 2021). Setting up of new energy projects typically requires state-support, in form of clearances for land acquisition, access to supporting infrastructure owned by the state, e.g., transmission and distribution networks etc. Unclear policy signals also deter private investment, especially if prices are often regulated to meet policy objectives, such as ensuring access to energy and mitigating cascading effects of energy price volatility on essential commodities such as food. Conflicting legacy policies such as provision of free or highly subsidized electricity to the agriculture sector in India (Sharma, 2015) can be counterintuitive to fossil-fuel phase out and development of new climate moonshot technologies.

These challenges are analogous to those faced during the development of space and biopharmaceutical capabilities within the country. Like clean energy technologies, these were faced with a rapidly changing technological landscape and required specific policy and infrastructural support. Space research, in particular, required large upfront patient capital along with cultivation of skilled manpower within the country. Specific insights can be drawn from biopharmaceutical industry on drawing private participation to boost indigenous R&D and requisite support for downstream commercialisation.

This section will delve into the existing ecosystem for offshore wind, green hydrogen, and energy storage systems, examining current status quo and future projected requirements. The evolution of these technologies has been studied through the lens of the innovation dimensions outlined in the previous section, to inform the role of state in its growth.

3.1. Offshore wind development in India

India has the fourth highest wind installed capacity in the world, with a total installed capacity of 41.6 GW as of September 2022 (Central Electricity Authority, 2022). Despite exponential growth in onshore wind capacity, many onshore wind energy projects have been adversely affected due to land acquisition challenges in the past few years. Accompanied by rising e-auction tariffs due to exhaustion of best wind sites, the expansion of onshore wind energy in the country faces certain future limitations (Dash, 2019). Offshore wind holds the potential of alleviating some of these challenges.

India has a coastline of approximately 7,600km, with relatively shallow water near to coast (upto 12 nautical miles of the coast), indicating promise for harnessing offshore wind energy in the country (MNRE, 2022). While offshore wind is more costly as compared to onshore wind, it offers large wind resources, higher wind speeds and can operate at a higher Capacity Utilisation Factor (CUF). That being said, offshore wind development comes with significant regulatory, technical and financial challenges.

While India can learn from experiences in offshore wind development in other parts of the world, it currently has no installed offshore wind capacity and would require a local 'learning-by-doing' model. Deploying wind turbines in marine environment remains complex, with lead times of 7-9 years from lease to operation along with long-term capital-intensive investments; thus making it a financially risky endeavour.

The state would need to play a crucial role in the development of offshore wind industry, with the right impetus of incentives, infrastructure, policy regime, research and capacity building. This will help lower project risk and drive maturity of technology in the market. We examine the current landscape for offshore wind development in the country below, specifically across the proposed innovation dimensions.

Governance and oversight*:* The Ministry of New & Renewable Energy (MNRE) has been designated as the nodal ministry for offshore wind development in Indian territorial waters (upto 12 nautical miles) and within the Exclusive Economic Zone (upto 200 nautical miles) of the country. As the nodal ministry, MNRE will be responsible for promotion, coordination, regulation and oversight of overall offshore wind development in the country. It will be supported by other implementing and monitoring agencies at national and sub-national level[5]. The National Institute of Wind Energy (NIWE) has been authorised as the corresponding nodal agency. It would carry out allied functions with related ministries and agencies along with setting up of offshore wind power projects, research, and development activities (MNRE, 2015).

While the designation of clear responsible entities provides a clear governance structure and is a promising step, offshore wind development could be hindered due to capacity constraints and bureaucratic roadblocks. The national offshore wind policy defines up to ten departments and ministries required for clearances regarding surveys, studies and development of offshore wind projects. While NIWE will facilitate this process, each requisite clearance will be dependent on and granted by the relevant ministry. This runs the risk of long project initiation delays and subsequent project development. The lack of a dedicated national-level climate commission further hinders direct political oversight and coordination between various ministries for strategic planning on the renewable energy mix, considering the trade-offs with other climate moonshot technologies and initiatives.

Policy and technology infrastructure: The Government of India released the National Offshore Wind Policy in 2015. The policy identified the nodal entities, potential incentives and processes that could be employed for development of offshore wind, providing an overarching framework. The objectives outlined in the policy, including exploration of offshore wind farm deployment in the EEZ, Public Private Partnerships and promotion of investments in energy infrastructure, signal the intended direction of travel. However, the policy and technological infrastructure is currently at a nascent stage and is likely to be more specifically defined following a demonstration project.

Research and development capabilities: NIWE will extend its mandate as an autonomous Research and Development (R&D) institution (for onshore wind) to development of Offshore Wind Turbine Models, in accordance with international standards (ibid). It will also undertake activities such as organising workshops and symposiums to generate awareness in the local wind turbine manufacturers, components manufacturers and potential investors to boost offshore wind power development.

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[5] Other implementing and monitoring agencies include the Offshore Wind Energy Steering Committee (OWESC), who will steer offshore wind energy development by providing policy guidance and overseeing the execution and effective implementation of related activities, under the chairmanship of Secretary, MNRE. Coordination will be established with Ministry of Shipping, State Maritime Board, State Government, central and state transmission utilities, as required.

Research efforts are complemented by the Facilitating Offshore Wind in India (FOWIND) consortium, which seeks to establish structural collaboration and knowledge sharing between the European Union and India on offshore wind technology, policy and regulation. Preliminary assessment from satellite data and other data sources, conducted by FOWIND and NIWE, identified eight zones each in Gujarat and Tamil Nadu as potential offshore zones for exploitation of offshore wind energy, suggesting 36 GW and 35 GW of offshore wind energy potential respectively (FOWIND, 2015). The state also facilitated data exploration exercises by commissioning a Light Detection and Ranging (LiDAR) in one of the identified zones in Gujarat. Two years of data was collected through the deployed LiDAR and is publicly available to all interested parties.

The current R&D infrastructure is limited to preliminary feasibility and must be strengthened to develop an interface for industry, academia and government. Indian academic institutes could be utilised to develop centres of excellence in collaboration with industry and government. Significant research and development capabilities need to be established within technology and process components such as offshore cable technology (high voltage alternating current (HVAC) subsea cables), ocean temperature gradients for power and desalination, high voltage direct current (HVDC) transmission systems etc.

Incentives: No specific incentives have been designed for private and industry participation, apart from feasibility demonstration and preliminary assessments as of now. The offshore wind policy states that the development of offshore wind energy may be facilitated through fiscal incentives, allowing Foreign Direct Investment (FDI) participation, Public Private Partnership, and international collaborations. Fiscal and financial incentives deployed for onshore wind power projects could be extended to offshore wind power projects. The Government may also promote viability gap funding along with bundling of power generated from offshore wind power projects with conventional power, subject to availability of unallocated conventional power for cost reduction.

Commercialisation: The Government of India released a tender for the first offshore wind energy project of 4 GW capacity, leasing seabed areas in the identified zone off Tamil Nadu coast in a commercial scale, following LiDAR assessments. MNRE has floated the bid, proposing a single-stage two-envelope e-tender for the demarcated area and will enter into a lease Agreement for 35 years with the successful bidders (MNRE, 2022). The project size of 4 GW may realize the economy of scale and bring down the tariff, along with demonstration of technological feasibility.

Experience from other countries indicate that while a demonstration project will serve to stimulate private sector and provide clarity on various risks involved, a clear plan for progression from demonstration to commercialisation is required. This would include strategies for developing scale, driving competition among developers, risk mitigation at various development stages and pipeline development (FOWIND, 2015). The state must also develop a strategic vision on development of a local supply chain. The national offshore wind market would need to grow enough to create a commercially viable local supply chain and harness export opportunities.

3.2. Development of green hydrogen in India

Green hydrogen production can offer deep decarbonisation opportunities in hard-to-abate sectors such as refinery, ammonia, methanol, iron and steel and heavy-duty trucking, aiding India's 2070 net-zero goal. However, due to limited cost-competitiveness, the industry has begun transitioning through grey hydrogen, with current consumption of almost 6 million tonnes largely concentrated in industrial uses in refining and as feedstock to produce ammonia and methanol.

India has a distinct advantage in offering low-cost renewable electricity, which complemented with rapidly falling electrolyser prices, could potentially enable it to leap-frog to green hydrogen consumption. As a green hydrogen production and manufacturing hub, opportunities in job creation, industry and economic development could be unlocked within the country. Various initiatives and requirements for green hydrogen development have been assessed below.

Governance and oversight: The National Hydrogen Mission was announced by the Prime Minister on India's 75th Independence Day, August 15, 2021. The mission aims to establish India as a green hydrogen hub, among other objectives. The Ministry of Power (MoP) released the broad guidelines of the green hydrogen Policy in February 2022.

The recently released green hydrogen mission document designated MNRE as the nodal agency for development of green hydrogen industry. The mission envisages a coordinated effort between different ministries such as MoP, Ministry of Petroleum and Natural Gas, Ministry of Road Transport and Highways, Steel, Heavy Industries etc. The announcement of the national hydrogen mission by Prime Minister's office signals highest political backing and a long-term vision. However, this would require concrete policy support to indicate policy certainty. The mission document suggests creation of an 'empowered group' chaired by the cabinet secretary and comprising of representatives from various abovementioned ministries, to steer and guide the implementation of the mission. The specification of overall direction of travel and oversight boundaries within the mission document is a positive step towards potential technological development in the sector.

Policy and technology infrastructure: The green hydrogen policy released by MoP provides a clear definition of green hydrogen, along with outlining some incentives for green hydrogen production and broad process guidelines. The policy also proposes setting up of manufacturing zones for green hydrogen and ammonia plants and allocation of land in renewable energy parks for said manufacturing. Finally, the policy set a target of producing 5 million metric tonnes (MMT) of green hydrogen per year by 2030 (Ministry of Power, 2022) .

The green hydrogen mission document, released in early January 2023, provided a budgetary outlay of INR 19,744 crore (USD 2.4 billion), including INR 17,490 crore (USD 2.1 billion) for Strategic Interventions In Green Hydrogen Transition (SIGHT), INR 1,466 crore (USD 179 million) for pilot projects, INR 400 crore (USD 49 million) for R&D, and INR 388 crore (USD 47 million) towards other Mission components. The Mission reiterates the target set by MoP, with potential to reach production capability of 10 MMT per annum contingent on growth of export market. The green hydrogen transition will be carried out in phases, wherein the first phase (2023-26) will aim to provide clarity on the priority sectors along with requisite fiscal and non-fiscal support. It will also provide guidance on the requirement of renewable energy capacity in the country for the targeted green hydrogen output, while laying out Green Hydrogen Consumption Obligations (GHCO) (MNRE, 2023).

The government has also attempted to stimulate domestic demand for green hydrogen by directing public sector refineries and fertiliser producers to target a 10 and 5 percent addition of green hydrogen from 2023–24, respectively. This directive may be supported through fertiliser production subsidies, with the objective of driving costs down to USD 1 per kg, making it competitive with natural gas (Ahluwalia, 2022). The technological and industry infrastructure is being facilitated through green hydrogen-based pilots in the country. However, it would require additional inputs to develop scale, investments and long-term directional vision. The hydrogen electrolyser ecosystem would need to be substantially expanded to realise the current annual production target of 5 million tonnes.

Research and development capabilities: MNRE has been engaged in supporting a broad-based Research Development and Demonstration programme on hydrogen fuel and energy. The programme objective is to support industrial, academic and research institutions in addressing challenges related to green hydrogen production, safe and efficient storage along with utilisation within transport industry through combustion or fuel cells. Specific research on fuel cells have been conducted by Indian academic institutions along with some industry partners.

Research and development efforts can be strengthened by increased industry-academia partnerships. Industry coalitions such as the Independent Green Hydrogen Association (IGHPA) could be channelled to promote R&D necessary for establishing India as a green hydrogen production and export hub. This could be operationalised through targeted research funding towards commercial technology development, focusing on electrolysers, fuel cells, materials for efficiency improvement, cost reduction, stack life extension, among others (NITI Aayog & RMI India, 2022).

Incentives: The green hydrogen policy outlines initial set of initiatives such as waiver of inter-state transmission charges for a period of 25 years along with possibility of banking renewable energy for a month. The renewable energy consumed for green hydrogen production would also count towards the renewable purchase obligation of the consuming entity. To enable ease of operation and reduce logistical costs, manufacturing units will also be allowed to setup bunkers near ports for storage, export, and shipping of green hydrogen.

Specific fiscal and policy incentives are likely to be announced in the coming two years under Phase-1 of the SIGHT program. These should be tailored towards commercialization and industry uptake. The mission document signals creation of several de-risking mechanisms along with first-mover incentives such as tax rebates and subsidies.

Commercialisation: The green hydrogen industry is currently at demonstration stage and must now progress towards commercialisation stage. However, technology viability, maturity and renewable intermittency persist to be significant challenges to commercialisation. The costs of hydrogen production through electrolysis is relatively high, between USD 7 to USD 4.10 per kg (ibid). These costs make it hard to compete with grey or brown hydrogen and natural gas, offering some of most competitive levelized cost of electricity for solar and wind globally.

Pilot projects by industry giants such as Tata Motors Ltd., Mahindra & Mahindra, Indian Oil corporation etc can offer important insights for commercialisation. Industry linkages with automotive and transport industries, chemicals and fertilizers must be strengthened to leverage cross-industry benefits and efficient cost reductions. At the same time, we see that the private sector outlook for development of green hydrogen industry appears to be positive, with several large domestic manufacturers announcing investment plans for green hydrogen[6]. This momentum can and should be utilised in outlining sectoral plans to aid commercialisation.

3.3. Development of battery storage in India

With its target of meeting 50% of cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030, India is in the midst of a massive energy transition. Renewable power intermittency continues to form a challenge to maintaining a reliable power system. Energy storage has the potential to help solve these challenges and accelerate India’s transition.

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[6] For instance, Reliance India has partnered with renewables pioneer Henrik Stiesdal to develop and manufacture hydrogen electrolysers, while Adani Group and Ballard Power Systems have joined hands for a joint investment in hydrogen fuel cells manufacturing in India (The Hindu, 2021).

Energy storage systems could help reduce grid instability, quickly respond to ramp-up or ramp-down needs and relieve stress on the electricity transmission and distribution services. The declining cost trend for some energy storage technologies are increasingly presenting cost-effective solutions to provide reliable power, reduce fossil-based emissions and promote a new industry hub in India. The indigenous development of energy storage systems is examined below in India's context.

Governance and oversight: Energy storage systems (ESS) are often categorised under the gambit of renewable energy and electric mobility. The government has sought to promote energy storage system development within both sectors through various initiatives. While a specific nodal ministry has not been assigned, Ministry of New and Renewable Energy, Ministry of Power and Ministry of Road Transport have included energy storage systems within their transition agenda.

Given its cross-cutting characteristic, potential for technological innovation and spillovers, a National Mission on Transformative Mobility and Battery Storage, governed by an inter-ministerial steering committee, was announced in 2019. Complemented by an expert committee constituted by MNRE to set up a draft proposal for National Energy Storage Mission in 2018, energy storage systems could benefit from an inter-ministerial governance structure. However, this must be accompanied by a nimble organisational structure and provide clarity on short and long-term objectives. This could help prevent policy uncertainty and stimulate private sector into long-term investments for technological improvements.

Policy and technology infrastructure: The National Energy Storage Mission (NESM) identifies key areas of energy storage applications, wherein the draft NESM document focuses on reducing the costs of domestic batteries and promoting the battery manufacturing industry. A target of 15-20 Gigawatt hours (GWh) of grid-connected storage was put forth for the next five years. Concrete policies are yet to be defined based on the draft NESM document and analysis.

The National Mission on Transformative Mobility and Battery Storage announced a Phased Manufacturing Programme (PMP) valid for 5 years targeting setup of large-scale, export-competitive integrated batteries and cell-manufacturing Giga plants in India. This was followed by an increase in Basic Customs Duty (BCD) to 15% for Lithium-ion cells and battery packs via the PMP, notified by Ministry of Heavy Industries to promote domestic manufacturing (Ministry of Heavy Industries & Public Enterprises, 2019). The inter-ministerial steering committee is expected to come up with an end-to-end policy framework regarding manufacturing, specification and standards, fiscal incentives, demand creation, regulatory framework and research and development.

Tangentially, the Ministry of Power has also guidelines for procurement and utilisation of battery energy storage systems (BESS) to create transparency in procurement processes and create a framework for intermediaries (e.g., aggregators) to sell and purchase power from BESS within and across the Indian state boundaries. The risk-sharing framework aims at encouraging competition within industry and improve bankability.

Significant technological infrastructure would need to be built and facilitated to promote India's battery manufacturing ecosystem. India currently does not have any major producers of electric vehicle batteries and lacks accompanying state-of-the-art facilities of sufficient capacity and capability. Another critical component to consider is the critical raw material supply chain. India has limited reserves of key minerals required for lithium-ion (Li-ion) batteries such as lithium, cobalt, nickel and copper. As India's battery manufacturing capabilities increase, even with import of cathodes and/or raw materials, it stands to capture 80% of the total economic opportunity (NITI Aayog & RMI India, 2017). However, secure and continued access to raw materials, especially given its global geographic concentration, will need to be ensured. India would likely require strategic geo-political partnerships and supply chain trade negotiations to advance itself as a battery manufacturing hub.

Research and development capabilities: The past few years have seen an increase in research and development efforts for energy storage systems and battery storage. Dedicated research centers are dedicated to electrochemical research in India, working on various technologies such as Lithium-ion, Sodium-ion, solid state, flow and lead-acid batteries[7]. Several other research groups within Indian universities are also working on battery technologies, with setup of bilateral international research partnerships[8]. Government programs such as Materials on Energy Storage (MES) program supports R&D activities on battery and storage device, while Materials for Energy Conservation and Storage Platform (MECSP) supports research and development for entire spectrum of energy conservation and storage technologies (NITI Aayog & RMI India, 2022); (ETN, 2021).

International collaborations would particularly play a key role in knowledge transfer and technology transfer. To that extent, the Department of Science and Technology (DST) has collaborated with the Ministry of Science and Technology, Israel, for joint research on low-cost, stable lithium-sulphur batteries. Strong industry linkages with ongoing research programs will aid deployment and scaling of storage technologies, in line with industry challenges.

Incentives: Several incentives are being provided by the Indian government for development of battery storage. In 2021, the Ministry of Power waived off inter-state transmission system charges for energy storage system projects commissioned prior to June 2025, providing a first mover advantage. The Indian Union Budget 2022/23 also awarded infrastructure status to grid-scale ESS, enabling developers to apply for low-cost infrastructure loans. The government also recently approved the Production Linked Incentive (PLI) Scheme 'National Programme on Advanced Chemistry Cell (ACC) Battery Storage' for achieving manufacturing capacity of 50 Giga Watt Hour (GWh) of ACC, with a budgetary outlay of ₹18,100 crore (Ministry of Heavy Industries, 2022). This will aim at maintaining globally competitive levelized cost of battery manufacturing in India.

The incentives signal India's ambition and policy direction. However, questions on critical raw material access, evolving technologies and scaled manufacturing infrastructure units would perhaps need to be answered to reach industry inflexion points.

Commercialisation: To drive industrial participation and commercialisation, the government is facilitating creation of standalone BESS facility(ies) through tenders issued by state-owned Solar Energy Corporation of India Limited (SECI) and NTPC Renewable Energy. SECI will also offtake 60% of the capacity on behalf of Buying Entities, thus reducing project risk (MNRE, 2022). However, achieving scale would likely require concerted effort and clarity on sectoral roadmaps, required capacity addition, access to raw materials along with supply chain coordination.

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[7] Indian Institute of Technology Madras has a research and development centre devoted to new and advanced battery technology. Council of Scientific & Industrial Research (CSIR) and Central Electrochemical Research Institute (CECRI) are primarily dedicated to electrochemical research. CECRI has also set up India's first indigenous Li-ion fabrication facility for batteries.

[8] Researchers from IIT Madras and Karlsruhe Institute of Technology (KIT), Germany, are working on advanced LIB cathode materials for better performance and long-lasting batteries. Monash University, Deakin University, Australia, and IIT-Bombay, funded through an Australia India Strategic Research Fund (AISRF), are developing affordable high-performance batteries

3.4. Financing climate moonshot technologies

A key challenge to developing climate moonshot technologies in India lies in the quantum and pace of financing required. Offshore wind, green hydrogen and energy storage system technologies, albeit evolving rapidly, are yet to reach maturity. Technology development and innovation will be highly dependent on provision of patient capital, with various risk-mitigating measures built into the financing instruments. In order to estimate financing requirements, we have used the Energy Policy Simulator (EPS) to run optimistic scenarios on these three moonshot technologies.

Energy Policy Simulator is a systems dynamics model, adapted for India in collaboration with Energy Innovation LLC and World Resources Institute India. It assesses the effects of numerous energy and environmental policies on carbon emissions, energy mix, cash flow changes for government, industry and consumers and includes five major sectors: Electricity supply, Transportation, Buildings, Industry and Forestry. The model chooses the least-cost technology options (subject to the specified policy mandates). The choice for a least-cost model was based on the rationale of gaining insight into various policy levers that could be used to derive a financially viable scenario including the penetration of the three moonshot technologies in question.

The model assumes a reduction in technology costs via local deployment due to enhanced learnings in the industry and supported local innovation over and above the projected reduction in global technology costs over time. It however does not provide insight into soft costs for developing research and development infrastructure along with capacity building efforts. The key levers used to derive the scenario was to implement a 75% clean electricity mandate (with grid battery storage to support renewable energy deployment), 100% industrial replacement of fossil fuel (not including feedstocks) by electrification and green hydrogen, 20% and 80% new sales mandate for hydrogen and electric passenger cars respectively by 2050, along with subsidy and capital cost reductions through R&D efforts for offshore wind and hydrogen-run vehicles.

The table below provides a breakdown of annual financing requirements (cumulative) along with corresponding capacity addition for the respective technologies. The costs do not indicate ecosystem costs and specifically look at technology components. For instance, A CEEW (2021) study projects a total investment requirement of 44 billion by 2030 to catalyse hydrogen production. Of this, hydrogen electrolyser accounts for 63% of the total cost, going by EPS projections. Despite the large financing requirements, the projected savings in fuel and O&M costs surpass the upfront investment projections over time.

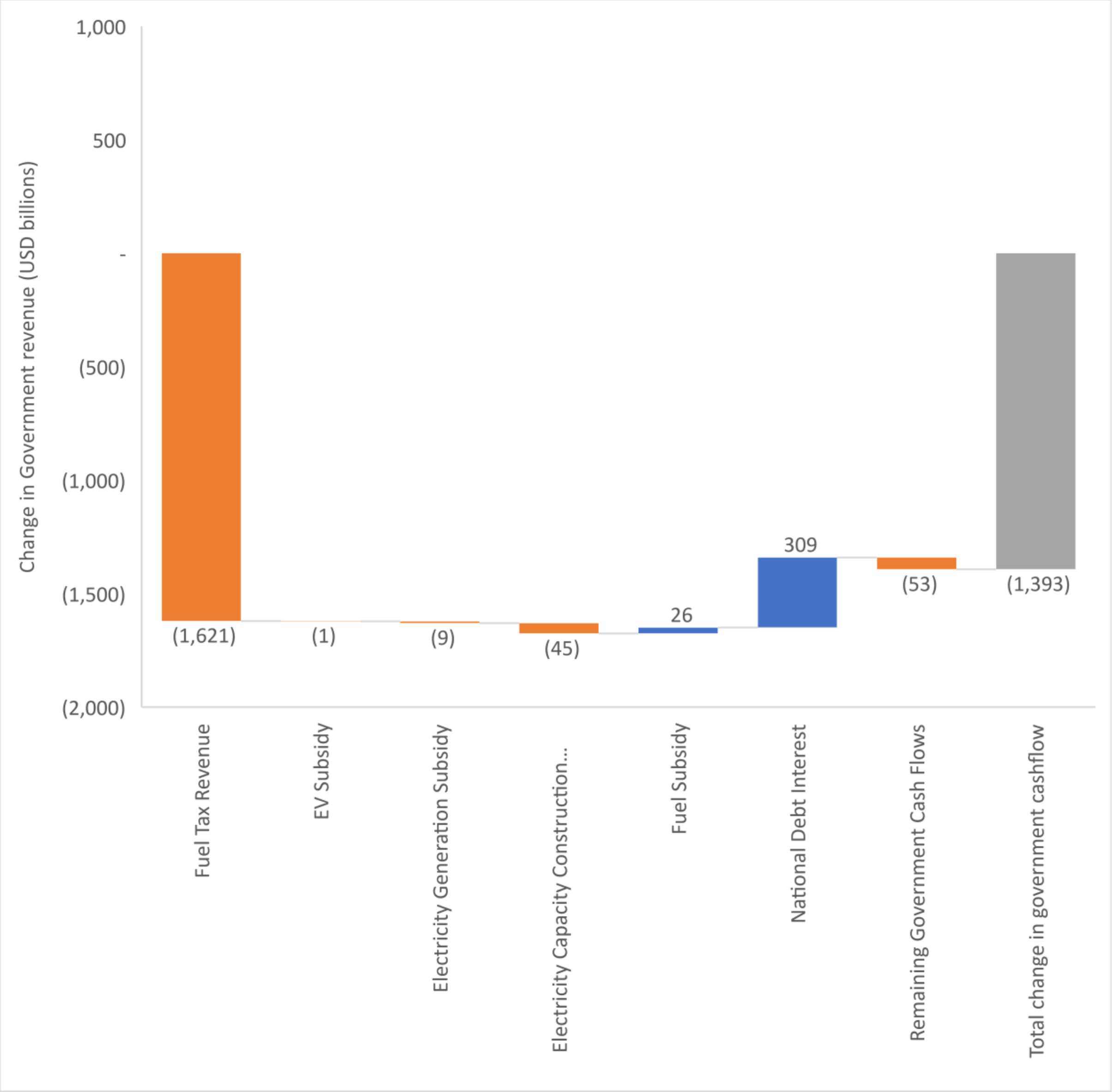
Table 1: Projected investment requirements for capacity addition in offshore wind and green hydrogen

Year	Cumulative Capital Expenditure (in USD Billion)		Cumulative Capacity Addition		
	Offshore wind with Battery storage	Hydrogen Electrolyser	Offshore Wind (GW)	Battery Storage -grid (MWh)	Hydrogen demand (thousand tonnes)
2025	16	7	4	41,210	4,118
2030	80	28	33	154,647	16,378
2035	152	92	86	260,929	59,391
2040	220	226	144	400,025	158,156
2045	272	395	179	581,734	296,040
2050	323	571	205	802,792	459,591

**All numbers have been converted to USD in 2018 terms using the average exchange rate of 1 USD = 68.49 INR, rounded up to whole number*

The impact on government revenues and costs have been graphically depicted below (figure 1). The largest change in government cashflow components is due to the loss in fuel tax revenue from the declining use of fossil fuels across the economy. This could constrain the ability of the government to support the uptake of moonshot technologies, for example in the form of technology or R&D subsidies and the development of supporting infrastructure. The loss in government cashflows could be compensated through various fiscal instruments and financing mechanisms. Imposing a carbon tax could relieve some burden on government cashflows, which are already competing for various development objectives. However, a carbon tax is politically sensitive and runs the risk of a regressive tax regime, and thus may only offer itself as a delayed solution. An alternative solution may be offered by carbon markets, where private sector is incentivised to make green investments through revenues generated from carbon trading units, offsetting the investment risk to certain extent. A percentage of the revenue generated from carbon markets could be used by the state in financing green investments.

Figure 1: Change in total government cashflow by 2050 (in USD billions)



The state can raise additional finance through leveraged funds for green investments. The European Green Deal Investment plan proposes utilisation of EU emission trading investment funds and the EU budget to facilitate a leveraged InvestEU program to mobilise €1 trillion over the next decade. Under the InvestEU program, guarantee structures would be combined with funding from European Investment Bank along with contribution from National Promotional Banks and International financial institutions, to mobilise additional finance. Over 30% of the European Union Recovery Instrument funds will be raised through issuance of green bonds. The controversial Cross Border Adjustment Mechanism simultaneously encourages domestic green manufacturing in EU, while compensating for loss in revenues through import tax duties.

The Inflation Reduction Act in the United States of America, on the other hand, provisions for over USD 373 billion in energy security and climate investments through fiscal and tax incentives. It includes production and investment tax credits for domestic clean energy manufacturing and decarbonisation, loan and grant instruments along with investments in national labs and accelerators. These incentives are envisioned to unlock private sector investments and infrastructure funding.

In India's case, a one-size-fits-all approach would likely not be applicable. The choice of instruments for raising, deploying, and mobilizsng (leveraged) finance should be dependent on the relevant industry risks and objectives. Financial mechanisms to monetise the projected savings in fuel and O&M would add to the business case, requiring lesser subsidy incentives from the government. Public capital could then be shifted towards R&D infrastructure and skilled manpower development within the industry. A combination of fiscal incentives, tax and market instruments could be structured in combination with dedicated state funding to operationalise the required investment projections. Indian development banks such as National Investment and Infrastructure Fund (NIIF) and Small Industries Development Bank of India (SIDBI) could be utilized to create leveraged programs for green development projects.

IV. Conclusion

The Government of India has strongly indicated its interest in development of indigenous capacity and manufacturing capability for the three moonshot technologies in question. However, progress has been slower than anticipated, with technology development status varying between pre-demonstration to demonstration stage. Substantial scale and pace must be realised to drive industrialised opportunities within the related sectors.

The role of industrial policy and state support has been substantiated in various countries such as South Korea, Taiwan, Singapore and Hong-Kong during its industrial and technological progress in the 1970s and 80s. Through planned state investments in basic research, policy support to private sector, infrastructure, education and skill development, indigenous technologies and value chains were built in sectors such as automobiles, micro-processors, robotics, and heavy machinery. In the Indian context, similar successes were achieved in biopharmaceutical industry. Developing globally competitive, indigenous climate moonshot technologies would require significant state support and vision in the coming decade(s).

The draft Science, Technology, and Innovation (STI) policy released by the Department of Science and Technology could lead to a few welcome changes in India's National Innovation System. This includes an open science and data framework, dedicated STI funding (including earmarked funds for private corporations) and institutionalized industry-academia collaborations (Department of Science & Technology, 2020). Apart from serving to boost the overall innovation ecosystem in India, it will foster a conducive environment for climate innovation in India. However, specific mission-mode support would likely be required to develop globally competitive climate technologies.

Key recommendations for development of climate moonshot technologies such as offshore wind, green hydrogen and battery storage are given below. The recommendations ponder on the role of state and are derived from innovation theory, contextualized based on the insights generated from the examined case studies.

- **Establishment of an integrated commission or council for energy transition:** Creating a dedicated governmental commission for climate-aligned energy activities and net-zero transition in the country would allow for a nimble, vertically integrated organisational structure. Currently, significant delays are observed between announcement of intent and subsequent roll-out of policies, sectoral strategies, and roadmaps. Akin to Department of Biotechnology or Department of Space, a dedicated commission or council could oversee strategic development of climate moonshot technology, industries and stimulate private sector action. This would involve effective coordination among different ministries along with coherent communication on sectoral strategies and roadmaps. An integrated council could facilitate deliberation on trade-offs involved between various energy and technology mixes to signal long-term plan for industry. The council could also initiate and co-ordinate any geopolitical alliances required for access to critical raw material and knowledge transfer necessary for long-term development of indigenous climate technologies.

- **Creation of comprehensive Research & Development infrastructure:** India's past experience strongly favours creation of robust tri-partnerships between industry, academia and government to facilitate long-term vision. The overall research and development architecture strongly correlates with domestic innovation and commercialisation opportunities created in local markets. This includes setup of various incubators, accelerators along with building capacity among domestic researchers. Leveraging public and private funding for R&D activities will be crucial in lowering government expenditure (as opposed to a pure subsidy support) and deriving commercial returns on risk capital.

- **Market formation and development**: The state will play a critical role in establishing new markets through facilitation of technology transfer, product development and commercialisation. A large component of said market creation would involve provision or enabling of appropriate financing mechanisms to draw commercial interest. Emphasis should be drawn on directed financial assistance as opposed to general financial incentives, depending on the required risk mitigation across various stages of commercialisation. In case of offshore wind, viability gap funding structures can be designed to increase financial feasibility along with risk reduction through guaranteed electricity offtake and preferential grid access. Similarly, for increased adoption and investment in green hydrogen and battery storage, specific de-risking mechanisms can be structured through partial risk guarantee mechanisms, tax-efficient trusts, and credit enhancement schemes. Other relevant points of attention would be towards increasing ease of business through establishment of appropriate legal infrastructure, streamlining of clearance processes and fiscal incentives through tax exemptions. The government could raise capital through sovereign green bonds and proceeds generated from an integrated domestic carbon market. Private capital could be more effectively leveraged through facilitation of domestic debt market, green loans and bonds, along with securitisation and pooling of green assets.

Early government support and vision would be paramount in establishing India as a key player in the new low-carbon developmental paradigm. This forms the core argument on expedited action by the Indian government in the advancement of indigenous climate moonshot technologies. The case for fostering climate-aligned technologies in India is perhaps best explained by former President APJ Abdul Kalam (citing the Indian space program): “Neither Prime Minister Jawaharlal Nehru nor Professor Vikram Sarabhai had any ambiguity of purpose. Their vision was very clear: If Indians were to play a meaningful role in the community of nations, they must be second to none in the application of advanced technologies to their real-life problems.”

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