Budgeting for Net Zero

Government support needed to meet India's 2030 clean energy goals

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December 2024

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Geneva Office

International Environment House 2
9 Chemin de Balexert 1219
Châtelaine Geneva, Switzerland

Tel: +41 22 917 8683
Website: iisd.org
X: @IISD_news

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Head Office

No. 18, 10th Cross, Mayura Street
Papanna Layout, Nagashettyhalli
RMV Stage 2, Bengaluru 560094
Karnataka (India)

Tel: +41 22 917 8683
Website: cstep.in
X: @cstep_India

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Head Office

Via San Giovanni Battista 2,
21057 Olgiate Olona (VA), Italy

Tel: +39 366 20 98 011
Website: ke-srl.com
X: @AndreaMBassi

Budgeting for Net Zero: Government support needed to meet India's clean energy goals

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Written by Swasti Raizada, Tara Laan, Sunil Mani, Saumya Jain, Deepak Sharma, Andrea M. Bassi, Anasuya Gangopadhyay, Upasna Ranjan, Gautham Molleti, Sarah Khan, Bidisha Banerjee, Jaymin Gajjar, Georg Pallaske

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Acknowledgements

The authors would like to thank a number of individuals who contributed to this project, including, on project design, Chris Beaton, Shruti Sharma, and Siddharth Goel from the International Institute for Sustainable Development (IISD); Abhishek Nath, Ramya Natarajan, and Saptak Ghosh from the Center for Study of Science, Technology & Policy; on outreach, Aia Brnic, Sydney Hildebrandt, and Elise Epp from IISD; and experts from the following institutions, who participated in consultations and technical workshops to provide valuable inputs to the project:

- NITI Aayog
- Danish Energy Agency, Centre of Excellence
- World Economic Forum
- World Resources Institute India
- Centre for Energy, Environment and Water
- Vasudha Foundation
- Auroville Consulting
- BloombergNEF
- Ola Mobility Institute
- Global Wind Energy Council, India
- DNV

The authors would also like to thank the following individuals and institutions for the valuable comments and recommendations that they provided as peer reviewers:

- Vibhuti Garg, Director (South Asia), Institute for Energy Economics and Financial Analysis
- Alice Tipping, Director (Trade and Sustainable Development), IISD
- Ieva Baršauskaitė, Lead, Trade and Green Transition, Economic Law and Policy, IISD
- Balasubramanian Viswanathan, Energy Officer, Sustainable Energy for All (SEforALL)
- Runa Sarkar, Professor, Indian Institute of Management Calcutta
- Mritiunjoy Mohanty, Indian Institute of Management Calcutta
- Aditya Lolla, Asia Programme Director, Ember
- Satish Triplicane Damodaran, TRAIL+7 student, World Trade Institute
- Alexander Hogeveen Rutter, Electricity Sector Lead, Third Derivative
- Indira Urazova, Policy Analyst, IISD
- Ramya Natarajan, Research Scientist, CSTEP
- Dr. S.S. Krishnan, Advisor, CSTEP
- Martand Shardul, Policy Director, Global Wind Energy Council India

We would also like to thank the governments of Denmark, Norway, and Sweden for their generous support of this publication. The opinions expressed and the arguments employed in this update do not necessarily reflect those of peer reviewers and funders, nor should they be attributed to them.

Executive Summary

India is a champion of clean energy. The Central Government has set ambitious goals to ramp up a range of clean technologies by 2030 (Table ES1) as part of its strategy to increase energy independence, energy security, and energy access while promoting industrial development and reducing air pollution and greenhouse gas (GHG) emissions. To deliver on these goals, the Central Government has introduced a suite of financial and non-financial support measures.[1] But will these measures be sufficient to reach the goals in full and on time? This report answers this question for five technologies. Three are in the power sector—battery energy storage systems (BESSs), offshore wind, and solar photovoltaic (PV); one is in transport—electric vehicles (EVs); and one is in industrial technology—green hydrogen (GH_2).

Table ES1. Current capacity and goals for key clean energy technologies

Technology	Indicator	Capacity or market penetration in 2024	2030 goal[a]
BESSs	Energy capacity	0.2 GWh[b]	208 GWh
Offshore wind	Auction capacity	0 GW[b]	37 GW
Solar PV	Installed capacity	82 GW[b]	293 GW
EV	% of new vehicle sales	6.4%[c]	30%
GH_2	Annual production capacity	235 tonnes[d]	5 million tonnes (Mt)

Source: [a] 2030 goals were compiled by authors from Central Electricity Authority, 2023c; Clean Energy Ministerial, n.d.; Ministry of New and Renewable Energy, 2023a, 2023b. See chapters on individual technologies for details.
[b] Installed capacity as of March 2024.
[c] Calendar year 2023.
[d] As of March 2023 (the latest year publicly available).

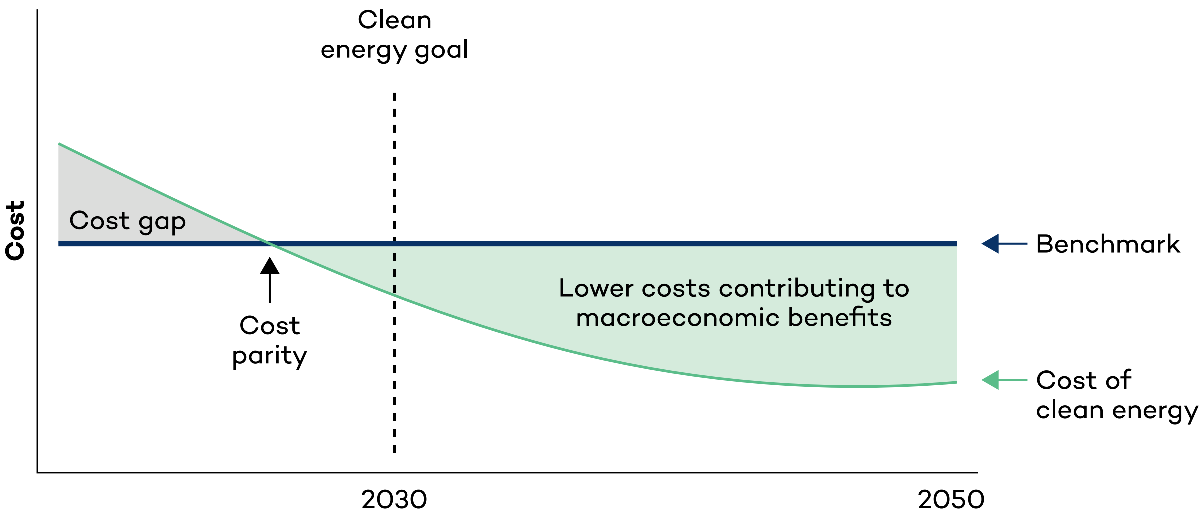
To answer this question, we first estimated the amount of money or changes in policy needed to achieve the clean energy goal: the "cost gap" (Box ES1). The cost gap varied from INR 2,637 crore (USD 321 million) for BESSs, a relatively mature technology, to INR 5.1 lakh crore (USD 61 billion) for offshore wind, a nascent technology in India with a large deployment goal (Table ES2).

[1] "Support" refers to all policies that provide a financial benefit to consumers or producers, including subsidies, concessional financing, expenditures by public sector undertakings, and regulations, such as mandates.

Box ES1. Estimating the cost gap

The cost gap was calculated as the marginal cost differential between one unit of clean energy and a benchmark conventional equivalent, multiplied by the number of units needed per year to reach India's stated goal (Figure ES1). The size of the cost gap varied with (i) the maturity of the technology (nascent technologies are typically more expensive relative to conventional equivalents), (ii) the size of the goal, and (iii) the chosen benchmark. We used India-specific data on costs and factored in expected falls in costs of production over time (based on individual learning rates for each technology). The cost gap is distinct from an investment gap, which considers the total investment needed to achieve energy goals.

Figure ES1. A simplified illustration of the study approach to model cost gap



Source: Authors.

Existing Central Government subsidies (provided and announced) were found to be sufficient to fully cover the cost gap for solar PV and BESSs (Table ES2). Our analysis for these technologies therefore focused on other types of support measures that could speed up deployment to achieve the 2030 goals. For offshore wind, GH_2, and EVs, current Central Government subsidies cover up to 1%–59% of the cost gap, suggesting that additional policy measures might be needed to achieve the goals..

Central and state governments do not need to fund the full gap. Small public financial flows can crowd in much larger private investments. The private sector can be encouraged to invest in a business that they are confident will become profitable over time or help them capture market share, especially if a green premium is expected. Regulatory approaches, such as purchase obligations, can require the private sector to direct investment toward clean technologies. International climate finance can contribute to bridging the cost gap for technologies that have the largest viability gaps and are farthest from market maturity.

Table ES2. The cost gap to achieve India's 2030 clean energy goals for selected technologies

Technology	Cost gap to achieve 2030 target[a]			Central Government outlay compared to amount needed (%)[b]
	INR (crore)	USD (billion)	% of GDP (2024)	
BESSs	2,637	0.32	0.01%	100%
Offshore wind	5.1 lakh	61	1.75%	1.43%
Solar PV[c]				
Large-scale solar PV	6,700	0.81	0.02%	100%
Small-scale solar PV	7,800	0.95	0.03%	100%
EV				
e2W[d]	19,000	2.29	0.06%	14.1%
e3W	-	-	-	-
e4W	4,300	0.52	0.01%	4.65%
e-buses	7,500	0.92	0.03%	58.55%
GH_2	2.8 lakh	34	0.96%	4.59%

Source:

Notes: Figures are based on undiscounted, constant prices.

[a] The gap does not reflect current levels of support already budgeted, which we compare separately in the final column.

[b] Existing Central Government support (provided and announced) divided by the cost gap.

[c] For solar PV, the cost gap is the gap in unit costs between imported solar and domestically manufactured modules since the technology is already cost-competitive with other power generation technologies.

[d] e2W = electric two-wheeler; e3W = electric three-wheeler; e4W = electric four-wheeler.

Finally, we assessed the optimal size and form of support if governments (Central and state) were to bridge the cost gap, in part or full. We used multiple scenarios and macroeconomic modelling to assess economy-wide impacts, compare benefit-to-cost (BCR) ratios of varying levels of government support (100%, 30%, and 5%, with the private sector bearing the remaining costs through higher energy prices) and recommend support measures to minimize costs and maximize benefits.

Even if governments were to meet 100% of the cost gap, we found that economic growth, employment, and net revenue increased in response to government support to achieve the clean energy goals for all technologies except GH_2 (Table ES3; 2050 results are shown to allow time for long-term macroeconomic impacts to fully emerge). This is due to several factors. First, the new industry stimulates growth and employment, which increases government revenues. Second, all technologies except GH_2 achieve cost parity before 2050. From that point forward, the lower energy costs relative to business as usual (BAU) generate only upsides for the economy. Third, clean energy has lower air pollution and GHG emissions, both of which impose costs on society; reducing these costs provides tangible net benefits.

Table ES3. Macroeconomic impact of providing government support to achieve cost parity for clean energy technologies relative to BAU (cumulative to 2050)

	BESSs	Offshore wind	Solar PV	EVs	GH_2
GDP (cumulative, INR crore)	0.005	15,80,000	9,52,320	13,80,000	(9,00,000)
Employment (cumulative FTE[a])	46,085	8,21,573	10,96,759	3,70,70,776	Not estimated
Energy savings (cumulative, INR crore)	-	-	1,135	41,50,000	-
GHG emission reduction (cumulative, million tonnes)	34	5,300	336	1,200	1,900
Public revenue (cumulative, INR crore)	0.0016	4,70,000	4,14,942	4,14,000	(2,60,000)
BCR	1.89	2.16	1.6-4.5	2.6	-0.24

Source:

Notes: [a] For employment, we present cumulative full-time equivalent (FTE) jobs created directly and indirectly as a result of government support to 2050. Direct job creation for wind and solar is net (i.e., it considers reductions in employment from coal and thermal generation). Direct job creation for EVs is not net: it only considers new jobs from EV manufacturing, batteries, and chargers and assumes full downstream domestic manufacturing.

The macroeconomic model only assessed the impact of government support to bridge the cost gap relative to the BAU scenario (where no support is provided), not the absolute impact of achieving 2030 clean energy goals. In the model, support was provided until cost parity was reached (or 2050, in the case GH_2). For example, in the case of offshore wind, all of the new capacity—and therefore all of the societal benefits—result from government support (in the BAU scenario, there is no support and therefore no offshore wind). For BESSs, however, the positive but modest results reflect the low level of support needed to bridge the cost gap.

The key findings are discussed below in sections for each technology. Recommendations were based on quantitative analysis coupled with in-depth qualitative research, including literature reviews, interviews with experts and stakeholders, and workshops. Therefore, the recommended approaches extend beyond our cost gap or modelling exercises.

Power Sector: BESSs

In India, BESSs were projected to reach cost parity with our benchmark, the peak evening electricity tariff, in 2028. The current viability gap funding (VGF) scheme of INR 3,760 crore (USD 458 million) was found to be sufficient to cover the cost gap of INR 2,637 crore (USD 321 million) (Table ES2). We, therefore, do not recommend that any additional support be provided; instead, the government should accelerate the pace of BESS auctions to spread the VGF funding more thinly across projects and beyond the 4 GWh capacity by 2030/2031 (about 2% of the total required capacity for India's energy storage needs of 208 GWh by 2030). The government should also introduce power market reforms and establish other regulatory policies to incentivize investment in BESSs to mobilize additional investment.

The provision of existing support to help BESSs achieve the 2030 target was projected to have a positive impact on the economy by 2050, reducing pollution while stimulating employment and economic growth (Table ES3). The results are positive but small, proportional to the level of support currently being provided.

Recommended policy options:

- Accelerate the pace of BESS auctions and spread the VGF funding already available across more BESS capacity, given the smaller funding amounts needed per unit. Overall, the current size of the VGF scheme is sufficient for further market development.
- Reduce the Goods and Services Tax (GST) on BESS components, which would make BESSs cost-competitive immediately.
- Introduce a mandatory Energy Storage Obligation (ESO) target that includes BESSs (this was introduced in 2022 but was later dropped as part of the RPO).
- Undertake electricity market reforms that allow BESSs to earn revenue as a provider of a wider range of ancillary services.
- Provide funding support for training and capacity building of state-level actors such as State Electricity Regulatory Commissions, State Load Dispatch Centres, and distribution companies (discoms) in BESS project development and preparing resource adequacy plans.
- Incentivize states to fully implement the Resource Adequacy Guidelines and ensure that all new planned power generation capacity undergoes an economic comparison against firm and dispatchable renewable energy with energy storage solutions such as BESSs, rather than on a cost-plus basis.

Power Sector: Offshore Wind

Offshore wind is currently an expensive technology in India but is worthwhile to develop because it offers a relatively stable renewable energy supply. We found that offshore wind could take at least 12 more years to reach the grid parity in India.

The recent VGF scheme of INR 6,853 crore (~USD 821 million) for the installation of the first 1 GW offshore wind plants is an important development. However, it might not be sufficient given that we identified an additional cost gap of around INR 9,000 crore (USD 1.1 billion) per GW of capacity. To achieve the aspirational goal of 37 GW by 2030, the total cost gap was INR 5.1 lakh crore (USD 61 billion), or INR 73,000 crore (USD 8.75 billion) per year between 2024 and 2030. This estimate was based on a capital-based incentive; a generation-based incentive was even higher. Sharing the support costs between public and private investors was projected to increase GDP gains while reducing government spending due to more efficient allocation of funding and resources. Even if governments were to bridge 100% of the cost gap, we projected a positive BCR under all scenarios, indicating that supporting offshore wind makes economic sense (Table ES3).

Recommended policy options:

- Postpone the 2030 capacity goal to allow costs to fall before the full capacity needs to be achieved, but do not delay the provision of support; the sooner India starts deployment, the sooner domestic costs will decline.
- Align government support policies—financial and non-financial measures—with the goals for the offshore wind sector, noting this is likely to require an increase in both kinds of support.
- Consider a new model for pooling renewable energy with different variabilities so that offshore wind is bundled with cheaper and more intermittent renewable energy sources to create demand and secure offtakers for initial projects.

Power Sector: Solar PV

Power generation from solar PV is already cheaper than new coal and gas installations in India; therefore, there is no cost gap with conventional equivalents on an energy basis. However, our consultations and unit cost analysis revealed that the government's domestic manufacturing policies for solar have an upward impact on project costs. In 2024, domestic modules were at least 30% costlier than imported modules (with a 40% customs duty). Using a cost optimization model, we assessed the impact of these policies on the achievement of the capacity goal for solar PV. We found that the higher costs result in a slowdown of deployment for both large- and small-scale projects between 2024 and 2026, and India is falling short of its 2030 capacity goal by around 20 GW. Beyond 2030, we projected that the cost gap will be removed as India develops economies of scale in both cell and module manufacturing.

To address the ~20 GW shortfall, the government has three main choices: 1) remove or reduce trade and non-trade barriers, 2) increase subsidies to manufacturing or deployment, or 3) address other impediments to solar deployment. We do not recommend that any additional support be provided: current levels of support provided through the Production Linked Incentive are already sufficient to bridge the cost differential between domestic and imported panels—India's manufacturing sector just needs time to respond to the scheme and develop economies of scale. Our modelling indicates that reducing the customs duty from 40% to 10% and removing the non-trade barriers could boost deployment by around 7 GW by 2030. The remainder of the shortfall could be addressed through the electricity sector and the reform of government solar PV programs, which our qualitative analysis suggests could be more important than incentives in accelerating deployment (see below).

The macroeconomic results for solar PV indicate that lowering the customs duty to 10% would have a positive impact on deployment relative to the BAU scenario (current policies). The higher deployment results in increased GDP and GHG emission reductions.

Recommended policy options:

- Carefully track the price of internationally and domestically manufactured modules and remove all trade and non-trade barriers once cost competitiveness is achieved—or even earlier—to expose the domestic market to competition and drive down prices.
- Address the health of discoms through cost-reflective tariffs and direct benefits transfers to vulnerable consumers, allowing discoms to invest in renewable energy and modernizing the grid.
- Accelerate grid integration of new solar PV projects through earlier planning and faster connection times.
- Support states in overcoming technical challenges associated with higher adoption and integration of variable renewable energy, including small-scale solar PV such as irrigation and rooftops.

Transport Sector: EVs

Our analysis indicated that demand-side incentives would continue to be needed for all EVs except e3Ws to achieve the government's aspirational target of 30% of vehicle sales being EVs by 2030. In the absence of any incentives, e2Ws and electric cars are projected to reach cost parity by 2034, and buses by 2045. However, with incentives, e2Ws and electric cars can achieve cost parity by 2025. Providing government support to bridge the cost gap and the EV target would result in the second-highest macroeconomic benefits among the technologies, with a BCR of 2.6. This is because the provision of support boosts EV uptake substantially, leading to productivity gains from job creation, economic stimulation, and reduced pollution.

The Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India (FAME India) has been replaced with a new 2-year PM E-DRIVE scheme totalling INR 10,900 crore, with nearly INR 2,679 crore to support further adoption of e2Ws and e3Ws and INR 4,391 crore for public e-buses. While the PM E-DRIVE scheme may help segments covered for the next 2 years, it may not be sufficient to reach the desired adoption in most segments. Government support is also needed to boost the uptake of shared and commercial e4Ws. Non-fiscal interventions, such as strengthening existing vehicle emissions standards, are also needed to encourage sales of private EV cars. Government support exists for EV manufacturing in India, but these supply-side incentives were outside the scope of this study. Given the high cost of EVs, it may be premature to introduce domestic content requirements for EV manufacturing or sales, which would push up prices and reduce sales.

Recommended policy options:

- Articulate and formalize EV adoption rate targets across vehicle segments to have a clear 2030 vision.
- Continue EV support measures to 2030. Integrate all existing demand and supply incentives for EVs into a comprehensive roadmap with a clear trajectory for government support to 2030 to help ensure policy stability and attract long-horizon private investments.
- For specific support measures, we recommend
    - renewing the income tax exemption on interest on car loans, which lapsed in 2023, to 2030 and leveraging banking channels to design information campaigns around the concessional financing and tax deductions available to consumers;
    - continuing demand incentives for shared electric car fleet operators to 2030 at the levels of FAME-II;
    - expanding incentives for leasing electric buses to private operators who own and operate nearly 93% of buses in India;
    - expanding support to electrifying commercial freight and heavy-duty vehicles for faster adoption up to 2030; and
    - expanding support for charging infrastructure, which is one of the key drivers for EV adoption.

Industrial Sector: GH_2

Our results suggest that GH_2 will not become cost-competitive with hydrogen from natural gas ("grey" hydrogen, the benchmark) until after 2050. This benchmark was chosen because the government's stated objective is for GH_2 to replace grey hydrogen in the domestic market to reduce import dependence on natural gas for refineries, fertilizers, and city gas distribution. Current subsidies cover only ~5% of the cost gap and will be exhausted well before 2030. Nearly 0.96% of the GDP would be required for the government to bridge the full cost gap for GH_2 to 2030, with further support required until cost parity is reached after 2050. The high costs result in a poor BCR of -0.24, given economic benefits accrue outside the period of our study.

Given these findings, the government may want to re-evaluate the current target, which was set in 2020 when the prevailing assumptions for cost reduction GH_2 were more optimistic. A revised timeline should aim for India to still develop a GH_2 industry but at a realistic level of ambition, allowing the learning curve to bring prices down before ramping up domestic production.

Recommended policy options:

- Revise the current target and timeline and align these with the support policies, noting that GH_2 is likely to require higher financial and non-financial assistance than currently provided.

- Extend the tenure of GH_2 subsidies beyond the current 3-year period to help secure long-term offtake agreements and provide financial stability.
- Impose a carbon tax on hydrogen from natural gas in sectors such as refining to allow GH_2 to become competitive sooner while also generating tax revenue (this effectively raises the benchmark price in our scenarios, allowing GH_2 to become cost-competitive sooner).
- Accompany the carbon tax with a GH_2 purchase obligation, including for Public Sector Undertakings (PSUs) or specific emissions reduction targets under the Carbon Credit Trading Scheme for hydrogen-using sectors (refineries, fertilizers, steel, and city gas distribution).
- Offer incentives for manufacturing end-use products like green steel, green urea, and green chemicals to drive demand for GH_2 in key sectors. These incentives will help build a domestic market for GH_2, encourage offtakers, and create long-term demand.
- Facilitate GH_2 exports by developing robust testing and certification facilities to ensure that Indian producers meet international standards. This will allow Indian GH_2 producers to access international carbon credit markets, including internationally traded mitigation outcomes and voluntary offset markets.
- Seek international climate finance, given that many economies see India as a geography that is able to produce large volumes of relatively low-cost green power for exports.
- Provide additional research and development funding to support innovators working on alternative GH_2 production technologies.

Overarching Key Findings

Government support has been vital for the rise of renewable energy globally, and India has been no exception. Government support—along with other enabling policies—is now bearing fruit. Three of the five key technologies we examined have either reached cost parity with their conventional equivalent or will do so in the next decade when supported by governments, resulting in energy price reductions, economic growth, new jobs, industrial development, and pollution reduction. Thus, it is critical that the Government of India continues to support these technologies through financial or non-financial support measures. This report signals that carefully targeted interventions continue to be needed to achieve India's clean energy goals, including domestic manufacturing ambition, with associated benefits for the economy, health, and environment.

The cost gap method helps identify the need for government interventions, but direct budgetary transfers, such as viability gap funding, are not the only option. In our modelling, we focused on the cost gap as a proxy for the financial support needed because it is the primary type of financial support used in India for these technologies (including solar PV before it reached parity). In practice, there are many regulatory, financial, and fiscal options that can encourage investors and consumers to favour clean energy, such as mandatory targets, renewable purchase obligations, guaranteed offtake from PSUs, concessional financing, loan guarantees, provision of infrastructure or land, tax concessions, and manufacturing support.

Our recommendations have highlighted specific policies that arose during consultations. Increasing fossil fuel taxation and creating carbon markets—currently under consideration—would also create an enabling environment for clean energy while raising revenue to support vulnerable businesses and households. The government can also reform support for existing schemes so that they work more effectively.

We did not model every potential measure or pathway, but our results suggest that bridging the cost gap for clean energy now—whether by the public or private sector—is likely to deliver net economy-wide benefits. Clean energy technologies result in energy savings, create new jobs and industries, and reduce pollution—all of which deliver productivity gains and improve standards of living. Only GH_2 showed persistent reductions in GDP because our modelling does not project it to reach cost parity until 2050: the pay-off is in the years outside the time frame of our analysis. Even so, GH_2 was still projected to deliver significant co-benefits in terms of GHG and air pollution reductions.

Funding for clean energy incentives will need to be identified from a range of domestic and international sources. On the domestic side, investments by PSUs could be redirected to clean energy, and a climate finance taxonomy can help domestic financial institutions to align with India's stated clean energy goals. Climate financing and carbon markets will also be critical. Indeed, India stated in its latest nationally determined contributions under the United Nations Framework Convention on Climate Change that its clean energy goals are conditional on technology transfer and concessional climate financing. International donors will need to step up to meet the new climate finance package proposed at the 29th UN Climate Change Conference (COP 29) called the New Collective Quantified Goal. International partners can also assist by shifting their own public lending from fossil fuels to clean energy, as agreed by countries and financial institutions under the Clean Energy Transition Partnership.

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Abbreviations and Acronyms

2W	two-wheeler
3W	three-wheeler
4W	four-wheeler
ALMM	Approved List of Models and Manufacturers
BCD	basic customs duty
BCR	benefit-to-cost ratio
BESS	battery energy storage system
CapEx	capital expenditure
CCS	carbon capture and storage
CEA	Central Electricity Authority
CLD	causal loop diagram
DCR	domestic content requirement
discom	distribution company
ESO	Energy Storage Obligations
e2W	electric two-wheeler
e3W	electric three-wheeler
e4W	electric four-wheeler
EV	electric vehicle
FAME	Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles
FDRE	firm and dispatchable renewable energy
FIMOI	Financial Modelling of Offshore Wind in India
FTE	full-time equivalent
FIT	feed-in tariff
FY	fiscal year
GBI	generation-based incentive
GDP	gross domestic product
GEM	Green Economy Model
GH_2	green hydrogen
GHG	greenhouse gas

GST	Goods and Services Tax
GW	gigawatt
ICE	internal combustion engine
IEA	International Energy Agency
IISD	International Institute for Sustainable Development
IRENA	International Renewable Energy Agency
ISTS	Inter-State Transmission Charges
LCOE	levelized cost of electricity
LCOH	levelized cost of hydrogen
LCOS	levelized cost of storage
Li-ion	lithium-ion
MNRE	Ministry of New and Renewable Energy
PEM	proton exchange membrane
PIB	Press Information Bureau
PLI	Production Linked Incentive
PRAS	Primary Reserve Ancillary Service
PSU	Public Sector Undertaking
PV	photovoltaic
R&D	research and development
RAP	resource adequacy planning
REC	Renewable Energy Certificate
RPO	Renewable Purchase Obligation
RTC	round-the-clock
SIGHT	Strategic Interventions for Green Hydrogen Transition
SOE	state-owned enterprises
SRAS	Secondary Reserve Ancillary Service
TCO	total cost of ownership
TRAS	Tertiary Reserve Ancillary Service
VGF	viability gap funding

1.0 Introduction

Governments around the world, including India, support clean energy[2] for several reasons. Energy security, price stability, and balance of trade can be improved by developing a domestic source of clean energy that is not dependent on price-volatile imported fossil fuels. Lower pollution will reduce health costs and productivity losses. Developing new industries can create jobs and economic growth. Rapidly falling prices for some renewable energy and battery technologies can deliver significant cost reductions compared to conventional coal and gas-power technologies.

A transition to clean energy is also critical for reducing greenhouse gas (GHG) emissions. In India, energy accounted for 76% of total GHG emissions in 2019 (the latest year available) (Ministry of Environment, Forest and Climate Change, 2023). Of this, electricity generation contributed the largest share—53% of total energy emissions, followed by industry (17%) and transport (13%) (Ministry of Environment, Forest and Climate Change, 2023). Therefore, decarbonizing the energy sector will be pivotal in achieving India's ambition of net-zero emissions by 2070.

During its G20 presidency in 2023, India spearheaded the initiative to "pursue and encourage efforts to triple renewable energy capacity globally," a key action to keep average global temperature increases to below 1.5˚C from pre-industrial levels (G20 Leaders, 2023). This ambition became a pledge by 198 parties at the 28th UN Climate Change Conference (COP 28) (International Energy Agency [IEA], 2024b). Projections show that the world will fall short of the tripling goal (IEA, 2024b), suggesting that governments need to step up their interventions to crowd in further private investment (Laan et al., 2024).

India has set ambitious national goals for clean energy, including achieving 50% of its cumulative electric power installed capacity from renewables, 500 GW of non-fossil electric capacity, and specific targets for individual technologies (Table 1). Three goals are in the power sector—battery energy storage systems (BESSs), offshore wind, and solar photovoltaic (PV); one is in transport—electric vehicles (EVs); and one is in industrial technology—green hydrogen (GH_2).

[2] Clean energy in this report refers to electricity generated from renewable sources (including solar PV and wind energy) and low-carbon technologies that can integrate or use renewable power including battery storage, green hydrogen, and electric vehicles.

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Source: Central Electricity Authority [CEA], 2023c; Clean Energy Ministerial, n.d.; Ministry of New and Renewable Energy [MNRE], 2023a, 2023b. See chapters on individual technologies for details.
Notes: [a] 2030 goals are compiled by authors.
[b] Installed solar PV capacity as of March 2024.
[c] In calendar year 2023.
[d] As on March 2023 (the latest year for which figures were publicly available).

A diverse range of policies are in place to achieve these ambitions, including

- viability gap funding (VGF) and other subsidies;
- intervening in the energy market directly, such as through state-owned enterprises (SOEs) (referred to nationally as Public Sector Undertakings [PSUs]);
- policies to influence private investment or consumer behaviour, such as mandates, direct provision of goods and services, and market-based incentives; and,
- behavioural policy interventions to change purchases and consumption, such as voluntary commitments and education campaigns.

But will these policies be sufficient to achieve national targets? To inform policy-makers on the question of "the right type and magnitude of support" for clean energy, the International Institute for Sustainable Development has mapped government support for energy in India over the last decade. Estimates show that between fiscal year (FY) 2014 and FY 2023, India has provided at least INR 1.3 lakh crore (USD 19 billion) in national government support to promote clean energy, including renewables and EVs (Raizada et al., 2024). Our data describe the measures that currently provide this level of support to clean energy policy by policy. But detailed studies on the size and form of support that *should* exist to achieve government goals lack policy convergence and remain dispersed, limited in scope, and sporadic.

This study aims to bridge this knowledge gap and provide guidance to policy-makers on the size and form of policy instruments needed to achieve India's 2030 clean energy goals. We introduce a novel method of analysis, offering prescriptive recommendations regarding the volume, type, focus, and interlinkages necessary for effective government support for five clean energy technologies—BESSs, EVs, GH_2, solar PV installations, and offshore wind.

We address the following research questions:

1. Is there a gap in the government's stated plans for 2030 for these technologies and the current adoption trajectory?
2. How much government support will be needed to close the gap, if any?
   a. What can be the size and form of this government support?
   b. Where is support most needed?
3. How will the provision of increased support to achieve government clean energy targets impact the broader energy system, economy, society, and environment?
4. How do government efforts interact with technological cost reductions and private sector investments?

The study aims to guide strategic decision making at a national level and proposes an evidence-based approach to designing government support through scenario construction. The work focuses on India but has important lessons for emerging and developing economies looking to decarbonize through green growth.

2.0 Background

2.1 Scope and Definitions

We use the definition of subsidy agreed upon by World Trade Organization members: a financial contribution by a government that provides a benefit to a recipient (Agreement on Subsidies and Countervailing Measures, 1994). The World Trade Organization's subsidy definition includes direct budgetary transfers (e.g., grants), indirect transfers through price and regulatory support (e.g., price setting above or below market rates), government revenue forgone (e.g., tax incentives), underpricing of government goods and services (e.g., free land or water), and transfer of risk (e.g., environmental remediation).

The term "government support" is broader than subsidies—it also includes investments by SOEs and concessional lending by public financial institutions. The term "support" is used in this report because, for some measures, the extent of the "financial contribution by a government" in the subsidy definition is unclear. For example, capital spending by SOEs could be 100% commercial and involve no government contributions or be 100% government funded. In the absence of this information, we classify this type of spending as "support" because—regardless of the origins of the funding—it is public payment in the energy sector.

Government support can also include other non-financial measures such as voluntary agreements, regulatory mandates, and behavioural change policies. While the focus of this report is to study the impact of government financial support, the study also builds a commentary on other non-financial measures to comprehensively assess future government support that may be needed to achieve 2030 clean energy targets for selected technologies.

In the scope of this study, we have only included Central Government targets and support mechanisms. India's states and union territories are responsible for delivering their electricity supply and have their own clean energy targets and policies. However, it was beyond the scope of this study to include a full assessment of subnational policies.

For each technology, we focused on the dominant model currently in place:

- BESSs: Lithium-ion (Li-ion) batteries
- Offshore wind technology (15 MW turbines)
- Solar PV: Large- and small-scale, as well as solar manufacturing
- EVs: Electric two-wheelers (e2Ws), three-wheelers (e3Ws), and four-wheelers (e4Ws) and buses
- GH_2: The two dominant types of electrolyzers: alkaline and proton exchange membrane (PEM)

2.1.1 The Role of Government Support in Clean Energy

Similar to other new technologies, government support has been instrumental in the development of clean energy. Different types of support are generally provided at different phases of technology development (Table 2).

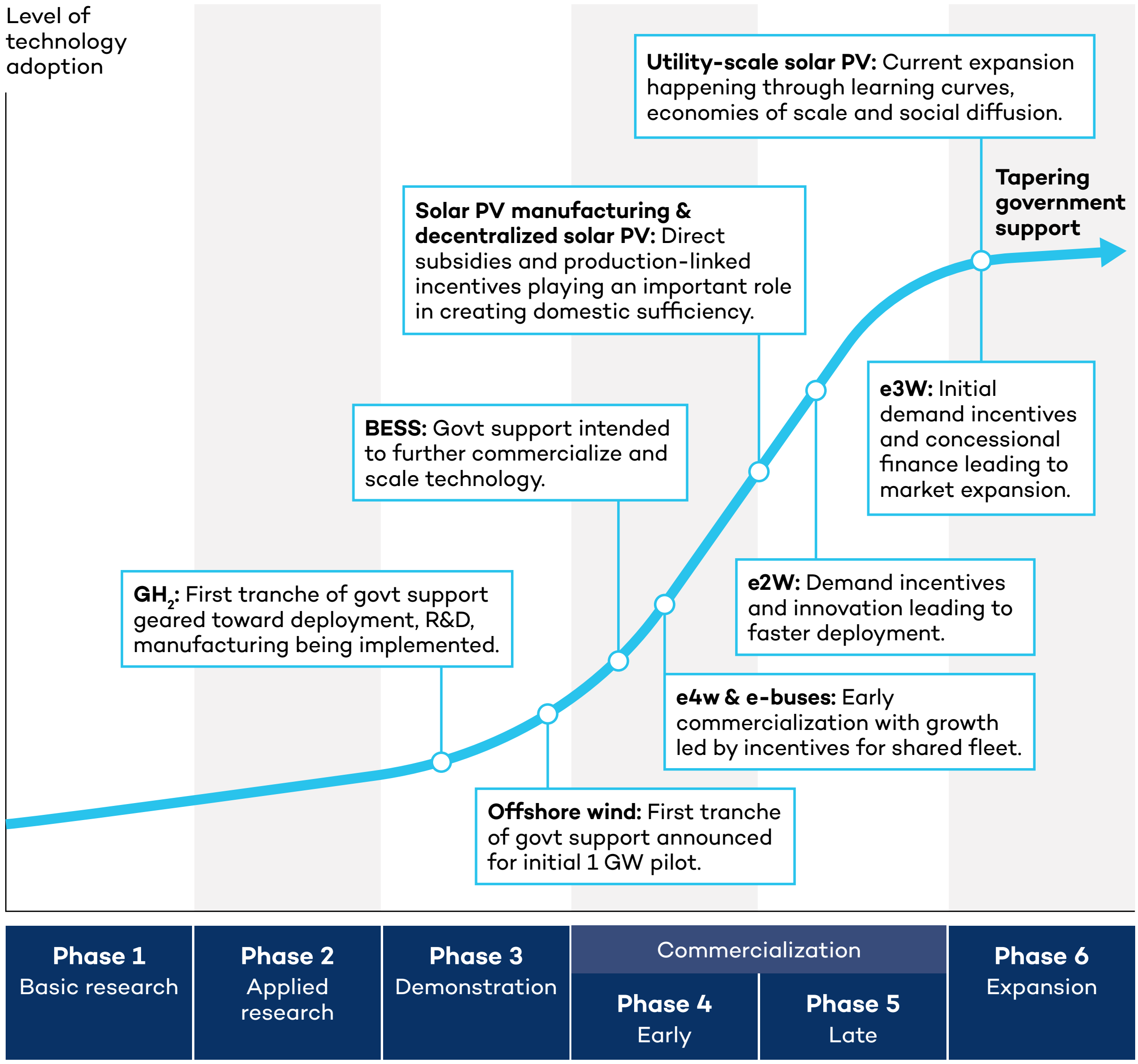
Table 2. Technology development phases and government support: A framework for clean energy in India

Phase	Objectives of support	Type of government support
Basic research	Understand fundamental scientific principles and exploring new materials or processes that could lead to breakthroughs	Grants for research at universities, national labs, and other research institutions
Applied research	Translate scientific discoveries into practical applications	Grants and loans for academia, industry, and government labs to accelerate technology development
Demonstration and development	Help companies scale up prototypes, conduct field trials, and demonstrate the commercial viability of innovations	Grants, loans, and loan guarantees to support pilot projects and large-scale demonstrations
Early commercialization and deployment	Bring technologies to market and deploy them at scale; create market demand	Loans and loan guarantees, feed-in tariffs (FITs), production tax credits, investment tax credits
Late commercialization and deployment	Accelerate deployment by levelling the playing field, providing long-term certainty for investors	Auction trajectories, loans and loan guarantees, mandatory usage, possibly with a market element, through renewable portfolio standards, green certificates, or capacity schemes
Expansion	Accelerate deployment by removing barriers and level the playing field so that markets can choose the new, cheaper, cleaner option	Infrastructure investment (including electricity transmission and distribution, hydrogen transport), supporting skilled labour (migration or education), incentives that affect the overall investment environment (carbon pricing, fossil fuel subsidy reform)

Source: Authors, compiled from Hao et al., 2020; Popp, 2019; Rogge & Reichardt, 2016.

The technologies covered in this study range from early commercialization and deployment in India (GH_2 and offshore wind) to large-scale expansion (solar PV). Figure 1 plots the relationship between technology S-curves and the need for government support, respectively: low levels of support at the early research and demonstration phases, followed by high support (while the technology is being deployed but has not reached cost parity) that eventually tapers after cost parity is achieved.

Figure 1. Diagram mapping the need for government support along the technology S-curve



Source: Authors.

Governments also intervene to correct for market failures and externalities in clean energy development. Market failures occur when the free market fails to allocate resources efficiently, leading to outcomes where societal welfare is not maximized. In the context of energy, market failures are often due to negative externalities associated with conventional energy sources, such as pollution and GHG emissions, which are not reflected in market prices (Aldy et al., 2010). The second market failure relates to companies underinvesting in developing new technologies with positive spillovers due to an inability to capture all benefits of investments

(Jaffe et al., 2005). These externalities result in higher social costs and lower social benefits, necessitating government intervention to correct these market distortions.

To address market failures and promote renewable energy, governments employ various policy instruments and mechanisms. These instruments can be broadly categorized into regulatory, economic, and informational tools (Somanathan et al., 2014):

- **Regulatory instruments** include mandates and standards, such as renewable portfolio standards and FITs, which require or incentivize the generation of renewable energy.
- **Economic instruments** include subsidies in the form of direct transfers, tax incentives, and grants that lower the financial barriers for renewable energy projects.
- **Informational tools** encompass public awareness campaigns and educational programs that promote the benefits of renewable energy and encourage adoption.

Finally, government support can be required when the pace and scale of change that will be delivered by markets is insufficient to meet public policy goals. This is the case in the context of climate change, where decades of under-investment in low-carbon transition have left the world with an extremely narrow window of opportunity in which to limit global warming to the scientifically recommended threshold of 1.5°C.

Effective renewable energy promotion often requires a mix of policy instruments rather than reliance on a single approach. A balanced policy mix can address different barriers simultaneously, from economic hurdles to technological innovation. Policy sequencing is equally crucial, as it involves the strategic introduction of policies over time to build market readiness and avoid potential negative impacts. An optimal public policy approach would involve a combination of policy-based instruments to facilitate early market penetration and a mix of market-based instruments to sustain investment in renewable energies in the long term (Hao et al., 2020; Marques et al., 2019).

Industrial policy plays a critical role in supporting the domestic manufacturing of renewable energy technologies. By fostering a local manufacturing base, countries can reduce dependence on imports, create jobs, and stimulate economic growth. They can also build political support for clean energy by demonstrating its benefits to the domestic economy. However, there can be trade-offs between supporting domestic industries and the rapid deployment of renewables and EVs. Protectionist measures like tariffs on imported solar panels, while supporting local manufacturers, can increase costs and slow down deployment (McWilliams et al., 2024). Balancing industrial policy with open market principles is essential to optimize both economic and environmental benefits.

2.1.2 Effectiveness of Government Support for Clean Energy

Government support has been highly successful for several clean energy technologies, resulting in dramatic cost reductions and exponential rates of adoption. An econometric analysis of renewable energy policies in 20 Latin American and 30 European countries over 20 years revealed that such policies have a positive impact on investment in renewable energy (Bersalli et al., 2020). An analysis of 1,500 climate policies from 41 countries revealed that successful approaches combine different and complementary measures, such as using tax and price incentives with government support and regulations (Stechemesser et al., 2024).

As a result of decades of supportive policies in several countries, the global electricity system may have already tipped irreversibly in favour of renewable energy (Laan & Urazova, 2024; Lenton et al., 2023; Nijsse et al., 2023). In 2024, clean energy installations and investments reached record levels (IEA, 2024f). Global solar PV capacity additions increased by over 33% from 2022 to 2023, with 346 GW added in 2023 (International Renewable Energy Agency [IRENA], 2024b). Similarly, global wind capacity additions jumped almost 60% in 2023, with an annual increase of 116 GW (IRENA, 2024b; REN21, 2024). The cost of Li-ion batteries plunged 99% over the past 30 years, while the energy density of best-performing cells increased five times (Walter et al., 2023). This represents one of the fastest cost declines in any energy technology, resulting from research and development (R&D) and economies of scale (Bajolle et al., 2022).

2.1.3 Government Support May Still Be Needed After Cost Parity Is Achieved

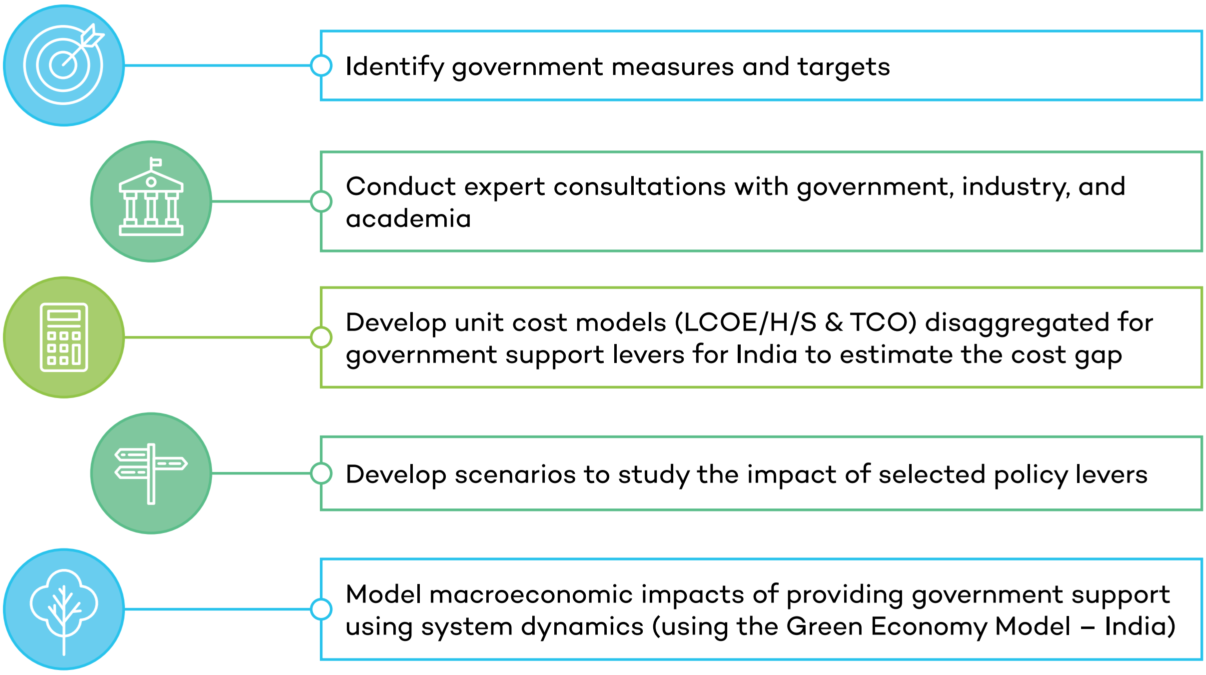
Despite these dramatic cost reductions, government support may be needed to accelerate clean energy for four main reasons (Laan & Urazova, 2024):

1. Some technologies are still in their early stages of development and require assistance, at least until they reach cost parity.
2. Even after cost parity is reached, clean energy technologies can face substantial barriers, given that energy, social, and political systems are built around fossil fuels.
3. The pace of clean energy deployment needs to accelerate to achieve national and international targets aligned with climate change goals.
4. The pace of the energy transition is not even across economic groups or geographies—support is needed to ensure all people have access to clean, sustainable and reliable energy (per Sustainable Development Goal 7).

3.0 Approach and Methodology

We used quantitative and qualitative approaches to answer the research questions. The methodology is summarized in Figure 2, then described briefly in the sections below and in detail for each technology in Appendix A and Appendix B of the supplementary technical note.

Figure 2. Summary of research methodology



Source: Authors.

Notes: LCOE/H/S: levelized cost of energy, hydrogen, and storage; TCO: total cost of ownership (EVs).

3.1 Qualitative

Literature reviews were conducted for each technology to find background and contextual information, including government goals, support policies, other data needed for quantitative analysis, and nuanced opinions on policy needs to accelerate deployment. For each policy, we identified the mechanism by which support was provided to beneficiaries. This included but was not limited to central sector schemes that provide direct benefit transfers and VGF.

The research team conducted over 40 interviews with government officials, national think tanks, community service organizations, project developers, investors, academics, and other experts. Consultations helped us understand the sector-specific challenges to reach the deployment targets and to identify and shortlist effective policy levers to promote each of the clean energy technologies. This qualitative research helped shape our recommendations on the forms of government support that could most effectively achieve government targets.

3.2 Quantitative

To understand the current and projected cost of production for each technology, we developed or tailored existing unit cost models to suit India's local circumstances. These included

- levelized cost of electricity (LCOE) for solar PV and offshore wind
- levelized cost of hydrogen (LCOH) for GH_2
- levelized cost of storage (LCOS) for battery storage, and
- total cost of ownership (TCO) for EVs.

The models for estimating the levelized cost and the total cost of vehicle ownership included capital expenditure (CapEx) and operational expenditure (OpEx) parameters. They were disaggregated as far as possible to further study the impact of existing government support measures on levelized costs. The unit cost models were then used to estimate the cost gap needed to achieve national targets. This was done in two ways.

For BESSs, EVs, GH_2, and offshore wind—technologies that had not yet achieved cost parity in India at the time of the study—we measured the cost differential between the cost of one unit of the clean energy technology (LCOE/H/S and TCO) with the cost of a unit of the conventional equivalent (a benchmark). This was effectively an estimate of the "cost gap"—the amount of funding needed to make the technology cost-competitive. For solar PV, which is already cheaper than new coal or gas installations in India for power generation, we used the unit cost difference in project costs using domestically manufactured modules and cheaper imported ones. The unit cost and benchmark were projected to 2050 with annual adjustments for expected cost changes for the technology (the "learning rate") and the benchmark. Where possible, we used government-stated adoption rates to project the uptake of the technology to achieve the target. In all cases, we assumed the government would meet its target and estimated the funding required to do so (which could be public or private investment). This method effectively yielded a "cost gap" for each technology. Several projections were made for each technology with varying assumptions. Details are provided in Appendix A of the supplementary technical note, and the general formula for calculating the cost gap is provided below.

$$\text{Cost Gap} = \sum_{t \in 2024-50} (\text{levelized cost}_t - \text{benchmark}_t) \times A_t$$

$$\forall \ \text{levelized cost}_t > \text{benchmark}_t$$

where,

t = year

levelized cost = levelized cost of clean energy technologies each year

benchmark = cost of conventional technologies

A = annual addition

3.3 Macroeconomic Impacts

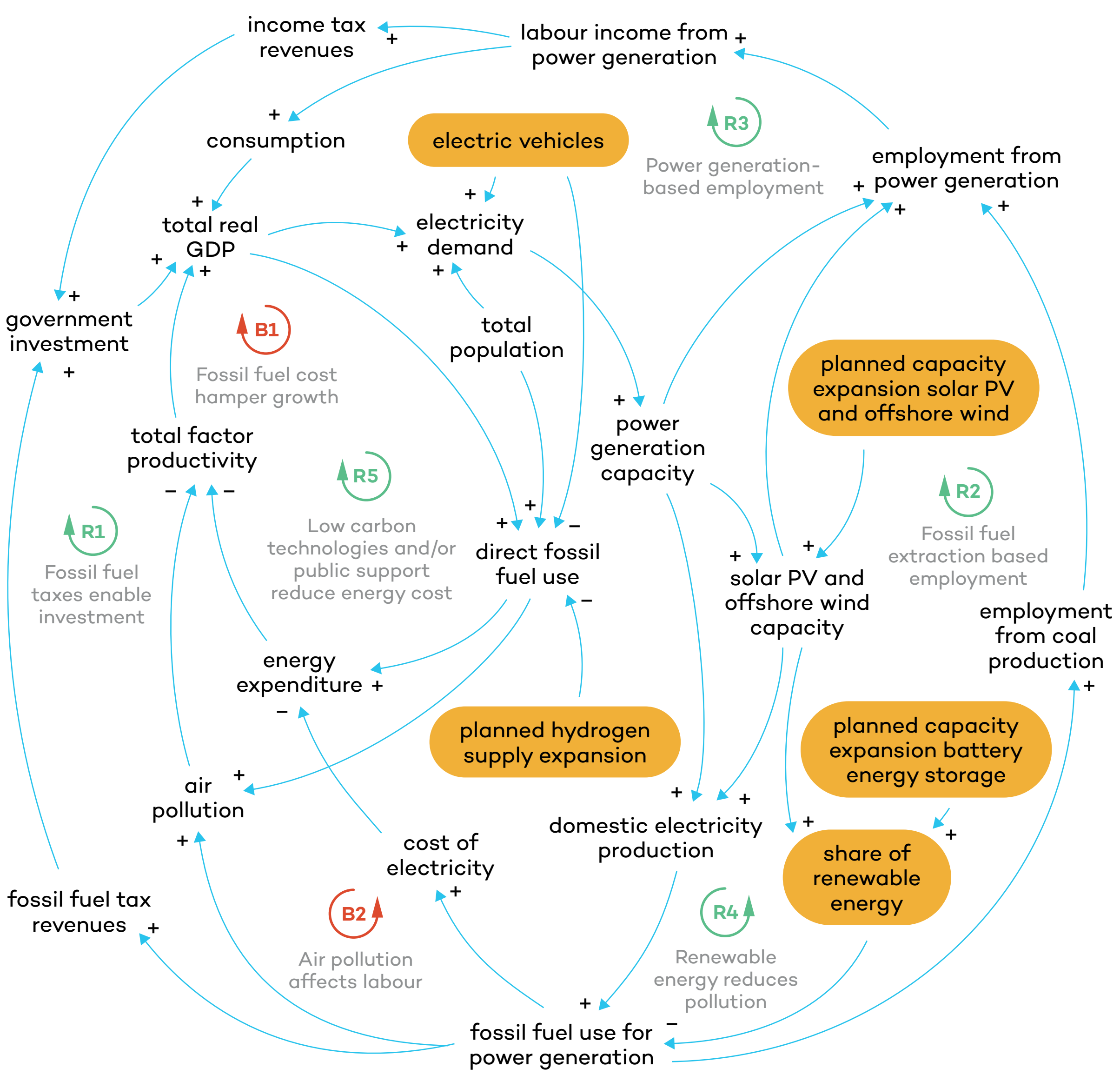
Using the data from the previous analysis, an integrated energy–economy–environment model was used to project the impacts of achieving the government's clean energy targets and providing the necessary financial support on key economic, environmental, and social indicators: revenue, GDP, air pollution, GHG emissions, job creation, and productivity. The scenarios used also examined the effect of different splits of public and private investment to bridge the cost gap.

Following an initial review of potential models, we worked with the Green Economy Model (GEM), given that (Golechha et al., 2022; KnowlEdge, n.d.).

- it was recently updated and calibrated for use in India, adjusted to the economic shocks of COVID-19;
- it is already designed to project how clean energy creates economic benefits, reduces emissions (GHGs and local air pollution), and influences jobs;
- it exists for more than 50 countries, making it easily adaptable to other contexts; and
- there is, as far as we are aware, no other "trusted" country-specific model that has particularly strong credibility among national policy-makers in India.

The systemic approach used to carry out the macroeconomic analysis is presented in Figure 3. This causal loop diagram (CLD) shows that economic activity is influenced by energy spending (represented by R5 in the diagram, affected by energy consumption and energy price, in turn affecting capital productivity), air pollution (represented by R4 in the diagram, affecting labour productivity), and employment (represented by R3 in the diagram, affected by construction and operation and maintenance). Changes in energy supply technologies influence the energy mix, and hence energy spending and air pollution. For instance, the use of solar PV and offshore wind reduces fossil fuel use and the generation of air pollution emissions, pushing GDP upwards. On the other hand, when a new technology comes with a higher levelized cost, downward pressure will be exerted on GDP unless this is mitigated by government support. Conversely, when the new technology offers a lower levelized cost, a second upward push to GDP emerges. As a result, several simultaneous drivers of change have been considered in the analysis, as well as how these change over time (for more details, see Appendix B of the supplementary technical note).

Figure 3. CLD on the systemic approach for macroeconomic analysis



Source: Authors.

3.4 Consultation on Methods and Results

Stakeholder consultation was used to validate the methods and input assumptions for the unit cost analyses, particularly for technologies in their early stages of development in India, like GH_2 and offshore wind.

We organized technical workshops to discuss the year-on-year expected trajectory of required government support for technology uptake and related macroeconomic findings. We presented preliminary results in workshops and sought experts' feedback. Based on our learning from the stakeholder dialogues, we reviewed additional literature to enhance the report. A key message that emerged from the workshops was the need to supplement the quantitative analysis with a qualitative discussion on potential non-fiscal measures that governments can provide. We addressed this feedback by adding discussion on types of policy measures other than direct financial support that can be used to achieve government clean energy goals and sectoral developments relevant to designing overall government support.

3.5 Limitations

The interactions between clean energy deployment and the economy are complex. For this reason, our study makes use of system dynamics and CLDs to model these interactions to the extent possible. For example, higher adoption of EVs and GH_2 increases electricity demand but lowers fuel costs. Similarly, higher adoption of utility-scale solar PV, GH_2, and offshore wind necessitate adequate transmission, storage, and port infrastructure (where local supply chains are absent or under development). While these linkages are often known, they can be hard to model for several reasons: (i) data constraints for baseline creation (especially in the case of emerging technologies), (ii) limited understanding of the balancing and reinforcing effects of an intervention across the economy, and (iii) model boundaries (see Appendix B of the supplementary technical note for details). Further, the analysis in this study is contingent on assumptions such as learning rates and government's own target setting. In the real economy, these may also undergo rapid changes when it comes to clean energy technologies. While these elements may lead to minor differences in estimating the cost gap, the non-fiscal recommendations of this report still hold true for informing policy action in the near term.

4.0 The Power Sector: Battery energy storage systems

4.1 Background

Energy storage systems such as BESSs play an important role in integrating renewable energy, as they store surplus energy during high-output but low-demand periods, reducing the need for curtailment (REN21, 2023). Energy storage systems also provide important ancillary services[3] for grid stability (IEA, n.d.). IEA's Net Zero Emissions by 2050 scenario[4] projects that, to facilitate the rapid uptake of upcoming solar PV and wind, the global energy storage output will have to increase to 1,500 GW by 2030, out of which 1,200 GW is expected to come from BESSs (IEA, 2024a).

4.2 Status of Technology

Global

Increasing renewable energy capacity and decreasing battery prices have led to BESSs experiencing a rapid deployment phase. BESSs provide grid-scale, short-term storage, ancillary services, and off-grid storage for distributed renewable energy. In 2023 alone, 742 Li-ion-based BESS projects with a total power output/capacity[5] of 31.8 GW/68.9 GWh were commissioned globally (Figure 4). Most recent growth in battery storage came from utility-scale systems, with behind-the-meter battery storage accounting for 35% of 2023 annual growth (IEA, 2024a).

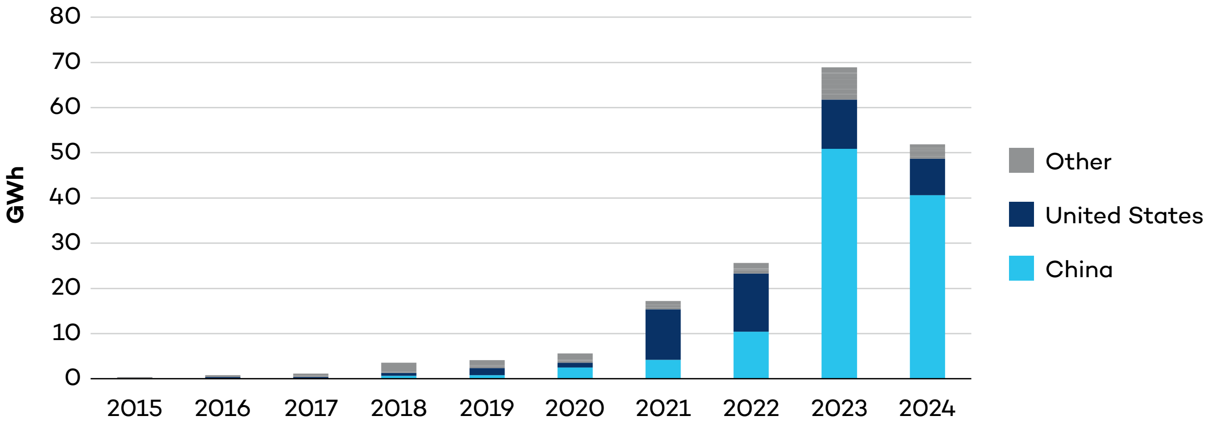
China accounts for over half of the batteries in use in the energy sector today, followed by the EU and United States, with smaller markets in the United Kingdom, Korea, and Japan (IEA, 2024a). China, Europe, and the United States accounted for more than 90% of 2023 investment in BESSs spending (USD 40 billion), with the remainder concentrated in other advanced economies (IEA, 2024a). Countries have used a combination of targets, regulatory market-based measures, and financial incentives to foster growth in the sector (Box 1).

[3] Ancillary services refer to functions that help grid operators maintain a reliable electricity system to maintain the proper flow and direction of electricity, address imbalances between supply and demand, and help the system recover after a power system event (Greening the Grid, n.d.).

[4] IEA's Net Zero Emissions scenario is consistent with limiting the global temperature rise to 1.5°C (with at least 50% probability).

[5] The power output of a BESS is measured in watts and is the maximum amount of power that the system can deliver at any given moment. The energy capacity of a BESS is measured in watt-hours and shows how much energy can be stored or released during a certain period.

Figure 4. Global capacity of Li-ion-based battery energy storage systems



Source: BNEF, Energy Storage Assets. Extracted on September 11, 2024.

Filters used: storage sector: grid-scale storage, distributed storage, and microgrids; technology: lithium-based batteries.

Notes: Each bar shows the annual capacity of projects that reached commissioning in a given year.

Box 1. Policies used by advanced economies and China to promote investment in BESSs

Countries leading in BESSs have been setting ambitious targets to encourage a fast pace of deployment. China set a national target in 2020 to install an additional 30 GW of energy storage by 2025, which has already been exceeded (Reuters, 2021). At the subnational level, China's Regional 14th Five-Year Plans target nearly 80 GW of energy storage by 2025, driven by mandates. For example, Qinghai municipality requires wind farms to integrate at least 10% of their installed capacity with energy storage—a model adopted by several provinces, which extended the mandate to solar PV, with pairing rates ranging from 5% to 30%, significantly accelerating the expansion of battery storage capacity across China (IEA, 2024a). Other countries, including the United States, Australia, Japan, Korea, and select countries in the EU have also set targets at the national and, in some cases, subnational levels.

In many regions—such as the United Kingdom; Ontario, Canada; Texas, United States; Germany; and South Australia, Australia—BESSs are being installed on a market basis with supporting power market reform. Capacity markets and ancillary markets have been key drivers in accelerating BESS deployment. In the February 2024 capacity market auctions in the United Kingdom, BESSs secured the highest capacity among clean technologies due to their strong economic performance and suitability for frequency response services (Martins, 2024). While only a few countries, including the United Kingdom, parts of Australia, and South Korea, have developed capacity markets to incentivize investment and ensure long-term grid reliability, adopting similar mechanisms in India could provide adequate compensation for BESSs, attract more investment, and foster competition (Walia, 2024).

Countries have also provided a range of fiscal incentives, including tax credits, waivers on taxes and other charges, and grants, especially for pilot projects, to encourage BESS deployment. The United States has implemented various fiscal incentives through the Inflation Reduction Act and the Bipartisan Infrastructure Law. These incentives include the Investment Tax Credit for stand-alone energy storage and the Energy Storage Demonstration and Pilot Grant Program, which makes USD 355 million available in grants for demonstration or pilot projects. In addition, the Long-Duration Energy Storage Demonstration Initiative and Joint Program offers USD 150 million in grants, cooperative agreements, or other rewards for projects demonstrating promising long-duration energy storage technologies at different scales and helping innovative technologies reach commercial viability (Bertagnini et al., 2023).

India

India is also entering a rapid deployment phase for BESSs. According to the National Electricity Plan 2023, India will need BESS output/capacity of nearly 41 GW/208 GWh by 2029/2030 to integrate renewables and ensure supply adequacy (CEA, 2023a). The plan also states that the total investment needed to achieve this capacity by 2030 is nearly INR 3 lakh crore (USD 37 billion) (CEA, 2023a).

Another study highlights that reaching India's goal of 500 GW of non-fossil capacity supplemented by 63 GW/252 GWh of grid-scale battery storage by 2030 is the least-cost pathway to meet India's rising electricity demand as storage costs continue to decline (Abhyankar et al., 2021).

This capacity can come through different tender designs, including round-the-clock (RTC), firm and dispatchable renewable energy (FDRE), solar co-located with BESSs, BESSs for peak power supply, and stand-alone BESSs. As of March 2024, India's BESS power output/capacity had reached 111 MW/219 MWh (Mercom, 2024). Additionally, 1 GW/1.6 GWh of stand-alone BESSs and 9.7 GW of renewable energy projects with BESSs were at different development stages (Mercom, 2024). However, based on 2023 tariff trends, tariffs for stand-alone BESSs remained high.

Another challenge for BESS projects in India—like many emerging economies—is that investments are hard to come by. In 2023, for every dollar invested in battery storage in advanced economies and China, only USD 0.02 was invested in other emerging markets and developing economies, mainly due to factors like legal uncertainty and currency risks (IEA, 2024a). Particular challenges in India have been the low investor confidence in BESSs, demand uncertainty, and public trust, which act as non-fiscal barriers to scaling up investments (Kolaczkowski et al., 2024).

4.2.1 Government Policies Supporting BESSs in India

Multiple initiatives and schemes are currently underway to promote the deployment of BESSs in India. These policies encompass a range of regulatory, market-based, and information-based measures aimed at fostering a conducive environment for BESSs (see Table 3 for a summary of key policies). India has experimented with several tender designs involving BESSs: co-located solar and BESSs, BESSs for meeting peak power supply, BESSs for RTC supply, FDRE, and stand-alone BESSs, which still face higher tariffs.

To bridge this, the government introduced the Viability Gap Funding scheme for stand-alone BESSs in September 2023. The scheme envisages the development of 4,000 MWh of BESSs by 2030/2031 with up to 40% financial support as VGF, targeting an LCOS between INR 5.50 and INR 6.60 per kWh, with budgetary support of INR 3,760 crore (USD 458 million) (Press Information Bureau [PIB], 2023b). At the time of writing, the first tranche of bids for BESSs with VGF is underway (NTPC Vidyut Vyapar Nigam Limited, 2024; Solar Energy Corporation of India, 2024).

Table 3. Summary of major government support measures to promote BESS deployment

Name of the support measure	Type of support measure	Type of policy instrument	Objective
Viability Gap Funding	Fiscal	Capital subsidy	To reduce the capital cost of stand-alone BESSs and assist the technology in becoming competitive in the market.
Energy Storage Obligations (ESO)	Non-fiscal	Regulatory mandate	Mandates ESOs and sets a trajectory for the same; however, it has been recently dropped.
Inter-State Transmission Charges (ISTS) waiver for BESS projects	Fiscal	Price support	Promotes BESSs' cost competitiveness; it is applicable for projects commissioned up to June 2025 for a period of 12 years, provided that 51% of the electricity required annually by BESSs is met by solar or wind energy.
Electricity (Promotion of Generation of Electricity from Must-Run Power Plant) Rules	Non-fiscal	Regulatory mandate	Promotion of BESSs to prevent renewable energy curtailment by classifying certain power plants as must-run, except for security or technical reasons.

Source: Authors' compilation.

4.3 Approach

Since this study focuses on government support, we focus on stand-alone BESSs, given that other tender designs like FDRE and RTC are fast approaching near cost parity. For this, we use the LCOS to estimate the need for government support and compare it to the existing level of support being provided.

LCOS is the total lifetime cost of investment in an electricity storage technology divided by the cumulative delivered electricity (Pawel, 2014). To estimate the LCOS for utility-scale stand-alone BESSs and the impact of government interventions, we customized and updated the Levelized Cost Calculator developed by Auroville Consulting to reflect the latest market trends and Li-ion battery prices (Auroville Consulting, 2021).

The LCOS analysis helped us to

- conduct a sensitivity analysis to identify important policy levers, such as VGF and existing taxes and duties on batteries, inverters, and services, and
- calculate the cost gap under business-as-usual (BAU) policies.

We then used the GEM–India to evaluate the macroeconomic and energy system impacts of government support for stand-alone BESSs under different scenarios. Appendix A of the supplementary technical note has a detailed note on methodology with our assumptions and data sources.

4.4 Results

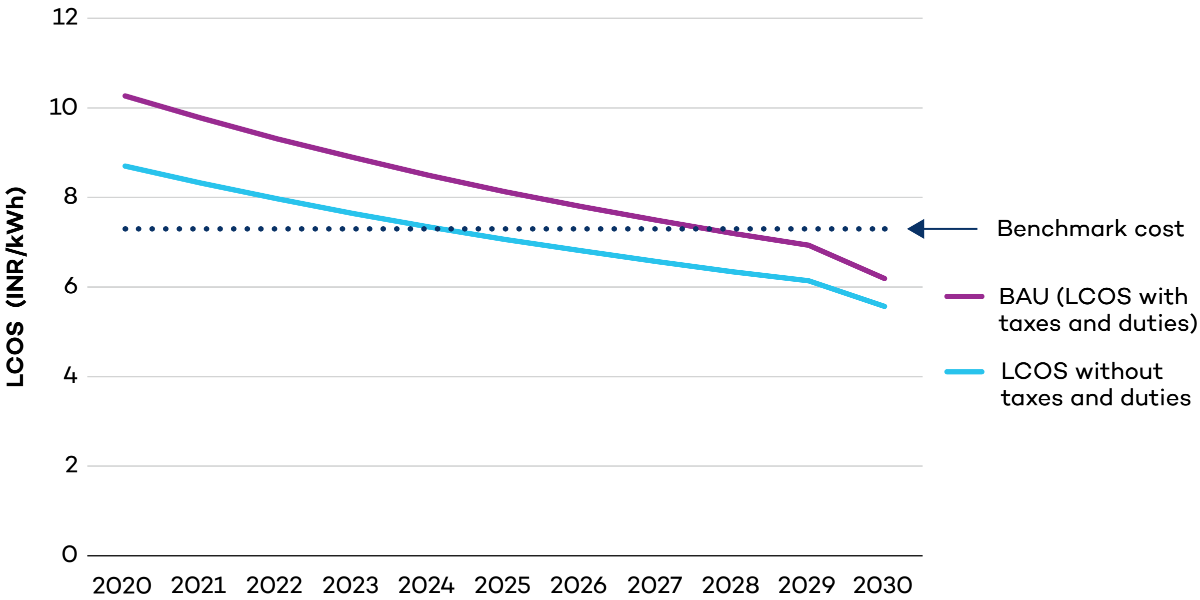
4.4.1 LCOS

We find that with the current policies, the LCOS for stand-alone BESSs (in 2024) is nearly INR 8.49/kWh (BAU, in the absence of VGF). Despite the decline in Li-ion battery prices over the last 2 years, this is still higher than the benchmark evening price[6] of 7.30 INR/kWh (India Energy Exchange, n.d.), thereby demonstrating a cost gap over the next few years. In the BAU scenario (without VGF), BESSs reach cost parity in 2028. A 40% VGF (the current ceiling for stand-alone BESSs as per announced policies) reduces the LCOS by nearly INR 1/kWh, and cost parity is accelerated to 2025.

In our LCOS analysis, we also studied the impact of current rates of duties and taxes on BESS components and services. We used the current customs duty and Goods and Services Tax (GST) levels on Li-ion batteries (13% and 18%, respectively) alongside the 28% GST on inverters and 18% GST on installation for this analysis. We found the impact of these government levers to be significant on the LCOS—nearly INR 1.15/kWh in 2024 (see Figure 5 and Appendix A for assumptions).

[6] We have assumed BESSs to mainly serve the evening peak demand till 2030 and selected our benchmark cost accordingly. In 2023, the average price of electricity during the evening on the Indian Energy Exchange (IEX) was 7.30 INR/kWh (India Energy Exchange, n.d.).

Figure 5. Year-wise LCOS projections for stand-alone BESSs



Source: Authors' analysis.

4.4.2 Cost Gap

Under the BAU scenario (without VGF), we calculate the cost gap for BESSs to achieve 2030 goals to be nearly INR 2,637 crore (USD 321 million). The current budgetary allocation of INR 3,760 crore (USD 458 million) as VGF for stand-alone BESSs is able to fully cover this cost gap estimated in our study. Declining battery prices over the last few years are a major driver in reducing the cost gap for BESSs. Alternatively, if the current taxes, such as the GST, on BESS components and services are lowered, the cost gap and—hence the need for government support—drops even further.

4.4.3 Macroeconomic Results

Next, we further evaluate the effectiveness and trade-offs of different interventions of varying levels by the government to bridge the cost gap using scenarios (Table 4) in the GEM—key ones being VGF and reducing GST.

Table 4. Scenarios considered for the GEM analysis

Scenarios	Description
Scenario 1	**LCOS, including the impact of existing levels of duties and taxes**
100% public support	All of the cost gap gets bridged by government funding
30% public support	30% of the cost gap gets bridged by government funding
Scenario 2	**LCOS, excluding the impact of existing levels of GST**
100% public support	All of the cost gap gets bridged by government funding
30% public support	30% of the cost gap gets bridged by government funding

Source: Authors.

Our study finds that the benefit-to-cost ratio (BCR) for providing government support to bridge the cost gap for BESSs is positive under all scenarios. Support needed is minimal in both scenarios, amounting to only [0.003%] of the GDP between 2024 and 2027 when taxes and duties are included. This amount falls to close to zero when taxes and duties are forgone as the LCOS reaches cost parity already in 2024. No support is required past 2028 when taxes and duties are considered. In Scenario 1 (BAU), even when the cost gap is fully bridged by the government (100% public support), the BCR is 1.89, thus showing that continuing with the current VGF scheme for stand-alone BESSs makes economic sense and will help in bringing stand-alone BESSs near cost parity in the short term.

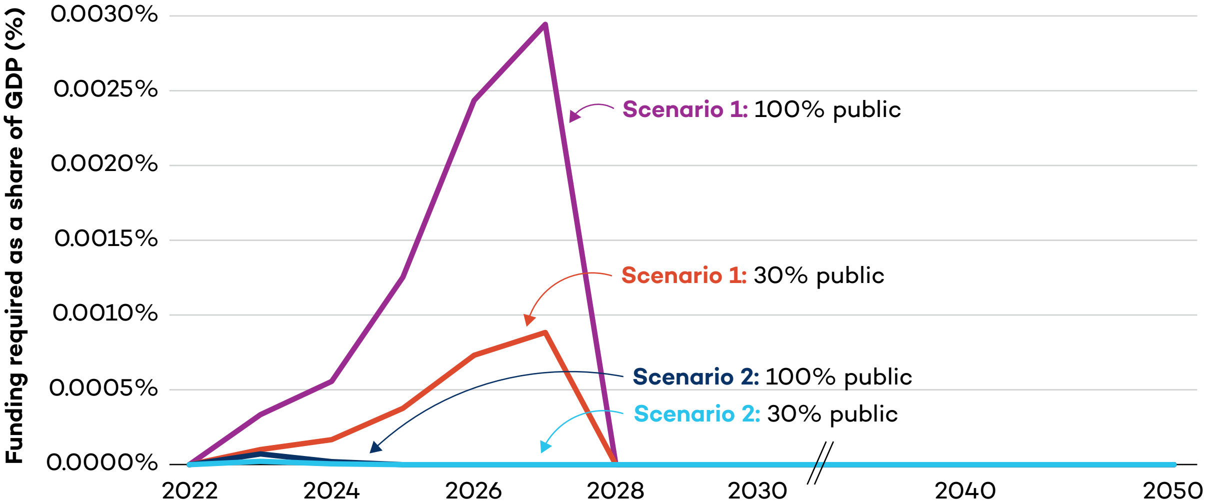
Table 5. The macroeconomic impact of providing government support to achieve cost parity for BESSs relative to BAU (cumulative to 2050)

	BESSs
GDP (cumulative, INR crore)	0.005
Employment (cumulative FTE[a])	46,085
Energy savings (cumulative, INR crore)	-
GHG emission reduction (cumulative, million tonnes)	34
Public revenue (cumulative, INR crore)	0.0016
BCR	1.89

Source:
Note: Cost parity for BESSs, in this case, is achieved by 2028. The BCR results, thus, only represent the macroeconomic impacts generated by providing 100% government support to help BESSs reach cost parity. For full benefits arising from the deployment of BESSs, see Box 2.

Overall, our analysis projected that deployment of stand-alone BESSs can yield significant macroeconomic benefits that far outweigh the costs of providing government support under all scenarios. The size of current government support in the form of a VGF scheme is sufficient and would be required only in the short term (2024–2028).

Figure 6. Cost gap as a share of GDP



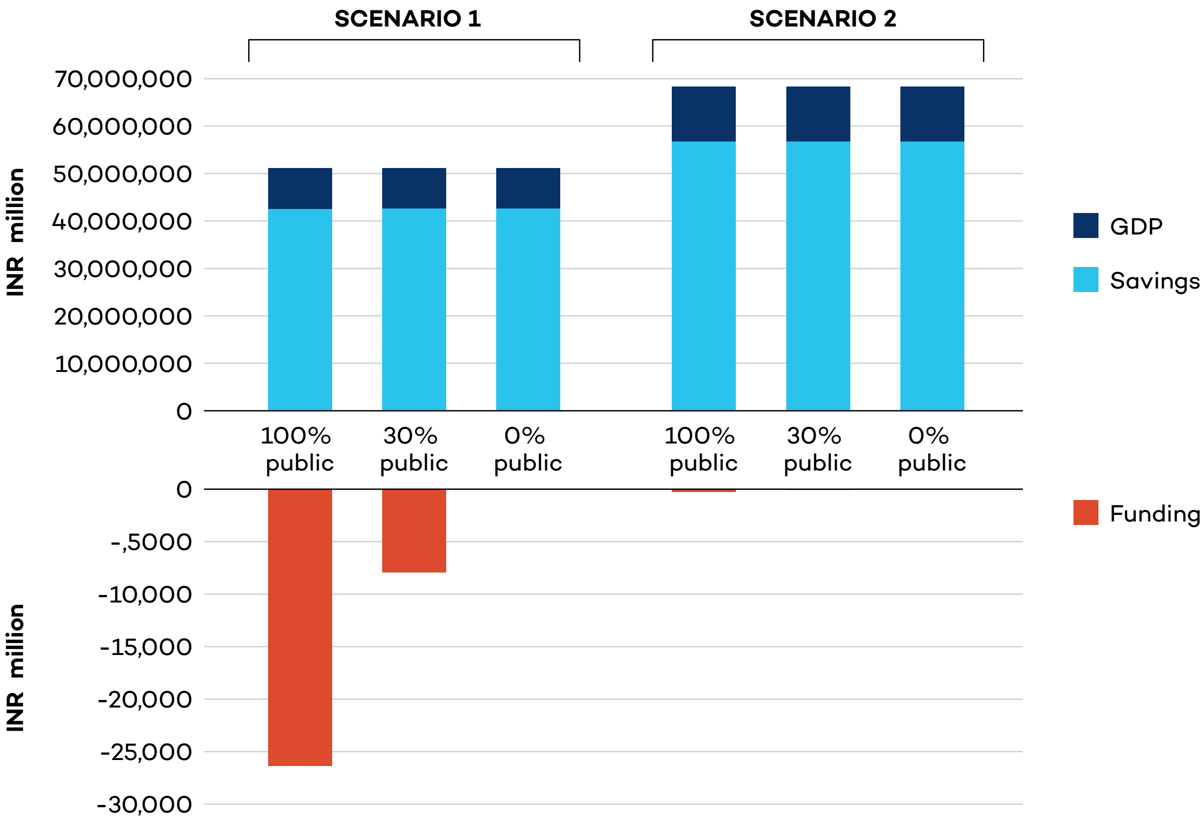
Source: Authors' analysis.

Box 2. The full macroeconomic impact of deploying BESSs up to 2050

Since the cost gap was minimal in the case of BESSs, we also studied the macroeconomic impacts if India achieves its 2030 energy capacity goals for BESSs and keeps adding BESSs beyond—until 2050 on a market basis. We find that adding BESSs leads to cumulative GDP gains estimated at INR 8.52 lakh crore (USD 104 billion) between 2022 and 2050, based on current tax and duty levels. During this period, we find that the BCR for BESSs is exceptionally high because of the low support required both in absolute terms and over time, indicating substantial economic benefits with minimal government support required. BESSs have a significant impact on GDP growth and energy cost reductions, and these benefits are further amplified when taxes and duties are lowered, resulting in further cost declines for consumers.

Figure 7 presents the net impact of government support on GDP growth and energy savings in three cases under two scenarios each. These scenarios involve closing the cost gap with varying levels of government and private spending—we used 100%, 30%, and 0% for illustrative purposes. In Scenario 2, where GST was waived with 100% government support, the cumulative GDP gain between 2023 and 2050 was INR 11.6 lakh crore (USD 141 billion), which was overshadowed by the substantial energy savings of INR 56.8 lakh crore (USD 692 billion). Similarly, in Scenario 1, which included taxes and duties, GDP growth between 2023 and 2050 was INR 8.5 lakh crore (USD 104 billion), also dwarfed by the substantial energy savings of INR 42.6 lakh crore (USD 520 billion). In both scenarios, when the percentage of government support provided is changed from 100% to other shares, there is minimal impact on GDP growth and energy savings, due to the near-term cost parity of BESSs.

Figure 7. Net impact on GDP and energy savings



Source: Authors' analysis.

4.5 Discussion

Our results also reflect the current market development in India's BESS sector. From 2022 to 2024, we observed a 66% drop in the tariff.[7] Moreover, this tariff decrease was achieved without the support of the VGF scheme, which was only introduced in September 2023. The recent Solar Energy Corporation of India (SECI) tender for 1,000 MW/2,000 MWh stand-alone BESSs, the largest tender issued in India to date (Hazarika, 2024), also highlights the impact of falling LCOS, as described in our study, and the fast-decreasing tariff in the market, indicating the increasing depth of the market.

The cost gap to 2030 for stand-alone BESSs in India has rapidly dropped over the last 2 years. The current gap needed to achieve cost parity (at current levels of taxes and duties) was projected to be INR 2,637 crore (USD 321 million). Thus, we find that the current VGF scheme for BESSs, amounting to INR 3,760 crore (USD 458 million), will be sufficient at present. However, the scheme only targets 4 GWh of BESS projects by 2025/2026, which is only about 2% of the total required capacity for India's energy storage needs by 2030, according to the CEA.

[7] JSW Energy won the first stand-alone BESS tender for 500 MW/1,000 GWh at a tariff of INR 1.08 million/MW/month (Shetty, 2022). In June 2024, Gensol Engineering Ltd tendered for 250 MW/500 MWh stand-alone BESSs at a tariff of INR 0.37 million/MW/month (Gupta, 2024b).

We find that taxes and duties alone account for nearly INR 1–1.5/kWh of the LCOS and are major cost drivers at the current levels. When rationalized and lowered, the required cost gap falls even lower. This implies that reducing these cost barriers on BESSs could significantly enhance its overall attractiveness and effectiveness in driving economic growth and energy savings. Our study also reveals that GST rationalization and VGF support have a very similar impact on BESSs' LCOS in the short term. However, since there is scope for GST rationalization to continue beyond the 4 GWh capacity specified in the VGF scheme, GST rationalization will yield more economic growth and energy savings in the long term.

BESS deployment can also be accelerated through several non-fiscal and regulatory support mechanisms alongside larger power market reforms. This can help BESSs access more revenue streams and further reduce the need for fiscal support. For example, India currently does not have a formal capacity market,[8] despite BESSs reaching cost parity with peak tariffs soon (Bose & Kumar, 2015). As India moves to a higher renewable energy scenario, capacity markets can support states in resource adequacy planning (RAP) and evaluating existing power purchase agreements with strategies for catering to new demand. The recently issued guidelines on the RAP framework by the Ministry of Power are a welcome step in this direction and emphasize the consideration of energy storage and other flexible resources to address the intermittency of renewable energy, increase reliability, and reduce costs (Ministry of Power, 2023a). However, there are currently no clear details on the reserve margin (extra generation capacity that exceeds the expected peak demand) and capacity credits (a measure used to indicate the generator's ability to meet the peak demand in a power system) for BESSs. In the United States' electricity markets, RAP has been in practice for a long time, with capacity prices in these markets providing a strong investment signal; for instance, resource adequacy capacity payments in the California Independent System Operator market have led to the addition of 5 GW of storage capacity in the last couple of years (Murray, 2023).

BESSs should also be eligible for a wider range of ancillary services. BESSs, with their fast ramp rates, can provide ancillary services such as frequency control, voltage control, and fast response, as well as peak shifting across time horizons ranging from seconds to minutes. India has historically procured ancillary services through an administered mechanism but has recently introduced three ancillary service products: Primary Reserve Ancillary Service (PRAS), Secondary Reserve Ancillary Service (SRAS), and Tertiary Reserve Ancillary Service (TRAS)[9] (Bertagnini et al., 2023). Currently, as per the Central Electricity Regulatory Commission, BESSs are only eligible to provide SRAS and TRAS under certain conditions (Ministry of Power, 2023b). Despite being highly suitable for PRAS with its fast response time and precise frequency control, BESSs are currently not allowed to provide this service. This restriction limits an important revenue stream for new and upcoming technology,

[8] A capacity market is a formal market where capacity, rather than energy, can be explicitly traded.

[9] PRAS provides an immediate, automatic response to grid frequency changes, activating within seconds to stabilize the power supply after sudden disruptions. It operates for a short duration, usually under a few minutes. SRAS is manually activated after PRAS has stabilized the system initially, within 30 seconds to a few minutes, to restore grid frequency. It offers longer support, generally lasting several minutes to an hour, until the system is balanced. TRAS is manually activated to provide extended grid stability, coming online after PRAS and SRAS. It is slower to respond but supports the grid for longer periods, often several hours when needed.

potentially deterring investment in BESSs. This is not unique to India—we see a similar need for regulatory reforms in other developing countries, such as South Africa, where an inability to access these multiple revenue streams acts as a key obstacle in attracting sufficient capital investments to the sector (Halsey et al., 2024).

Given that BESSs are near cost parity now, the government needs to evaluate new thermal projects against FDRE solutions. Currently, all new thermal is being built using Section 62 of the Electricity Act, 2003 (on a nomination or cost-plus basis, introduced when India was still in a power deficit and wanted to ensure long-term returns given thermal's long, useful life). Renewable tariffs are instead discovered based on auctions (Section 63 of the Electricity Act, 2003). Last year, India implemented multiple FDRE auctions, and the discovered tariffs were very competitive, even cheaper than new thermal. To ensure that the cheapest generation options are being built, the government should incentivize state governments to fully implement Resource Adequacy Guidelines to particularly ensure that all new planned power generation capacity undergoes an economic comparison against FDRE (with energy storage solutions such as BESSs), rather than on a cost-plus basis.

Further, given the declining costs of BESSs, the government should consider reintroducing ESOs. In July 2022, the Ministry of Power notified an ESO trajectory, starting at 1% in FY 2023/2024 and increasing to 4% by FY 2029/2030. The ESO was to be considered part of the Renewable Purchase Obligation (RPO) fulfillment (Ministry of Power, 2022). However, an amendment to the Energy Conservation Act 2001 in October 2023 introduced a revised RPO until FY 2029/2030, omitting the ESO component and instead including a target for distributed renewable energy (Ministry of Power, 2023c).

Li-ion batteries have experienced one of the fastest cost declines of any technology ever (IEA, 2024a), with uncertainty about long-term performance and further forthcoming cost decreases that may lead to counterparties hesitating to sign long-term agreements. Therefore, PSUs like Solar Energy Corporation of India and NTPC Ltd. need to provide guaranteed offtake in larger quantities to ensure investor confidence.

Capacity building for state actors can also help BESS deployment. Our consultations revealed that state-level entities such as State Electricity Regulatory Commissions, State Load Dispatch Centres, and discoms have limited knowledge of BESS project development, grid services, and preparing resource adequacy plans. Therefore, implementing pilot projects could effectively showcase the value of BESSs and help in building knowledge and understanding among these entities. In addition, BESS operators would benefit from a centralized market operator or regulator providing guidance, participation standards, and best practices on BESS deployment and coordinating the management of BESSs across stakeholders, including discoms and commercial and industrial end users (Bertagnini et al., 2023).

During our consultations, industry experts also highlighted how India's battery manufacturing capacity is still in its early stages. While the push for domestic manufacturing is crucial for India's long-term energy security, it is likely to increase the cost of the energy transition in the short term due to higher production expenses compared to established global leaders like China, the European Union, and the United States, all of which benefit from substantial subsidies. Since India is expected to begin scaling up its battery manufacturing capacity only around 2026, with substantial output anticipated by 2028, it is important to maintain strategic trade relationships, leverage international imports to manage costs effectively, and establish sustainable raw material value chains for battery manufacturing during this transition period.

Recommendations for government:

- Accelerate the pace of BESS auctions and spread the VGF funding already available across more BESS capacity, given the smaller funding amounts needed per unit. Overall, the current size of the VGF scheme is sufficient for further market development.
- Reduce the GST on BESS components, which would make BESSs cost-competitive immediately.
- Introduce a mandatory ESO target that includes BESSs (this was introduced in 2022 but was later dropped as part of the RPO).
- Undertake electricity market reforms that allow BESSs to earn revenue as a provider of a wider range of ancillary services.
- Provide funding support for training and capacity building for state-level actors, such as State Electricity Regulatory Commissions, State Load Dispatch Centres, and discoms in BESS project development and preparing resource adequacy plans.
- Incentivize states to fully implement the Resource Adequacy Guidelines and ensure that all new planned power generation capacity undergoes an economic comparison against FDRE with energy storage solutions such as BESSs, rather than on a cost-plus basis.

5.0 The Power Sector: Offshore wind

5.1 Background

Offshore wind is a "variable baseload" technology (IEA, 2019), delivering a more reliable electricity supply, even during peak hours, owing to higher capacity factors (between 39% and 62%) (Centre of Excellence, 2022), compared to variable renewable energy sources. Moreover, offshore wind is not as affected by land constraints, which is a growing concern associated with renewable energy projects in many Indian states, although suitable locations in the sea are also finite. Increasing the share of offshore wind in India's renewable energy mix will improve peak electricity demand management and foster stability in India's power grid—an issue that is fast gaining centre stage as India's grid is decarbonizing.

5.1.1 The Status of Technology Globally and in India

Global installed offshore wind capacity was around 72.6 GW by the end of 2023, with established markets in the United Kingdom, Germany, Denmark, the Netherlands, and China, plus new emerging markets in Taiwan, the United States, Japan, South Korea, India, and Vietnam (Statista, 2023).

India has a combined potential of 71 GW of offshore wind, all of which is in the two coastal states of Gujarat and Tamil Nadu (Prasad, 2020). India aims to auction more than half of this capacity (37 GW) by 2030 (MNRE, 2023b). However, India has yet to install its first offshore wind plant. In the current context, generating electricity using offshore wind is very expensive (at least three times more than solar, thermal, and onshore wind power plants), especially due to significantly higher upfront capital costs.

5.1.2 Government Policies to Support Offshore Wind in India

A national offshore wind energy policy has been in place since 2015 (MNRE, 2015a). However, the Government of India only put in place measures to initiate investment in the sector in February 2024, when it invited bids for the development of offshore wind power projects, with a total capacity of 4 GW off the coast of Tamil Nadu. Under this arrangement, the developer(s) who win the bid for each block would set up the projects and sell electricity directly to consumers under the open access regime. As of August 2024, there was no formal communication from the government about the progress in the above bidding process.

In June 2024, the government announced the first fiscal support for offshore wind, totalling INR 7,453 crore (~USD 893 million), specifically to provide

- VGF for 1 GW of installed capacity from two 500-MW wind farms, each off the coast of Gujarat and Tamil Nadu (INR 6,853 crore; USD 821 million)
- Capital funding to upgrade two ports to accommodate offshore wind components (INR 600 crore; USD 72 million).

Table 6. Summary of government support measures to promote offshore wind deployment

Name of the support measure	Type of support measure	Type of policy instrument	Objective
Viability Gap Funding	Fiscal	Capital subsidy	Promotes cost competitiveness of the offshore wind projects and compensates the developers for any losses
Solar Energy Corporation of India seeks bids for 4 GW offshore wind projects in Tamil Nadu	Non-fiscal	Quantity-based instrument	Kickstarts offshore wind development
Exemption of ISTS	Fiscal	Revenue forgone	Promotes cost competitiveness of offshore wind projects
Development of transmission system	Fiscal	Capital grant	Facilitation and development of a transmission system for 10 GW of offshore wind deployments in Tamil Nadu and Gujarat by 2030

Source: Authors.

5.2 Approach

To estimate the cost gap and government support required for achieving the offshore wind target in India, the project team used an Excel-based model that is a product of the Financial Modelling of Offshore Wind in India (FIMOI) initiative (Centre of Excellence, 2022).[10] This model provides an approach to estimate the LCOE and cost gap for both Gujarat and Tamil Nadu (separately accounting for their diverse capacity utilization factor). Most of the input variables used in the model were based on the literature review and stakeholder consultations conducted by FIMOI. However, to suit our project-specific requirements, we changed some of the input parameters after validating them with the experts during our own stakeholder consultations. For our detailed approach, see Appendix A.

The GEM–India was then used to evaluate the macroeconomic and energy system impacts of covering the cost gap in the offshore wind sector by the public and private sectors in different proportions.

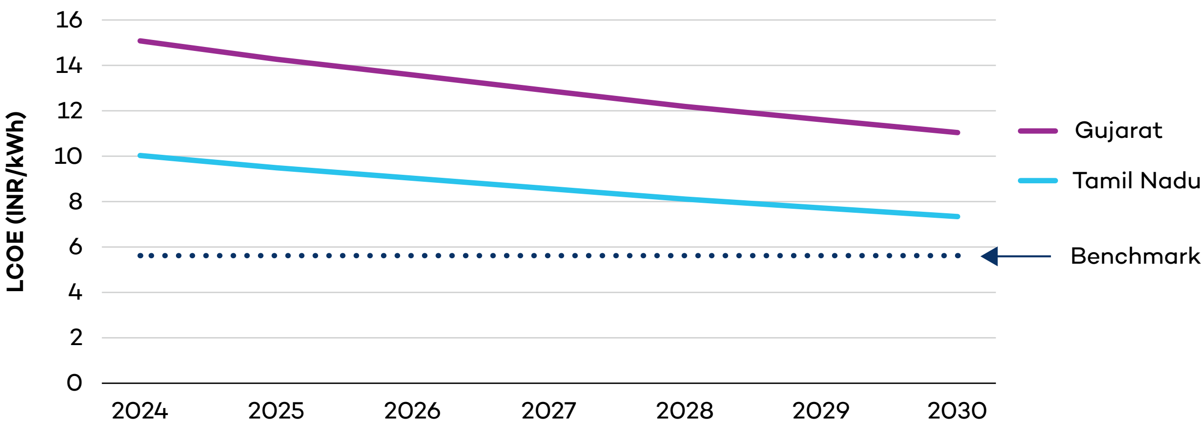
[10] FIMOI is an initiative launched within the Centre of Excellence for Offshore Wind and Renewable Energy (COE), established as part of the India-Denmark Energy Partnership programme. The partnership is centred on government-to-government cooperation between India's MNRE, the National Institute of Wind Energy, and the Danish Energy Agency under the Ministry of Climate, Energy and Utilities.

5.3 Results

5.3.1 LCOE

We found that the LCOE values for Tamil Nadu and Gujarat are expected to drop by around a third by 2030, compared to their 2024 values (from INR 10/kWh to INR 7.34/kWh and from INR 15/kWh to INR 11/kWh, respectively, by 2030) (Figure 8). This suggests that the sector will continue to require significant external support to reach 2030 targets (and even beyond), assuming the benchmark RTC price of INR 5.62/kWh (Indian Energy Exchange) (see methodology section). LCOEs in India are expected to be higher than the global average because India is not yet experienced in offshore wind installations and does not have the economies of scale present in early adopter countries (Box 3).

Figure 8. LCOE values for Tamil Nadu and Gujarat



Source: Authors' analysis.

Box 3. Validation of LCOE from other relevant sources

In the international context, the LCOE generated from offshore wind plants dropped from USD 218/MWh (INR 18.07/kWh) in 2009 to USD 74/ MWh (INR 6.13/kWh) in 2023 (BloombergNEF, 2023). BloombergNEF expects a fall of more than 10% in offshore wind LCOE for projects financed in 2025 and by one third by 2035 (Vasdev, 2023). A few researchers from Rajiv Gandhi Institute of Petroleum Technology, India also expected a decline of 15% in the offshore wind tariff between 2020 and 2025 (Kumar et al., 2022). This is also in line with the IEA renewable tariff estimation (IEA, 2019).

In a 2023 analysis, the United Kingdom government estimates the LCOE of offshore wind as GBP 44/MWh (INR 4.61/kWh) for the plants that will be installed in 2025 (Department for Energy Security & Net Zero, 2023). Such a significant reduction in LCOE is driven by several factors, like the use of larger, more powerful, and more efficient wind turbines and economies of scale that would set in with the installation of larger projects. The economies of scale would result in reduced installation cost per unit, operation, and maintenance costs, which would finally lead to a lowering of LCOE.

5.3.2 Cost Gap

The cost gap for making offshore wind competitive in India can vary based on the nature of government support. Our study used two approaches to model the funding required to reach grid parity and the need for government support:

1. a CapEx-based approach (one-off transfers at the beginning of the project) that reduces the upfront capital costs.
2. a generation-based incentive (GBI) approach that provides an incentive on each unit of electricity generated over the project's lifetime. The advantage of a GBI over a CapEx-based approach is that the transfers within a GBI are spread over time.

We found that under the CapEx-based approach, the cumulative cost gap needed to achieve the 2030 goal will be INR 5.1 lakh crore (USD 61.1 billion), which is slightly lower than the GBI approach (nearly INR 7.7 lakh crore) (Table 7). To better contextualize these numbers, the sector will need annual funding support of at least ~INR 73,000 crore until 2030, which is ~1.5% of the Government of India's current annual budget (INR 48.21 lakh crore in 2024/2025). The current VGF allocation of INR 6,853 crore for 1 GW of offshore wind falls significantly short of this requirement, which suggests the need to align the level of support with the aspirational goals for this sector.

Table 7. Cost gap and the expected benefits of achieving the 2030 targets (37 GW) and full potential (of 71 GW) by 2037

Support model		CapEx-based	GBI-based
Cost gap to achieve 2030 national target (37 GW)	(A)	INR 5.1 lakh crore (or USD 61.1 billion)	INR 7.7 lakh crore (or USD 92.3 billion)
Cost gap to achieve the full potential of 71 GW by 2037	(C)	INR 7.2 lakh crore (USD 86.3 billion)	INR 10.8 lakh crore (USD ~130 billion)
Expected GDP gains as per GEM by 2037[11]	(D)	INR 15.7 lakh crore (or USD 189 billion)	INR 14.5 lakh crore (or USD 173.2 billion)
BCR (in 2037)	(E=D/C)	2.16	1.34

Source: Authors.

However, it is also important to highlight that the above cost gap is only indicative of the total resources required to bring this technology on par with conventional alternatives, but the Central and state governments do not need to bridge the entire gap. Various other policy tools, such as international climate finance, additional support from states, and increasing taxes on fossil fuels, could also be explored to meet the financial requirements of this sector. In case the

[11] While we have only presented the cost gap requirements until 2030 in the main text of this report, we also extend this analysis by estimating the LCOE and cost gap requirements for offshore wind until 2037 (when India can achieve a full potential of 71 GW for offshore wind) in the supplementary technical note. To quantify the long-term macroeconomic impacts of bridging the cost gap in the offshore wind sector, we use the extended cumulative figures until 2037 in the upcoming sections (as well as in the last two columns of Table 7 above).

government finds it difficult to bridge the cost gap even after exploring all the potential policy tools, extending the timeline for the current 2030 goal (of 37 GW) could also be considered to allow the capital costs and VGF requirements to fall further. However, it is also important to highlight that the sooner India starts the deployment process, the sooner the domestic costs will start declining, which will eventually reduce the VGF requirements.

Based on the stakeholder consultations, we also found that the government will only go ahead with a CapEx-based funding approach for offshore wind. One of the reasons for prioritizing a CapEx-based approach could be that a GBI-based approach requires 50% more spending, as shown above. Further, some stakeholders also revealed that government prefers using a GBI-based approach only when there is a perceived risk of assets being left idle without proper operations and maintenance. Given the high upfront cost of offshore wind projects, this risk can be assumed to be fairly lower. We therefore recommend using a CapEx-based funding approach to save significant costs in needed government support. For Figure 9 and Figure 10 in the next section, we only consider the results associated with a CapEx-based approach.

5.4 Macroeconomic Results

Our analysis shows that if the government bridges the entire cost gap until 2037, when India reaches the full potential of offshore wind (71 GW), it will yield significant macroeconomic benefits in the form of GDP gains. If the government covers 100% of the cost gap until 2037 (INR 7.2 lakh crore in the case of a CapEx-based approach, which reaches up to 0.32% of India's GDP in 2026, as shown in Figure 9), it will lead to an overall increase in GDP by INR 15.7 lakh crore (or USD 189 billion) by 2050, as per the GEM model analysis shown in Figure 10.

In the GEM model, the GDP gain happens as a result of three main dynamics: (i) a change in energy spending, with net cost reductions emerging from 2038; (ii) an increase in investments in offshore wind and corresponding employment creation; and (iii) a reduction in emissions and air pollution, resulting in higher labour productivity in the long run.

Since the overall GDP benefits outweigh the investment requirements, this also results in the BCR becoming greater than 1 over time. Under the CapEx-based approach (shown in Table 7) and when using the assumption of 100% government support, the BCR is 2.16, showing economic viability for government support.

Further, due to an increase in GDP, the government's tax revenues also increase. Assuming a tax rate of 30%, it will result in increased tax revenues in the range of INR 4.7 lakh crore in the CapEx-based approach, or 65% of the overall support to be provided to offshore wind. Despite the time delay (i.e., support is required in the short term while tax revenues increase in the medium-to-long terms), the tax benefit is substantial.

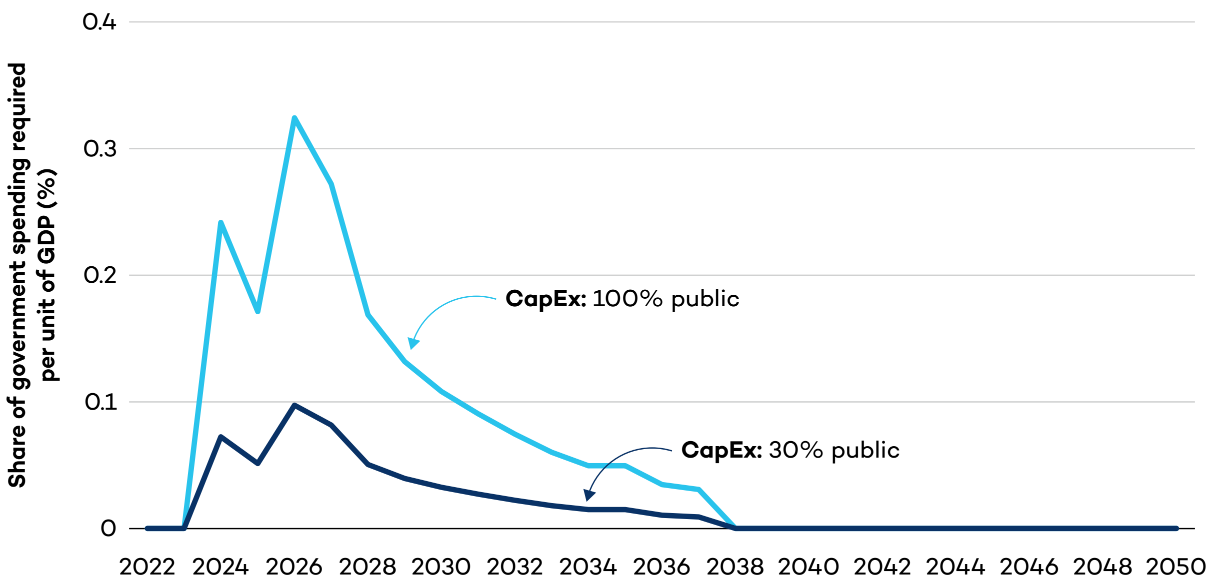
If the government were to consider transferring some of the burden of bridging the cost gap to the private sector, such as through a renewable energy mandate (for industries that are already in the higher tariff bracket), the result would change, but not considerably. We ran several scenarios through the GEM to understand the macroeconomic implications of such a transfer of burden, which varies the proportion of direct government support from 100% (baseline) to 0% of the cost gap. The private sector would cover the remaining cost gap by paying higher energy prices.

A reduction in public spending (combined with an equal increase in private sector spending) on offshore wind will lead to several interconnected outcomes:

- It improves the economic viability of the public incentives (and so does the BCR for public investment) due to cost sharing.
- It triggers an initial increase in electricity costs for the private sector, which is partly offset by an incentive to conserve electricity and use it more efficiently in the future.
- The increase in electricity conservation efforts leads to a reduction in the country's energy intensity, resulting in lower energy spending, higher energy productivity, and higher value addition (i.e. GDP, as shown by the dark blue bars in Figure 10).

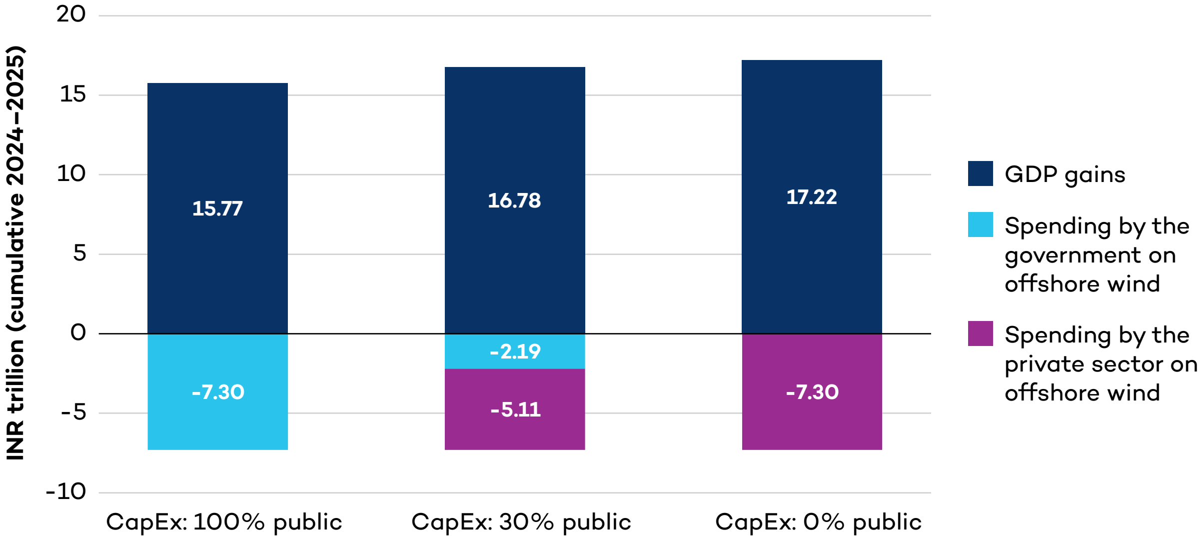
In other words, when some part of the cost gap is transferred to the private sector, the private sector implements various measures to counter the cost increase, resulting in higher productivity in the use of electricity and hence triggering comparatively higher value creation. The impact becomes bigger over time, as higher GDP (due to reduced emissions and higher labour productivity) results in higher public revenues and higher public and private investment over time (Figure 10).

Figure 9. Share of government spending required in different scenarios as a share of India's GDP



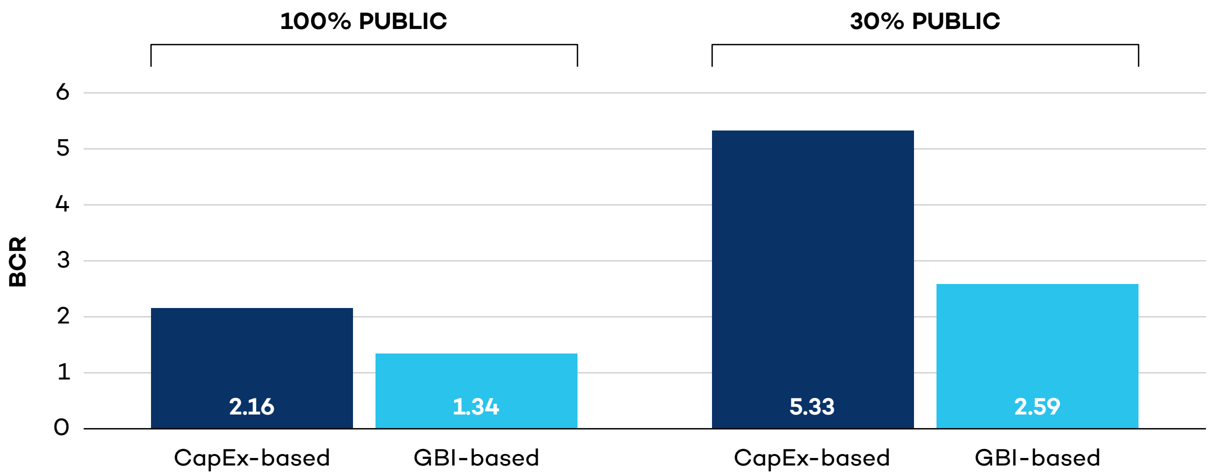
Source: Authors' analysis.

Figure 10. The net impacts of varying the level of government support on GDP, public funding, and private funding



Source: Authors' analysis.

Figure 11. Benefits to cost ratio for CapEx and GBI-based approaches to meet the cost gap

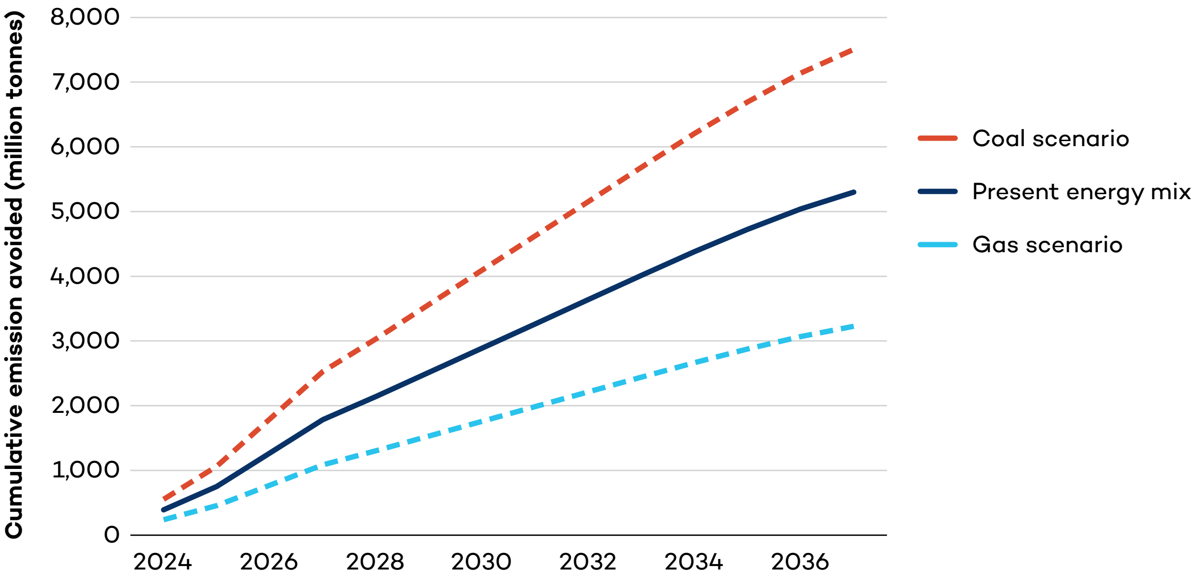


Source: Authors' analysis.

We found that support required to bridge the cost gap peaked in 2026 (up to 0.48% of GDP) and then declined year-on-year (Figure 9).

Considering India's current energy mix, offshore wind generation could avoid 5.3 billion tonnes in CO_2 emissions, as shown in Figure 12. The cumulative emissions that can be avoided by using expected offshore wind generation (considering the plant lifetime of 25 years) from future plants range from 7.5 billion tonnes (if coal generation is replaced) to 3.2 billion tonnes (if gas-based generation is replaced).

Figure 12. Cumulative emissions avoided by offshore wind generation depending on the source of electricity that the generation replaces



Source: Authors' analysis.

5.5 Discussion

The government's recent VGF announcement is a welcome move to kickstart the domestic offshore wind industry. However, in the current cost scenario, the VGF allocation of INR 6,853 crore for 1 GW would only cover about 25% of the overall upfront cost of INR 28,200 crore per GW. As per our analysis, the sector would require additional funding support worth at least ~INR 9,000 crore (~USD 1.08 billion) per GW of capacity for market development. According to some industry experts, the VGF should cover at least 50% of the initial cost (which means it should be at least double the levels that were announced in June 2024), considering the sector is still in its nascent stage in India.

In the short run, VGF is the most effective way to support and kickstart offshore wind development in India. However, the government could explore different approaches to reduce the VGF support requirements over time. For instance, a new model that combines expensive offshore wind power (with higher capacity utilization factor and greater reliability throughout the day) with cheaper solar PV (with lower capacity utilization factor) would enhance the overall reliability of renewable energy technologies. Such a bundling scheme would reduce the cost of overall energy from offshore wind power and could cater to demand from industries that are willing to pay a premium for steady and reliable clean power supply, thereby creating the initial demand for the sector and securing offtakers for the initial projects.

Box 4. What do the critics say about meeting the cost gap for offshore wind in India?

Critics argue that offshore wind is already a very expensive source of electricity, and its costs increased even more rapidly in the last few years (due to high global inflation and interest rates post-COVID). Therefore, given the amount of support required for India just to reach the 2030 targets (in the range of ~USD 61 billion to ~USD 92 billion), it may not make financial sense for the government to invest in this sector, instead using that money to promote other renewable energy sources, including solar with battery energy storage. Critics also argue that the wind speeds in India are not as good as those in countries that have been successful in offshore wind deployments, such as Denmark, the United Kingdom, and Germany.

However, it is important to highlight that wind and solar energy complement each other, and wind works better during monsoon season and during nights when solar is less or not available. Therefore, in order to achieve India's renewable energy targets, it would be important for the government to promote both solar and wind simultaneously (including offshore wind, which is even more reliable than onshore wind) with storage capacity so that RTC power can be supplied through this hybridization.

The government could also explore designing a "front-loaded" FIT agreement, which guarantees a higher tariff in the early years (and which decreases over time with economies of scale) instead of the same tariff throughout the project's lifetime. This approach could potentially be a better way to financially support the early investors.

Meanwhile, the government could also identify the large-scale industries that are already paying higher electricity tariffs in and around Gujarat and Tamil Nadu (which are both industrial states) and extend RPOs to them for electricity generated from offshore wind. It will not only reduce the requirements for government support but will also invite more and more developers/investors into the sector, promoting competitiveness. Even in Germany, Denmark, the United Kingdom, and China, to safeguard the developers from price volatility in the industry's initial phase of deployment, the government either provided predefined FITs or depended on renewable obligation certificates, similar to renewable energy certificates (RECs) in India.

The Government of India has also been exploring such avenues to keep VGF requirements under control. For instance, in the 4 GW bids that were invited in February 2024, the electricity generated is supposed to be sold to industrial consumers (under open access), which are currently in the high-tariff band, and therefore, there was no VGF support involved. However, it is important to highlight that in the same bidding process, there is no support, even in terms of guaranteed offtake, which means that developers will have to find such buyers on their own. This significantly increases the offtake risk.

Further, offshore wind projects may become less bankable due to the likelihood of more frequent extreme weather events due to changing climatic trends, which could compel offshore wind turbines to stop producing energy. This would make it harder for offshore generators to place a bid on the open energy market. Therefore, in order to attract continued investments into the sector and maintain bankability, it may be necessary to provide guaranteed offtake (at least in the initial phase).

Offshore wind is currently an expensive technology for India compared to dominant fossil and renewable energy technologies. However, it uniquely offers variable renewable baseload and the opportunity to diversify India's renewable energy portfolio. Achieving the government's targets for offshore wind capacity by 2030 will require a much larger funding allocation and supportive policies than are currently in place. This study suggests that splitting these costs between public and private investors would reduce the impact on the government, reduce the overall cost gap through efficiency gains, and still deliver strong net GDP benefits.

Recommendations for government:

- Postpone the 2030 capacity goal to allow costs to fall before full capacity needs to be achieved, but do not delay the provision of support; the sooner India starts deployment, the sooner domestic costs will decline.
- Align government support policies—financial and non-financial measures—with the goals for the offshore wind sector; this will likely require an increase in both kinds of support.
- Consider a new model for pooling renewable energy with different variabilities so that offshore wind is bundled with cheaper and more intermittent renewable energy sources to create demand and secure offtakers for initial projects.

6.0 The Power Sector: Solar PV

6.1 Background

Solar PV has globally emerged as a dominant technology for governments to drive their renewable energy targets and green industrial policies. Governments are increasingly putting in place policies and support to promote both deployment and manufacturing, the combined effect of which remains understudied at a country level. This chapter, for the first time, explores the short-term and long-term impacts of these policies in India to inform the need, scale, and nature of future government support.

6.1.1 Status of Technology

Global

In 2023, the world added nearly 346 GW of new solar PV capacity with cumulative solar PV capacity at 1,411 GW, a 33% increase over 2022 (IRENA, 2024a, 2024b). Solar PV capacity additions increased by 55% in China, 50% in the United States, and 37% in the European Union from 2022 (REN21, 2024). Public financial flows by G20 nations for solar PV were at least USD 33 billion[12] in 2022 and, although small in size compared to total investments in the sector, are playing an important role in lowering tariffs, mobilizing private investments, and shifting consumer behaviour toward more sustainable forms of energy (Laan et al., 2024). Small public financial flows can help secure much larger private investments.

Multiple government programs, such as the Bipartisan Infrastructure Deal and Solar for All program in the United States, REPowerEU, the European Solar Rooftops Initiative in the EU, and the Whole County PV Program in China, are particularly important government initiatives to promote solar PV deployment. Most of these programs make use of grants, tax credits, and mandates to promote solar. Globally, they have contributed to mobilizing private investments alongside global investments in solar, crossing USD 320 billion in 2022 (IEA, 2023c).

In parallel, to diversify and overcome supply chain barriers, governments are also supporting solar manufacturing. At the end of 2023, solar manufacturing capacity reached almost 800 GW, with nearly 330 GW of new manufacturing plants built during the year (Blackburne, 2024). By the end of 2024, forecasted demand is expected to lag behind supply by nearly three times. Due to the overcapacity, capacity utilization rates of these manufacturing facilities remain low at 50% (Bellini, 2024; Blackburne, 2024). China is expected to maintain its 80%–95% share of the supply chain (depending on the manufacturing segment), but trade protection policies in the United States and India are expected to increase supply diversity (IEA, 2024e; Weaver, 2024).

[12] These public financial flows to solar include subsidies, investments by SOEs and public financial institutions.

India

In 2023, India ranked fifth in solar PV capacity addition globally (IRENA, 2024a). In March 2015, India's solar PV installed capacity stood at 4 GW (MNRE, 2015b). As of March 31, 2024, the country's total installed solar capacity grew to ~82 GW (or 19% of India's total installed electricity generation capacity), with nearly 69 GW in the pipeline and another 28 GW under bidding (JMK Research & Analytics, 2024b; MNRE, 2024c). Out of the installed capacity, nearly 64 GW is ground-mounted solar PV, 12 GW is rooftop solar, 3 GW is off-grid solar, and 3 GW is hybrid solar (MNRE, 2024c).[13] Rooftop PV has seen particularly rapid growth over the last 3 years.

India has also been developing solar manufacturing. As of December 2023, India's annual solar module and cell production nameplate capacity stood at 64.5 GW and 5.8 GW, respectively (Mercom India Research, 2024). During FY 2024, solar module exports reached nearly USD 2 billion—rising by 91%, with the United States emerging as a key trade partner (Gupta, 2024a). Based on the project pipeline, studies estimate that India's module manufacturing nameplate capacity will surpass 150 GW, and cell capacity will likely exceed 75 GW by 2026 (Mercom India Research, 2024).

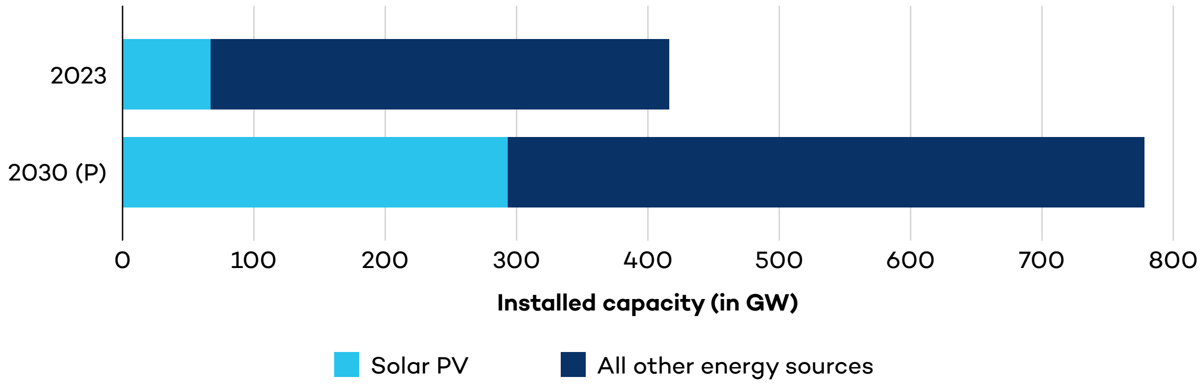
6.1.2 Government of India Targets and Goals

Based on the availability of land and solar radiation, the National Institute of Solar Energy assessed India's solar potential to be 748 GW_p (Giga Watt peak), assuming that 3% of wasteland (agriculturally unviable rural land) becomes covered by solar PV modules (MNRE, n.d.-d). Currently, there is no official physical capacity target for solar for 2030 or any other year. However, India's nationally determined contribution under the United Nations Framework Convention on Climate Change states that India will meet 50% of its cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030 (Government of India, 2022). Based on this, the CEA estimates that solar PV will become the dominant technology in India's capacity mix, with at least 293 GW by 2030 to provide for growing electricity demand at the least cost (see Figure 13). This is also aligned with the IEA's projections for India under the Announced Pledges Scenario[14] (IEA, 2022). We have used the 293 GW figure as a *de facto* goal for 2030 for our analysis.

[13] Hybrid solar PV systems combine the features of on-grid and off-grid systems by making use of storage technologies such as batteries, thus increasing the reliability of the system.

[14] The Announced Pledges Scenario assumes all climate pledges are achieved in full and on time, including net-zero emissions targets.

Figure 13. India's optimal generation capacity mix, as per the CEA

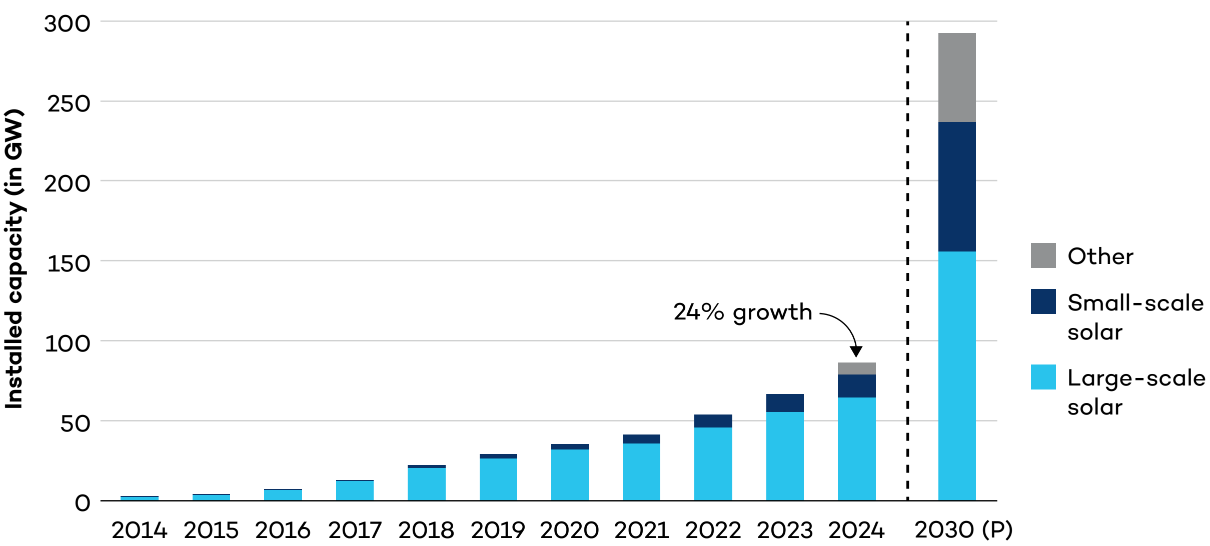


Source: CEA, 2023b.

Note: 2023 figures exclude 2,136 MW of hydro imports from neighbouring countries and 589 MW of diesel-based capacity, while 2030 figures exclude hydro imports of 5,856 MW.

To achieve a cumulative installed capacity of 293 GW of solar PV capacity by 2030, India will need to add an average of ~35 GW every year between 2024 and 2030. In the last 5 years, the average annual solar PV capacity addition has been nearly 11 GW, with an annual growth rate of ~24%—a rate that, if sustained from here on, can get India to 293 GW by 2030 (Figure 13).

Figure 14. Current status and projected solar PV capacity for India

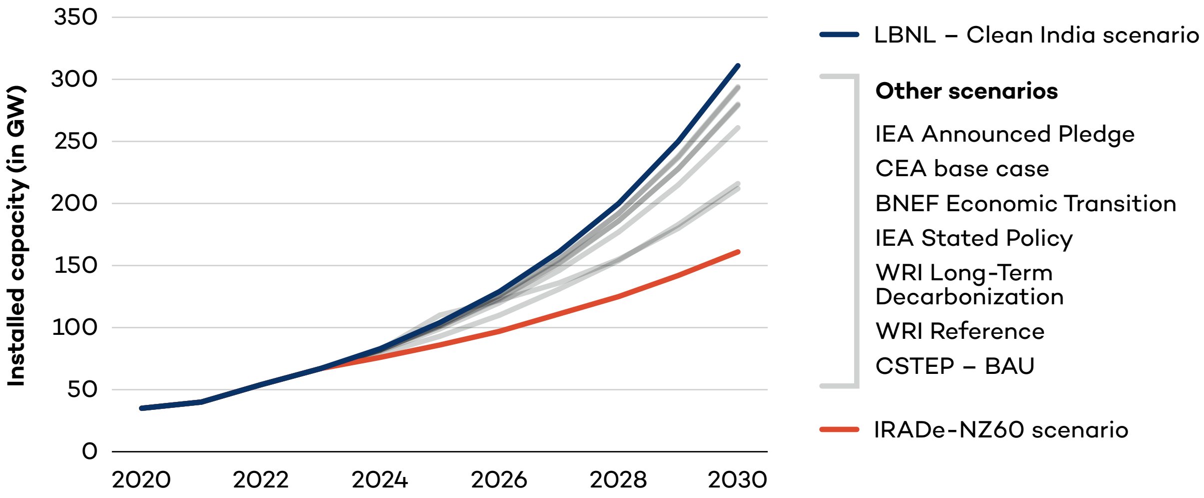


Source: Author's analysis based on the underlying model and data from the MNRE.

Note: The installed capacity until 2024 is based on actual capacity as of March 31 each year and includes all solar applications. The CEA projection of 293 GW does not provide disaggregation of large-scale and small-scale solar PV. The disaggregation presented here is based on estimations used in the study. "Others" include new demand drivers, such as GH_2.

Besides the CEA's research, multiple studies suggest that India's installed solar PV capacity by 2030 will be between 150 GW and 310 GW, with all but the most optimistic projections being below 293 GW (Figure 15).

Figure 15. Summary of projections on India's cumulative solar PV capacity between 2024 and 2030



Source: Compiled by authors based on multiple sources.

Solar PV power tariffs in India increased marginally in 2023/2024 but remain among the lowest in the world. Over the last 3 years, India has introduced multiple policy levers to balance the interests of solar PV developers and domestic manufacturers (see the following sections). These measures led to a marginal increase in solar tariffs in 2023/2024 but aim to incentivize local value addition, reduce import dependency for solar modules, improve quality control and after-sales service, and position India as a global solar manufacturing hub.

6.1.3 Existing Government Support Measures

Over the last decade, the Central Government has put multiple support measures in place to support large-scale and small-scale solar deployment under its umbrella National Solar Mission. Instruments used to do so broadly include capital subsidies, grants, tax expenditures, price supports, and mandates (see Table 8 for a summary). The recent elevation of four SOEs as official renewable energy tendering authorities with an annual bidding trajectory of 50 GW is also providing a boost to tendering activity for solar PV. In terms of government support, currently, the largest government programs for solar PV deployment focus on small-scale solar PV and include the following:

1. **Pradhan Mantri Surya Ghar Muft Bijli Yojana:** Launched in February 2024, the scheme aims to increase the adoption of solar rooftops and incentivize residential consumers through central financial assistance in the form of direct cash transfers. The scheme is to be implemented until March 31, 2027, and has a financial outlay of INR 75,021 crore (USD 9 billion) (MNRE, 2024b). The scheme requires the use of domestic modules and cells to access financial benefits (MNRE, 2024b).

2. **Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM):** Launched in 2019, the scheme aims to add nearly 31 GW solar PV capacity by March 31, 2026, with a financial outlay of INR 34,422 crore (USD 4.2 billion) (MNRE, n.d.-b). The scheme provides central financial assistance and consists of three distinct components aimed at solarizing agriculture: (i) Component A – aimed to install 10 GW of decentralized ground-mounted, grid-connected renewable power plants on farmers' land; (ii) Component B – 2 million stand-alone solar-powered agriculture pumps; and (iii) Component C – solarization of 1.5 million grid-connected pumps under either of two models—individual pump solarization or feeder-level solarization (Rahman et al., 2023). From April 1, 2024, the scheme also requires the use of domestic modules/cells for availing financial benefits.

Table 8. Summary of government support measures to promote solar PV deployment

Name of the support measure	Type of support measures	Type of policy instrument	Objective
Central Financial Assistance – (large-scale)	Fiscal	Capital subsidy	Cover project costs such as the cost of preparing detailed project reports and grid connection costs
Central Financial Assistance – (small-scale)	Fiscal	Capital subsidy	Cover upfront capital costs of rooftop PV for residential consumers and solarizing agriculture
Accelerated Depreciation	Fiscal	Tax expenditure	Enable commercial and industrial consumers to offset upfront capital costs by claiming higher depreciation in initial years
Viability Gap Funding	Fiscal	Capital subsidy	Cover the price differential of domestic modules in government procurement
Waiver of ISTS charges	Fiscal	Price support	Reduce evacuation costs and encourage faster capacity addition
Renewable Purchase Obligation	Non-fiscal	Quantity-based instrument	Increase adoption of renewable energy sources, including solar
Must-run status for all renewable energy plants	Non-fiscal	Offtake guarantee	To avoid curtailment of renewable energy, including solar PV projects

Source: Authors.

The government also supports domestic solar PV manufacturing (Table 5). The primary measure is a Production Linked Incentive (PLI) scheme, with a total budget of INR 24,000 crores (USD 2.9 billion) (MNRE, n.d.-c). The objective of the PLI scheme was to substitute PV imports worth INR 1.40 lakh crore (USD 17 billion) annually and create 975,000 direct and indirect jobs.

The government has also introduced measures to protect the domestic solar industry from competition from solar manufacturers in China and Southeast Asia. From April 2022, the government imposed a 40% basic customs duty (BCD) on imported solar modules and a 25% BCD on imported solar cells (Verma, 2022). Select manufacturing goods and materials used in manufacturing solar cells or modules have been exempted from customs duties, while anti-dumping duties have been imposed on other PV inputs that are manufactured domestically. The government is therefore selectively using trade barriers in ways that benefit some manufacturers but result in higher costs for others and for the overall cost of domestic modules.

Table 9. Summary of government support measures to promote solar PV manufacturing

Name of the support measure	Type of support measure	Type of policy instrument	Objective
PLI	Fiscal	Production-based incentive	Promote development of the domestic solar manufacturing value chain, promote innovation, boost exports, and create local jobs
BCD on imported solar modules/cells	Fiscal	Tariff barrier	Protect domestic solar module manufacturers from cheap imports
Approved List of Models and Manufacturers	Non-fiscal	Non-tariff barrier	Promote quality assurance, improve after-sales service, and create local jobs
DCR	Non-fiscal	Regulatory mandate	Create market demand for domestic manufacturers, shield domestic manufacturers, and encourage domestic value addition
Custom duty exemptions	Fiscal	Tax expenditure	Reduce the cost of select manufacturing goods and materials used in solar cells/ modules

Source: Authors.

In addition, the government has implemented an Approved List of Models and Manufacturers (ALMM) and domestic content requirement (DCR) (MNRE, n.d.-a, 2024a). ALMM rules require that PV modules in the ALMM list be used for all government-related procurements.

The government's stated policy objective for the ALMM was to ensure compliance with India's quality standards and ensure after-sales services. Given that the ALMM list currently contains only domestic module manufacturers, the rules effectively mean that the modules should be domestically manufactured. The DCR rules go one step further and require that the cells used in these modules should also be domestically manufactured. DCR rules are applicable only for three solar schemes—PM-KUSUM (solarizing agriculture), PM Surya Ghar (rooftop solar), and CPSU (solar procurement by SOEs).

6.2 Approach

In this study, we divided solar PV projects in India into three broad categories, given that the size, form, and desired outcomes from providing government support to them can be different:

- large-scale solar PV (ground-mounted utility-scale solar),
- small-scale solar PV (including rooftop PV and solarizing agriculture), and
- solar manufacturing facilities.

To study government support measures and the impacts of selected government support levers on solar PV costs, the project team developed Excel-based LCOE models for large-scale solar PV and small-scale solar PV technologies for different sets of consumers (see Appendix A for the detailed methodology). Since solar PV tariffs are already cost-competitive with other technologies and the government has introduced tariff and non-tariff barriers, we used the levelized cost of solar when cheaper imported modules are used as the benchmark price to estimate the cost gap. These cost models were developed to disaggregate the impact of government measures (such as duties, GST, accelerated depreciation, and capital subsidy schemes such as VGF for the CPSU scheme for utility-scale solar and central financial assistance for rooftop solar PV). These bottom-up, policy-disaggregated, time-based LCOE models were then used to

- conduct a sensitivity analysis to shortlist important government support levers, such as import duties, and
- construct scenarios to study the macroeconomic impacts of shortlisted government support levers.

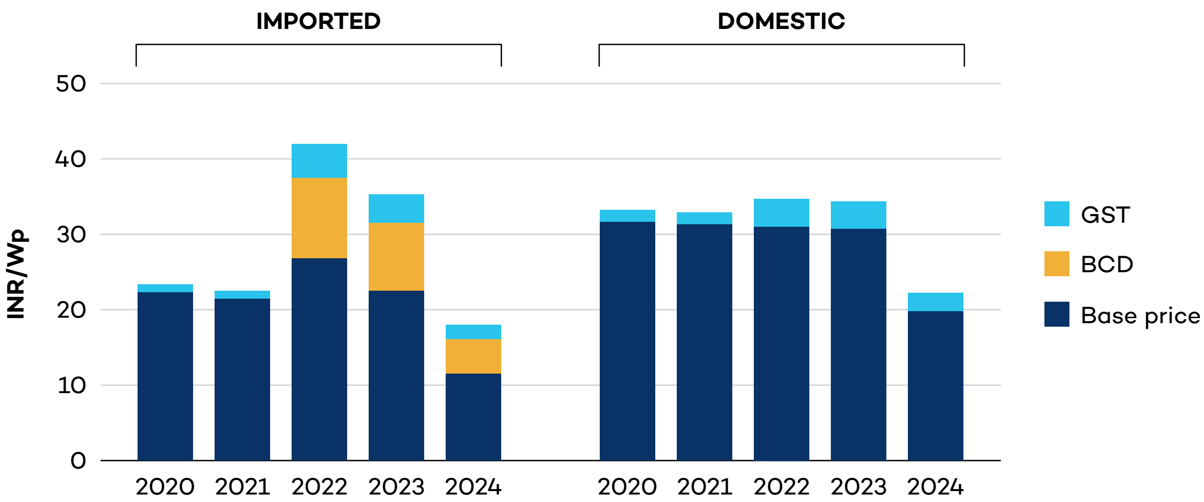
The GEM–India was then used to evaluate the macroeconomic and energy system impacts of government bridging the cost gap.

6.3 Findings

6.3.1 LCOE Analysis

Through the sensitivity analysis, we found that solar module prices are the largest single cost driver, comprising ~60%–70% of solar PV costs. Over the last 3 years, solar module prices have been sharply declining (by nearly 50%–70% across technologies), mainly due to the global supply glut. In response, India was quick to introduce tariff barriers in 2022 and non-tariff barriers in 2024 to protect its nascent domestic solar manufacturing industry. As a result, module prices in India experienced volatility, and government support measures such as duties, subsidies, taxes, and domestic content requirements had a major impact (see Figure 16). Overall, we find that domestically manufactured modules were nearly INR 6-7/Wp costlier than imported modules in 2024 (blue column).

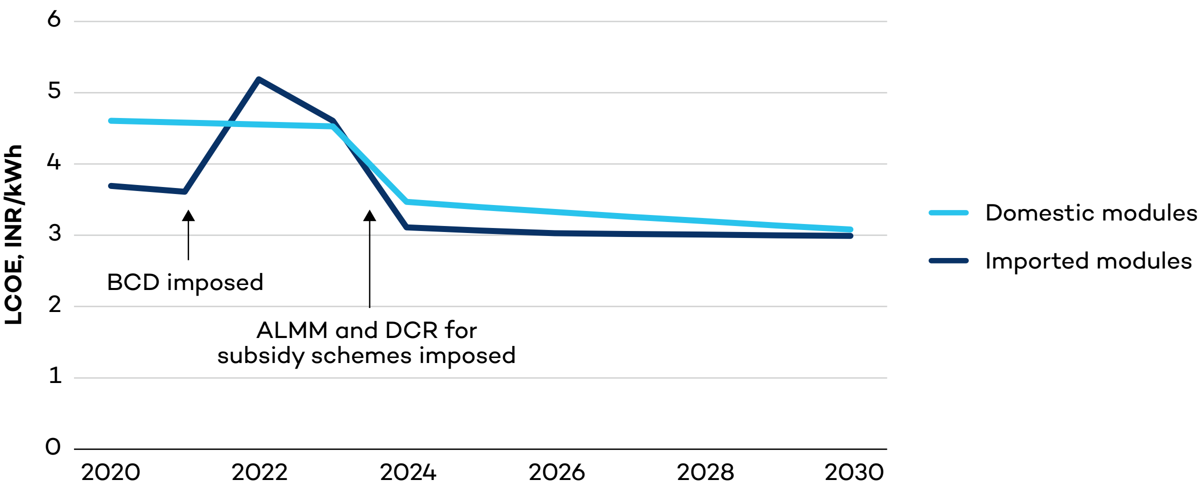
Figure 16. Average module prices over the last 3 years in India



Source:

Note: The prices above represent mono-PERC module prices in the first quarter of each year. The actual price may vary based on technology, size, and company.

Figure 17. Impact of government levers on large-scale solar LCOE



Source: Authors.

6.3.2 Cost Gap

We find that despite the imposition of tariff and non-tariff barriers, solar PV is cost-competitive with conventional power generation technologies. As a result, for this study, we use the per unit cost differential between cheaper imported modules ("Low Trade Barrier") and domestically manufactured ones (BAU) to calculate the total cost gap to achieve the goal of 293 GW by 2030. Given that the imposition of ALMM, DCR, and customs duties will lead to an increase in costs in the near term, we estimate a cost gap of INR 14,500 crore to achieve the 2030 goals (see Table 10). The cost gap is higher for small-scale solar compared to utility-scale solar. However, when compared to the size of the current government outlay (already announced in the form of PLI, PM-KUSUM, and PM Surya Ghar Muft Bijli Yojana), this is small. We, thus, do not find the need for any additional government support to meet solar PV deployment targets. Beyond 2030, we projected that the cost gap will be removed as India develops economies of scale in both cell and module manufacturing.

Table 10. Cost gap between 2024 and 2030 for solar PV

Segment	LCOE based on the domestic module in 2024	LCOE based on imported modules in 2024 (benchmark)	Difference	Cost gap
Large-scale solar PV	~ INR 3.5/kWh	~ INR 3.1/kWh	INR 0.4/kWh	INR 6,700 crore
Small-scale solar PV	~ INR 4.4/kWh	INR 3.5/kWh	INR 0.9/kWh	INR 7,800 crore

Source: Authors.

6.3.3 Macroeconomic Results

In the BAU scenario, with the introduction of ALMM and DCR for select government schemes coupled with higher custom duties, we projected that India would slightly fall short (~20 GW) of the 2030 capacity goal, reaching around 260–270 GW. This is mainly a result of the slowdown in deployment between 2024 and 2026 due to higher costs.

Table 11. The macroeconomic impact of providing government support to achieve cost parity solar PV relative to BAU (cumulative to 2050)

	Solar PV
GDP (cumulative, INR crore)	9,52,320
Employment (cumulative FTE)	1,096,759
Energy savings (cumulative, INR crore)	1,135
GHG emission reduction (cumulative, million tonnes)	336
Public revenue (cumulative, INR crore)	4,14,942
BCR	1.6–4.5

Source:

To address the ~20 GW shortfall, the government could ease tariff and non-tariff barriers. Our modelling indicated that reducing the customs duty on imported modules from 40% to 10% and removing the non-trade barriers could help boost deployment. This would have a positive BCR due to higher deployment relative to the BAU scenario. The higher deployment results in increased GDP and GHG emissions reductions (Table 11).

Box 5. The full macroeconomic results of achieving the 293 GW goal

Expanding solar PV deployment was projected to result in positive economic returns, employment creation, and lower GHG emissions and air pollution.

The economic benefits of deploying solar PV were found to be substantial. Achieving the 2030 goal was found to result in a cumulative gain in GDP. By 2050, this is expected to reach (i) INR 10 lakh crore in the 293 GW scenario and (ii) INR 9.5 lakh crore in the Low Trade Barrier scenario. These results highlight the emergence of a positive economic return, with a BCR (when considering GDP impacts and hence societal benefits) in the range of 1.6 and 4.5 across scenarios (using undiscounted values, only inflation adjustment).

In addition to boosting GDP, the increased economic activity leads to a significant rise in government revenues. By 2050, government revenues are projected to increase cumulatively by (i) INR 4.38 lakh crore in the 293 GW scenario and (ii) INR 4.15 lakh crore in the Low Trade Barrier scenario. In the Low Trade Barrier scenario, solar PV capacity is also 6.2% higher in 2050 relative to BAU.

These figures underscore the dual benefits of solar PV adoption: not only does it drive substantial economic growth, but it also enhances government revenue streams, reinforcing the importance of strategic support in renewable energy infrastructure.

Employment creation follows the trend of capacity installation. Renewable energy is labour intensive, especially if manufacturing is considered, and generates a net gain in employment. We estimate that the additional number of full-time equivalent (FTE) jobs for electricity generation (considering both job gains in solar PV and job losses in thermal generation) reaches (i) 36,850 in the 293 GW scenario and (ii) 38,400 in the Low Trade Barrier scenario.

The peak for construction jobs for solar PV power projects is in 2038, with 150,000 additional jobs as a result of government support in the 293 GW scenario (the total number of jobs in construction across all energy sources is 2 million in 2038).

Compared to the BAU scenario, solar PV uptake results in an overall reduction in energy emissions by 0.1% in 2050, or a cumulative reduction of (i) 355 million tonnes in the 293 GW scenario and (ii) 336 million tonnes in the Low Trade Barrier scenario.

6.4 Discussion

Policies to promote both solar deployment and manufacturing have led to some trade-offs. The introduction of ALMM, BCD, and DCR was projected to result in a slight slowdown in deployment between 2024 and 2026 and a shortfall of nearly 20 GW capacity below the 293 GW goal in 2030. However, during this time, India positions itself as a solar manufacturing hub.

To address the ~20 GW shortfall, the government has three main choices: i) remove or reduce trade and non-barriers, ii) increase subsidies to manufacturing or deployment, or iii) address other impediments to solar deployment. We do not recommend that any additional support be provided: current levels of support provided through the PLI are already sufficient to bridge the cost differential between domestic and imported panels—India's manufacturing sector just needs time to respond to the scheme since these output-linked incentives and manufacturing facilities commence operations in 2026 and develop economies of scale. Our modelling indicated that reducing the customs duty from 40% to 10% and removing the non-trade barriers could boost deployment by around 7 GW by 2030. The remainder of the shortfall could be addressed through the electricity sector and the reform of government solar PV programs, which our qualitative analysis suggested could be more important than incentives in accelerating deployment (see below).

The macroeconomic results for solar PV indicate that lowering the customs duty to 10% would have a positive impact on deployment relative to the BAU scenario (current policies). The higher deployment results in increased GDP and GHG emissions reductions.

Further, our qualitative research indicates that government-backed decentralized renewable energy schemes for solarizing irrigation (PM-KUSUM) and rooftop solar installations (PM Surya Ghar Muft Bijli Yojana) will assist the achievement of 2030 clean energy goals. To reach India's clean energy goals, approximately 65 GW will need to be added by 2030 through decentralized renewable energy solutions. Since the current schemes make an annual allocation of this size, we find that the volume of support for the deployment of small-scale solar programs is sufficient. However, the current policy of DCR to avail financial incentives under these schemes may lead to a slowdown in deployment between 2024 and 2026.

Schemes like rooftop solar PV and PM-KUSUM also face several implementation delays: frequent module price volatility and policy changes have led to challenges for the states in setting benchmark prices, unbidded tenders, and Letters of Awards not getting fulfilled in several states.

Overall, the government's pivot to domestic manufacturing does slow down the achievement of the 293 GW goal. However, the projected shortfall of 20 GW could be achieved with some slight changes to current policy settings and without the need for new subsidies beyond those already allocated for domestic manufacturers.

Recommendations for government:

- Carefully track the price of internationally and domestically manufactured modules and remove all trade and non-trade barriers once cost competitiveness is achieved—or even earlier—to expose the domestic market to competition and drive down prices.

- Address the health of discoms through cost-reflective tariffs and direct benefits transfers to vulnerable consumers, allowing discoms to invest in renewable energy and modernizing the grid.
- Accelerate the grid integration of new solar PV projects through earlier planning and faster connection times.
- Support states in overcoming technical challenges associated with higher adoption and integration of variable renewable energy, including small-scale solar PV such as irrigation and rooftops.

7.0 Passenger Transport: EVs

7.1 Background

EVs with zero tailpipe emissions are crucial for decarbonizing road transport and achieving net-zero emissions. As battery technology improves worldwide and EVs become more affordable, they can replace internal combustion engine vehicles, transforming the automotive industry into a key player in sustainable energy. As a result, government support and policy certainty will be crucial in helping bring costs down.

7.1.1 Status of the Industry Globally and in India

Global

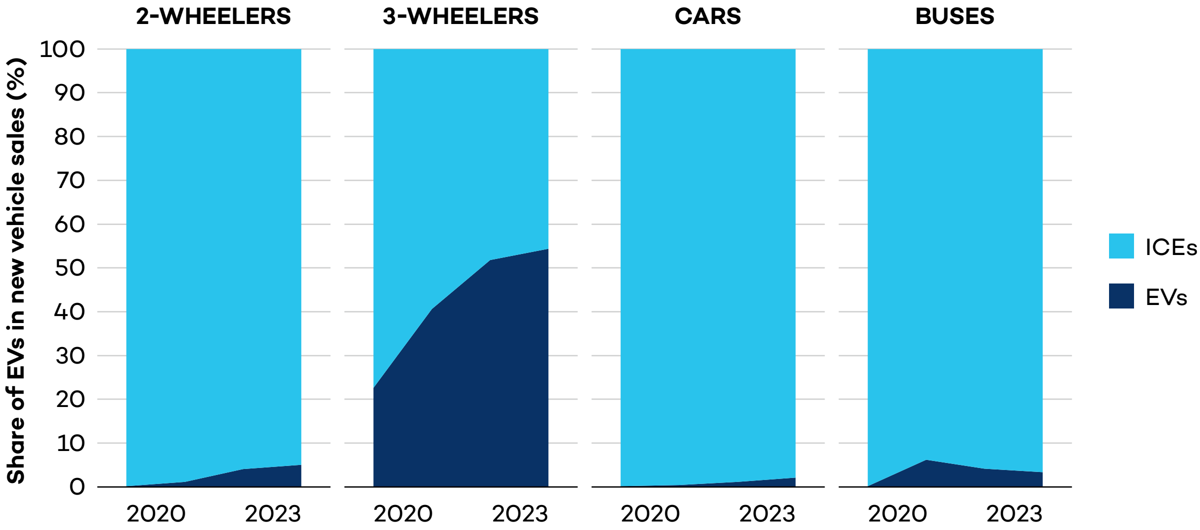
In 2023, almost 14 million new electric cars[15] were registered globally—accounting for around 18% of all cars sold in 2023—bringing the total on the roads to 40 million (IEA, 2024c). The sales share of electric two-wheelers (e2W) and three-wheelers (e3W) was 13% globally (IEA, 2024c). However, in terms of stock shares, it is the most electrified road transport segment, with about 8% of 2W/3Ws on the roads being electric (IEA, 2024c). China, India, and the Association of Southeast Asian Nations countries led in e2Ws/e3Ws in 2023, with over 30%, 8%, and 3% of 2W/3W sales being electric, respectively (IEA, 2024c). Most governments across the world have been incentivizing EV adoption through direct and fixed purchase incentives. Other policy instruments used by governments included scrappage schemes, tax reductions, and income tax credits.

India

In 2023, the EV industry achieved a significant milestone in India by selling over 1.5 million units—a remarkable growth of 49% compared to 2022 (Clean Mobility Shift, 2024). Nearly 95% of these sales came from e2Ws and e3Ws. Despite the strong growth, annual EV sales were overall a mere 6.4% of all vehicle sales in 2023 (Clean Mobility Shift, 2024). This sluggish adoption can be attributed to several factors, with one major hurdle being the comparatively high upfront purchase cost and TCO of EVs in contrast to internal combustion engine (ICE) vehicles—the focus of this study.

[15] "Electric vehicles" (EVs) refers to battery electric and plug-in hybrid vehicles, excluding fuel cell electric vehicles. Unless otherwise specified, EVs include all modes of road transport (IEA, 2024c).

Figure 18. Share of EVs in India's new vehicle sales, by segment and year



Source: Clean Mobility Shift, 2024.

7.1.2 Government of India Targets and Goals

As part of its EV30@30 pledge, India has the aspirational goal of achieving a 30% share of EVs in new sales by 2030 (Clean Energy Ministerial, n.d.). With the current policies in place, India could achieve 8 crore EVs by 2030 and realize EV purchase rates[16] of 30% of private cars, 70% of commercial cars, 40% of buses, and 80% of 2Ws and 3Ws by 2030 (Climate Trends & JMK Research & Analytics, 2022; Singh et al., 2019). While these segment-wise goals are not formalized as official targets, these figures have often been quoted by the Minister of Road Transport and Highways of India and are considered synonymous with the national vision (Climate Trends & JMK Research & Analytics, 2022).

To increase EV adoption, the government has also set an ambitious goal to establish a total of 46,397 public charging stations by 2030, which is in line with India's EV infrastructure expansion efforts (PIB, 2023d).

However, the current trajectory of domestic sales and the rate of EV adoption remains sluggish for achieving these ambitious goals. Table 11 shows the current purchase rates and goals across segments.

[16] In this study, we have used the term "purchase rate" as the percentage of new EV sales to keep it comparable with India's 2030 goals.

Table 12. EV purchase rates and India's goals for 2030

Category	EV purchase rates as of 2024 (%)	Goal by 2030 (%)
e2Ws	5.2	80
e3Ws	53.9	80
Private cars	2.2	30
Commercial cars	0.3	70
Buses	3.3	40
Total	**6.6**	**30**

Source: Clean Mobility Shift, 2024 (purchase rates); Climate Trends & JMK Research & Analytics, 2022.

7.1.3 Existing Government Support Measures

The Indian government has policies in place to support both demand and supply of EVs. This report mainly focuses on demand incentives to estimate the cost gap. On the demand side, the government's flagship program—Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India (FAME India)—incentivized over 1.6 million EVs over its two phases (Phase I between 2015 and 2019 and Phase II between 2019 and 2024) with nearly INR 8,300 crore (USD 1 billion) (Kohli, 2024). The primary thrust of the scheme was on electrification of public and shared transport, with particular emphasis on 2Ws, 3Ws, and buses. The government has also allocated nearly INR 0.2 crore (USD 140 million) to facilitate the establishment and expansion of charging networks across the country.

Further, after a review of Phase II, the Ministry of Heavy Industries formulated the Electric Mobility Promotion Scheme 2024 with an outlay of INR 500 crore (USD 61 million), which was implemented over a period of 4 months, in effect from April 1, 2024, until July 31, 2024, for faster adoption of e2Ws and e3Ws. This scheme has now been subsumed under the new PM Electric Drive Revolution in Innovative Vehicle Enhancement (PM E-DRIVE) scheme (PM India, 2024b). The government also announced the setting up of a payment security mechanism for e-buses in Union Budget 2024-25 and launched a new PM-eBus Sewa Scheme with central assistance of INR 20,000 crore (INR 2.4 billion) to augment bus operations by deploying 10,000 electric buses on a public–private partnership model (Ministry of Finance, 2024a; PM India, 2024a).

Table 13. Summary of major Central Government support policies to support EV adoption

Name of the support measure	Type of support measure	Type of policy instrument	Objective
Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India (FAME)	Fiscal	Demand incentive	Encourages adoption of electric and hybrid vehicles in public and shared transport
Electric Mobility Promotion Scheme	Fiscal	Quantity-based instrument	Encourages adoption of e2Ws and e3Ws
PM-eBus Sewa Scheme	Fiscal	Public procurement	Provides central assistance to nearly 10,000 electric buses through demand aggregation
PM Electric Drive Revolution (PM E-DRIVE)	Fiscal	Demand incentive	Provides subsidies and demand incentives for EVs, promotes the procurement of e-buses, and supports the installation of EV public charging stations
Tax deductions, including concessional GST and income tax deductions or credits	Fiscal	Tax expenditure	Encourages consumer demand for EVs
Exemptions on road taxes, fees, registration	Fiscal	Tax expenditure	• Road tax exemptions or reductions for EV buyers • 100% registration fee exemption • State GST reimbursement

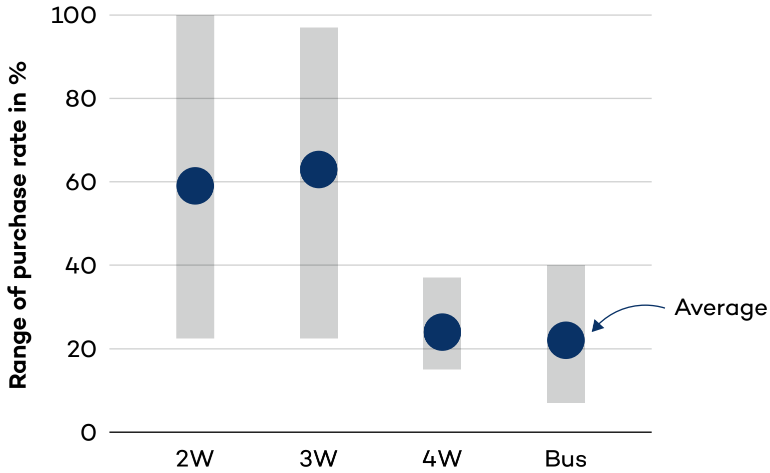
Source: Authors.

7.1.4 Study Approach

In addition to a systematic review of Central Government EV support schemes (above), we conducted expert consultations to identify the most important policy and government support levers. For the quantitative analysis, modelling was used to analyze the impacts of these policy levers. We used the TCO models for EVs and ICE vehicles in 2W, 3W, 4W, and buses to segregate the impact of government incentives on total costs (World Resources Institute, n.d.). TCO encompasses various factors, such as purchasing, maintenance, charging costs, and incentives. Lower maintenance costs and reduced fuel consumption of EVs, when coupled with the right amount of scale and nature of incentives, can help offset the initial higher cost when compared to ICE vehicles. Other non-financial measures to promote charging infrastructure and the need for payment guarantees for bus operators were also studied qualitatively.

A systematic review of EV purchase rates forecasted for India was studied across the shortlisted sub-segments. Estimates varied widely (Figure 19).

Figure 19. Projected purchase rates across different vehicle segments by 2030



Source: Compiled by authors from multiple sources.

Given that there was a huge variation among the forecasts, we used the TCO analysis to inform future purchase rates, as shown in Table 14.

Using the GEM–India, we then used these adoption curves to study the impact of incentives—with or without demand incentives for all EV sub-segments—to evaluate their macroeconomic impacts. Initial results were also shared in a workshop with stakeholders organized by the project team in January 2024.

7.1.5 TCO and the Future of Demand Incentives

Financial support can help reduce the TCO of EVs (i.e. on a life-cycle basis) or when provided in the form of upfront purchase subsidies (such as under FAME). Our study showed that the need for subsidies differs across vehicle sub-segments. For segments where consumers are highly price-sensitive, such as 2Ws, subsidies may be needed beyond cost parity with ICE vehicles to drive further adoption (Kohli, 2024). Such consumers may not always consider TCOs but rather upfront costs when thinking about vehicle purchases. To account for such consumer behaviour, we used different adoption curves based on the TCO differential (EV cost/ICE cost), as given in Table 14.

Table 14. Adoption curves used for this study

Adoption curves	Description
Linear scenario	Assumes EV adoption is proportional to the TCO differential between EVs and ICE vehicles.
S-shaped scenario	Assumes that when EVs are more expensive than ICE vehicles on a TCO basis, no adoption occurs; however, when EVs are at least 30% cheaper than ICE vehicles based on TCO, full adoption occurs.
Rapid scenario	Full adoption occurs when EVs are marginally cheaper than ICEs on a TCO basis.

Source: Authors.

Based on these adoption curves that model consumer behaviour, we selected the best-suited scenario for each segment to align with the stated government goals in 2030 to estimate the need and size of the cost gap across segments, as outlined in Table 15.

Table 15. Key findings on future of demand incentives from TCO analysis and resulting purchase rates (adoption refers to % of new sales)

EV segment	Adoption curve most suited to get to 2030 goals	Year of TCO parity with incentives	Year of TCO parity without incentives	Need for additional support	Cost gap (2024–2030)
e2Ws	Rapid scenario (~80% by 2030)	2023	2034	Funding needed	~INR 19,000 crore
e3Ws	S-shaped scenario (~80% by 2030)	Already achieved	Already achieved	Not needed	-
e4Ws	Linear scenario (~30% by 2030)	2025	2034	Continue the existing level of support	~INR 4,300 crore
E-buses	Linear scenario (~40% by 2030)	2035	2045	Funding needed	~INR 7,500 crore

Source:

From the above analysis, we find:

- **e2Ws:** At the level of incentives under FAME-II, the purchase rate will reach 34% by 2030. Given that India aims to more than double this to 80%, a rapid scale-up will be needed. To achieve this, additional funding of nearly INR 19,000 crore will be needed beyond the incentives that were being provided under FAME-II.

- **e3Ws:** At the level of incentives under FAME-II, the purchase rate will reach 93%, thereby removing the need for further subsidies for the segment. This is the only segment where purchase rates could be achieved ahead of time, as early as 2026.
- **e4Ws:** At the level of incentives under FAME-II, the purchase rate will reach 30% by 2030. Therefore, it is important that the government continues with the existing scale of incentives under FAME-II, up to 2030. For this, funding of INR 4,300 crore will be needed until 2030.
- **E-buses:** At least INR 7,500 crore of additional funding is needed beyond the current levels, given that cost parity is not reached for at least a decade. Consultations showed that this would be particularly important to help drive large-scale procurement among private bus operators, which comprises a large share of buses in India.

At an aggregate level, the purchase rate of EVs, as indicated above, is highly influenced by government support. On this, we find that, without support, the share of EVs in the vehicle fleet will reach 8.6% (S-shaped), 11.9% (Linear), and 37% (Rapid). This value is forecasted to grow to 76% (S-shaped), 71.7% (Linear), and 91% (Rapid). On the other hand, government support can speed up and anticipate EV adoption considerably to meet short- and medium-term targets. With government support, the share of EVs in the vehicle stock in 2030 will reach 38.9% (S-shaped), 37.1% (Linear), and 48.7% (Rapid). This highlights the value of government support, especially under a scenario of slow, more cautious adoption of EVs. In this case, government support that eliminates the cost gap would push EV adoption by as much as 30% by 2030.

7.2 Macroeconomic Results

Our analysis shows that incentives for transport electrification are economically viable and generate net benefits for the economy across scenarios. Overall, a cumulative average investment of INR 23 lakh crore to 2050 results in INR 60 lakh crore of avoided costs and added benefits, representing a BCR of 2.6.

Specifically, the additional incentive until 2050 totals INR 27 lakh crore (Rapid scenario), INR 20.8 lakh crore (Linear), and INR 21.6 lakh crore (S-shaped). The higher and faster the adoption goal, the larger the support required from the government.

On the other hand, the adoption of EVs results in lower energy costs, vehicle maintenance costs, and higher GDP. First, energy spending is forecasted to decline, with cost savings up to INR 41.5 lakh crore in 2050. Second, the operation and maintenance (O&M) costs of vehicles decline in the range of INR 4.7 lakh crore by 2050. Third, GDP increases due to electrification (e.g., as a result of lower energy spending and reduced air pollution), but the implementation of incentives generates a comparatively small net impact, in the range of INR 13.8 lakh crore relative to the BAU scenario.

Further, when considering emissions reductions and additional job creation, EV demand incentives generate considerable societal value across social, economic, and environmental indicators. Regarding emissions, reductions were forecasted in the range of 14% (S-shaped), 7% (Rapid), and 12% (Linear), compared to the respective BAU scenarios over time. This is the net contribution of incentives to emissions reductions. Concerning employment, the forecasted adoption of EVs is estimated to generate up to 10 million jobs over time, including downstream EV manufacturing, O&M of vehicles, and manufacturing of chargers (with EV manufacturing representing 80% of job creation in the short term and then declining to 60% by 2050). Public incentives are responsible for the creation of between 290,000 and 1.2 million additional jobs between 2024 and 2050. At its peak, employment creation directly stimulated by government support reaches 5.3 million in 2030 in the S-shaped scenario.

7.3 Discussion

Only e3Ws are currently at cost parity with ICE vehicles without incentives. In the absence of incentives (at the same level as provided under FAME-II), e2Ws and electric cars and electric buses do not reach cost parity with ICE vehicles for at least another decade. With incentives at the level of FAME-II, e2Ws and cars reached cost parity in 2024 or 2025. Therefore, ongoing incentives are needed to accelerate EV uptake and keep India on track to achieve 30% EV sales by 2030.

However, cost is not the only factor holding back EV adoption. Consultations revealed that problems in administering FAME subsidies caused financial uncertainty for manufacturers. These problems included slow payment of subsidy entitlements and changes in eligibility (i.e., manufacturers thought they would receive the subsidy but later found they would not, primarily due to domestic content requirements). In the case of electric buses, stakeholders commented that indebted public transport authorities were often unable to afford e-buses, even with subsidies. Due to low financial viability, EV suppliers and financial institutions were reluctant to provide new equipment in case of default. These factors signal that a major review and restructuring of the government's approach to EV incentives are needed, developed in close consultation with stakeholders.

The focus on FAME for public and shared transport for EV cars and commercial vehicles is important from an equity perspective: the government should not directly subsidize EV cars for relatively wealthy private car owners. However, other fiscal and non-fiscal measures could be considered to boost EV car uptake. Consultations also showed that better financing terms and awareness of financing products could help market penetration of EV cars. A recent study shows that three out of every five Indians prefer getting their cars financed, owing to ease and accessibility (CARS24 Financial Services Pvt Ltd, 2023, p. 5). The average age of people preferring to finance their cars is 32 years, indicating a strong presence of working millennials, including salaried employees and young entrepreneurs. Further, Section 80EEB introduced by the Finance (No.2) Act, 2019 (No. 23 of 20 19) allows an income tax deduction of up to INR 1,50,000 from the gross total income of an individual with respect to the interest payable on loans from any financial institution for the purpose of purchasing an EV if the loan has been sanctioned by the financial institution during the period from April 1, 2019 to March 31, 2023 (Cleartax, 2024; Ministry of Finance, 2022). The revenue impact for government due to this tax incentive was INR 223 crore in FY 2022 and INR 251 crore in FY 2023 (Ministry of Finance, 2024b).

Another form of financial support being provided is concessional financing for electric cars. Most public sector banks and select private sector banks in India now offer specialized green car loans at a rate that is 20–50 basis points lower than normal car loans (HDFC Bank, n.d.; Kulkarni, 2022; Pradhan, 2024; State Bank of India, n.d.).

Non-fiscal measures could include mandatory fuel efficiency standards, which require vehicle manufacturers and importers to supply a minimum amount of low-emission vehicles as a proportion of total stock sold domestically. Given costs for key EV segments are still above cost parity without incentives, imposing trade restrictions to protect the domestic EV industry is not recommended at this time, as it would push up prices and slow the transition to cleaner transport.

A renewed and more effective EV support program is highly worthwhile. Our macroeconomic results indicated that electrification of transport would deliver major net benefits in terms of employment, economic growth, and reduced pollution.

Recommendations:

- Articulate and formalize EV adoption rate targets across vehicle segments to have a clear 2030 vision.
- Continue EV support measures to 2030. Integrate all existing demand and supply incentives for EVs into a comprehensive roadmap with a clear trajectory for government support to 2030 to help ensure policy stability and attract long-horizon private investments.
- For specific support measures, we recommend
    - renewing the income tax exemption on interest on car loans, which lapsed in 2023, to 2030 and leveraging marketing channels of banks to design information campaigns around the concessional financing and tax deductions available to consumers;
    - continuing demand incentives for shared electric car fleet operators to 2030 at the levels of FAME-II;
    - expanding incentives for leasing electric buses to private operators that own and operate nearly 93% of buses in India;
    - expanding support to electrifying commercial freight and heavy-duty vehicles for faster adoption up to 2030; and
    - expanding support for charging infrastructure, which is one of the key drivers for EV adoption.

8.0 Industrial Sector: Green hydrogen

8.1 Background

GH_2 development is important for countries striving to reduce global GHG emissions, as the current hydrogen economy is both a significant contributor to emissions and a key opportunity for deep decarbonization. In 2023, hydrogen production accounted for around 2.5% (920 Mt) of global energy-related CO_2 emissions, roughly equivalent to the total energy-related CO_2 emissions of France and Indonesia (IEA, 2023a). Most of this comes from carbon-intensive grey hydrogen produced from natural gas. Depending on the production methods and energy sources, hydrogen can be classified into various types (Table 16).

Table 16. Types of hydrogen based on their energy source and production method

Hydrogen category	Production method or source
Green	Electrolysis of water using renewable energy sources
Blue	Natural gas with carbon capture and storage (CCS) to reduce emissions
Turquoise	Methane pyrolysis, where solid carbon is a by-product and can be stored or utilized, minimizing CO_2 emissions
Grey	Natural gas without CCS
Brown	Coal gasification

Source: Marchant, 2021.

GH_2 has emerged as one of the key levers in the IEA's Net Zero Emissions by 2050 scenario and plays a vital role in reducing emissions across several sectors, including industry (e.g., as a feedstock in steel production and fertilizers), long-distance ground transportation (e.g., powering heavy trucks, buses, and long-range vehicles), global travel (e.g., producing synthetic fuels for shipping and aviation), heating (e.g., providing high-temperature industrial heat), and electricity generation (e.g., as a dispatchable energy source and for backup power) (IEA, 2023b).

8.1.1 Status of the Industry Globally and in India

Globally

Global hydrogen demand in 2023 reached nearly 97 million tonnes (Mt)—99% of which was derived from fossil fuels—and was projected to reach 150 Mt by 2030 (IEA, 2023a). Natural gas without CCS and unabated coal, primarily sourced from China, contributed 62% and 21% of global production, respectively, and by-product hydrogen generated from refineries, and the petrochemical industry constituted 16% of the total global production. In addition, 0.6% of hydrogen was produced using fossil fuels with carbon capture, utilization and storage

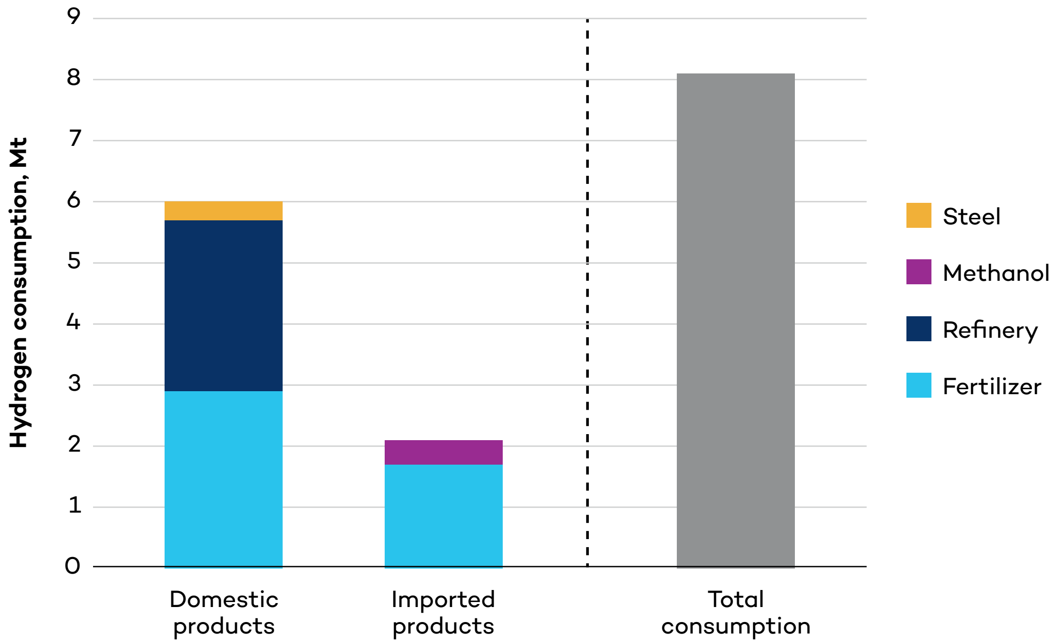
(IEA, 2023a). Electrolysis-based hydrogen production was less than 1 Mt and constituted less than 0.1% of total hydrogen production (IEA, 2023a).

The anticipated annual production of low-emission hydrogen could reach 38 Mt by 2030 if all the announced projects come to fruition, although a significant portion of this, around 17 Mt, is attributed to projects in the early stages of development (IEA, 2023a). This is significantly below a 1.5°C–2°C-aligned pathway, which requires around 50% of hydrogen production to be from low-emission sources by 2030 (50 Mt of GH_2 and 30 Mt of blue hydrogen) (IEA, 2023a). This will require installed capacity of more than 550 GW of electrolyzers, which in turn requires both a rapid scale-up of electrolyzer manufacturing capacity and significant deployment of dedicated renewable capacity for hydrogen production and enhancement of the power grid (IEA, 2023a).

India

India ranks fourth in global hydrogen consumption in 2020, with consumption of 8.1 Mt, comprised of 6 Mt of direct hydrogen consumption domestically in refineries, fertilizers, and the steel industry and 2.1 Mt of indirect consumption through imported fertilizers, ammonia, and methanol (MEC+, 2023). Most of India's hydrogen supply of 6 Mt is currently produced using domestic and imported natural gas via steam methane reforming and coal gasification. India is forecast to have direct hydrogen demand of 11.7 Mt by 2030 (Ministry of Coal, 2022).

Figure 20. Cumulative hydrogen demand in India from domestic production and imports, 2020



Source: Adapted from MEC+, 2023.

Note: Hydrogen imported through urea and diammonium phosphate are considered for hydrogen consumption in imported products. Urea and diammonium phosphate per kg contain ~0.57 kg and ~0.2 kg of ammonia, respectively. Ammonia per kg in turn contains ~0.17-0.2 kg of hydrogen. Methanol per kg contains ~0.19 kg of hydrogen.

India's GH_2 production capacity was 235 tonnes per annum in 2023 (PIB, 2023a). India aims to produce 5 Mt of GH_2 per annum by 2030. In the longer term, India will require 55 Mt of hydrogen to reach net-zero by 2050. India has the potential to produce up to 35 Mt per annum domestically, with the remaining supply being met through imports (Sharma et al., 2024).

Additionally, India is exploring opportunities to capture 10% (~10 million tonnes) of the global GH_2 export market. Oil sector PSUs are collectively targeting 1 Mt of GH_2 by 2030 (Anand, 2023). The private sector has announced investments of INR 1.75 lakh crore (USD 21 billion), mainly targeting exports as of March 2024 (JMK Research & Analytics, 2024a). There are pilot projects on GH_2 applications in the mobility, shipping, and steel industries.

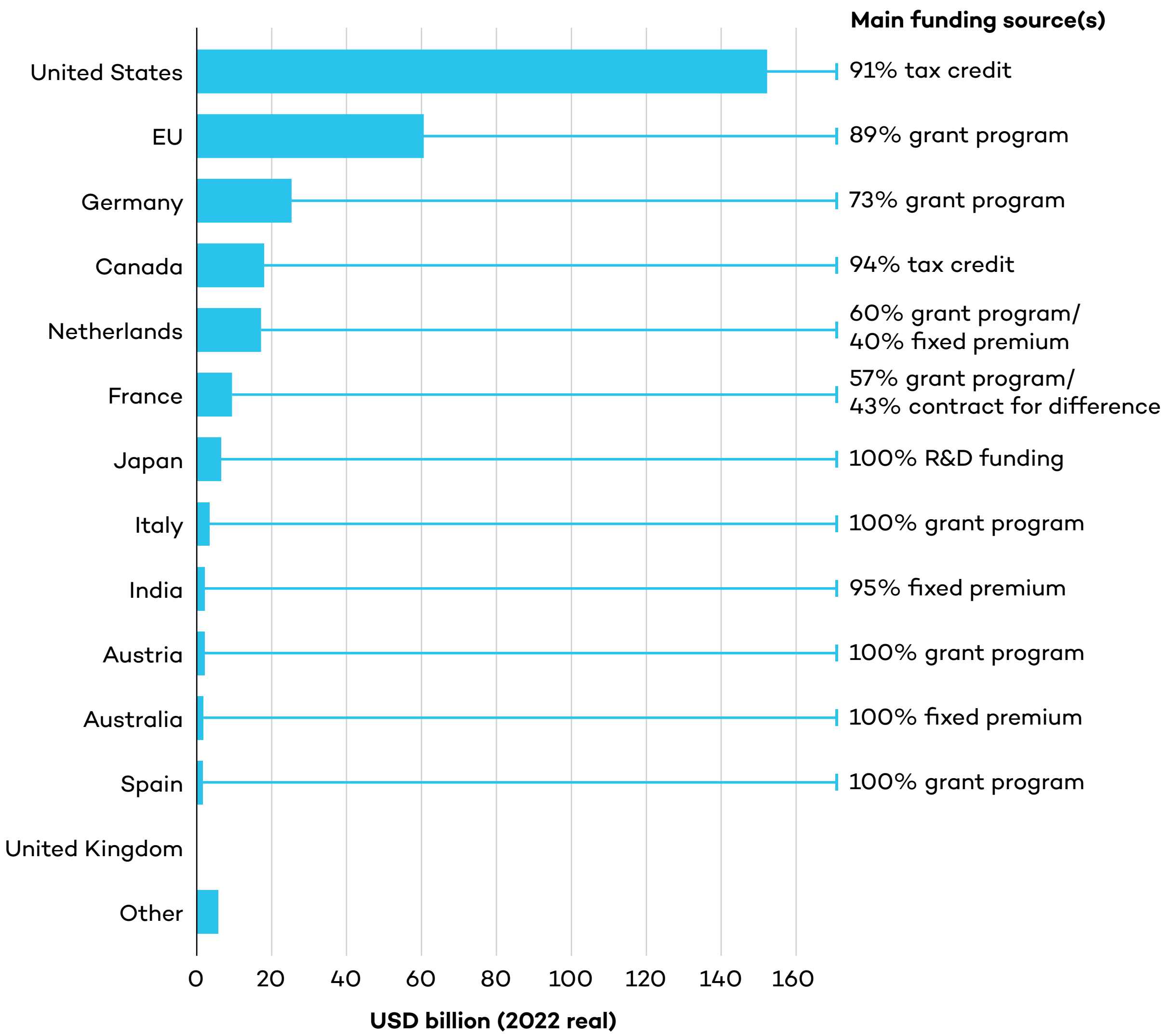
India's GH_2 producers are increasingly focusing on export markets as global demand for GH_2 grows, particularly in Europe, Japan, and South Korea. However, these countries have varying emissions standards and certification requirements for what qualifies as GH_2 based on the source of production, the carbon intensity of the process, and sustainability criteria.

The lack of standardized global certification creates a challenge for Indian producers to navigate multiple regulatory environments, each with its own thresholds for defining and accepting GH_2. To ensure Indian producers can access premium markets and sell their hydrogen at a competitive price, a robust testing and certification ecosystem is crucial. Establishing such facilities in India would help verify that the GH_2 produced meets the emissions and sustainability standards required by different export markets.

8.1.2 Government Policies to Support GH_2

GH_2 is significantly more expensive to produce than fossil-based equivalents on a levelized cost basis (see Section 8.3), therefore government intervention has been crucial to overcoming initial market barriers, fostering innovation, and scaling up production (Figure 21). The United States leads the funding efforts with substantial tax credits, followed by the European Union and Germany with grant programs. Other common policies are R&D funding and contracts-for-difference (Bhashyam, 2023). International markets, such as those in Europe and the United States, offer longer-term support of 5–10 years, providing greater financial certainty for GH_2 producers and encouraging long-term investment. A longer subsidy period helps in securing long-term offtake agreements, which are crucial for financial viability. The varied approaches highlight the need for tailored strategies that address specific national contexts and market conditions.

Figure 21. Hydrogen funding by major regions as of October 2023



Source: Adapted from Bhashyam, 2023.

The Indian government launched the National Green Hydrogen Mission in early 2023, which aimed to (MNRE, 2023a)

- develop GH_2 production capacity of at least 5 Mt per annum (50% of its total hydrogen demand),
- stimulate over INR 8 lakh crore in total investments,
- create 6 lakh jobs,
- cumulatively reduce fossil fuel imports worth over INR 1 lakh crore,
- abate nearly 50 Mt of annual GHG emissions, and
- create associated renewable energy capacity of about 125 GW by 2030.

The initial outlay was INR 19,744 crore, mostly for the Strategic Interventions for Green Hydrogen Transition (SIGHT) program, funding domestic manufacturing of electrolyzers and GH_2 production (INR 4,440 crore and INR 13,050 crore, respectively), as well as pilot projects in steel, shipping, and mobility (Table 17).

The first phase of the SIGHT program (from 2022/2023 to 2025/2026) focuses initially on the deployment of GH_2 in sectors (refineries, fertilizers, and city gas) that are already using hydrogen and evolving an ecosystem for R&D, regulations, and pilot projects. In the second phase (from 2026/2027 to 2029/2030), GH_2 costs were expected (in the program design) to become competitive with fossil fuel-based alternatives in the refineries and the fertilizer sector. The potential for taking up commercial-scale GH_2-based projects in steel, mobility and shipping sectors would be explored. At the same time, it is proposed that pilot projects be undertaken in other potential sectors like railways, aviation, etc.

Table 17. Government support measures for GH_2

Name of the support measure	Type of support measure	Type of policy instrument	Objective
Incentive scheme for electrolyzer manufacturing	Fiscal	PLI (auction-based)	Providing incentives to boost domestic electrolyzer manufacturing capacities, reducing reliance on imports
Incentive scheme for Green Hydrogen Production	Fiscal	Production-based incentive (auction-based)	Providing incentives for GH_2 producers to make it competitive with fossil fuel-derived hydrogen
Scheme for Pilot projects for the use of hydrogen in the shipping, steel, and transport sectors	Fiscal	Grant	Providing incentives for supporting pilot projects for a green transition in steel production, long-haul heavy-duty transport, and shipping
Scheme for setting up Hydrogen Hubs	Fiscal	Grant	Providing incentives for developing supporting infrastructure in regions capable of large-scale production and/or utilization of hydrogen as Green Hydrogen Hubs
Scheme for Research and Development	Fiscal	Grant	Providing incentives for increasing the affordability of GH_2 production, storage, transportation, and utilization and to enhance the efficiency, safety, and reliability of the relevant systems and processes

Name of the support measure	Type of support measure	Type of policy instrument	Objective
Scheme for skill development	Fiscal	Grant	Providing incentives for skilling/re-skilling of manpower and helping develop an ecosystem for carrying out training covering key aspects of the GH_2 value chain
Scheme for funding testing facilities, infrastructure, and institutional support for the development of standards and regulatory framework	Fiscal	Grant	Providing incentives for developing testing and certification infrastructure for the components of the GH_2 value chain
Waiver of ISTS charges for 25 years for plants commissioned before 2025	Fiscal	Revenue forgone	Provision of 25-year exemption on ISTS charges to GH_2 and green ammonia plants commissioned before 2025

Source: Authors.

8.2 Approach

To estimate the cost gap and government support required for achieving the GH_2 target in India, the project team used the Excel-based model LCOH tool developed by Agora Energiewende and customized it to meet our project-specific needs. The customization included

- the price of renewable electricity in India, based on the output of the solar LCOE developed in this report;
- the CapEx reductions in alkaline and PEM electrolyzers, based on a literature review of the learning rates and used to estimate year-wise LCOH for alkaline and PEM electrolyzers between the years 2024 and 2050; and
- the LCOH, assumed to be an average of the LCOH of alkaline and PEM electrolyzers.

The overall cost gap was estimated as the difference between the LCOH of green and grey hydrogen multiplied by the adoption rate of GH_2. The adoption rate of GH_2 was adapted from government targets and projections from other reputable organizations (EY, 2022; Hall et al., 2020). The LCOH of grey hydrogen was adapted from secondary literature (Raj et al., 2022).

8.3 Results

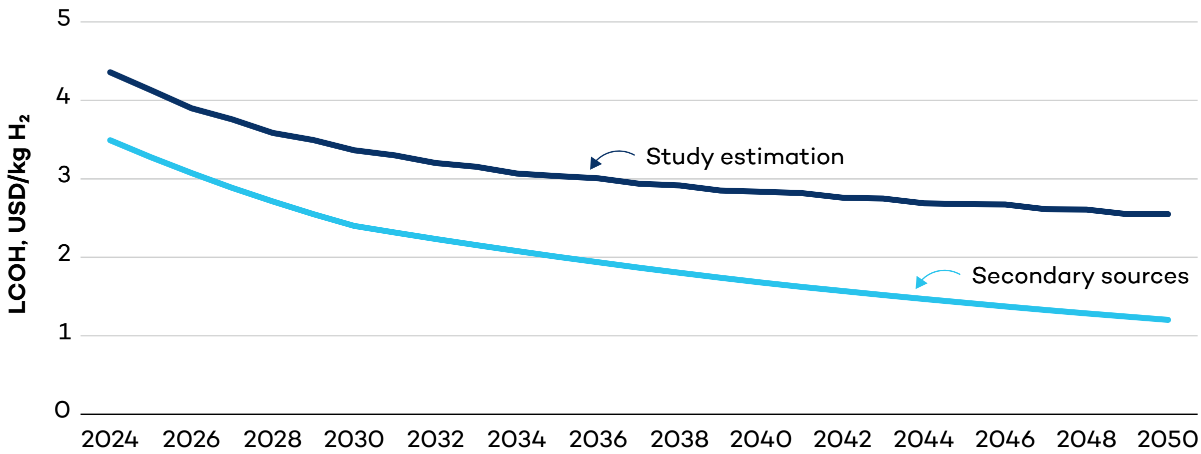
8.3.1 LCOH Analysis

The estimated average LCOH for GH_2 was (INR 362/kg H_2 (USD 4.36/kg H_2) in 2024, which declines to INR 212/kg H_2 (USD 2.55/kg H_2) by 2050. The trajectory of decline in LCOH for alkaline and PEM electrolyzers is highlighted below:

- LCOH for alkaline membrane electrolyzers showed a decrease from INR 286/kg H_2 (USD 3.45/kg H_2) in 2024 to INR 194/kg H_2 (USD 2.34/kg H_2) in 2050.
- LCOH for PEM electrolyzers started with a higher LCOH of INR 437/kg H_2 (USD 5.27/kg H_2) in 2024 but exhibited a steeper decline, reaching INR 228/kg H_2 (USD 2.75/kg H_2) by 2050.

Early studies ("secondary sources") on the LCOH of GH_2 reflected a steep decline from INR 289/kg H_2 (USD 3.49/kg H_2) in 2024 to INR 100/kg H_2 (USD 1.2/kg H_2) in 2050 (Figure 22), based on aggressive assumptions about decreasing electrolyzer and renewable electricity costs (Biswas et al., 2020; Raj et al., 2022). However, recent literature shows that the assumption of an aggressive decline in electrolyzer costs and renewable electricity costs is not being borne out due to a slower decline in the capital cost of electrolyzers, higher renewable electricity costs, and the increasing cost of capital (IEA, 2023a). Based on recent literature and our consultations with experts, we consider a moderate decline in electrolyzer costs and renewable electricity prices to better reflect current and predicted conditions.

Figure 22. Comparison of LCOH results from the study with secondary sources

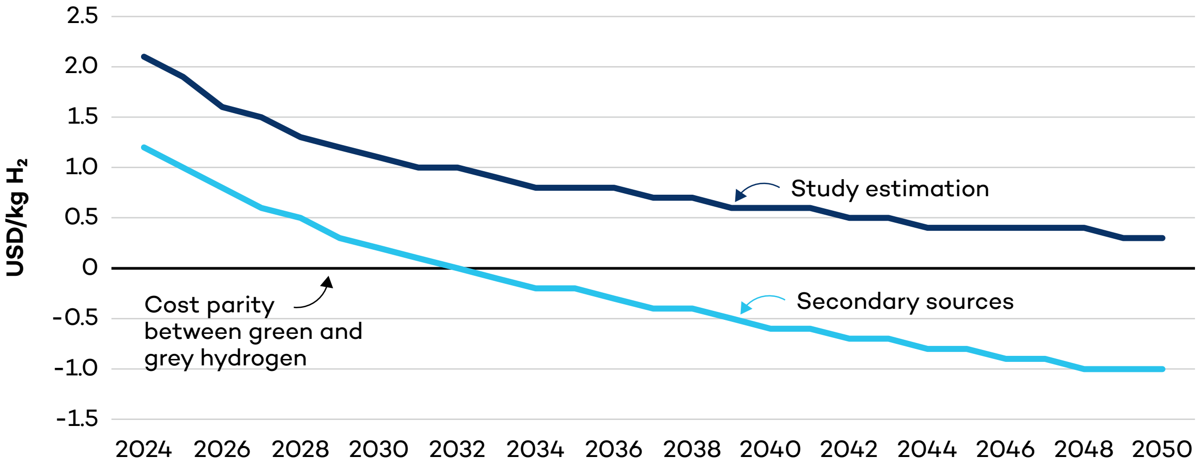


Source: Authors' calculations based on data from Biswas et al., 2020; Raj et al., 2022.

8.3.2 Cost Gap

Based on our average LCOH projections, GH_2 does not become price competitive with grey hydrogen until 2050. This assumes that GH_2 costs decline from INR 362/kg H_2 (USD 4.36/kg H_2) in 2024 to INR 212/kg H_2 (USD 2.55/kg H_2) in 2050 and a constant cost of grey hydrogen of INR 187/kg H_2 (USD 2.25/kg H_2).

Figure 23. Cost differential between green hydrogen and grey hydrogen, 2024-2050

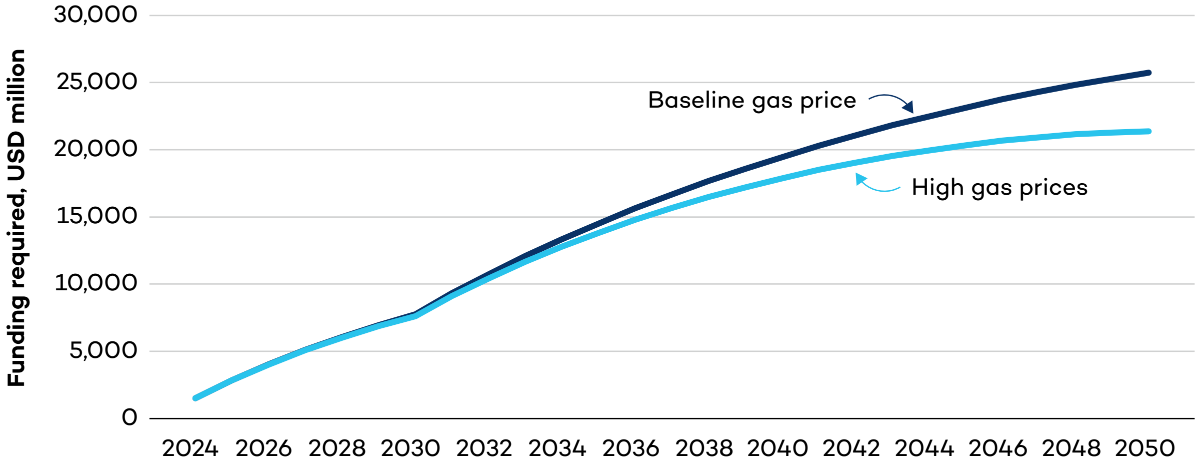


Source: Authors' analysis.

The cost gap per kg of GH_2 with respect to grey hydrogen was estimated to be INR 175/kg H_2 (USD 2.11/kg H_2) in 2024 and gradually declines to INR 25/kg H_2 (USD 0.298/kg H_2) by 2050 (Figure 23). Multiplying this by the adoption rate, we find the total cost gap. Between 2024 and 2030, the cost gap required for GH_2 adoption exhibits a significant upward trend, indicating growing investment in this sector. The cumulative cost gap escalates significantly, reaching over INR 2.8 lakh crore (USD 34 billion) by 2030, reflecting higher adoption rates. While the government's INR 13,050 crore PLI under the SIGHT program is a significant step toward GH_2 production, it only covers 4.59% of the total cost gap needed by 2030.

According to our study and global estimates, the levelized cost of GH_2 is INR 415–581/kg (USD 5–7/kg), while the levelized cost of GH_2 is INR 125–249/kg (USD 1.5–3/kg), which creates a green premium of INR 291–332/kg (USD 3.5–4/kg). Government incentives of around INR 44/kg (USD 0.5/kg) are not enough to cover the green premium. Additionally, based on the trajectory of the successful bids for Tranche I of GH_2 production, 23% (INR 3,055 crore out of an INR 13,050 crore outlay) of the financial incentives for GH_2 production has already been committed for 8% (0.4 Mt out of the 5 Mt target) of the 2030 targets. A conservative estimate suggests that the current financial outlay for GH_2 production will only be able to support 1.7 Mt of GH_2 production (34% of the 5 Mt target).

Figure 24. Sensitivity analysis for funding required for GH_2 with respect to grey hydrogen considering adoption rate in different scenarios



Source: Authors' analysis.

8.4 Macroeconomic Results

Our analysis shows that achieving the government targets for GH_2 production would have a negative macroeconomic impact, given that GH_2 costs are forecasted to be higher than the benchmark (grey hydrogen) throughout the period of our study (to 2050). This is because of two main factors:

1. The higher cost of energy supply would be a drag on economic growth.
2. If government spending were to fill the cost gap, there would be opportunity costs because public spending could be used in more efficient ways.

A benefit emerges, though, in relation to reduced air emissions and air pollution, although this is small when compared with grey hydrogen.

Two scenarios were considered in the macroeconomic analysis, as presented in Table 18. These include a comparison between green and grey hydrogen and then variations on the cost of grey hydrogen (using a high assumption). The level of government support was tested for four scenarios: 100%, 30%, 4.59% (the current support being provided to GH_2), and 0%.

Table 18. Summary of investment requirements for two key scenarios for GH_2

Scenario	Description	Investment required (100% by the government)
Baseline	Green vs. grey (baseline)	INR 34.43 lakh crore
Scenario 1	Green vs. high grey cost (assumes natural gas prices increase or a carbon tax)	INR 31.24 lakh crore

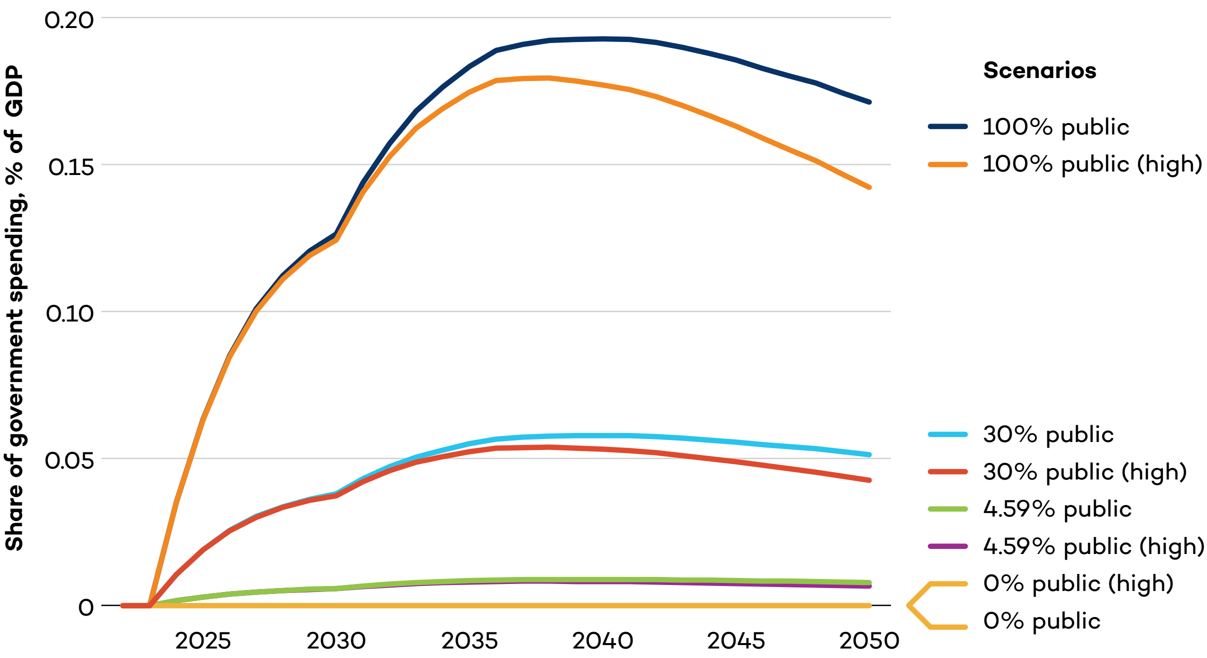
Source: Authors.

As a result of the higher cost of GH_2, the government support required as a percentage of GDP ranges between 0.18% (2036 in the green vs. grey high-cost scenario) and 0.21% (2041 in the green vs. grey scenario) at its peak. After that point, because of the assumed adoption rate and unit cost reduction, the relative size of the government support is projected to stabilize and slightly decline (Figure 25).

Further, all scenarios project a negative BCR for government support, although the benefit of using hydrogen, as opposed to consuming liquid fuels, is not considered in this calculation (Figure 26). In other words, reductions in air emissions and air pollution, and the potential positive impact of creating a new value chain in the country, are not quantified as benefits.

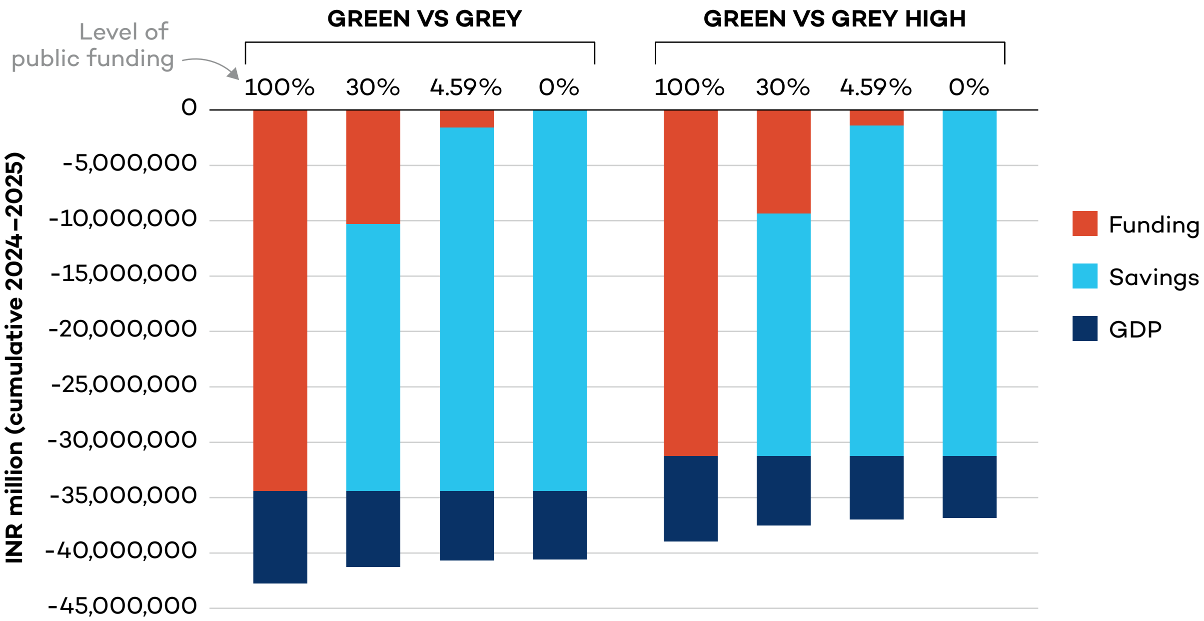
The co-benefit estimated instead, only when comparing green and grey hydrogen, was emissions reductions, which totalled 1.9 billion tonnes of cumulative emissions avoided by 2050, about 2% of national emissions per year.

Figure 25. Share of government spending required in different scenarios as a share of India's GDP



Source: Authors' analysis.

Figure 26. Net impact of varying the level of government support on GDP, public funding, and private funding



Source: Authors' analysis.

8.5 Discussion

Current government support is very unlikely to be sufficient to achieve government targets for GH_2 in India. According to our LCOH estimates, GH_2 does not become price competitive with grey hydrogen till 2050. The current government incentive (INR 19,744 crore) stands at 11% of the total announced private investment of INR 1.76 lakh crore (by March 2024) in the GH_2 sector. The private sector is mainly targeting export markets that fetch higher premiums and incentives for GH_2.

While the Indian government has taken significant steps to support the GH_2 sector, domestic support alone is not sufficient to bridge the substantial cost gap required to scale up GH_2 production and infrastructure. The high cost of GH_2 compared to grey hydrogen, combined with the need for large-scale investments in technology and industry hubs, means that new government interventions would be needed to meet India's ambitious goals. International climate finance could support domestic efforts. Multilateral development banks are stepping in with significant funding and technical assistance, playing a key role in accelerating India's GH_2 mission. The European Investment Bank will be supporting India's GH_2 mission by developing a large-scale industry hub with funding of EUR 1 billion. The Asian Development Bank has recently conveyed its intent to provide USD 20 billion–USD 25 billion over 5 years to aid India's aspirations for green growth. The World Bank has approved USD 1.5 billion in financing to support India's low-carbon transition journey (PIB, 2023c). The next tranche of USD 1.5 billion has also been announced recently (World Bank, 2024).

Current funding covers only ~5% of the cost gap and will be exhausted before 2030, requiring a second tranche to continue even at this minimal level of support. Overall, for the government to bridge the full cost gap for GH_2 between 2024 and 2030, nearly 0.96% of the GDP would be required.

Box 6. Strategic public investment in GH_2: Unlocking long-term benefits despite high costs

The climate impact of a hydrogen economy depends on how hydrogen is produced. Although GH_2 is currently more expensive than its fossil fuel-based counterpart, it remains the most commercially viable hydrogen decarbonization technology for many industries. The use of GH_2 between 2030 and 2100 with a 0% leakage rate could result in a cumulative reduction of 331 $GtCO_2$ emitted into the atmosphere, while a mix of grey, blue, and GH_2 has lower climate benefits (Hauglustaine et al., 2022).

In emerging economies, demand for hydrogen is rising in hard-to-abate sectors. Continuing to invest in fossil fuel alternatives such as blue or grey hydrogen may be cheaper now but would lock in emissions for decades and keep industries vulnerable to fluctuating fuel prices, potentially requiring costly retrofits in the future (IEA, 2024d).

While GH_2's higher cost presents a challenge for project developers in the short term, its impact on final product prices is often marginal. For industries where hydrogen is used as an intermediate feedstock, such as steel production for EVs, the added cost may only increase the final product price by a small percentage. For example, using GH_2 in steel production for EVs would raise the total price of an EV by just 1% (IEA, 2024d). As GH_2 production scales up and technology improves, these cost premiums are expected to shrink, making it a wise long-term investment for governments focused on decarbonization.

Refining is one of the largest users of hydrogen, yet hydrogen accounts for only a small fraction of operational costs in the sector (Raj et al., 2022). A carbon tax on grey hydrogen would incentivize refineries to switch to GH_2, which is cleaner and helps meet both domestic and international climate targets. Additionally, such a tax would create a financial disincentive for continued reliance on fossil fuel-based hydrogen, pushing industries toward adopting cleaner alternatives sooner. To enable the transition to GH_2, India will need a policy mix of government support and carbon pricing. Our study finds that in the absence of carbon pricing on grey hydrogen, the BCR remains poor since most of the cost gets passed on to the private sector. The revenue generated (in the case of a carbon tax) could be directed to increase support for GH_2.

India's carbon credit trading scheme, launched as part of its broader climate action strategy, aims to reduce GHG emissions across key industries, like refining, fertilizers, and steel, by allowing businesses to earn or buy credits based on their emissions reductions. Carbon credits could contribute to funding GH_2 adoption in refining and other sectors.

Non-fiscal incentives will be equally, if not more, important to further help bring costs down and reduce the scale of government support needed. Currently, a lack of offtake agreements is a significant barrier in the domestic GH_2 market, and the government could lower the barrier by coming out with a GH_2 purchase obligation for existing users of grey hydrogen, such as refineries, fertilizers, and city gas distribution. However, this does push costs onto the private sector through higher energy costs, creating inefficiencies and becoming a drag on GDP.

GH_2 is an important emerging sector for industrial development and climate action. However, the benefits of early adoption need to be balanced against the high costs. The government may wish to revise its expectations and plans for Phase II of the SIGHT program, which was developed with the expectation that GH_2 would become cost-competitive in the late 2020s with fossil alternatives in the refinery and fertilizer sectors.

Recommendations:

- Revise the current target and timeline and align these with the support policies, noting that GH_2 is likely to require higher financial and non-financial assistance than currently provided.
- Extend the tenure of GH_2 subsidies beyond the current 3-year period to help secure long-term offtake agreements and provide financial stability.
- Impose a carbon tax on hydrogen from natural gas in sectors such as refining to allow GH_2 to become competitive sooner while generating tax revenue (this effectively raises the benchmark price in our scenarios, allowing GH_2 to become cost-competitive sooner).
- Accompany the carbon tax with a GH_2 purchase obligation, including for PSUs or specific emissions reduction targets under the Carbon Credit Trading Scheme for hydrogen-using sectors (refineries, fertilizers, steel, and city gas distribution).
- Offer incentives for manufacturing end-use products like green steel, green urea, and green chemicals to drive demand for GH_2 in key sectors. These incentives will help build a domestic market for GH_2, encourage offtakers, and create long-term demand.
- Facilitate GH_2 exports by developing robust testing and certification facilities to ensure that Indian producers meet international standards. This will allow Indian GH_2 producers to access international carbon credit markets, including internationally traded mitigation outcomes and voluntary offset markets.
- Seek international climate finance, given that many economies see India as a geography that is able to produce large volumes of relatively low-cost green power for exports.
- Provide additional R&D funding to support innovators working on alternative GH_2 production technologies.

9.0 Conclusion

India's eventual transition to clean energy seems highly likely based on the results of this study. Several technologies have already achieved or will soon achieve cost parity with conventional equivalents and are now dominating their respective markets (BESSs, solar PV, and e3Ws). Others, like e2Ws, e-buses and electric cars, and offshore wind, are projected to reach cost parity in the next decade or so, after which their adoption will primarily deliver upsides for India as energy savings, pollution reduction, and new jobs.

However, the speed of the transition will be critically linked to the timing, sizing, and nature of government support. For technologies that have not yet reached cost parity, ongoing support is needed to help bridge the cost gap, secure macroeconomic benefits, and achieve government goals, particularly the fast-approaching ones for 2030.

Our macroeconomic analysis indicates that government support for four of the five technologies we examined is highly worthwhile. In the 2050 time frame, BESSs, solar PV, offshore wind, and EVs deliver economic paybacks and boosts to GDP. Only GH_2 did not show macroeconomic benefits because cost parity was reached outside the period of our study—beyond 2050. Financial support from government is not the only kind that will be needed. Many other policy alternatives are available: for example, regulatory instruments, such as power market reforms, can enable BESSs to realize better value and reduce costs and fuel efficiency standards, such as Corporate Average Fuel Efficiency norms and zero-emissions vehicle mandates, can help EV supply. Thus, deployment or consumer discounts for GH_2 users can help secure offtaker agreements. Governments can also intervene with regulations like emissions taxes or cap-and-trade systems to make emissions costlier, prompting companies to invest in cleaner technologies. Informational tools such as public awareness campaigns and educational programs that promote the benefits of clean energy technologies can also help alter consumer behaviour and encourage adoption.

Making existing programs work better can also help achieve the targets. For example, the flagship program for distributed solar PV for agricultural irrigation, PM-KUSUM, has huge potential to add solar capacity while taking financial pressure off discoms. The current program is underspent due to implementation problems, with regular changes in solar module prices leading to uncertainty for regulators and bidders. The government, therefore, has an opportunity to redesign and support the states more closely to ensure maximum effectiveness.

India has a strong PSU sector that could be decisive in accelerating the clean energy transition. The Central Government could require PSUs to develop detailed energy transition plans that see them divesting from fossil fuels and moving to clean energy within specific time frames.

We did not model every potential measure or pathway, but our results suggest that investing in clean energy now—whether in the public or private sector—is likely to deliver net economy-wide benefits. This is because they all encourage investment in technologies that are on a growth trajectory, reduce pollution, and ultimately result in energy savings. Only GH_2 showed persistent reductions in GDP because it does not reach cost parity until 2050: the pay-off is in the years outside the time frame of our analysis. Even so, GH_2 was still projected to deliver co-benefits in terms of GHG and air pollution reductions.

Funding for clean energy incentives will need to be identified from a range of sources. Climate financing and carbon markets are one key source. Indeed, India stated in its latest nationally determined contributions under the United Nations Framework Convention on Climate Change that its clean energy goals are conditional on technology transfer and concessional climate financing. International donors will need to step up to meet the new climate finance package proposed at the 29th UN Climate Change Conference (COP 29) called the New Collective Quantified Goal. Countries can also assist by shifting their international lending from fossil fuels to clean energy, as agreed under the Clean Energy Transition Partnership.

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