Budgeting for Net Zero

Supplementary technical note

TECHNICAL NOTE

International Institute for Sustainable Development

December 2024

Published by the International Institute for Sustainable Development

International Institute for Sustainable Development

The International Institute for Sustainable Development (IISD) is an award-winning, independent think tank working to accelerate solutions for a stable climate, sustainable resource management, and fair economies. Our work inspires better decisions and sparks meaningful action to help people and the planet thrive. We shine a light on what can be achieved when governments, businesses, non-profits, and communities come together. IISD's staff of more than 200 people come from across the globe and from many disciplines. With offices in Winnipeg, Geneva, Ottawa, and Toronto, our work affects lives in more than 100 countries.

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

Budgeting for Net Zero: Supplementary technical note

December 2024

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

Photo: iStock

Table of Contents

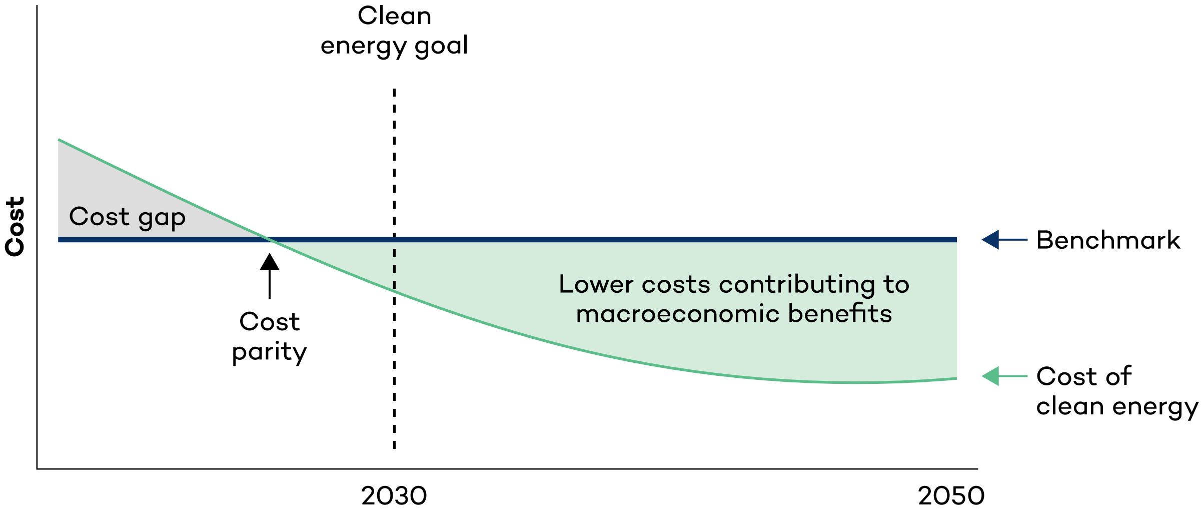
List of Figures

List of Tables

Appendix A. Detailed Methods for Cost Gap Estimates and Unit Cost Models

For this study, we used unit cost models for each technology to estimate 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 A1). 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. To the extent possible, we used India-specific data on costs and factored in expected falls in the costs of production over time (based on individual learning rates for each technology).

Figure A1. A simplified illustration of the study approach to model cost gap



Source: Authors.

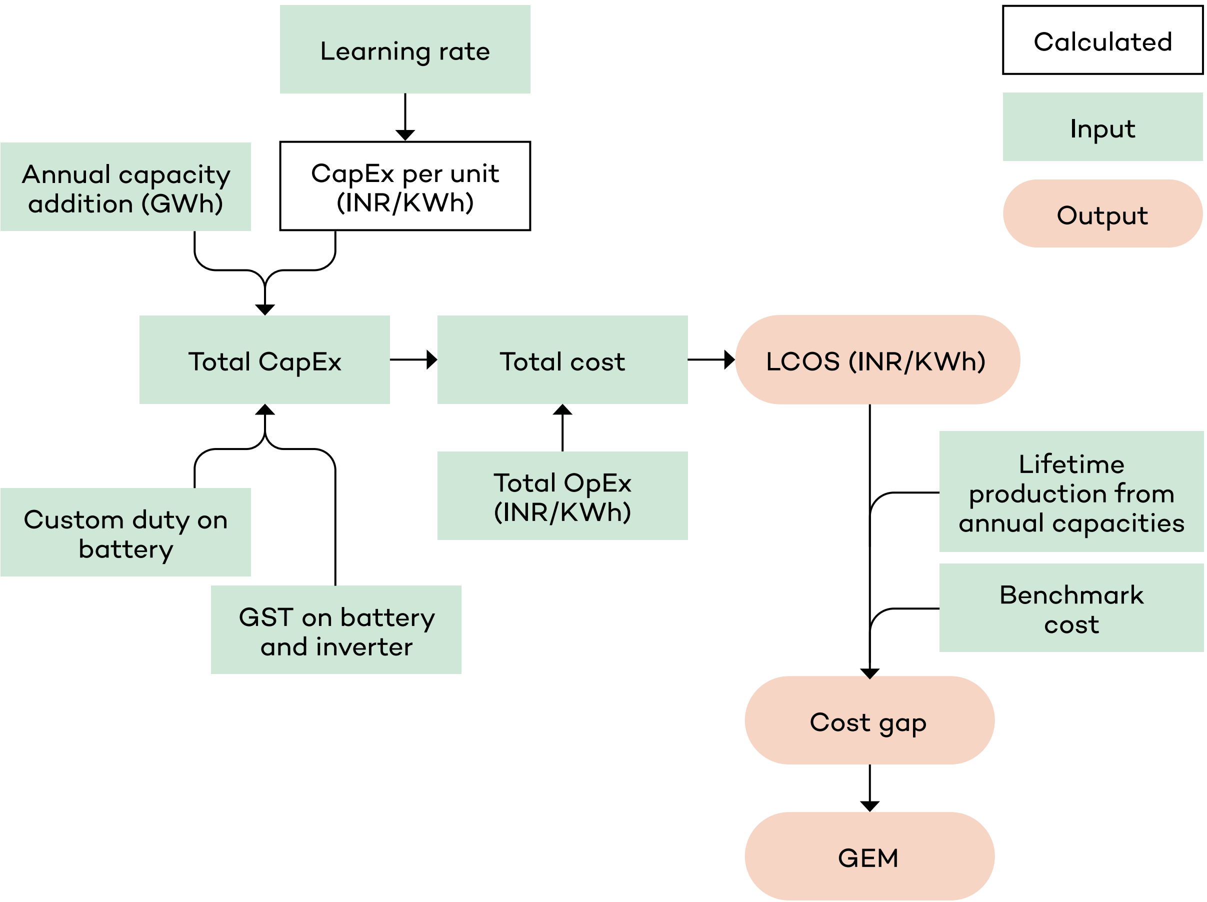
This section describes our detailed methods for each technology.

A1. Battery Energy Storage Systems

A1.1 Methodology

Figure A2 shows the overall methodology and model structure used to compute the cost gap for standalone battery energy storage systems (BESSs).

Figure A2. The overall approach for estimating the cost gap for standalone BESSs



Source: Authors.

Note: Variables inside green boxes are the input variables, and variables inside pink boxes are the output variables. The cost gap calculated in the above flowchart is used as an input in the Green Economy Model (GEM), which then estimates the potential net cost-benefit of government support for each technology at varying levels.

CapEx = capital expenditure; OpEx: operating expense; LCOS = levelized cost of storage; GST = Goods and Services Tax

The cost gap is determined based on the cost differential between the estimated LCOS and the benchmark electricity price multiplied by the lifetime production as per annual capacity addition based on the National Electricity Plan (Central Electricity Authority [CEA], 2023).

$$\textit{Cost Gap} = \sum_{t \in 2023-50} (LCOS_t - Benchmark_t) \times P_t$$

where,

t = year

LCOS = levelized cost of storage (standalone BESSs) each year

Benchmark = average price of electricity during evening hours

P = lifetime production from annual capacities (based on the lifetime generation of a 1 kWh system and annual capacity addition)

A1.2 Key Parameters

A1.2.1 LCOS of Standalone BESSs

To calculate the LCOS for standalone BESSs for each year of the study period, we used the Levelized Cost Calculator for Distributed Energy Resources v2.0, developed by Auroville Consulting, as the base model (Auroville Consulting, 2021) and customized it for utility-scale standalone BESSs to meet our project-specific needs. A detailed techno-economic analysis was conducted, incorporating various battery storage parameters. The cost parameters were also projected into the future based on learning rates. The inputs used in the model were based on secondary sources (Auroville Consulting, 2021; CEA & Danish Energy Agency [DEA], 2022; Deorah et al., 2020) and stakeholder consultations. Major inputs were also validated with supplementary references, and specific parameters were adjusted to align with our project's requirements.

Table A1 captures information regarding the underlying assumptions and specific parameters used in our LCOS analysis.

Table A1. Input parameters considered for the LCOS calculations (in base year 2023)

S. No.	Variables	Inputs used
A.	**System parameters**	
A1	Storage cycle life	6,000 cycles
A2	Storage duration at 100% depth of discharge	2 hours
A3	Depth of discharge	95%
A4	Storage round-trip efficiency	97%
A5	Time degradation	1%
A6	Cycle degradation	0.0006%
A7	Inverter efficiency	96%
A8	Inverter replacement year	15
B.	**Financial parameters**	
B1	Debt:equity	70:30
B2	Return on equity	16%
B3	Interest on loan	10%
B4	Loan tenure	15 years
B5	Discount rate	10%
B6	Salvage value	10%
B7	Cost of battery pack	INR 10,438/kWh

S. No.	Variables	Inputs used
B8	Custom duty – lithium-ion (Li-ion) battery	13%
B9	Goods and Services Tax (GST) – Li-ion battery	18%
B10	Cost of enclosure and balance-of-system	INR 2,153/kWh
B11	Cost of battery inverter	INR 1,187/kW
B12	GST – Inverter	28%
B13	GST – Installation	18%

Sources: Auroville Consulting, 2021; CEA & DEA, 2022; Deorah et al., 2020; authors.

A1.2.2 Benchmark Cost

The benchmark cost is the target or desired LCOS required to achieve market adoption of BESSs and reflects the cost per unit needed to achieve grid parity for the technology. Since BESSs are currently being deployed primarily to meet the evening peak demand, we have chosen the average price of electricity during evening hours on the Indian Energy Exchange as our benchmark cost for calculating the per-unit cost differential for each year. This was INR 7.30/kWh in 2023 (India Energy Exchange, 2024).

A1.2.3 Timeline

The cost gap is calculated until the year each technology achieves cost parity with the benchmark cost. In the case of standalone BESSs, we found that cost parity is achieved in 2028 in the business-as-usual (BAU) scenario. Thus, we used 2023–2027 as the timeline for estimating the total cost gap.

A1.2.4 Lifetime Production and Capacity Goals

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, 2023). The per-unit cost differential from steps 1 and 2 above was then multiplied by the lifetime production in each year based on India's capacity goals for BESSs to calculate the total cost gap.

The lifetime production is calculated as follows:

$$\textit{Lifetime production} = \textit{Annual capacity addition} \times \textit{Lifetime generation by a 1 kWh system}$$

Table A2. Summary of key parameters and model assumptions for BESS

Parameter	Unit	Base year (2023)	2030	2040	2050
CapEx	INR/kWh	17,228	10,670	9,650	8,727
Learning rate	%	5%	5%	1%	1%
OpEx	INR/kWh/year	172.3	106.7	96.5	87.3
LCOS	INR/kWh	8.89	6.19	5.72	5.21
Benchmark	INR/kWh	7.3	7.3	7.3	7.3
Storage duration	Hours	2	4	6	10
Capacity goal	GWh	0.04	208	587.92	1,840

Source: CEA & DEA, 2022; Deorah et al., 2020; India Energy Exchange, 2024; authors.

A1.3 Description of Scenarios Considered to Study Government Support

The aforementioned steps were used to calculate the cost gap in the BAU scenario. However, to further study the size, nature, and macroeconomic impact of bridging the estimated cost gap using government support, we also developed the scenarios shown in Table A3.

Table A3. Scenarios considered in the GEM for studying the impact of providing government support to bridge the cost gap for BESSs

Scenarios	Description
Scenario 1	**Cost gap, 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	**Cost gap, excluding 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

Source: Authors.

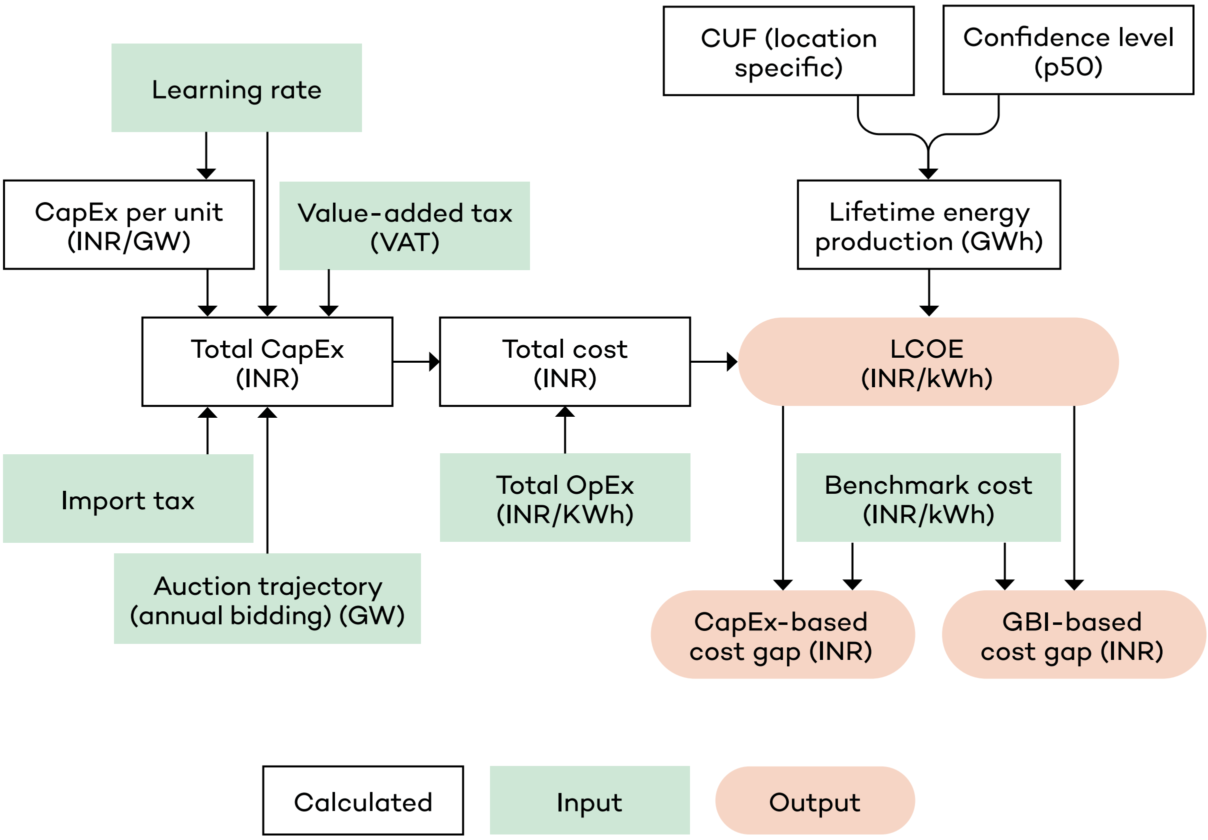
These scenarios helped us study the macroeconomic impacts of providing government support to BESSs on GDP, employment, energy savings, and greenhouse gas (GHG) and emissions reductions. Detailed results from the analysis can be found in the full report.

A2 Offshore Wind

A2.1 Methodology

Figure A3 shows the overall methodology and model structure used to compute the cost gap for offshore wind. The study objective is to estimate the cost gap for offshore wind that will need to be bridged to reach cost parity with the benchmark cost in order to achieve its goals for India.

Figure A3. The overall approach for estimating the cost gap for offshore wind



Source: Authors.

Note: Variables inside green boxes are the input variables, and variables inside pink boxes are the output variables. The cost gap calculated in the above flowchart is used as an input in the GEM, which then estimates the potential net cost-benefit of government support for each technology at varying levels.

GBI = generation-based incentive

The cost gap is determined based on the cost differential between the LCOE generated from offshore wind and the benchmark cost multiplied by the annual production needed to achieve India’s national goals.

$$Cost\ Gap = \sum_{t \in 2024-37} (LCOE\_OfW_t - Benchmark_t) \times P_t$$

where,

t = year

LCOE_OfWt = levelized cost of electricity generated from offshore wind each year

Benchmark = average electricity price each year

P = lifetime production from annual capacities of all offshore wind projects (based on the lifetime generation of 15 MW turbines and annual capacity addition)

A2.2 Key Parameters

A2.2.1 LCOE From Offshore Wind

To compute the LCOE for offshore wind, we used the Financial Modelling of Offshore Wind in India (FIMOI model) designed by the Centre of Excellence for Offshore Wind and Renewable Energy (Forman & Hansen, 2022):

$$LCoE\_OfW = \frac{\sum_{t=1}^{n} \frac{I_t + M_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

where,

t = year

I_t = investment cost in year t. This includes investments in wind turbine generators and foundation but not the strengthening of the supporting infrastructure.

M_t = operation and maintenance (O&M) costs in year t

E_t = electricity generation from the project in year t

r = discount rate

n = project life

The underlying assumptions about the system specifications, the capacity utilization factor, taxes, and financial parameters (such as plant CapEx and the cost of capital for the base year of the study) are provided in Table A4. The cost parameters were also projected into the future based on learning rates. For modelling electricity generation, we used four different confidence scenarios, p50, p75, p90, and p95[1]—as also used in the FIMOI model—to account for the uncertainty in generation for our initial LCOE calculations. However, we discovered through consultations that p75, p90, and p95 were seen as conservative estimations of annual electricity generation by various stakeholders. For subsequent analysis of the cost gap, we thus used p50 scenarios.

The electricity generation estimates in this analysis were done based on a 15 MW turbine that remains unchanged for the simulation duration. While we understand that increasing turbine size may help lower LCOE in the future, there are several uncertainties related to this assumption. To preserve the simplicity of the study, we keep this system specification fixed.

---

[1] In the p50 scenario, annual electricity production/generation value is expected to exceed the considered annual energy production (AEP) value (4,689 million units of electricity per year) 50% of the time during the project lifetime. Similarly, in p75, p90 and p95 scenarios, the generation values are expected to exceed the considered AEP values (4,057 million units per year for p75, 3,487 million units per year for p90, and 3,147 million units per year for p95) in 75, 90, and 95 per cent time of the project life, respectively.

We assumed a debt-equity ratio of 75:25. The cost of equity was considered to be 10% per annum and the interest rate on debt was assumed to be 8% per annum. The loan tenure was assumed to be 15 years. On the tax front, the FIMOI model incorporated a value-added tax of 5% and import duties of 13% on the CapEx, which we have retained for the purpose of this study. For all future years in our simulations, we kept these financial parameters fixed.

Table A4. Input parameters considered for the LCOE calculation (in base year 2024)

S. No.	Variables	Gujarat	Tamil Nadu
System parameters			
1	System size	15 MW turbines	
2	Hub height	125 m	
3	Net capacity utilization factor (after accounting for electrical losses)	36%	53%
4	Net annual energy production from 1 GW plant (p50 scenario)	4,689 GWh per year	3,119 GWh per year
Financial parameters			
5	Debt:equity	75:25	
6	Interest on loan	8% per annum	
7	Loan tenure	15 years	
8	Expected return on equity	10%	
9	Project lifetime	27 years	
10	CapEx	28.2 INR crore/MW	
12	GST	5%	
13	Custom duties on CapEx	13%	

Source: Forman & Hansen, 2022; authors.

The capital cost includes plant costs, taxes, and export system costs (including offshore substations, export cables, and onshore substations). Since the offshore wind sector is yet to develop in India, there could be several uncertainties involved in the capital cost estimation. For this study, we used the same capital cost for the base year as the FIMOI model and validated the assumptions on learning rate through stakeholder consultations. We used a learning rate of 7% per annum from the base year. Potential factors contributing to the learning rate are the evolving offshore wind ecosystem in India, the rising offshore turbine and component manufacturing capability, growing local supply chains, the project implementation experience, the deployment of larger turbines (>10 MW), and lower labour costs (Krishnan et al., 2022). However, there may also be an increase in capital costs due to various supply chain disruptions, which could widen the cost gap even further than estimated in this study.

A2.2.2 Benchmark Cost

The benchmark cost is defined as the unit cost (INR/kWh) required for offshore wind to reach cost parity with competing generation technologies. In 2023, the average price of round-the-clock electricity that was traded in the Indian Energy Exchange was INR 5.62/kWh (India Energy Exchange, 2024), which we use as the benchmark cost for offshore wind.

A2.2.3 Timeline

In our study, the base year for offshore wind is 2024, and the timeline for calculating the total cost gap is based on the year the technology reaches grid parity with the benchmark cost. In our analysis, the technology reaches cost parity with its benchmark in 2037. The cost gap was thus calculated for 2024 to 2037.

A2.2.4 Lifetime Production and Capacity Auction Goals

For this study, we used the annual auction trajectory for offshore wind sites as provided in a Ministry of New and Renewable Energy (MNRE) strategy paper, which proposes an indicative auction trajectory of 37 GW by 2030 to be developed off the coast of Tamil Nadu and Gujarat as the capacity addition goals (MNRE, 2023b). For example, the auction trajectories leading to a final investment decision for Tamil Nadu and Gujarat in the year 2023/2024 were 4 GW and 0.5 GW, respectively. In the model, we input them as "auction trajectory" for the respective states in 2023/2024.[2] Beyond 2030, we assumed that a similar pace of auctions will happen until India achieves its offshore potential of 71 GW (Prasad, 2020).

Since the offshore wind sector is yet to develop in India, it is important to highlight that the auction trajectory in Table A5 and the corresponding project commissioning schedule can undergo several changes over the next few years, but in the absence of any other official targets, we have continued to rely on this trajectory.

Table A5. Annual expected bid finalization of offshore wind considered for this study in the coming years

Year	Annual expected bid finalization (GW)
2025	8.5
2030	37.5
2035	62.5
2037	71

Source: MNRE, 2023b; Prasad, 2020; authors.

---

[2] Even though India missed achieving the 4.5 GW target for 2023/2024, it is important to highlight that the first offshore wind tender in India for a capacity of 4 GW (the target for 2023/2024 for Tamil Nadu) was issued on February 2, 2024, by the Solar Energy Corporation of India (SECI). This project will be set up under Model B off Tamil Nadu's coast.

Table A6. Summary of key parameters and model assumptions for offshore wind

Parameter	Unit	Base year (2024)	2025	2030	2035
CapEx	INR crore/MW	28.2	26.3	18.4	12.9
Learning rate	% reduction per annum in capital cost (CapEx)	7%			
OpEx	INR crore/MW/ year	0.56			
LCOE	INR/kWh	10.03 (TN) 15.08 (GJ)	9.49 (TN) 14.27 (GJ)	7.34 (TN) 11.04 (GJ)	5.88 (TN) 8.84 (GJ)
Benchmark cost	INR/kWh	5.62			
Auction goal	GW	4.5 GW	8.5 GW	37 GW	62.5

Source: Authors.
Note: TN = Tamil Nadu; GJ = Gujarat.

A2.3 Description of Scenarios Considered to Study Government Support

Finally, to calculate the cost gap in the BAU scenario, we multiplied the lifetime production with the per-unit cost differential between the estimated levelized cost each year and the benchmark cost. The cost gap for offshore wind can be met using government support in two different ways: (ii) a capital cost-based subsidy and (ii) a generation-based incentive that is disbursed throughout the lifetime of the project. To conduct a cost-benefit analysis of providing such government support and study its macroeconomic impact, we used the scenarios outlined in Table A7.

Table A7. Scenarios considered in the GEM for studying the impact of providing government support to bridge the cost gap for offshore wind

Scenarios	Description
Scenario 1	**Cost gap is bridged using CapEx-based incentives**
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	**Cost gap is bridged using generation-based incentives**
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.

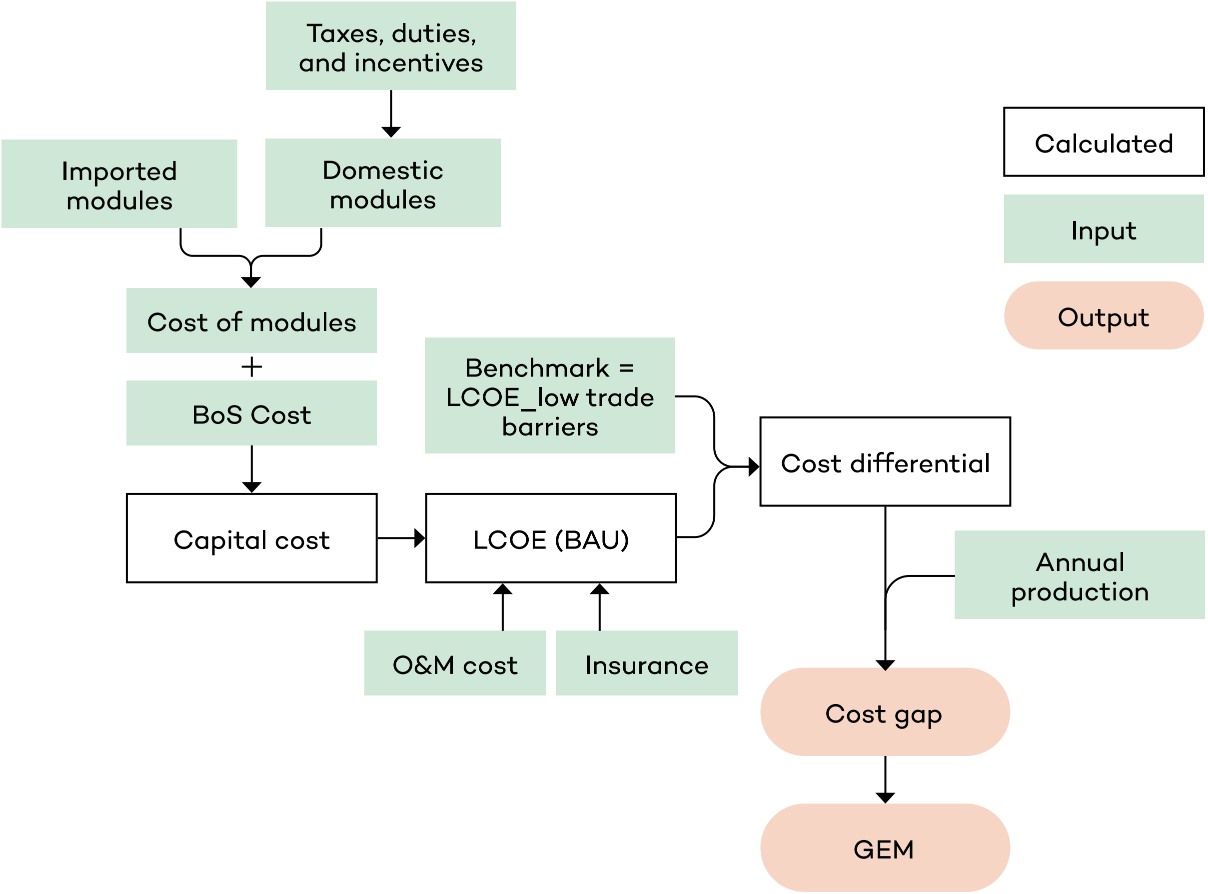
Detailed results from the analysis can be found in the full report.

A3 Solar Photovoltaic

A3.1 Methodology

Power generation from solar photovoltaic (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. We, therefore, used a slightly different approach in this module. Given the impetus on domestic solar manufacturing in recent years, we used the cost differential between imported solar PV modules and domestically manufactured solar PV modules in this module to calculate the cost gap. Figure A4 shows the overall methodology and model structure used to compute the cost gap for solar PV.

Figure A4. Methodology flow chart for estimating the cost gap required for solar PV



Source: Authors.

Note: This analysis was done separately for large-scale and small-scale solar PV. Variables inside green boxes are the input variables, and variables inside pink boxes are the output variables. The cost gap calculated in the above flowchart is used as an input in the GEM, which then estimates the potential net cost-benefit of government support for each technology at varying levels.

BoS = balance of system; O&M = operation and maintenance

The cost gap is the cost differential between LCOE arrived at by using domestic solar modules and imported solar modules multiplied by the annual production needed to achieve India's national goals for solar PV deployment.

$$Cost\ Gap = \sum_{t\, \epsilon\, 2024-37} (LCOE\_solar_t - Benchmark_t) \times P_t$$

where,

t = year

$LCOE\_solar_t$ = levelized cost of electricity from solar PV systems using domestic modules each year

Benchmark = levelized cost of electricity from solar PV systems using imported modules each year

P = lifetime production from annual capacity addition in solar PV

A3.2 Key Parameters

A3.2.1 Levelized Cost of Solar PV

To compute the LCOE for solar PV using different types of solar PV modules, we constructed a bottom-up Excel-based LCOE model for both large- and small-scale solar projects using the following formula:

$$LCoE\_solar = \frac{\sum_{t=1}^{n} \frac{I_t + M_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

where,

t = year

I_t = investment cost in year t. This includes investments in solar panels and inverters (including taxes and duties), mounting structures, electrical components, land (in case of large-scale solar), civil and general work, and evacuation costs.

M_t = O&M costs in year t. This comprises routine maintenance, repair, labour, cleaning, insurance, and any other expenses incurred to keep the installation running efficiently.

E_t = electricity generation from the project in year t

r = discount rate

n = project life

To account for rapidly evolving technologies, we also customized the LCOE model to calculate results for different panel technologies, namely polycrystalline, mono-PERC, and bifacial. Table A8 provides a list of key input parameters considered for the calculation of costs for large- and small-scale solar PV projects.

Table A8. Input parameters considered for solar PV LCOE calculations (in base year 2023)

S. No.	Variable	Inputs used
A.	**System Parameters**	
A1	Construction period	12 months
A2	Degradation loss	0.7%
A3	Capacity utilization factor	19% (large-scale), 14% (small-scale)
A4	Useful life	25 years
B.	**Financial Parameters**	
B1	Solar panel cost	INR 22.5/Wp (imported) INR 30.7/Wp (domestic)
B2	Basic custom duty (BCD)	40% for imported modules
B3	GST on solar modules	12%
B4	Capital cost (large-scale)	INR 5.2 crore/MW
B5	Capital cost (small-scale)	INR 45,767/kW
B6	O&M expenses	1.4% of capital cost
B7	Insurance cost	0.35% of net asset value
B8	Debt:equity	70:30
B9	Normative return on equity	14%
B10	Interest on loan	9%
B11	Loan tenure	15 years
B12	Discount rate	8.3%
B13	Salvage value	10%

Source: Authors.

A3.2.2 Benchmark Cost

In this module, we considered the benchmark cost for each year as the solar PV LCOE using imported modules since domestically manufactured modules are still costlier than imported ones, despite the imposition of a 40% customs duty. This helps calculate the need for government support to ensure that solar PV deployment is not negatively impacted by the current trade barriers.

A3.2.3 Timeline

The cost gap is calculated until the year each technology achieves cost parity with the benchmark cost. In solar PV, we found that the LCOE of solar PV projects using domestically manufactured modules achieves cost parity around 2030 in the BAU scenario (i.e., with a custom duty of 40% on imported modules).

A3.2.4 Lifetime Production and Capacity Goals

According to the National Electricity Plan 2023, India will need nearly 293 GW of solar PV by 2030 to ensure supply adequacy at the least cost (CEA, 2023). The per-unit cost differential from steps 1 and 2 above was then multiplied by the lifetime production in each year based on India's capacity goals for solar PV to calculate the total cost gap.

Table A9. Summary of key parameters and model assumptions for solar PV

Parameter	Unit	Base year (2023)	2030	2040	2050
CapEx	INR crore/MW	5.2	3.5	3.0	2.7
Learning rate	%	-	5%	2%	1%
LCOS	INR/kWh	4.5	3.5	2.6	2.4
Benchmark	INR/kWh	4.6	3.1	2.9	2.8
Capacity goal	GW	82	293	649	809

Source: Authors.

A3.3 Description of Scenarios Considered to Study Government Support

To calculate the cost gap for solar PV, we multiplied the annual generation from new capacity addition by the per-unit cost differential between the estimated levelized cost each year and the benchmark cost. The cost gap for solar PV thus calculated was compared with existing government support levels for the technology.

The GEM was then run to study different deployment-manufacturing trade-off scenarios by varying levels of trade barriers, such as basic customs duty (BCD) on solar PV costs, as described in Table A10.

Table A10. Scenarios used for solar PV analysis

Scenario	Description
BAU	BCD at 40%
Low trade barrier	BCD on imported modules at 10%
293 GW	Solar capacity reaches 293 GW by 2030

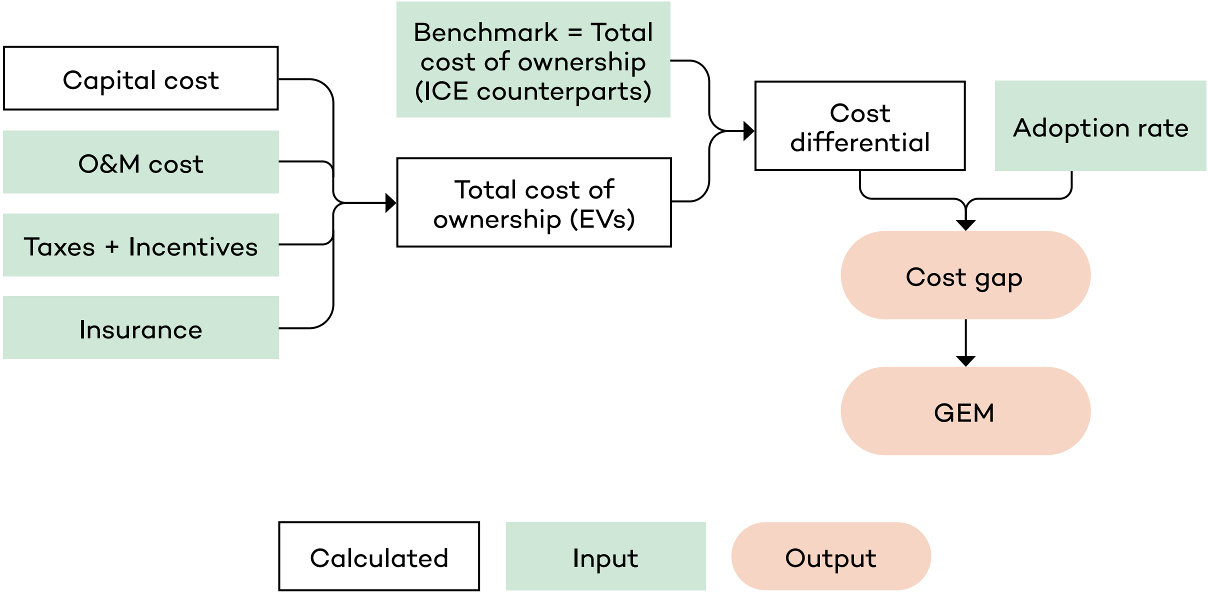
Source: Authors.

A4 Electric Vehicles

A4.1 Methodology

For the electric vehicle (EV) analysis, we used the total cost of ownership (TCO) models for EVs and internal combustion engine (ICE) vehicles in two-wheelers, three-wheelers, four-wheelers, and buses to segregate the impact of government incentives on upfront capital costs and total costs.

Figure A5. Methodology flow chart for estimating the cost gap required for EVs



Source: Authors.

Note: This analysis was done separately for electric two-wheelers, three-wheelers, four-wheelers, and buses. Variables inside green boxes are the input variables, and variables inside pink boxes are the output variables. The cost gap calculated in the above flowchart is used as an input in the GEM, which then estimates the potential net cost-benefit of government support for each technology at varying levels.

The cost gap is determined based on the cost differential between the total cost of ownership of EVs and their corresponding ICE counterparts multiplied by the annual EV sales needed to achieve India's national goals:

$$Cost\ Gap = \sum_{t \in 2020-50} (TCO\_EV_t - Benchmark_t) \times P_t$$

where,

t = year
TCO_EV = total cost of ownership of EVs each year
Benchmark = total cost of ownership of ICE counterparts each year
P = annual EV sales

A4.2 Key Parameters

A4.2.1 TCO

The TCO analysis was conducted using the World Resources Institute's (WRI's) Excel-based TCO model (WRI, n.d.). This model enables a comprehensive evaluation of the long-term costs associated with owning and operating a vehicle that considers various factors, such as purchase price, fuel costs, maintenance, insurance, and depreciation. The input data for this analysis were sourced directly from the WRI model and supplemented with data from secondary literature and consultations. In parallel, we also used the average capital costs of each vehicle type (two-wheelers, three-wheelers, four-wheelers, buses, and other categories) from the India Energy Security Scenarios 2047 (NITI Aayog & IIT Bombay, n.d.) to triangulate the data on economic parameters. The outputs from this analysis were then fed into the GEM model, enabling a more detailed and comprehensive analysis that links the financial implications of vehicle ownership with broader economic and environmental outcomes.

A4.2.2 Benchmark Cost

The benchmark cost for EVs for calculating the cost gap was the cost of ICE counterparts for each sub-segment.

A4.2.3 Timeline

The timeline for calculating the total cost gap is based on the year of cost parity of EVs with their ICE counterparts. Since this differed across sub-segments, in the case of EVs, this was dynamically calculated in the GEM.

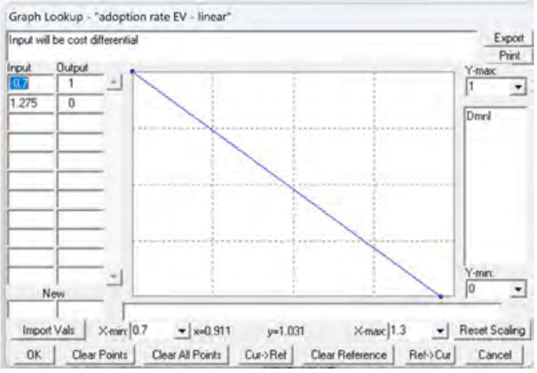
A4.2.4 Adoption Rate and Annual EV Sales

To calculate the annual EV sales needed to achieve the EV annual sales goals in each segment, we used historical data on vehicle flows and stocks from the Government of India's Vahaan database (Ministry of Road Transport and Highways, n.d.). These were exogenously analyzed and then fed into the GEM alongside economic parameters, such as upfront costs and TCO, to dynamically model the need for government support and future adoption rates.

Different adoption curves were used to estimate the potential adoption of EVs for a given cost differential with ICE vehicles. These are presented in Figure A6 and reflect examples of Linear, S-Shaped, and Rapid adoption.

Figure A6. Adoption curves considered for the analysis of EVs in GEM

Linear



Graph Lookup - "adoption rate EV - linear"

Input will be cost differential

Input	Output
0.7	1
1.275	0

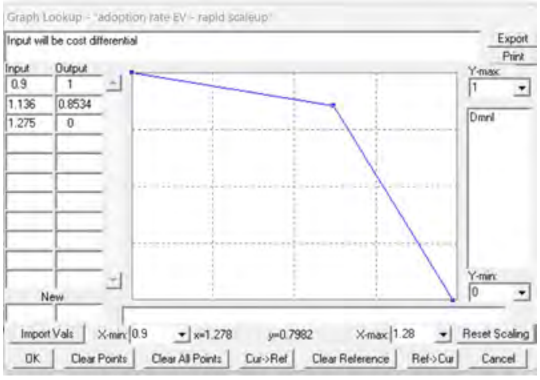
Y-max: 1

Dmnl

Y-min: 0

X-min: 0.7 x=0.911 y=1.031 X-max: 1.3

Rapid



Graph Lookup - "adoption rate EV - rapid scaleup"

Input will be cost differential

Input	Output
0.9	1
1.136	0.8534
1.275	0

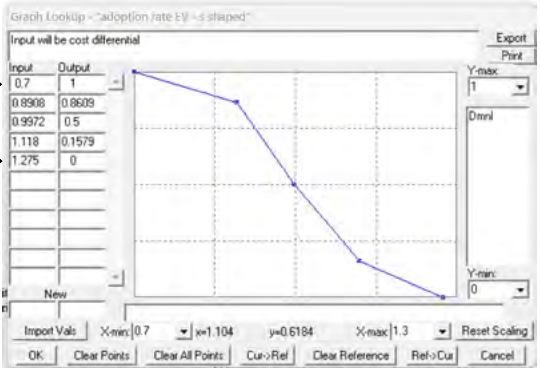
Y-max: 1

Dmnl

Y-min: 0

X-min: 0.9 x=1.278 y=0.7982 X-max: 1.28

S-shaped



Graph Lookup - "adoption rate EV - s shaped"

Input will be cost differential

Input	Output
0.7	1
0.8908	0.8609
0.9972	0.5
1.118	0.1579
1.275	0

Y-max: 1

Dmnl

Y-min: 0

X-min: 0.7 x=1.104 y=0.6184 X-max: 1.3

EVs are 30% cheaper than ICE based on TCO, full adoption

EVs are 27.5% more expensive than ICE based on TCO, no adoption

Source: Authors' analysis in the Green Economy Model, India.

Table A11. Descriptions of adoption functions (based on varying consumer preferences) used for further analysis

Adoption functions	Description
Linear adoption	Assumes that adoption of EVs is proportional to the price differential between EVs and ICEs. Further, EV purchase is 100% when EVs are 30% cheaper than ICE vehicles.
S-Shaped adoption	Assumes a more cautious approach for the adoption of EVs, with path dependence. Fewer EVs will be purchased if their TCO is higher than ICE vehicles, but more EVs will be purchased when their TCO is lower than ICE vehicles.
Rapid adoption	Assumes accelerated adoption of EVs, with an eye on future trends of electrification. Specifically, EV purchase is 100% when EVs are 10% cheaper than ICE vehicles.

Source: Authors.

A4.2 Description of ScenariosConsidered to Study Government Support

As stated above, the cost gap based on the price differential between EVs and their ICE counterparts was estimated using the TCO approach. The macroeconomic impacts of bridging this cost gap using demand-side incentives in the form of government support were then studied under two main scenarios, as described in Table A12.

Table A12. Scenarios used for EV analysis

Scenarios	Description
BAU	A scenario in EV adoption follows market dynamics (based on TCO differences).
Incentive	A scenario in which subsidies are provided to EVs to support and accelerate their adoption. The subsidy declines to zero as TCO parity is reached.

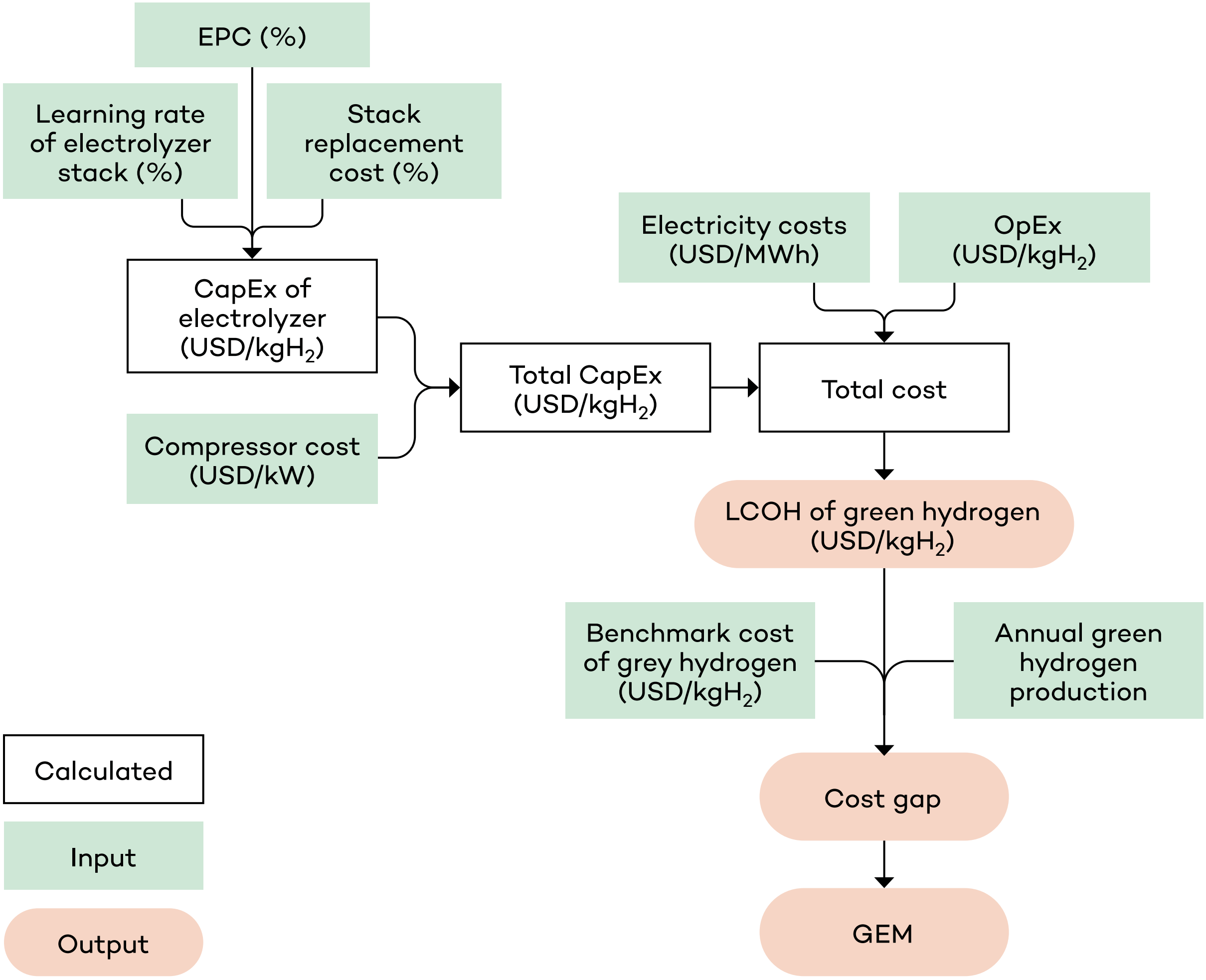
Source: Authors.

A5 Green Hydrogen

A5.1 Methodology

Figure A7 shows the overall methodology and model structure used to compute the cost gap for green hydrogen (GH_2).

Figure A7. Methodology flow chart for estimating the cost gap for GH_2



Source: Authors.

Note: Variables inside green boxes are the input variables, and variables inside pink boxes are the output variables. The cost gap calculated in the above flowchart is used as an input in the GEM, which then estimates the potential net cost-benefit of government support for each technology at varying levels.

The cost gap is determined based on the cost differential between the levelized cost of grey and GH_2 (LCOH) production multiplied by the annual GH_2 production needed to achieve India's national goals.

$$Cost\ Gap = \sum_{t \in 2024-50} (LCOH\_GH2_t - Benchmark_t) \times P_t$$

where,

t = year

LCOH_GH2 = levelized cost of green hydrogen production each year

Benchmark = levelized cost of grey hydrogen production each year

P = annual production

A5.2 Key Parameters

A5.2.1 Levelized Cost of GH_2

To calculate the levelized cost of GH_2 for each year between 2024 and 2050, we used the publicly accessible Levelized Cost of Hydrogen Calculation Tool developed by Accenture's Umlaut and Agora Energiewende as the base model (Umlaut & Agora Industry, 2023). The inputs in the base model were then modified to accommodate inputs received during expert and industry consultations, and the technical workshop was conducted as a part of this project to suit the Indian context. These consultations, alongside secondary sources, also helped inform the learning rate and system costs in future years (Biswas et al., 2020; International Energy Agency, 2023; International Renewable Energy Agency, 2021).

The underlying assumptions of the system parameters, such as electricity costs; electrolyzer costs; compressor costs; OpEx; engineering, procurement, and construction (EPC); discount rates; lifetimes; specific energy consumption; and full load hours are provided in Table A13. The learning rate for electrolyzers declines from 18% in 2024 to 11% in 2030 and is assumed to be 9% post 2030.

Table A13. Parameters considered for the LCOH (green) calculations (in base year 2024)

S. No.	Variables	Input used for alkaline membrane	Input used for proton exchange membrane
System specifications			
1	Lifetime electrolyzer system (kW)	30	30
2	Lifetime stack (manufacturer's data) (hours)	70,000	80,000
3	Specific energy consumption (kWh/ kgH_2)	47.62	51.3
4	Full load hours (h)	5,000	5,000
5	System pressure (bar)	10	25
6	CapEx electrolyzer system (USD/kW)	395	1531
7	EPC (% of CapEx electrolyzer system)	11	11
8	Stack replacement costs (% of CapEx electrolyzer system)	35	35
9	Compressor costs (USD/kW compressor)	267	267
10	Total CapEx (USD/kW)	599	2169
11	OpEx (% of CapEe per year)	3	2.25
12	O_2 selling price (USD/kgO_2)	2.1	2.16
13	Heat selling price (USD/MWh)	0	0

Source: Umlaut & Agora Industry, 2023.

The cost of electricity for GH_2 projections in this study was based on the LCOE model for utility-scale solar in this study.

A5.2.2 Benchmark Cost

To estimate the total cost gap for GH_2 and year of cost parity, we used the current cost of production for grey hydrogen at USD 2.25/kg (Raj et al., 2022). Throughout the study period (2024–2050), the LCOH for grey hydrogen production was assumed to be constant at USD 2.25/kgH_2 in the BAU scenario.

With the LCOH of grey hydrogen predominantly dependent on the cost of natural gas, a sensitivity analysis was also carried out to understand its impact on the LCOH and the cost gap required for GH_2 for the study period (2024–2050). This analysis involved increasing the benchmark LCOH (USD 2.25/kgH_2) for grey hydrogen by 10%, simulating a range of possible costs.

A5.2.3 Timeline

In our study, the timeline for calculating the total cost gap is based on the year of cost parity with benchmark technology. In the case of GH_2, we found that it does not reach cost parity with the cost of grey hydrogen until 2050 in the BAU scenario. We thus used 2024–2050 as the timeline for estimating the total cost gap.

A5.2.4 Annual Production of GH_2 (2024–2050)

According to a 2023 press release by the MNRE, India's total hydrogen production capacity from renewable sources was estimated to be around 235.4 tonnes per year (MNRE, 2023a). Projections from various secondary literature sources indicate an expected demand of nearly 35 million tonnes (MT) per annum by the year 2050 (Bakshi, 2023; EY India & SED Fund, 2022; Hall et al., 2020). Using this data, along with an expected target of 5 MT by 2030, linear interpolation was applied to project the annual production goals for GH_2 up to the year 2050. With linear interpolation, the year-wise adoption rate increases steadily by 0.7145 MT per annum till the year 2030 and subsequently increased by 1.5 MT each year till the year 2050.

Table A14. Summary of key parameters and model assumptions for GH_2

Parameter	Unit	Base year	2030	2040	2050
CapEx	USD/KW	1,384	591	293	224
Learning rate	%	18	11	9	9
Electricity costs	USD/MWh	58	55	51	46
LCOE	USD/kg	4.36	3.36	2.84	2.55
Benchmark	USD/kg	2.25	2.25	2.25	2.25
Annual production capacity	MT	0.000235	5	20	35

Source: Biswas et al., 2020; EY India & SED Fund, 2022; IEA, 2023a; IRENA, 2021; Raj et al., 2022; Singh et al., 2024.

A5.3 Description of Scenarios Considered to Study Government Support

Based on the above analysis, the scenarios in Table A14 were constructed for the GH_2 module to study the wider macroeconomic impacts of providing government support to bridge this cost gap. The investment scenarios were selected based on a combination of select drivers, including

- the type of investment support required (e.g., based on different cost methods/ assumptions), and
- the amount of investment support that is provided by the government (public support).

Table A15. Scenarios used for GH_2 analysis

Scenarios	Description
Scenario 1	**Cost gap for green LCOH versus grey LCOH**
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
4.5% public support	4.5% of the cost gap gets bridged by government funding
Scenario 2	**Cost gap for green LCOH versus grey LCOH (high)**
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
4.5% public support	4.5% of the cost gap gets bridged by government funding

Source: Authors.

The scenarios provide a better understanding of the role of government support and incentives needed for GH_2 to reach cost parity. Each of the scenarios is modelled in GEM, which takes inputs based on the LCOH comparison, sensitivity analysis, and the total investment required for GH_2.

Appendix B. The Macroeconomic Modelling Approach and Scenario Details

B1 Background of the Green Economy Model

While the cost gap (as discussed in Appendix A) helps estimate the total resources needed to bring the selected clean energy technologies on par with conventional alternatives, governments often do not need to bridge the full gap. To better understand the macroeconomic impacts of providing the varying levels and nature of government support—100%, 30%, and 5% of the cost gap through different support measures—we used the Green Economy Model (GEM) in this study.

The GEM[3] is an integrated, recursive system dynamics model that generates macro-level scenarios for climate, environmental, and socio-economic variables and serves primarily as a knowledge integrator for country-level planning. The GEM has already been customized and applied in more than 50 countries, including India, to support policy formulation and evaluation, primarily for green growth—hence including climate mitigation, adaptation, and circularity (e.g., for net zero and nature-positive plans).

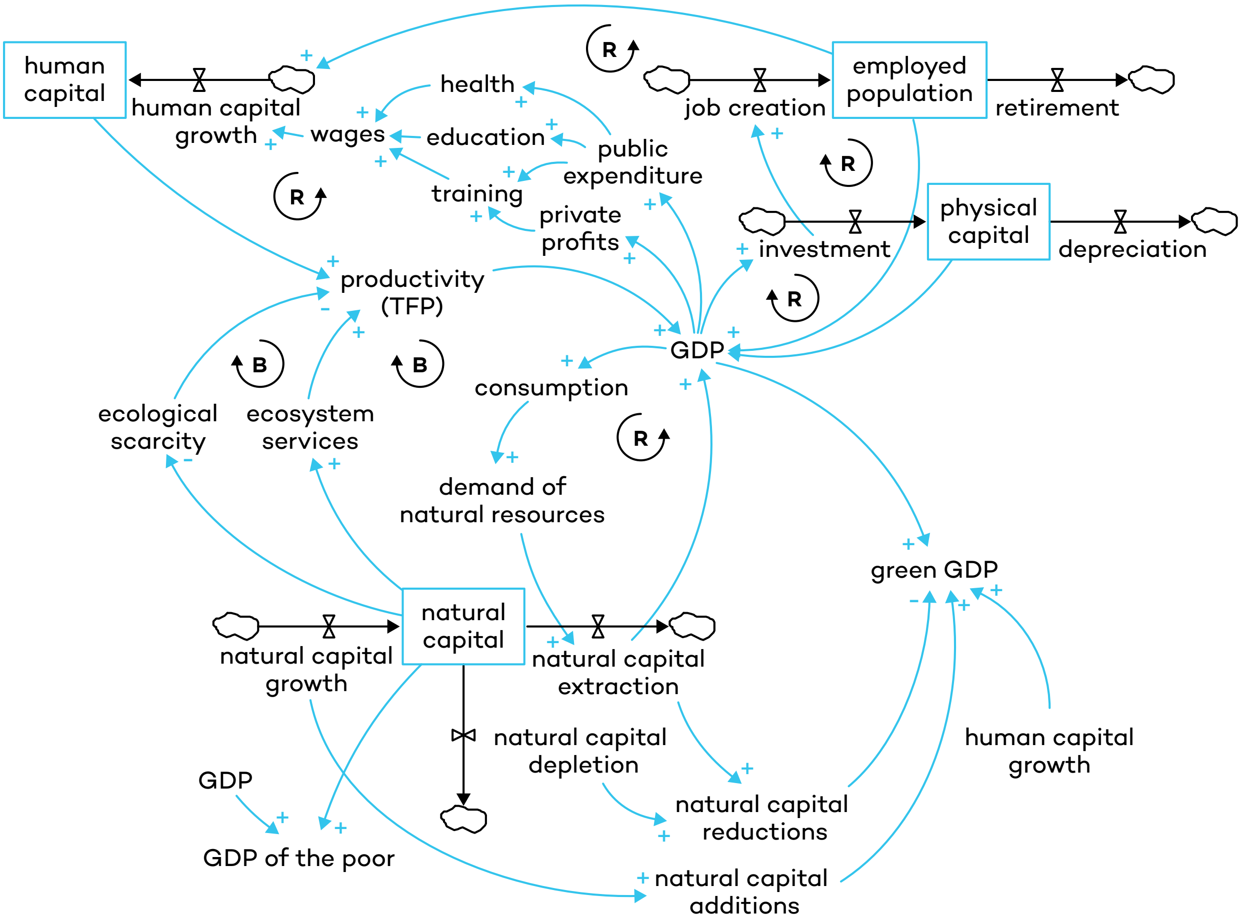
The GEM is particularly suited for studying the co-benefits of ambitious climate action by countries and aims to equip policy-makers with empirical evidence on the dynamic relationships between actions needed to strengthen economic performance while reducing the damaging factors of climate change (Bassi et al., 2024). It includes four key capitals (physical, human, social, and natural) that are interconnected via explicit causal linkages that allow the representation of feedback loops (reinforcing or balancing) (Figure B1). Thus, GEM makes use of causal loop diagrams (CLDs) to identify the main drivers of change in the system; stocks and flows[4] to quantify change over time across social, economic, and environmental variables; and nonlinearities and disequilibrium features of the system to forecast changes in the dominance of feedback loops over time and anticipate the emergence of synergies and side effects. Importantly, GEM is *not* a tool for optimization. Rather, it is attuned to the policy-maker mindset that makes it well-suited to work with national priorities. The outcomes of GEM are “what if” scenarios—rather than predictions—that can rationalize and quantify impacts and trade-offs, as well as compare the benefits of action to the costs of inaction.

---

[3] For more on this model, see https://www.ke-srl.com/gem.

[4] Stocks represent accumulations at a point in time. Examples include the value of physical capital, the size of the labour force, the level of technology, and the concentration of greenhouse gasses (GHGs) in the atmosphere. Flows are rates of change that increase (inflow) or decrease (outflow) the size of the stock.

Figure B1. Causal loop diagram representing the main variables and feedback loops of the GEM



Source: Viswanathan et al., 2022, p. 42.

For these reasons, we used the GEM to estimate the macroeconomic impacts and conduct cost-benefit analyses (CBA) of providing government support to bridge the cost gap estimated in this study. By varying the size and nature of government support to cover the estimated cost gap, we were able to quantify and study the trade-offs of government support on employment, emissions, public revenue, and GDP and suggest policy recommendations provided in the study.

B2 Macroeconomic Modelling Approach

The systemic approach used to carry out the macroeconomic analysis is presented in Figure B1. To estimate the macroeconomic impacts of bridging the cost gap by the government, we made use of a CBA in this study.

The CBA compares the public support provided with the macroeconomic impacts it generates. GDP is used as a proxy for the macroeconomic impact. Worth noting, GDP in the GEM is estimated using capital (i.e., the accumulation of investments over time), labour (considering employment creation and losses resulting from the adoption of new technologies), and Total Factor Productivity (an indicator that considers, among others, the cost of energy and air quality). As a result, by comparing the public support provided with impacts on GDP, a systemic approach is used that considers all economic, social, and environmental dynamics triggered by technology adoption.

Starting with energy spending, we consider that the adoption of a new technology can either result in (i) higher energy costs and hence additional energy spending or (ii) lower energy costs and hence cost savings. When the cost of energy is lower (i.e., the new technology offers a lower unit cost when compared to the option it substitutes), the GEM will forecast an increase in capital productivity and hence—all else being equal—higher value addition and GDP going forward. This is because the economic productivity of energy increases, and the incidence of energy costs in production declines. On the other hand, when the adoption of a new technology results in higher energy costs, the opposite would emerge if no public support were provided. Practically, energy spending would increase, resulting in lower sectoral value added and GDP. When public support is provided instead, the impact on energy spending would be mitigated. No impact emerges if the government provides support to cover the full gap, while some impact would still emerge should the public support only cover a portion of the gap. When government support is provided, the GEM considers that the corresponding amount has to be added to government expenditure, and hence contributes to deficit and debt. This may reduce future public investment, given the growing incidence of debt and interest payments.

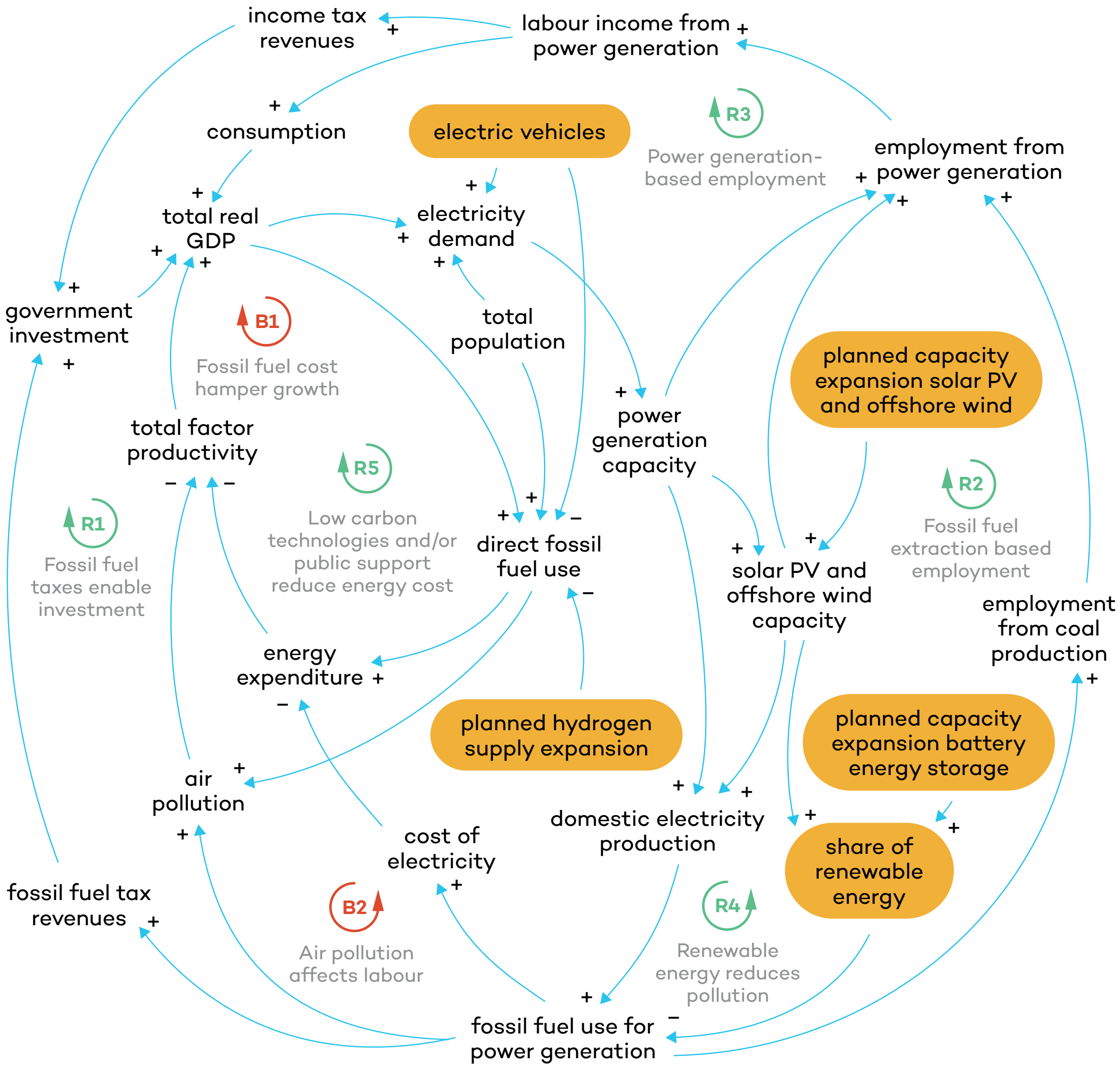
A second key factor is employment. If the adoption of the new technology results in net employment creation (i.e., manufacturing, installation, operation, and maintenance are comparatively more labour intensive), total employment would increase and further stimulate value added and the GDP. On the other hand, considerations are made regarding the import of equipment and the possibility that some of the job creation may occur outside of India.

A third key factor affecting GDP is air pollution. If the new technology results in lower air emissions (e.g., by stimulating the use of renewable energy or fuel switching to less carbon-intensive energy sources), labour productivity is forecasted to increase relative to the baseline scenario. This would result in higher value added and GDP going forward.

Overall, we consider (i) different amounts of public support provided to close the cost gap and (ii) the social, economic, and environmental outcomes emerging from the allocation of such public support, all contributing to the economic performance of the country.

The CLD shows, in a more systemic way that highlights ripple effects that accumulate over time, 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 photovoltaic (PV) and offshore wind reduces fossil fuel use and the generation of air pollution emissions, pushing GDP upward. 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.

Figure B2. CLD on the systemic approach for macroeconomic analysis



Source: Authors.

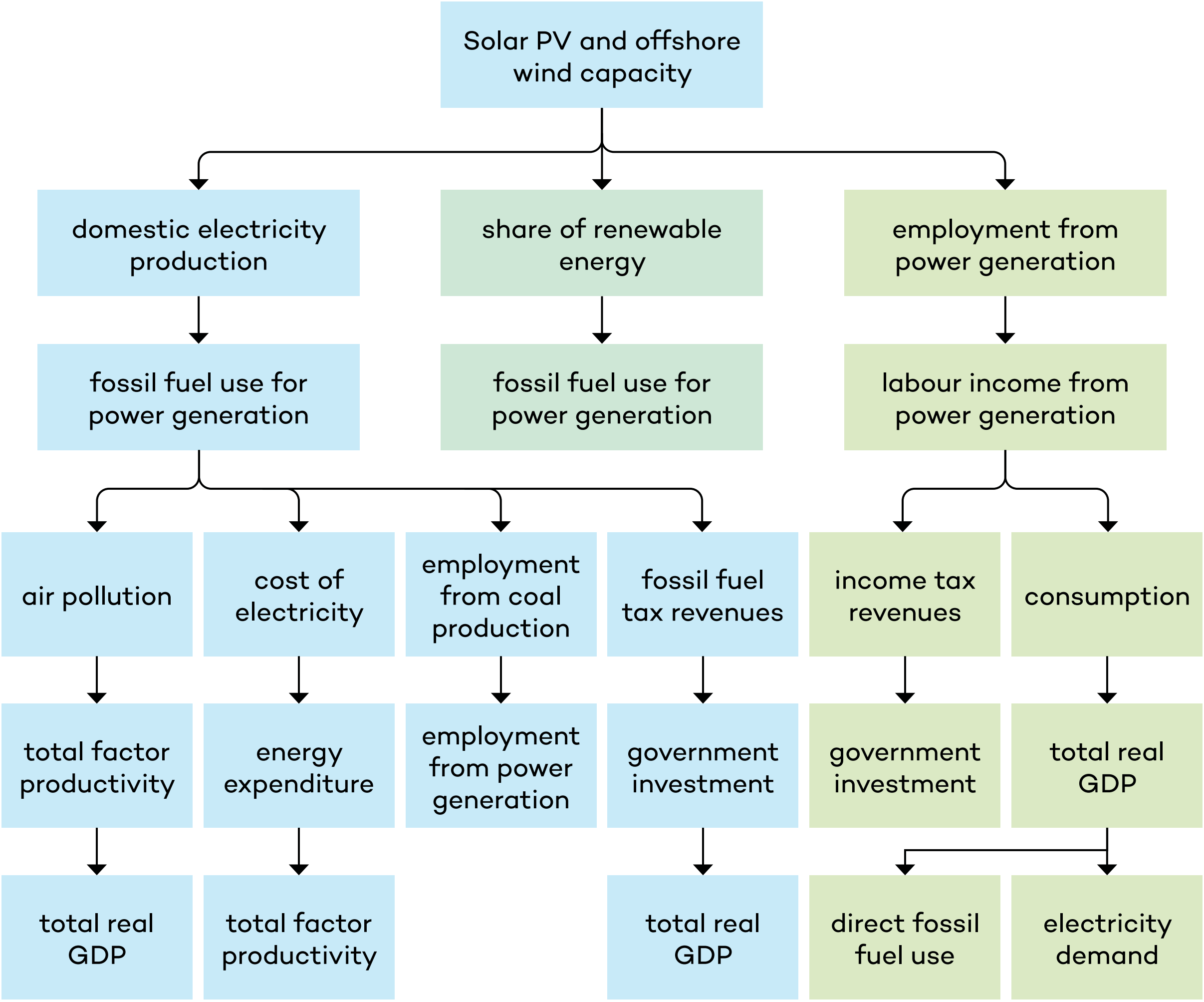
The following section includes a detailed description of the modelling approach for each technology.

B2.1 Solar PV, Offshore Wind, and Battery Energy Storage Systems

For the calibration of the energy demand module, we used the International Energy Agency's (IEA's) *World Energy Outlook 2023* (IEA, 2023b). While past data is sourced from India's national energy balance, the future trajectories for total final consumption by fuel and sector are calibrated to match IEA forecasts.

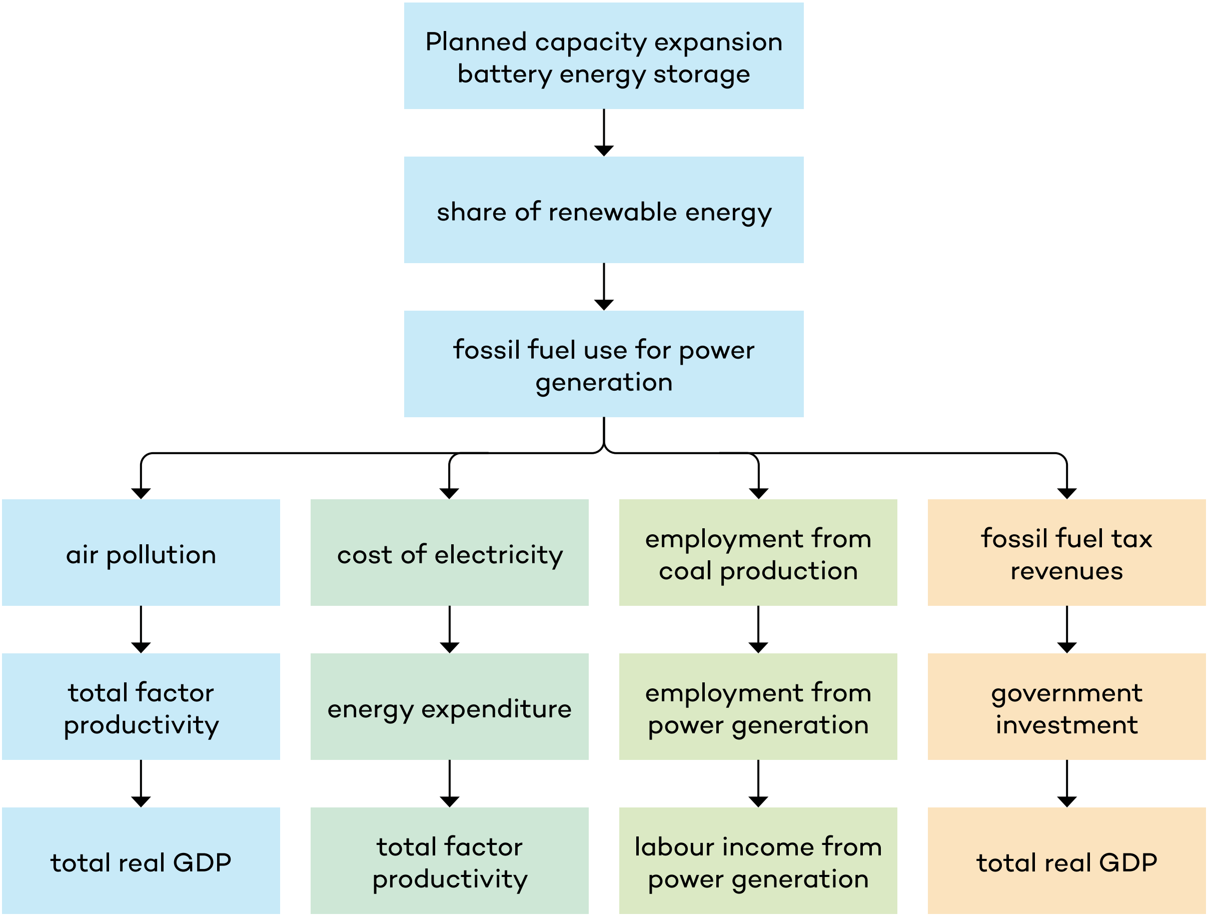
The power generation sector, which uses electricity demand as an input to determine the total amount of electricity generated, is currently calibrated based on the least cost optimization of the power module conducted by the CSTEP team using the SAFARI model. A new module was added for battery energy storage systems (BESSs), and a new parametrization was introduced for offshore wind.

Figure B3. Linkages of solar PV and offshore wind deployment to the wider GEM



Source: Authors.

Figure B4. Linkages of BESS deployment to the wider GEM



Source: Authors.

To estimate the macroeconomic impacts of the cost gap estimated in Appendix A, we first quantified the adoption of the technology and the resulting amount of electricity generated over time. We then estimated the cost of electricity supply by multiplying electricity generation by the levelized cost of the new technology. This represents the cost of energy with the adoption of the new technology. This amount was then compared with the cost of consuming the same amount of electricity, but considering the market (or grid) price. Up to this point, we have recreated the analysis of the cost gap presented in Appendix A for the total amount of technology adoption forecasted.

Subsequently, we have added a conditional function, indicating that (i) if a net saving emerges, energy spending would decline and contribute to higher total factor productivity and GDP; or (ii) if a net cost emerges, a given percent of public support can be applied (this a scenario choice ranging from 5% to 100%). When support is provided, the extra cost is reduced according to the proportion of public support, resulting in a smaller impact on energy spending but adding to deficit and debt.

A similar approach is followed for employment, where an employment factor was used to estimate job creation and assess if a net increase in employment emerges over time. Emissions were also calculated following a similar approach by estimating the extent to which solar PV, offshore wind, and BESSs reduce emissions compared to the baseline scenario, resulting in a positive impact on labour productivity and TFP.

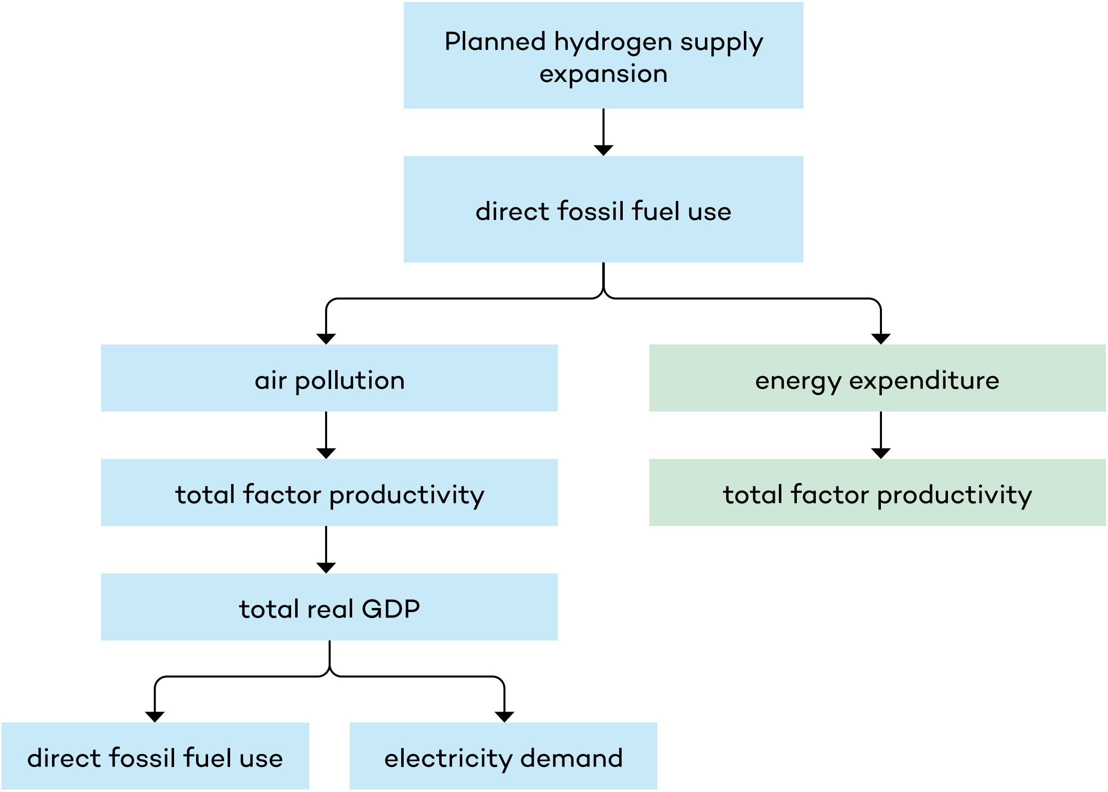
B2.2 Electric Vehicles

For electric vehicles (EVs), customized CLDs were developed to zoom into the dynamics surrounding them. Each of the CLDs highlights key indicators and interrelationships to illustrate how both affect larger systemic dynamics. In addition to highlighting dynamics complexity, the purpose of these CLDs was to identify where policy support measures become active in the system.

The first reinforcing loop highlights how the demand for vehicles leads to employment and income generation. The higher the demand for vehicles, the more vehicles are produced and jobs generated. The income resulting from these jobs increases the affluence of the population, which in turn stimulates vehicle ownership and the demand for vehicles.

B2.3 Green Hydrogen

Figure B5. Linkages between green hydrogen adoption and the wider GEM



Source: Authors.

For this study, a new module was added for green hydrogen (GH_2). The cost gap, when bridged, created the following impacts in the GEM: (i) it affects the consumption of energy, resulting in changes for energy spending and air emissions, two factors that affect GDP; (ii) when government support is provided, it affects government expenditure, public deficit and debt, and the amount of resources available for public investment. These two factors also affect each other dynamically: GDP is a key driver of public revenues. Therefore, the adoption of new technologies affects public revenue and public expenditure via public financing and the impact that technology has on energy use and emissions, energy spending, and—therefore—capital and labour productivity.

B3 Key Definitions and Concepts

1. **Adoption rate of EVs:** Adoption rate in this study is defined as the number of vehicles that enter the vehicle stock in a given year. For the EV analysis, we used the GEM to assess the impact of demand incentives on future adoption rates under different scenarios and evaluate their macroeconomic impact. The results obtained through scenario construction are expected to inform the future development of the sector.
2. **CO_2 emissions:** This module calculates national CO_2 emissions across all sectors, tracking their development over time and assessing policy impacts on per capita emissions and the social cost of carbon. This module is aligned with the national GHG inventory.
3. **Cost-benefit analyses:** GEM has structures set up to compute costs for low-carbon interventions, including capital investments and operation and maintenance costs. These costs are then compared with potential benefits, such as value addition, income, employment, human capital, air pollution and emissions, and depletion of environmental resources. This CBA helps policy-makers identify welfare-related variables, detailing the costs of interventions or packages and the associated benefits to support policy prioritization.
4. **Cost of energy interventions:** This module accounts for the costs of vehicle fleet electrification and changes in the power generation sector. It incorporates exogenous technology costs while considering learning rates and cost reductions over time, as sourced from the IEA and other relevant sources.
5. **Employment from power generation:** This module tracks employment generated through the construction and maintenance of energy capacity and fossil fuel extraction. It helps assess the impacts of different energy pathways on total energy sector employment.
6. **Energy demand:** This module projects national energy consumption by sector and source (2000–2050) and estimates total emissions by applying GHG emission factors. For the calibration of the energy demand module, we used the IEA's *World Energy Outlook 2023*. While past data is sourced from India's national energy balance, the future trajectory for total final consumption by fuel and sector is calibrated to match IEA forecasts.

7. **Employment and technology:** This module tracks total employment and technological development over time, assessing the employment impacts of policy interventions. Sectoral employment data, including energy-specific variables (e.g., for construction and operations and maintenance), feed into total employment, which is relevant for understanding green jobs and employment shifts by demographics, skill level, and wages.
8. **GDP:** The GDP module tracks total real GDP and sectoral value added (agriculture, industry, and services). It allows us to assess policy impacts on GDP growth and sectoral contributions via investment (i.e., capital accumulation), employment creation, and the improvement of Total Factor Productivity (e.g., via reduced energy spending and lower air pollution).
9. **Green jobs:** The GEM estimates employment resulting from decarbonization by comparing green jobs in policy scenarios to the baseline numbers. It can also account for job losses from conventional energy generation and allows for the inclusion of reskilling costs if it is a desired intervention to examine. This module considers jobs from renewable energy, hydrogen, BESSs, manufacturing EVs and buses, installing and maintaining chargers, and battery manufacturing for EVs.
10. **Power generation:** The power generation sector, which uses the electricity demand as an input to determine the total amount of electricity generated, is currently calibrated based on the least cost optimization of the power module conducted by the CSTEP team using the SAFARI model.

References

Auroville Consulting. (2021). *Levelised cost calculator for distributed energy resources v2.0.* https://www.aurovilleconsulting.com/levelised-cost-calculator-for-distributed-energy-resources-v2-0/

Bakshi, P. (2023). *The green hydrogen economy: Insights from India.* EUI Florence School of Regulation. https://fsr.eui.eu/the-green-hydrogen-economy-insights-from-india/

Bassi, A., Garrido, L., Harsono, A., & Pallaske, G. (2024). *Informing national climate action with the Green Economy Model: A technical description of the structures and processes.* World Resources Institute. https://www.wri.org/research/national-climate-action-green-economy-model-technical-note

Biswas, T., Yadav, D., & Baskar, A. G. (2020). *A green hydrogen economy for India: Policy and technology imperatives to lower production cost* [Policy Brief]. CEEW. www.ceew.in/sites/default/files/CEEW-A-Green-Hydrogen-Economy-for-India-14Dec20.pdf

Central Electricity Authority. (2023). *National electricity plan (Volume I: Generation).* https://cea.nic.in/wp-content/uploads/irp/2023/05/NEP_2022_32_FINAL_GAZETTE-1.pdf

Central Electricity Authority & Danish Energy Agency. (2022). *Indian technology catalogue: Generation and storage of electricity.* https://cea.nic.in/wp-content/uploads/irp/2022/02/First_Indian_Technology_Catalogue_Generation_and_Storage_of_Electricity-2.pdf

Deorah, S., Abhyankar, N., Arora, S., Gambhir, A., & Phadke, A. (2020). *Estimating the cost of grid-scale lithium-ion battery storage in India.* International Energy Analysis. https://international.lbl.gov/publications/estimating-cost-grid-scale-lithium

EY India & SED Fund. (2022). *Accelerating green hydrogen economy.* https://assets.ey.com/content/dam/ey-sites/ey-com/en_in/topics/energy-resources/2023/ey-accelerating-green-hydrogen-economy.pdf#:~:text=In%20this%20report,%20EY%20has%20contextualized%20the%20role%20of%20green

Forman, J., & Hansen, S. H. K. (2022). *The financial modelling of offshore wind in India: The FIMOI report.* Centre of Excellence. https://coe-osw.org/the-fimoi-report/

Hall, W., Spencer, T., Renjith, G., & Dayal, S. (2020). *The potential role of hydrogen in India: A pathway for scaling-up low carbon hydrogen across the economy.* The Energy and Resources Institute. https://www.teriin.org/sites/default/files/2021-07/Report_on_The_Potential_Role_of_%20Hydrogen_in_India.pdf

India Energy Exchange. (2024). *India Energy Exchange* [Dataset]. https://www.iexindia.com/tam-monthly

International Energy Agency. (2023a). *Global hydrogen review 2023.* https://www.iea.org/reports/global-hydrogen-review-2023

International Energy Agency. (2023b). *World energy outlook 2023.* https://www.iea.org/reports/world-energy-outlook-2023

International Renewable Energy Agency. (2021). *Making the breakthrough: Green hydrogen policies and technology costs.* https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_Green_Hydrogen_breakthrough_2021.pdf

Krishnan, D. S., Tilotia, A., Suresh Kumar, V., Bharadwaj, A., & Kajol. (2022). *Winds of change: Learnings for the Indian offshore wind energy sector* (Working paper). World Resources Institute. https://doi.org/10.46830/wriwp.21.00106

Ministry of New and Renewable Energy. (2023a). *Rajya Sabha Unstarred Question no 1597*. Government of India. https://pib.gov.in/PressReleasePage.aspx?PRID=1906819

Ministry of New and Renewable Energy. (2023b). *Strategy for establishment of offshore wind energy projects.* https://cdnbbsr.s3waas.gov.in/s3716e1b8c6cd17b771da77391355749f3/uploads/2023/09/202309271030958532.pdf

Ministry of Road Transport and Highways. (n.d.). *Vahan Dashboard* [Dataset]. https://vahan.parivahan.gov.in/vahan4dashboard/

NITI Aayog & IIT Bombay. (n.d.). *India Energy Security Scenarios* [Dataset]. https://iess2047.gov.in/#?inputs=1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1

Prasad, N. T. (2020, January 8). *Gujarat and Tamil Nadu have offshore wind energy potential of 70 GW: MNRE.* Mercom India. https://mercomindia.com/gujarat-tamil-nadu-offshore-wind-energy-potential-70-gw/

Raj, K., Lakhina, P., & Stranger, C. (2022). *Harnessing green hydrogen: Opportunities for deep decarbonisation in India.* NITI Aayog, RMI. https://rmi.org/insight/harnessing-green-hydrogen/

Singh, B. N., Ratn, T., & Jha, P. (2024). *India's green hydrogen revolution: An ambitious approach.* EY. https://static.pib.gov.in/WriteReadData/specificdocs/documents/2024/may/doc2024510336301.pdf

Umlaut & Agora Industry. (2023). *Levelized cost of hydrogen calculation tool (Version 1.0)*. https://www.agora-energiewende.org/data-tools/levelised-cost-of-hydrogen-calculator

Viswanathan, B., Raizada, S., Bassi, A.M., Pallaske, G., & Beaton, C. (2022, September). *India's state-owned energy enterprises, 2020–2050: Identifying evidence-based diversification strategies.* International Institute for Sustainable Development. https://www.iisd.org/system/files/2022-09/india-state-owned-energy-enterprises.pdf

World Resources Institute. (n.d.). *Total Cost of Ownership (TCO) EValuator.* https://www.wricitiesindia.org/content/tco-evaluator

Published by the International Institute for Sustainable Development

IISD

iisd.org