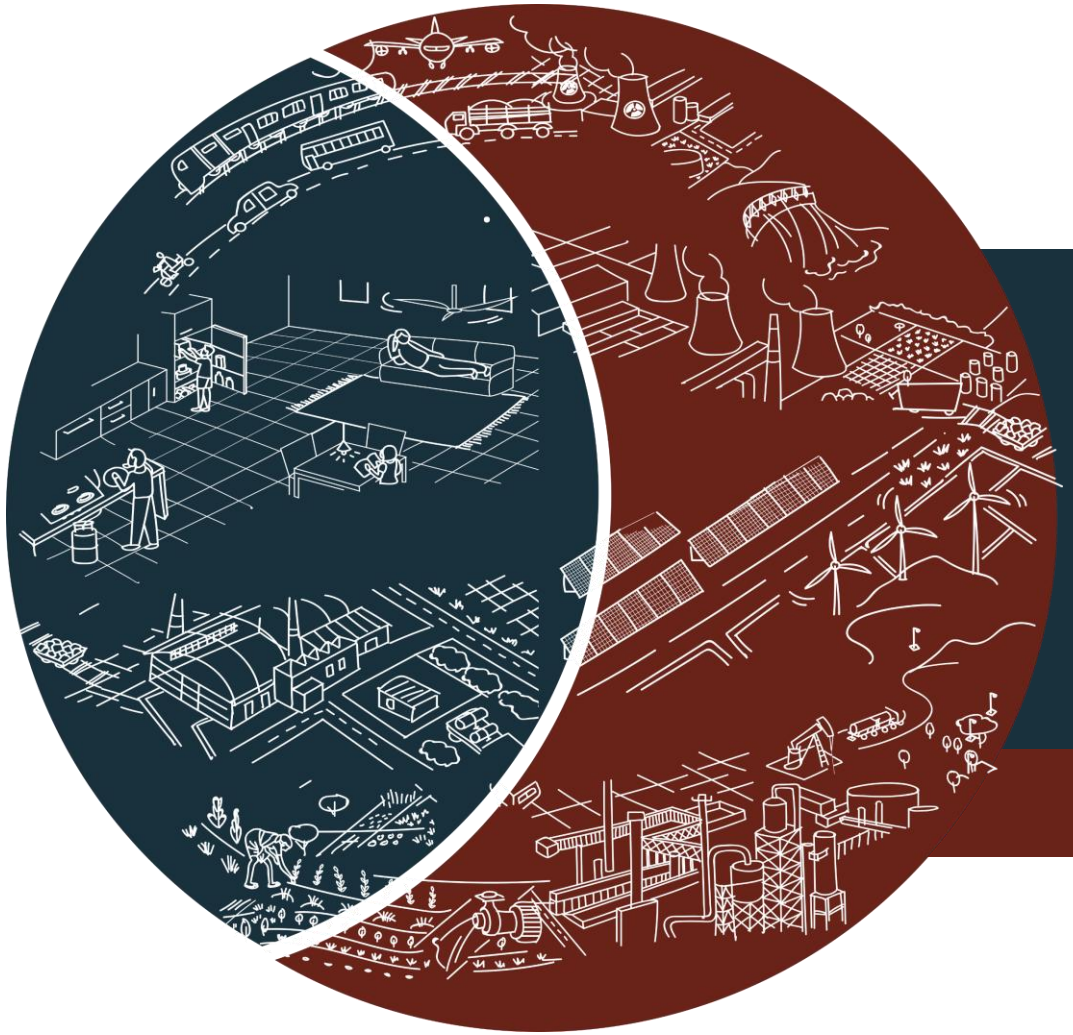


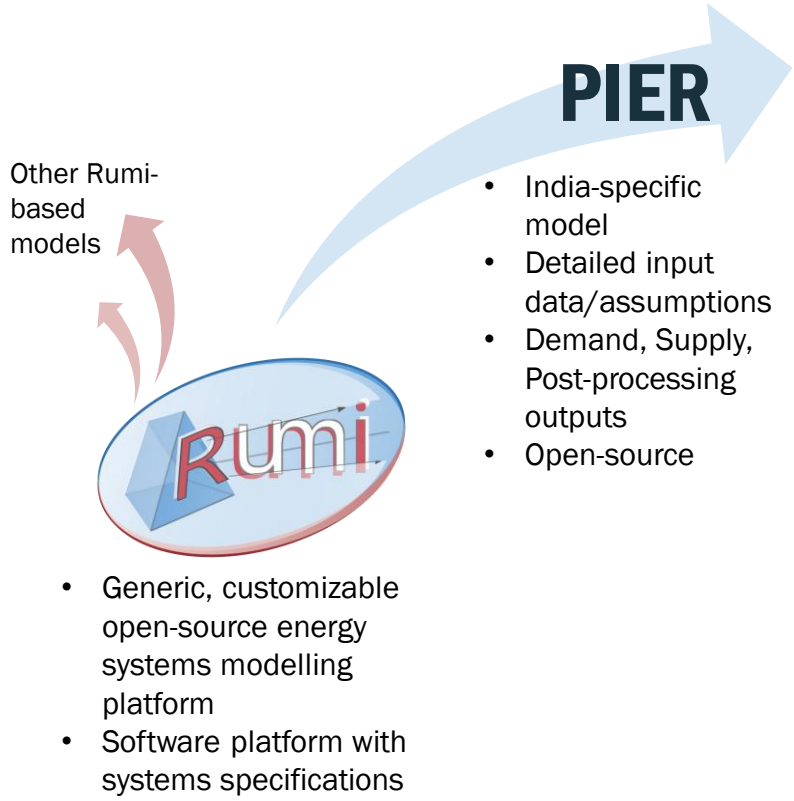
PIER 2.0: India's energy supply until 2040-41 (detailed model description)

Prayas (Energy Group), January, 2026

Rumi & PIER

PIER (Perspectives on Indian Energy based on Rumi) is an open-source India specific energy systems model built on the Rumi open-source modelling platform.

Feature	Rumi Modelling Platform (The Code/Framework)	PIER Energy Model (The Data/Application)
Core Identity	A **generic, open-source energy systems modelling platform** developed by Prayas (Energy Group)	A **fully functional open-source model of the Indian energy system** built upon the Rumi platform
Function	Provides a **software** platform (Python/Pyomo, demand accounting, supply optimization) that accepts input **CSV files** in pre-defined formats to describe an energy system and processes it	Provides the **detailed MS Excel workbooks and code to produce the CSV datasets** containing granular data and assumptions (e.g., demographics, efficiency standards, technology penetration, transmission network plans) required to model India's energy system
Scope & Customization	**Generic**; users define the geographic and temporal details, energy carriers, demand sectors, technologies etc.	**India-specific**; models regions, time, carriers etc. appropriate to India



What is this presentation about?

What it contains

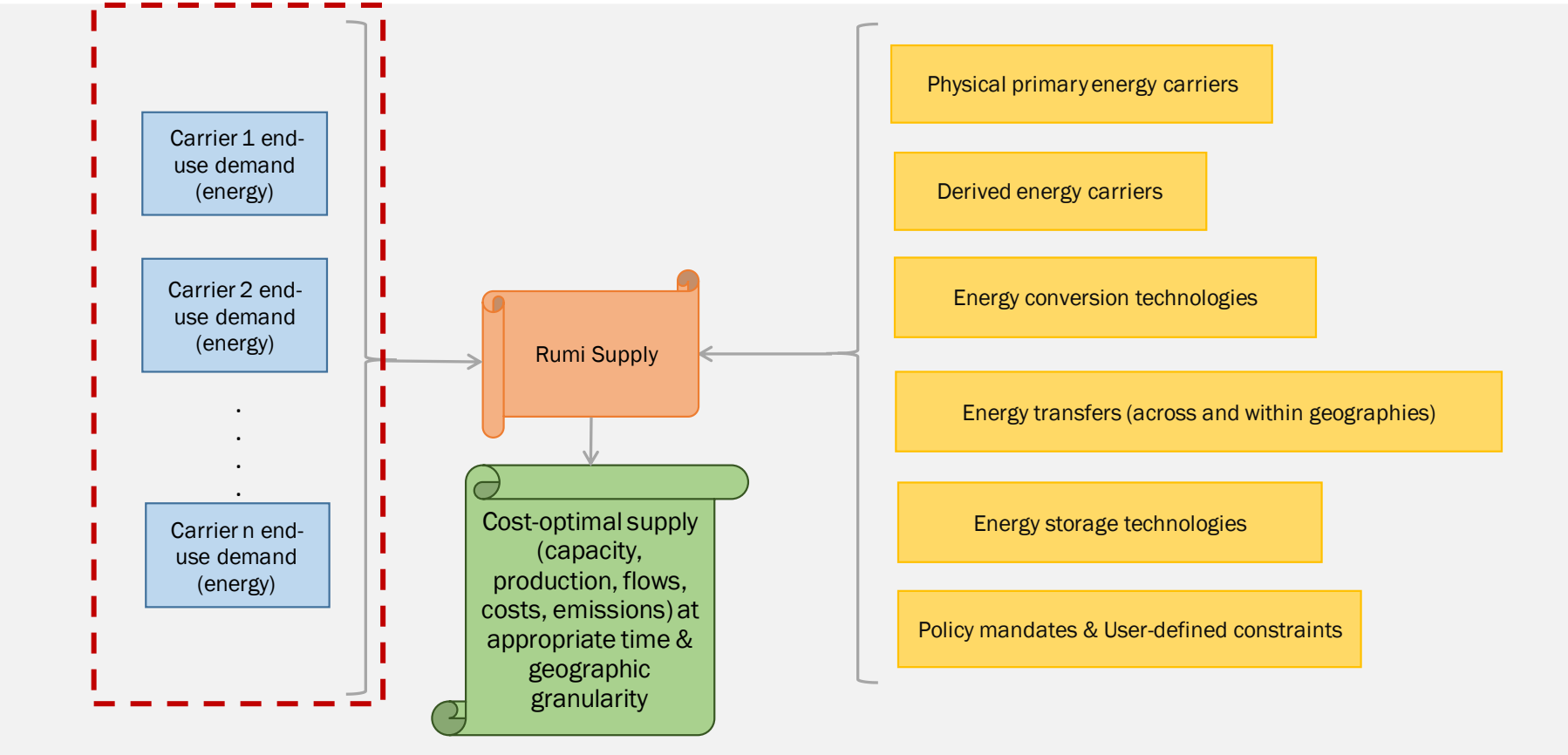
- Overview of the PIER 2.0 supply model
- Details of methods, inputs and approaches

What it does not contain

- Key results, insights and findings
- Details available within the various ‘source’ files and documentation released with the model

Rumi Supply model structure

Rumi will identify the various energy supply options to meet the energy demand in a cost-optimal manner based on the supply inputs given.



Key PIER 2.0 supply components

Time

Model time horizon: Financial Year 2023-24 to 2040-41

Temporal granularity (mainly for electricity): Each year divided into 12 months, each of which is represented by a typical day broken into 24 hours

Geography

India divided into 5 regions (ER, NER, NR, SR & WR) as defined by CEA.

Different from demand model (where granularity is at state level) due to computational complexity

Energy Carriers (EC)

Max production, costs and import limits for primary ECs

Cost & Max import limits for derived ECs

Raw price, taxes, transit costs of energy carriers

Energy Conversion Technologies (ECTs) Electricity Storage Technologies (ESTs)

Legacy & Capacity addition limits (min and max) and utilization factors

Annualised Fixed Costs for existing and candidate capacities

Conversion efficiencies, Additional production costs for ECTs

Energy Carrier Transfers

(across intra- & inter-geography)

Capacity / transfer limits

Cost of transfer per unit of EC

Transfer losses

User-defined Constraints

Can be constructed based on output variables

Useful for modelling policy mandates (e.g. RPO, SPO, import dependence) and other constraints

Scenarios in PIER 2.0 supply model

Detailed description of supply parameters in this slide deck refers to the Reference scenario.

Reference (REF)

- Based on past trends, known targets and likely changes

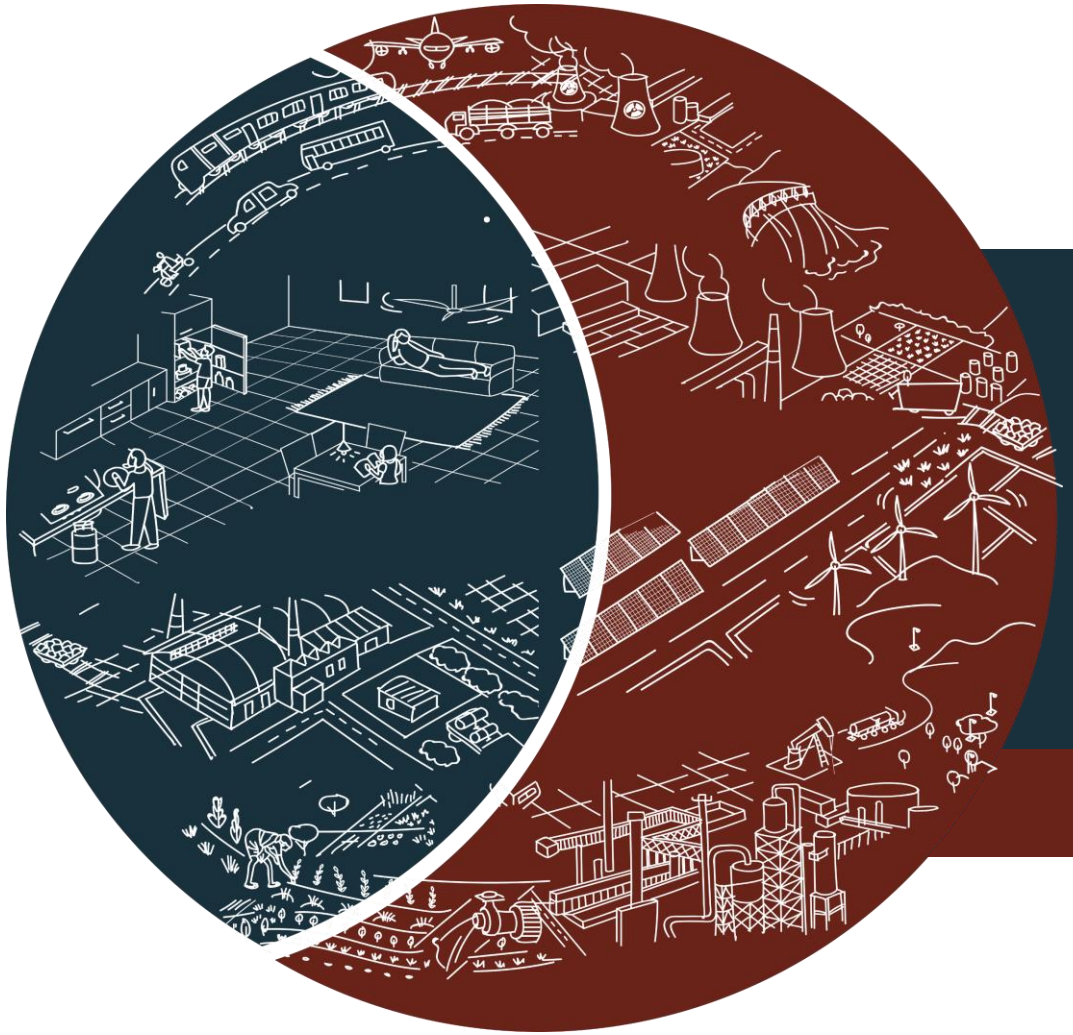
Vikasit Bharat

- Higher domestic production of coal, higher GR for natural gas
- Lower import limits for coal & electricity; higher for crude
- Post gestation, higher Max Cap for following energy conversion technologies (ECT) - solar, wind, hydro, nuclear & electrolysis; same as REF for coal, gas ECTs
- Higher fixed cost for coal, gas, solar & wind ECTs. Same for the rest
- Higher MaxCUF for solar & wind ECTs, rest same as REF
- Higher Max cap for Storage technologies (EST)
- Higher efficiency for BESS
- Lower transit loss than REF
- Same RPO, SPO targets as REF

Vichalit Bharat

- Lower domestic production of coal, 0% GR in natural gas
- Higher import limits for coal & electricity; same as REF for crude & natural gas
- Lower Max Cap for electrolysis ECT. Same as REF for solar, wind, nuclear, hydro, coal and gas ECTs
- Fixed cost same as REF for all ECTs
- Max CUF same as REF for ECTs
- Lower Max cap for ESTs
- BESS efficiency same as REF
- Higher transit loss than REF
- Lower RPO target for new wind & hydro in 2041; 5% pt. lower for total RPO

Note : Refer 03_supply-scenarios-description.pdf for more details



Energy Carriers

Energy carriers modelled in PIER 2.0

Primary carriers

- THERMAL_COAL: Thermal coal
- COKING_COAL: Coking coal
- CRUDE: Crude oil
- NATGAS: Natural gas
- BIOMASS: Traditional biomass
- BIOGAS: Biogas
- BIOMASS_WASTE: Commercial biomass & refuse derived fuel

Derived carriers

- ELECTRICITY
- LPG: Liquefied petroleum gas
- MS: Motor spirit or Petrol
- HSD: High Speed Diesel
- ATF: Aviation Turbine Fuel
- PETCOKE: Petroleum coke
- PP_OTHER: Other petroleum products used for energy
- GREEN_H2: Green hydrogen

Note : Refer PhysicalPrimaryCarriers.csv & PhysicalDerivedCarriers.csv in 'common-spec-data.xlsx' workbook for details

Physical primary energy carriers

- Physical primary energy carriers -
  - COKING_COAL – Domestic metallurgical coal (used in steel industry) production taken as domestic production of coking coal. Imports allowed
  - THERMAL_COAL – Balance non-metallurgical coal & domestic thermal coal production taken as total thermal coal production. Imports allowed to meet end-use demand and power generation needs
  - CRUDE – Input carrier to different types of Refineries for producing derived carriers like MS, HSD etc. Availability – domestic production supplemented by imports
  - NATGAS – For end-use demand and power generation needs. Availability – domestic production supplemented by imports
  - BIOMASS and BIOGAS – To meet end-use demand based on likely domestic production. No imports allowed
  - BIOMASS_WASTE – Represents use of Refuse derived fuel from municipal & chemical waste & commercial biomass. Domestic production to meet end-use demand, no imports allowed

Note : Refer PEC_Info_ImpConstrs.xlsx for details

Physical primary energy carriers…

- The relevant inputs for physical primary carriers are the limits on their domestic production and imports, and prices of domestically produced and imported variants of the carriers -
  - MaxDomesticProd – Likely Max Domestic production based on historical trends
  - MaxImport – Upper import limit based on likely demand and domestic production constraints
  - DomesticPrice & ImportPrice – Compiled from websites of relevant government ministries
  - FixedTaxOHDom & FixedTaxOHImp – Fixed Taxes comprising of excise, customs + surcharge and other duties etc. as applicable
  - AVTaxOHDom & AVTaxOHImp – Ad-Valorem taxes comprising of royalty, district mineral fund (DMF), excise duty, GST, customs duty and state-wise VAT as applicable
- Actual domestic production and imports for these carriers to meet end-use demand and use in any energy conversion technology are determined by the supply model based on these inputs

Note : Refer PEC_Info_ImpConstrs.xlsx for details

Physical primary carrier parameters

Primary carrier	Max Domestic Production				Max Import	Domestic Price, Million Rs per unit ($)			Imported Price, Million Rs per unit ($)		
	Unit ($)	2024	2031	2041		2024	2031	2041	2024	2031	2041
BIOGAS	BCM	87	87	87	--	54963	55748	55748	--	--	--
BIOMASS	MT	270	270	270	--	5683	5683	5683	--	--	--
BIOMASS_WASTE	MT	175	175	175	--	9000	9000	9000	--	--	--
COKING_COAL	MT	14	18	27	300	2789	2789	2789	21904	18474	14649
CRUDE	MT	32	32	32	330	47177	55376	70407	47177	55376	70407
NATGAS	BCM	34	39	48	200	24102	24005	28693	35196	25656	34254
THERMAL_COAL	MT	971	1380	2308	450	1156	1156	1156	10096	8515	6752

Derived energy carriers

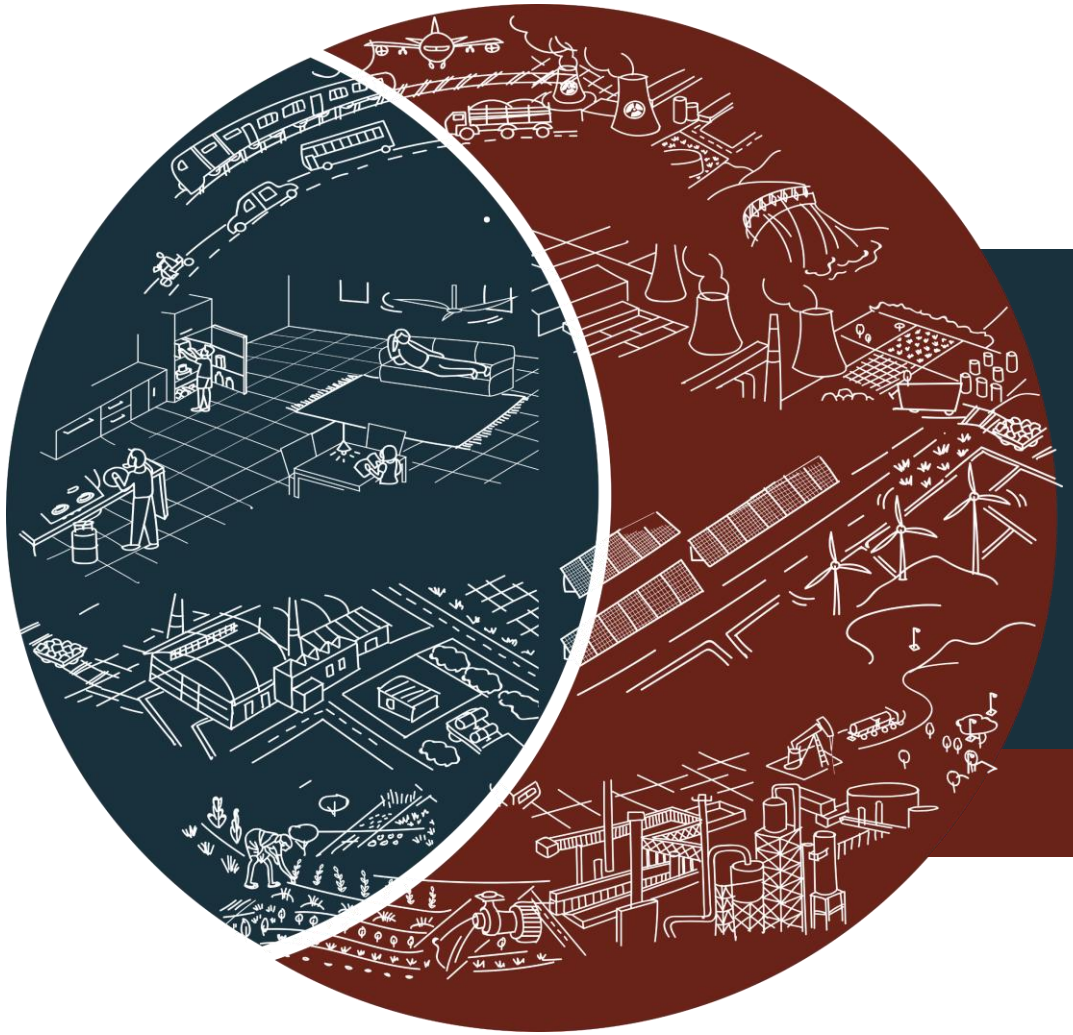
- Derived energy carriers (DEC) – Either produced domestically by energy conversion technologies (ECT) from other energy carriers or imported.
- Domestic production of DECs through ECTs modelled based on ECT inputs – described later
- The only relevant direct inputs for DECs are related to import limits and import prices
- Imports allowed for Electricity, MS, HSD, LPG, PETCOKE & PP_OTHER
- Electricity imports considered only from Nepal and Bhutan – assumed to be hydro
- Import prices for electricity taken from a mix of government sources and available news items
- Import limits for electricity based on past data and likely future projects
- Import prices for petroleum products taken from official data and projected
- Import limits for petroleum products based on past data and trends

Note : Refer DEC_Info_ImpConstrs.xlsx for details

Derived energy carrier parameters

Derived carrier		Max Import limits			Import Price, Million Rs per unit ($)		
	Unit ($)	2024	2031	2041	2024	2031	2041
ATF	MT	--	--	--	87914	103191	131202
HSD	MT	5.0	5.0	5.0	74286	87195	110864
LPG	MT	19.5	24.8	35.0	46646	54753	69615
MS	MT	5.0	5.0	5.0	76709	90039	114480
PETCOKE	MT	12.0	16.2	25.0	13061	15331	19493
PP_OTHER (#)	MT	12.6	12.6	12.6	37191	43654	55504
ELECTRICITY	GWh	11879	12792	15965	3.7	3.7	3.7

(#) PP_OTHER comprises other energy petroproducts viz. Superior Kerosene Oil, Fuel Oil, Low Sulphur Heavy Stock; Non-energy petroleum products like bitumen, wax & lubes are not considered.



Energy Conversion Technologies

Energy conversion technologies (ECTs) in PIER 2.0

Output DEC	ECT	Input EC	Remarks
ELECTRICITY	EG_COAL	THERMAL_COAL	Single type of thermal power plant
ELECTRICITY	EG_CCGT	NATGAS	Combined Cycle Gas Turbine
ELECTRICITY	EG_OCGT	NATGAS	Open Cycle Gas Turbine
ELECTRICITY	EG_PHWR	ATOMIC	Pressured Heavy Water Reactor: nuclear power
ELECTRICITY	EG_SMR	ATOMIC	Small Modular Reactor: nuclear power
ELECTRICITY	EG_LH	HYDEL	Large Hydro electric
ELECTRICITY	EG_SH	HYDEL	Small Hydro electric
ELECTRICITY	EG_SOLARGM	SUNLIGHT	Solar PV (Ground mounted)
ELECTRICITY	EG_SOLARRF	SUNLIGHT	Solar PV (Rooftop)
ELECTRICITY	EG_WINDON	WIND	Wind power (Onshore)
ELECTRICITY	EG_WINDOFF	WIND	Wind power (Offshore)
ELECTRICITY	EG_BIOMASS	BIOMASS	Biomass based power project

Refer EnergyConvTechnologies.csv for details

Energy conversion technologies (ECTs) in PIER 2.0...

Refinery modelled as separate technology for each petroleum DEC ($) & assumed to take input as crude and produce one output carrier (e.g. LPG, MS etc.)

Output DEC	ECT	Input EC	Remarks
ATF	RF_ATF	CRUDE	Refinery producing ATF
HSD	RF_HSD	CRUDE	Refinery producing HSD
LPG	RF_LPG	CRUDE	Refinery producing LPG
MS	RF_MS	CRUDE	Refinery producing MS
PP_OTHER (#)	RF_OTHERPP	CRUDE	Refinery producing PP_OTHER
PETCOKE	RF_PETCOKE	CRUDE	Refinery producing Petroleum coke
GREEN_H2	GH_ELECTROLYSIS	ELECTRICITY	Electrolyser using green electricity to produce hydrogen

Refer EnergyConvTechnologies.csv for details

$ - Non-energy petroleum products like bitumen, wax & lubes are not considered.
# - PP_OTHER comprises other energy petroproducts viz. Superior Kerosene Oil, Fuel Oil, Low Sulphur Heavy Stock

Energy Conversion Technology related inputs

Input parameter	Description
Legacy capacity	The capacity of this ECT that exists before the model period starts
Legacy retirement	The years in which legacy capacity of this ECT will retire
Min capacity	Minimum capacity of the ECT that must be added in a year in a geography. Usually represents the capacity already in the construction pipeline
Max capacity	Maximum capacity of the ECT that can be added in a year in a geography. Usually represents the physical / financial limits of capacity addition
CUF (capacity utilisation factor)	• MaxAnnualUF represents the maximum utilisation of this ECT in a year in a geography • MaxUF represents the maximum utilisation of this ECT in the balancing time of the output EC of the ECT in a geography – usually relevant for technologies whose utilisation depends on time or day or season

All ECT related inputs distributed across ECT_CapAddBounds.xlsx, ECT_EfficiencyCostMaxAnnualUF.xlsx, ECT_LegacyCapacity.xlsx, ECT_LegacyRetirement.xlsx, ECT_Lifetime.xlsx, ECT_Max_CUF.xlsx, ECT_OperationalInfo.xlsx

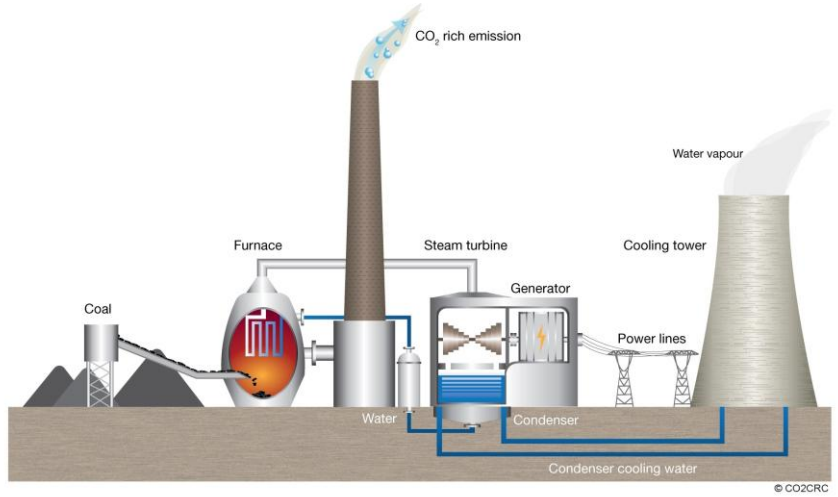
Energy Conversion Technology related inputs …

Input parameter	Description
Fixed cost	Annualised capital cost to install a unit capacity in a year in a geography
Variable cost	This is the cost of processing one unit of the input EC of the ECT – it is *not* what is usually meant by variable cost. May be zero for many ECTs
Conversion efficiency	Amount of output energy by ECT per unit input energy represented as a percentage. Not relevant when the input EC is a non-physical PEC such as sunlight.
Self consumption	Share of energy produced by the ECT consumed by itself
Ramp rates	The maximum and minimum share of ECT capacity by which the ECT output can change in a given time unit
Annual output per unit capacity	Represents the amount of output DEC that can produced from a unit capacity of the ECT in a year assuming 100% utilisation.
Life time	The number of years any new capacity set up during the model period will be operational

All ECT related inputs distributed across ECT_CapAddBounds.xlsx, ECT_EfficiencyCostMaxAnnualUF.xlsx, ECT_LegacyCapacity.xlsx, ECT_LegacyRetirement.xlsx, ECT_Lifetime.xlsx, ECT_Max_CUF.xlsx, ECT_OperationalInfo.xlsx

Coal (EG_COAL) and Gas (EG_CCGT , EG_OCGT)

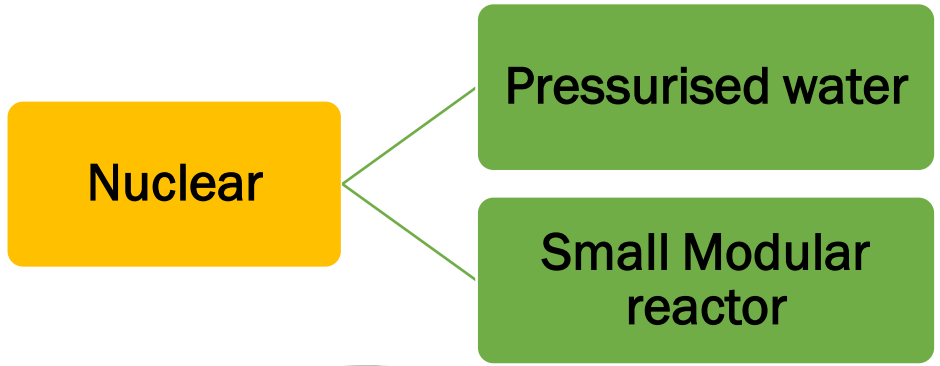
- Capacity:
  - Legacy and under construction for coal and gas: Details taken from CEA reports
  - Retirements for coal: Based on NEP 2023, Govt. notification on Category A plants with no FGD
- Operational parameters : Auxiliary consumption & ramp rates – from CEA General review($) and Optimal mix report(@)
- Fixed costs for coal taken from tariff orders (& MERIT database for gaps) for legacy plants and ITC(#) for new projects; For CCGT and OCGT, taken from ITC
- Variable costs for coal taken from MSPGCL's submission to MERC for MYT-2024. No variable costs assumed for CCGT, OCGT
- Escalation rate for variable costs assumed flat in real terms



$-CEA General review, @- CEA's Report on Optimal mix 2029-30, #- Indian Technology Catalogue published by CEA

Nuclear power - EG_PHWR & EG_SMR

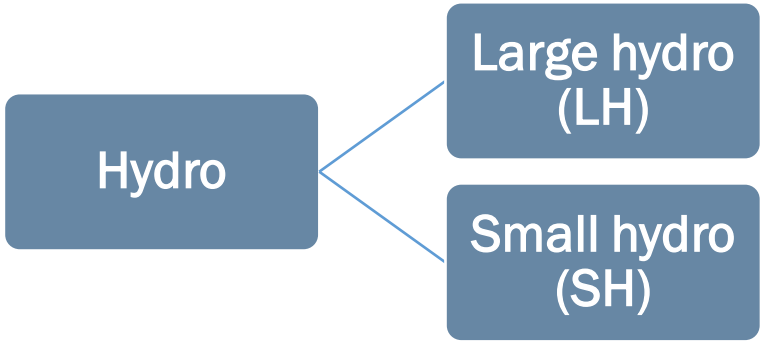
- Two types of reactors considered in India- Pressurized Heavy Water Reactor (PHWR) and Small Modular Reactor (SMR)
- SMR likely to come up in future based on Govt. press releases and news articles
- Gestation period increased for delayed PHWR projects based on current physical progress
- Fixed costs for PWHR taken from ITC(#) for legacy & new projects
- For SMR taken from government press releases
- Operational parameters like ramp rates and auxiliary consumption from ITC

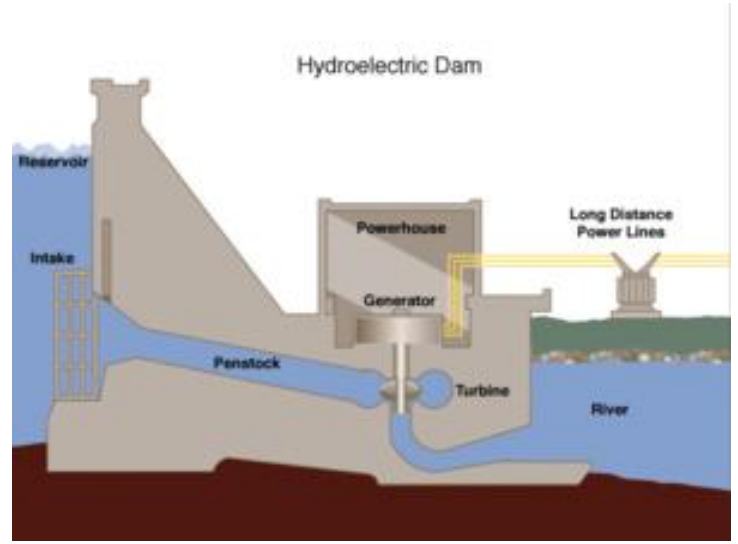


#- Indian Technology Catalogue published by CEA

Renewables: Hydro - EG_LH & EG_SH

- Hydro is bifurcated into Large Hydro (LH) and Small Hydro (SH)
- Capacity –
  - LH - Legacy and under construction from CEA Gen review
  - SH – Data taken from MNRE Annual report & CEA's NEP
- Fixed costs for LH & SH taken from ITC for both legacy and new projects
- Gestation period increased for delayed LH projects based on current physical progress
- CUF taken as national average for 2020-23 data for respective seasons from CEA monthly installed capacity reports.

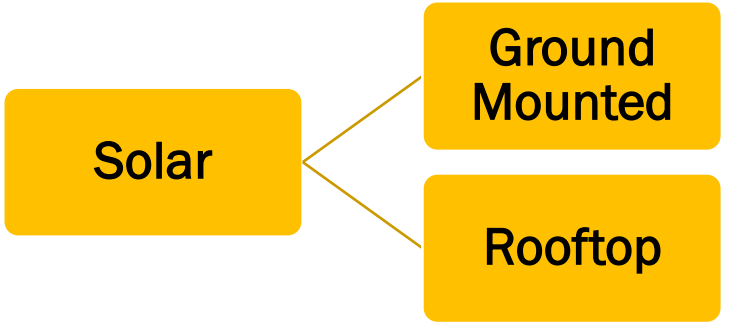




Solar – EG_SOLARGM & EG_SOLARRF

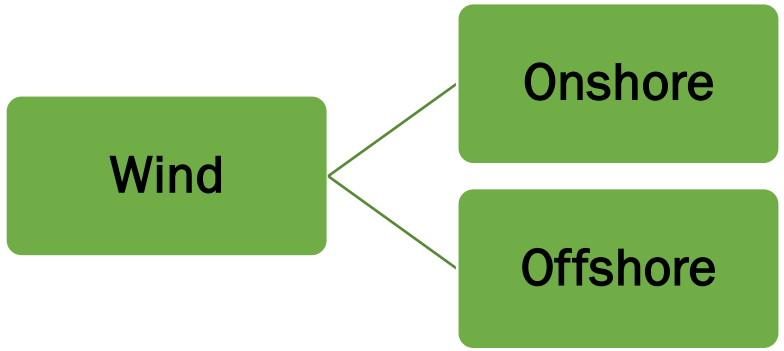
- Solar is bifurcated into ground-mounted (GM) and rooftop (RF). Their split based on state-wise ratio of FY 2023 installed capacity.
- PM KUSUM capacity is taken as SOLAR_GM and PM Surya Ghar Yojna capacity under SOLAR_RF for legacy and pipeline capacity.
- Legacy capacity taken from MNRE Physical progress reports. Pipeline capacity based on report on under construction RE projects by CEA
- Retirement age (25 years) taken based on definition of useful life from CERC RE Tariff Regulations 2017
- Fixed costs taken from ITC. For Rooftop, 80:20 debt-equity ratio assumed. 70:30 assumed for all other ECTs including GM
- CUF – Current national average CUF (19.2%) for FY2023. For GM solar we use 70:30 fixed tilt to single axis tracking ratio for average CUF. A 4% CAGR is taken till FY31 to account for increased tracking, post which it stabilizes.
- CUF profiles taken from GridPath India paper (#)

- G Terrén-Serrano et al, *GridPath India long-term (2020-2050) power system planning model data* (2025)



Wind – EG_WINDON & EG_WINDOFF

- Wind is bifurcated into Onshore and Offshore
- For Onshore, legacy capacity taken from MNRE Physical progress reports. Pipeline capacity based on report on under construction RE projects by CEA
- Offshore wind min capacity taken from the news article on pilot project
- Retirement age (25 years) taken based on definition of useful life from CERC RE Tariff Regulations 2017
- Fixed costs for both onshore & offshore taken from ITC. For offshore, interest rate on debt is taken 1% higher
- Onshore wind CUF – For 2023, national average CUF (19.8%) taken. 2% CAGR applied from 2025 till 2031. CUFs capped at 0.95.
- For Offshore, average of CUFs from 2017-19 considered.
- CUF profiles taken from GridPath India paper(#)



- G Terrén-Serrano et al, *GridPath India long-term (2020-2050) power system planning model data* (2025)

Refinery –RF_ATF, RF_HSD, RF_LPG, RF_MS, RF_OTHERPP & RF_PETCOKE

- Imports permitted for LPG, MS, HSD, PETCOKE & PP_OTHER based on import trends
- Max Import values for 2024 taken slightly higher than current as buffer. Max import for 2041 based on likely growth in consumption and shortfall
- Import prices for DECs calculated based on import quantity and value from PNG Statistics (#)
- Fixed & Ad-valorem taxes based on excise duty, cess, customs duty, CVD, GST etc. as applicable

Photo - pexels-tomfisk-10396416.jpg

#- Indian Petroleum & Natural Gas statistics 2023-24

Electrolysers – GH_ELECTROLYSIS

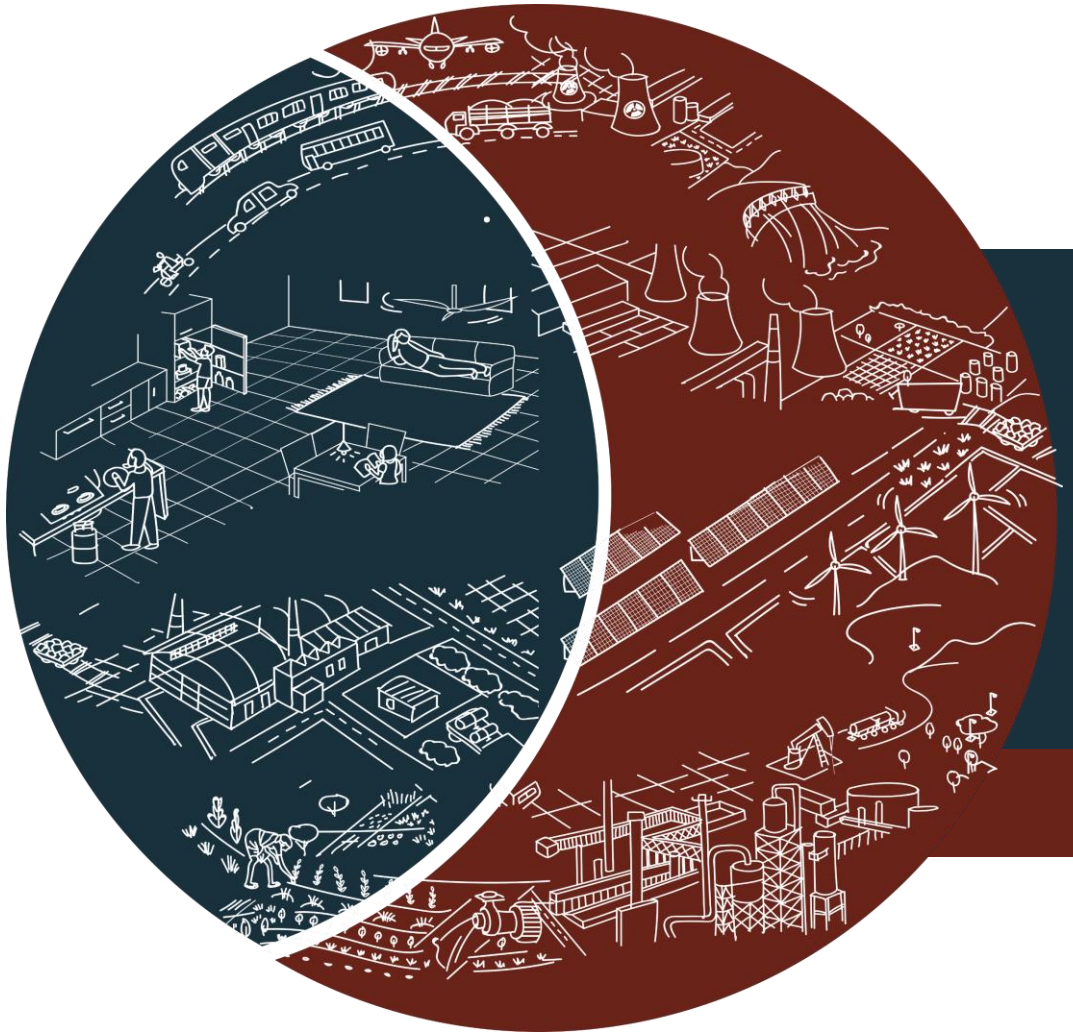
- Legacy capacity based on existing electrolysers commissioned till 2023 based on UKIBC report ($)
- Min capacity compiled based on confirmed news items for projects most likely to be commissioned in the coming decade
- Max capacity projected based on Niti Aayog target to achieve 60 GW electrolyser capacity by 2030
- Current ConvEff of 0.62 assumed to improve to reach 0.85 by 2041. Rate of improvement to slow down post 2031 by 0.5% every 5 years
- Annualised fixed cost taken from RMI report (#) for 2024 reducing by ~17% till 2031. Further cost reduction rate to halve every 5 years till 2041. No variable cost assumed
- No imports of GH2 considered, no tax is envisaged as it's a new technology

$ - UKIBC report : Green Hydrogen Landscape and Opportunities in India;
# - RMI report : *Green Hydrogen Production Pathways for India*

Image – Sungrow from https://www.hydrogeninsight.com/electrolysers/

Select Electricity generating ECT parameters

Electricity Generating ECT	Legacy capacity GW	Max capacity, GW			Fixed cost Rs/kW/year			Max Annual UF %		
Installation Year -->		2024	2031	2041	2024	2031	2041	2024	2031	2041
EG_COAL	264.4	0.0	10.1	10.0	12464	13442	13589	85%	85%	85%
EG_LH	46.5	0.0	2.3	1.5	19632	19632	19632	38.1%	38.1%	38.1%
EG_PHWR	8.2	1.4	0.0	1.0	20833	20833	20833	70.9%	70.9%	70.9%
EG_SOLARGM	58.4	12.0	40.0	48.4	5535	4922	4172	19.1%	25.1%	25.1%
EG_SOLARRF	9.5	3.2	10.0	12.1	5452	4871	4121	17.9%	23.5%	23.5%
EG_WINDOFF	0.0	0.0	0.0	1.1	34540	28994	26032	30.9%	30.9%	30.9%
EG_WINDON	46.2	3.3	20.0	24.2	10623	10378	10148	25.1%	28.8%	28.8%



Energy Storage Technologies

Energy Storage Technologies (EST)

Energy Storage technologies (EnergyStorTech) include Pumped Hydro Storage (PUMPED_STOR) and Battery electricity storage system (BESS)

EnergyStorTech	StoredEC	Remarks
PUMPED_STOR	ELECTRICITY	Pumped storage hydro (assumed to have 6 hour charge / discharge cycle)
TWOHR_BATTERY	ELECTRICITY	BESS with 2 hour discharge cycle
FOURHR_BATTERY	ELECTRICITY	BESS with 4 hour discharge cycle
SIXHR_BATTERY	ELECTRICITY	BESS with 6 hour discharge cycle

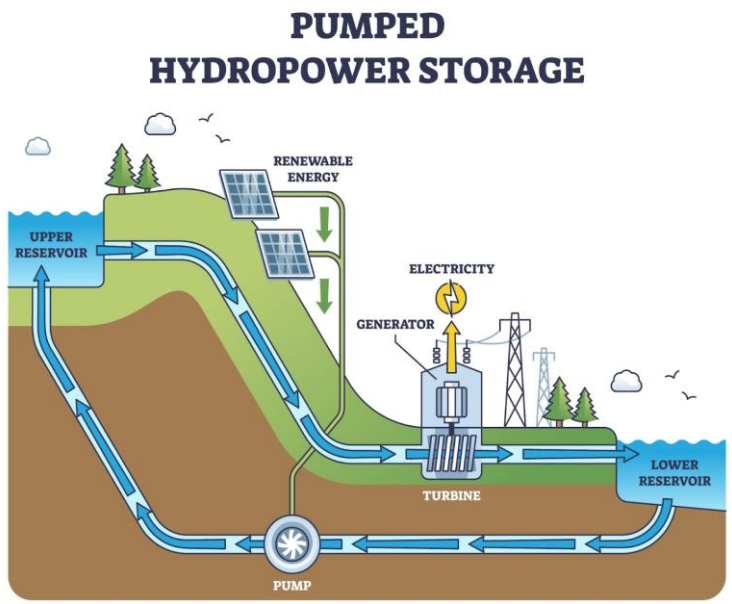
Energy Storage Technology related inputs

Input parameter	Description
LegacyCapacity	The capacity of this EST that exists before the model period starts
LifetimeYear	The years in which this EST is assumed to retire
LifetimeCycles	Number of charge & discharge cycles the EST can sustain over its lifetime
DepthOfDischarge	Maximum extent to which storage type can be discharged in a year Assumed 90% for all ESTs
Efficiency	Round trip efficiency is the ratio of the amount of energy stored out of total that is put in – 75% for Pumped storage, 80% for all BESS types
MinCap	Minimum capacity of a storage type that must be installed in a year in a geography. Usually represents the capacity already in the construction pipeline
MaxCap	Maximum capacity of the storage type that can be installed in a year in a geography. Usually represents the physical / financial limits of capacity addition
FixedCost	Annualised capital cost to install a unit capacity in a year in a geography

Refer to EST_Parameters.xlsx for all EST related inputs

Pumped hydro storage details

Input parameter	Description
LegacyCapacity	Current pumped storage projects in operation as of June 2023 taken as legacy capacity
LifetimeYear, BalLifetime	Lifetime for new projects taken as 40 years Balance lifetime for legacy PHS taken as 20 years
LifetimeCycles, BalCycles	Number of charge & discharge cycles that new & legacy projects can sustain over their lifetime. Taken as 50000 to ensure it can support 40 year lifetime with daily cycling.
MinCap	Represents the capacity already in the construction pipeline
MaxCap	Taken as 30% of the exploitable potential in the country that can be achieved in the model period. Gestation period assumed till 2027 and increase in max capacity from 2028.
FixedCost	Average annualized cost for PHS taken from compilation of winning bids by IESA (#). Assumed to remain constant in real terms because it's a mature technology



Source : YES Energy

Refer EST_Parameters.xlsx for all EST related inputs;
- India Energy Storage Alliance

Battery storage details

Input parameter	Description
LegacyCapacity	No legacy BESS capacity as there was almost no BESS capacity in the country as on 1.1.2024.
LifetimeYear	Lifetime for all 3 types of BESS assumed to be 10 years in REF scenario.
LifetimeCycles	Assuming one daily discharge, lifetime cycles assumed as 3650 in 2021 with a 2% YoY increase till 2041.
Min Capacity	Min capacity taken for under construction projects and projects for which tender is approved
MaxCapacity	Capacity addition assumed to start in 2024 with 100MW for each BESS type and increasing progressively
FixedCost	Average annualized power and energy costs for BESS of winning bids taken from IESA (#) with cost reduction every year from 2027 taken from GP-India paper ($)

Image source : Rheineck Large Battery Storage Device (https://www.flickr.com/photos/kecko/53777638626/in/photostream/)

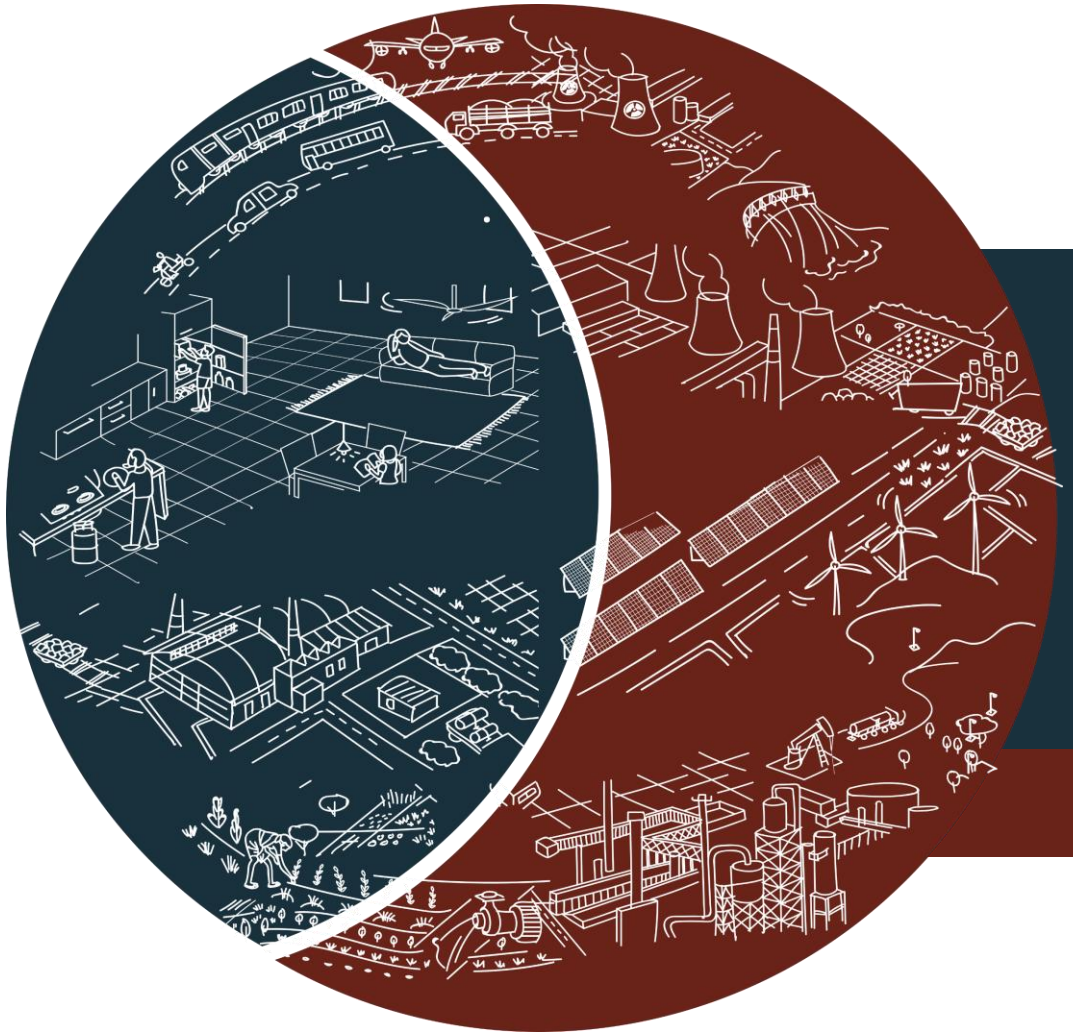
Refer EST_Parameters.xlsx for all EST related inputs and 03_supply-scenarios-description.pdf for scenario related changes

- Indian Energy Storage Alliance; $ - G Terrén-Serrano et al, *GridPath India long-term (2020-2050) power system planning model data* (2025)

Key Energy Storage EST parameters

Energy Storage Tech (EST)	Legacy Capacity GWh	Max Capacity, GWh / year			Costs Rs/kWh/year		
		2024	2031	2041	2024	2031	2041
FOURHR_BATTERY	-	0.4	38.6	40.0	1912	1537	1289
PUMPED_STOR	28.5	0.0	23.4	23.4	1900	1900	1900
SIXHR_BATTERY	-	0.6	57.8	60.0	1801	1447	1213
TWOHR_BATTERY	-	0.2	19.3	20.0	2248	1806	1514

Refer EST_Parameters.xlsx for EST related inputs



Energy Transfers

Energy Carrier Transfers

- Transfer of Energy carriers across geographies results in transit loss and additional costs incurred
- Additionally, there may be limits on the quantity of carrier that can be transferred in a given time
- Energy transfers modelled for electricity, coal, crude and related petro-products, natural gas and green hydrogen.
- For Electricity, distribution loss is considered as intra-regional transit loss and transmission loss is taken as inter-regional loss.
- Coal transfer assumed by railways. Transfer of crude & all liquid petroleum products by pipelines / tankers. Transfer of natural gas assumed by pipelines.
- Input parameters required in the model are
  - Transit loss – refers to reduction in amount of EC quantity during transfer from source area to destination and is given as a fraction of total quantity transferred.
  - Transit cost – represents the cost of supplying an EC from any point within source area to the boundary of the destination and is specified as currency units per physical unit for physical carriers and energy unit for non-physical carriers.
  - Maximum transit – maximum transfer of an EC possible from source to destination in a given unit time

Refer EC_Transfers.xlsx for more details

EC Transfer parameter details

Energy Carrier	Transit cost	Transit loss	Max Transit
Coal (Coking & thermal)	As per railway freight rates. Escalation rates for coal transportation based on CERC index and 4% inflation	Intra-region - Pit head loss (0.2%) Inter-region - Non-pit head loss (0.8%)	Unlimited
Electricity	As per 2017-23 distribution costs from PFC (#) report. Future growth in costs projected with tempered CAGR.	Based on 2006-2023 past trend reduction with a cap of 5% Max reduction rate and 15% loss (national level)	Intra-regional - unlimited. Inter-regional - As per current capacity & 5.2% CAGR based on CTU rolling plans & PEG assumption for future expansion.
Green hydrogen	Transit cost taken same as tariff order for natural gas pipeline by PNGRB ($)	1% (PEG assumption)	Unlimited
Biomass, Biogas & Biomass-Waste	Nil	Nil	Unlimited

Refer EC Transfers.xlsx for more details

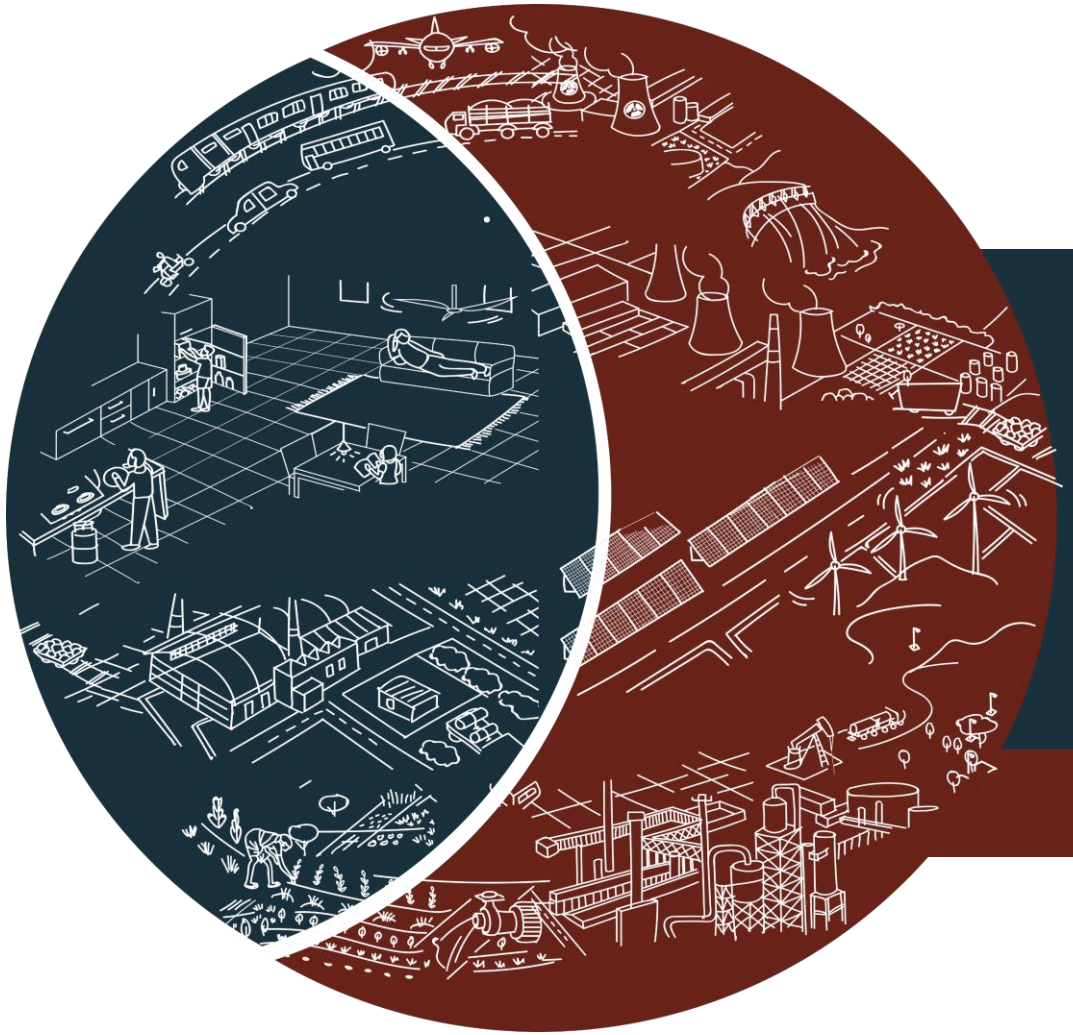
– Power Finance Corporation; $ - Petroleum & Natural Gas Regulatory Board

EC Transfer parameter details…

Energy Carrier	Transit cost	Transit loss	Max Transit
Crude & Other Petroproducts	Weighted average of transit cost for MS & HSD	0.015% (As per PNGRB regulation)	Unlimited
Natural gas	Transit cost as per tariff order for natural gas pipeline by PNGRB (#) (June 2024) + Distribution cost from standard piped natural gas bill	3% (Internal consumption for pipeline system from Petroleum Statistics)	As per current NG pipeline capacity and planned expansion till 2029. For future years, add 20 MMSCMD ($) per year till 2035, 10 MMSCMD thereafter.
MS, HSD, ATF	Freight cost given in the price build-up of retail selling price as on 01.04.2024 (from Petroleum statistics 2023-24)	0.015% (same as for crude)	Unlimited
LPG	5% of market price of 14.2 LPG cylinder (Based on average freight cost in last 5 years for LPG)	3% (assumed same as for natural gas)	Unlimited
Petcoke	Taken as per railway freight rate for average 1000 km distance travelled	0.8% (same as non-pit head loss for coal)	Unlimited

Refer EC Transfers.xlsx for details

– Petroleum & Natural Gas Regulatory Board; $ – Million metric standard cubic meters per day



Policy mandates & Technical constraints

Policy mandates

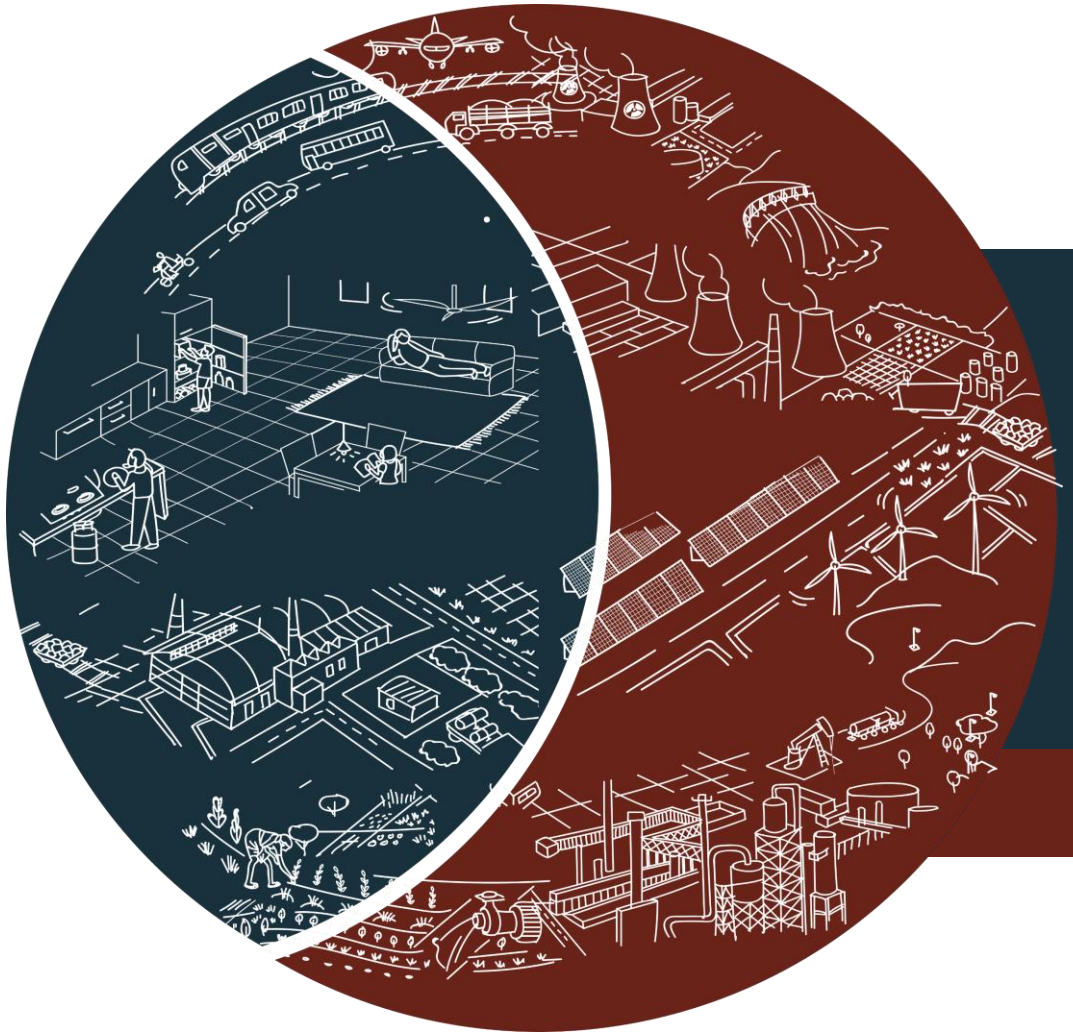
Mandate description	Details
Target to restrict import dependence by quantity of thermal coal	<= 15% by 2031 and <= 8% by 2041
RE installed capacity target (ensure minimum amount of renewable generation capacity)	>=450 GW by 2030
Ensure that minimum share of non-fossil fuel based generation capacity is met	>= 50% by 2030
Meeting renewable purchase obligation (RPO) or consumption obligation (RCO) targets on end-use demand of electricity	2030 target of overall RE share of 43.33% as per MoP notification (based on 0.5% annual increment). Projected forward with 0.4% annual increment till 2035 and with 0.3% annual increment till 2041 (reaching 55% in 2031, 70% in 2041). Specific technology-wise mandates from MoP also modelled.
Meeting Energy storage obligation (ESO) – Share of total energy consumed to be solar/wind with storage	2030 target for Storage on energy basis of 4.0% as per MoP notification (increasing at 0.5% annually from 1% in 2023-24). Projected with 0.4% increment till 2035 & with 0.3% increment till 2041 (reaching 6% in 2035, 7.8% in 2041).

Refer UserDefConstr-PolicyMandates.xlsx & TechMinConstraints.xlsx for details and 03_supply-scenarios-description.pdf & 04_policies-user-constraints.pdf for scenario related changes; Source : RPO & ESO Obligation trajectory till 2029-30, MoP

Technical constraints to model correct behaviour

Constraint description	Details
Ensuring sufficient green electricity to produce green H2	Total renewable electricity supply from all renewable technologies together to exceed or equal total renewable supply required to meet RPO target plus the total electricity required to produce green hydrogen.
Ensuring proper usage of electrolyser capacity	In any hour, electricity used as input to GH_Electrolysis is not more than the installed GH_Electrolysis capacity (#)
Simulating / approximating technical minimum and start-up shutdown constraints of coal-based generation	Product of following two parameters considered to decide minimum level of operation from the coal fleet in a region in any time slice of a year - i) Minimum share of fleet which is operational in any month (based on Max-CUF inputs) ii) Fleet technical operating minimum of the available fleet (assumed 60% in 2024 reducing to 50% in 2030 & 40% by 2041)

Refer UserDefConstr-PolicyMandates.xlsx and TechMinConstraints.xlsx for details and supply-scenarios-overview.pdf & policies-user-constraints.pdf for scenario related changes;
- Refer lyser-constrs.csv for constraint details



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Rumi: An open-source Energy Systems modelling platform

Rumi, is available to download from
https://github.com/prayas-energy/rumi