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Importance of Production Cost Models for Renewable Integration Studies in Developing countries

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ABSTRACT

Renewable energy, in particular wind and solar, has experienced a large increase in installed capacity in recent years. Power system planning has evolved rapidly in recent years to keep pace with advancements in generation technologies, formation, or interconnection of larger and more complex grids, and increasing consumer expectations. Uniquely, this paper tries to evaluate the importance of a planning model for developing countries.

INTRODUCTION

India has made significant progress in renewable energy integration in recent years, and the country has set ambitious targets to increase the share of renewable energy in its energy mix. As of 2021, India has a total installed renewable energy capacity of around 97 GW, which includes solar, wind, biomass, and small hydroelectric projects. One of the key drivers of renewable energy integration in India has been the government's policies and initiatives. The Indian government has implemented various policies and programs to promote the development and deployment of renewable energy projects, such as the National Solar Mission, which aims to install 100 GW of solar power by 2022. The government has also offered various financial incentives, such as tax exemptions and subsidies, to encourage private investment in renewable energy projects. Another important aspect of renewable energy integration in India is the development of grid infrastructure to support the integration of variable renewable energy sources, such as wind and solar. The Indian government has been investing in the development of grid infrastructure, such as the Green Energy Corridor project, which aims to strengthen the transmission system for renewable energy integration. However, there are still challenges to the integration of renewable energy in India, such as the intermittency of solar and wind power, and the need for energy storage solutions. These challenges require continued investment and innovation to develop new technologies and solutions that can improve the reliability and efficiency of renewable energy integration. Hence, there is a need of a long-term planning model in order to understand the integration of renewables onto the grid.

PRODUCTION COST MODELS (PCM)

Economic dispatch model

Production cost models seek to minimize the total cost of satisfying electricity demand and ancillary services requirements by controlling commitment and dispatch of an entire fleet of generators while adhering to system-level constraints on transmission capacity and generator physical or operational limitations. Hence, the resulting dispatch schedules provide a least-cost economic dispatch solution for the overall system. In principle, allowing the PCM to optimize the system dispatch.

Evolution of Power System Planning

Power system planning has evolved rapidly in recent years to keep pace with advancements in generation technologies, formation or interconnection of larger and more complex grids, and increasing consumer expectations. Load forecasting is an integral part of the planning process because it provides the bounds inside which the system must be planned. The traditional approach to power system planning is to ensure the system has adequate generation and transmission capacity to meet anticipated peak demand and annual or seasonal energy requirements.

BRIEF OVERVIEW OF THE POWER SYSTEM

For our analysis, we are using Indian Power system as our study region. This paper references to NREL's study and highlights and emphasizes the need of production cost models in the developing countries. As of 2019, India has an installed generation capacity of 357 GW, with coal and RE sources accounting for 194 GW (54%) and 78 GW (22%), respectively, and peak demand of 181 GW. India's peak demand is expected to increase from 181 GW in 2018–2019 and to 520 GW in 2036–2037, prompting the need for investments in generation infrastructure (CEA 2018b). Government targets and favorable economics could lead to an increasing share of generation capacity met with VRE technologies. Because VRE resources are not uniformly distributed in form or location, this could shift the mix and regional distribution of electricity supply.

USING THE MODELING FRAMEWORK

Capacity expansion models must balance the need for detailed representation of the electricity sector with computational complexity. Planning tools vary significantly in their treatment of operating constraints, energy prices, demand projections, as well as temporal and geographic resolution. For systems such as that of India, where Variable renewable energy (VRE) technologies may play an increasing role in the future generation mix, the appropriate tool should capture the diversity of candidate VRE technologies and their applications, the location-dependent quality of these resources, and inherent uncertainty and variability in wind and solar generation. This model is based on a linear optimization program that minimizes the net present value of investment and operating costs subject to several constraints. The major constraints include balancing electricity supply and demand, resource supply limits, planning and operating reserve constraints, transmission constraints, and policy targets. These constraints are met considering a broad portfolio of conventional generation, renewable generation, storage, and transmission technologies. India model is implemented in the General Algebraic Modeling System (GAMS) programming language and is publicly available at https://www.nrel.gov/analysis/reeds/.

Electricity Demand & Supply Dynamics

To capture anticipated growth in electricity demand, we create state-wise hourly demand profiles for each year over the planning period. each with its own techno-economic parameters. Table 1summarizes the generation technologies considered in the model.

Table 1: Generation Technology Candidates

Generation Technology Candidates		
Conventional	***Subhead***	***Subhead***
Combined-cycle gas turbine (CCGT) Gas	Distributed PV	BESS (4-hour)
CCGT liquified natural gas (LNG)	Hydro pondage	BESS (4-hour)
Combustion turbine (CT) gas	Hydro run-of-river	

Generation Technology Candidates		
Conventional	***Subhead***	***Subhead***
Cogeneration bagasse	Hydro storage	
Diesel	Onshore wind	
Subcritical coal	Utility PV	
Subcritical lignite		
Supercritical coal		

Simplifications are made in the representation of generation units to maintain a tractable optimization problem. Here we aggregate all units of the same technology within a BA, with the exception of wind and solar, which are aggregated by resource region. To capture differences in cost and performance of units of the same technology, we cluster units into "performance bins" based on their techno-economic parameters.

Existing and Committed Generation Capacity

Input data for exogenously defined capacity include existing capacity, planned capacity additions, and planned retirements. Table 2 shows the planned additions and retirements through planning forecast period.

Table 2: Summary of Installed Capacity (GW) by Technology

VRE	*Hydro*	*Nuclear*	*Thermal*	*Subhead*
50	45	6.9	196.7	298.6

Future Technology Options for Expansion

Future electricity supply needs can be met by any of the thermal, nuclear, or renewables-based technologies. The optimal mix of technologies is based on several factors, including the cost of development, operation and maintenance costs, policy targets, and resource availability. The capital costs assumptions are sourced from public data of CEA. Table 3 shows the typical cost and lifetime parameters.

Table 3: Capital Cost and Plant Lifetime Assumptions for Generation Technologies

Technology	*Capital Cost (crore/MW)*	*Plant Lifetime (yrs)*
BESS	9.1	15
CCGT gas / LNG	4.7	55
Gas CT	4	55
Hydro	10	100
Nuclear	10.2	100
Subcritical Coal	6.5	25
Supercritical Coal	6.5	25
PV	5.5	30
Wind	6	24

For all technologies, both mature and emerging, there is a learning rate that results in reductions in capital costs over time as manufacturers and developers gain experience with the technology. We adopt the same learning rates used in NREL's 2018 Annual Technology Baseline "Mid" estimates.

The investment constraints represent policy, resource, or technical criteria that may influence investment outcomes. We impose three types of investment constraints on generation additions: (1) first year for endogenous capacity additions, (2) absolute growth limits, and (3) relative growth limits. The first year for endogenous capacity additions is the initial year when new capacity can be built based on economic criteria. Before the first year, only prescribed additions can be added.

The absolute growth limit represents the state-wise capacity limits on hydro, biomass, and waste heat recovery (WHR) technologies based on their estimated potential. Finally, we use relative growth and geographic diversity constraints to prevent unrealistic rates of capacity growth in any single year or location. All technologies except BESS are constrained with a 50% year-over-year limit of growth relative to installed capacity in the previous year. Renewable Resource Supply Curves uses supply curves for wind and solar to characterize the potential sites available for development and directly evaluate the investments of these generation sources. These supply curves are estimated from detailed weather data, geospatial constraints, and economic assumptions.

These are combined with financial assumptions about technology capital costs, fixed operating costs, and grid integration costs (i.e., transmission upgrades) to calculate site-based levelized cost of energy (LCOE). Hourly profiles for each potential site are created to estimate generation, curtailment, and capacity credit for all wind and solar investments.

System Operations

uses a reduced form-dispatch where generation technologies, rather than individual units, are dispatched to meet requirements for operating reserves and electricity demand in each time slice. This section presents the operational characteristics and constraints designed to capture the cost and performance characteristics of each technology type.

Model uses the variable operation and maintenance cost parameter to capture differences in unit cost and performance for existing and planned units. Within each Balancing area (BA), we cluster individual units into "performance bins" or groups of units with similar costs.

As the penetration of VRE and storage technologies increases, more-detailed representation of system operations becomes increasingly important in planning. The Model addresses this through simulations of time-synchronous operations to estimate curtailment for each capacity expansion solution.

The operating constraints represent technical and resource-based limits on how technologies may be dispatched. These include (1) seasonal limits on hydropower generation, (2) limits on gas fuel supplies, (3) minimum loading for CCGT gas, and (4) seasonal minimum loading limits.

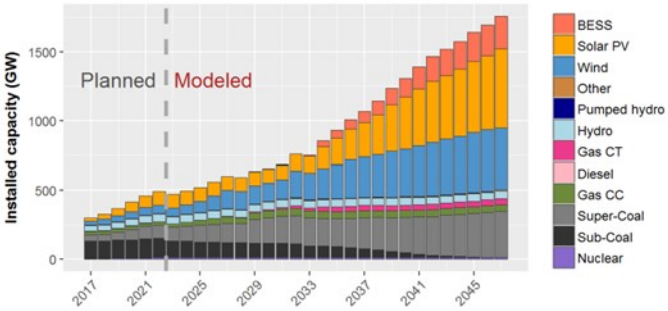
INTERPRETING THE MODELING RESULTS

The result of model shows an example of India modeling to examines the development of the India power system to 2047 under a Base scenario.

Electricity Installed Capacity

In the Base scenario, the total installed capacity over the planning period increases from 299 GW in 2017 to 1,718 GW in 2047. Capacity additions and retirements are fixed based on current plans through 2022. After that, the model optimizes the capacity mix in each year to achieve a least cost system. Figure 1 shows the total modeled capacity expansion under the Base scenario.

Figure 1: Total installed capacity, 2017–2047 in the Base scenario



Based on guidance from policies, all subcritical coal and diesel plants are retired by 2047. Most new investments are from supercritical coal, wind, solar PV and BESS technologies. After 2022, there are no prescribed additions, and all investments reflect economic, least-cost capacity additions. Gas CT plants have more generation dispatch flexibility and are better suited than gas CC plants to operate as peaking plants with very low utilization. Investments in wind, solar PV, and BESS account for most capacity additions after 2034; the fraction of installed capacity from solar and wind increases from 17% in 2017 to 58% in 2047. Supercritical coal and BESS also play a larger role in the future capacity mix, accounting for 19% and 13% of installed capacity in 2047 respectively.

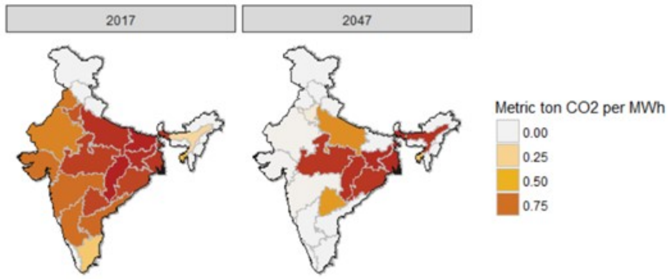
In a future system with high penetrations of Renewable Energy (RE), capacity additions are driven by the coincidence of demand and RE generation rather than peak demand alone. By 2047, the system has surplus capacity during the peak demand months of July –September because high wind speeds mean more wind generation is available to meet peak demand in these months. New capacity is needed to meet peak demand during the moderate demand months of October and November, when wind generation is lower.

Electricity Carbon Emissions

India has pledged a 33%–35% reduction in the emissions intensity of its economy from 2005 to 2030 (UNFCCC 2015). Reducing emissions from the electric power sector is a critical element of this goal. In the Base scenario, total emissions increase over the planning period as the amount of total electricity generated increases significantly. However, the emissions intensity decreases 47%, from 0.76 metric tonnes of carbon dioxide per megawatt-hour in 2017 to 0.40 in 2047.

Carbon emissions from the production of electricity also become more concentrated in a few states. Figure 2 shows the variation in CO2 emissions from the geographical variation.

Figure 2: Carbon emissions intensity from electricity production by state, 2017 and 2047



CONCLUSIONS

The supply of electricity in India is poised to undergo significant changes over the coming decades. A system previously dominated by subcritical coal plants could rely increasingly on supercritical coal, wind, and solar technologies. In this analysis, we find 95% of electricity demand could be met by these three technologies by 2047. As electricity supplies become more concentrated in areas with strong variable renewable energy (VRE) resources, new interstate transmission capacity is needed to evacuate excess power to neighboring states. This concentration also has implications for carbon emissions, which become increasingly concentrated in a few Eastern Region states where coal remains cost-competitive with other technologies.

The results from this long-term assessment are pertinent for a variety of decision makers. For example, policymakers must establish the policy and regulatory frameworks needed to enable cost-effective investments and system operations. And the results can allow utilities, project developers, and financing institutions to anticipate system changes and mobilize necessary expertise and funding to realize their long-term vision. Finally, the evolution of the power system is of interest to the broader public who will be impacted by issues related to land use, electricity prices, quality of supply, emissions, and domestic jobs in the energy sector.

However, some assumptions are needed wherever data are incomplete or unavailable. While many of these assumptions are unlikely

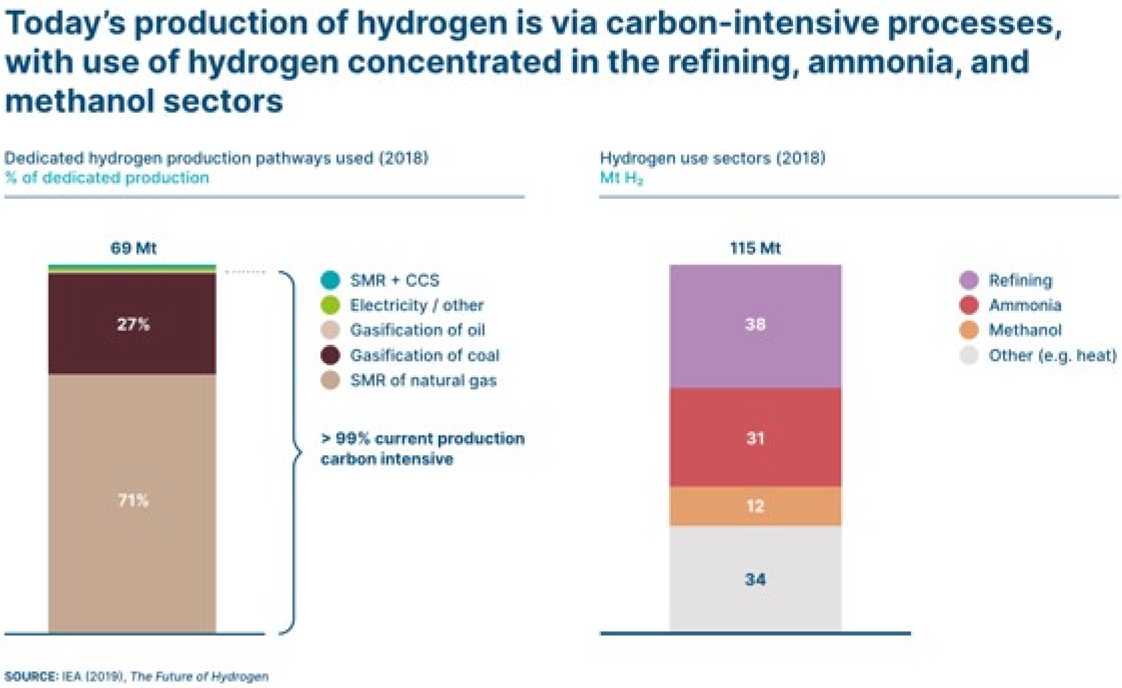


Figure 5 – Main Production Routes and Hydrogen Consumers (ETC Global Hydrogen Report, 2021)

conversion of syngas (CO + H2) in longer-chain hydrocarbons such as gasoline and other liquid fuel products, known as Gas to Liquids Technologies (GTL). The liquid hydrocarbons production can be carried out by direct syngas conversion, in Fischer-Tropsch synthesis reactions or through methanol production as intermediate product (Methanol to Olefins technologies).

Showed process in Figure 6 is based in the syngas gas generation from steam reforming of natural gas, this is the most common route, however, there are process variations applying syngas production through coal, biomass, or petroleum coke gasification route.

The process starts with syngas generation and, as aforementioned, the produced hydrocarbon chain extension is controlled in the Fischer-Tropsch synthesis step through the CO/H2 ratio in the syngas fed to the FT reactors (beyond temperature and reaction pressure), following the produced hydrocarbons are separated and sent to refining steps as isomerization, hydrotreating, hydrocracking, catalytic reforming, etc. According to application of the produced derivative (Gasoline, Diesel, Lubricant, etc.).

Some side reactions can occur during the hydrocarbons production process, leading to coke deposition on the catalyst, causing

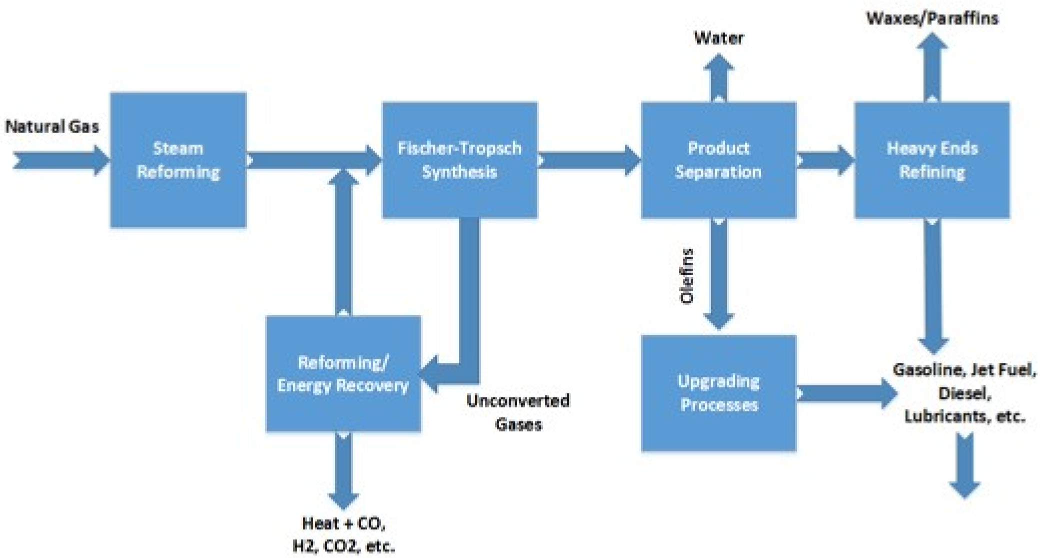


Figure 6 – Block Diagram to a Typical Fischer-Tropsch GTL Process Plant.

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