

RENEWABLE ENERGY TRANSITION IN INDIA: STRATEGIC ROLE OF CMAs THROUGH BIG DATA ANALYTICS ENABLED MANAGEMENT ACCOUNTING

Abstract

Indian energy sector is transitioning towards a renewable-energy-intensive ecosystem. The fundamental shift from conventional fossil fuel-based generation towards renewable sources involves a much more complex model, attributed by intermittency, storage, flexible generation-demand response, dynamic electricity pricing and data-oriented grid management. This demands a complete relooking of financial evaluation of integrated renewable energy (RE) projects based on levelized cost of electricity (LCOE). With the introduction of time-of-day (ToD) pricing system, it has become essential to leverage big data analytics (BDA) capabilities in system driven cost approach. The financial evaluation of renewable energy projects is now much beyond the LCOE, it has to integrate cost associated with storage, transmission, dynamic ToD tariffs, environmental and regulatory risks. This transition positioned CMAs to play a strategic role in renewable energy integration through energy project lifecycle costing, capital budgeting, environmental management accounting, sustainability and regulatory decision-making. This article establishes the nexus between renewable energy transition, management accounting practices, BDA and strategic role of CMAs for offering a cost-efficient architecture of renewable energy integration.



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Introduction

The global energy supply chain is facing frequent disruption due to geopolitical conflicts, trade wars, disruptive technologies

and climate related changes. Being a globally connected economy, Indian energy sector is highly sensitive to these geopolitical developments. The impact of uncertainties is not limited to oil and natural

gas supplies, but also exert adverse pressure on entire value chain and impede the development of country. As per IEA report, India recorded the second-largest increase in energy demand globally, which is more than the combined increase in energy demand of all the advanced economies (IEA, 2025). A substantial part of Indian energy comes from imports, and uncertain global market conditions presents challenges and opportunities for world's third-largest oil importer.

In last two decades, installed power capacity in India has more than doubled with a mix of 49% from non-fossil fuel sources amounting to 235.7 GW, including 226.9 GW renewable and 8.8 GW nuclear. (Press Information Bureau, 2026). This renewable transition has fundamentally altered the economics of electricity generation. The economics of conventional thermal and renewable wind and solar is significantly different. While former account for fuel expenditure as an important marginal cost determinant, the latter is mainly characterised by heavy initial capital expenditure and low marginal generation cost. The thermal installation typically requires a much longer period as compared to PV solar and wind projects. The coal based thermal utilities provide stable power supply, while variable solar and wind generation creates critical implication for matching the demand-supply patterns. Integration of renewable and non-renewable require advanced technologies like big data analytics and artificial intelligence (AI) for grid stability, efficient market operation, project financing and management accounting strategies. These aspects become critical due to integration of renewable power in system mainly characterised by long-term power-purchase agreements, regulated electricity tariffs, public and private sector distribution companies, cost-based dispatches and emerging electricity markets.

Therefore, traditional LCOE approach for evaluation of integrated renewable projects may not be appropriate and gives a hazy financial outlook. Jain and Shrimali (2022) through simulation-based study demonstrated the limitation of LCOE in evaluation of renewable and thermal power utilities. Researchers used a real-time 15-minute data for a merit-based-dispatch model and found that moderate level of renewable penetration can generate significant financial savings. The moderate renewable integration can reduce up to 11% of power-purchase costs under selected demand-growth and renewable penetration scenarios. Since, Indian utilities marginally procure electricity through spot-market,

the long-term purchase agreements and two-part tariffs (fixed and variable charges) significantly influence the renewable procurement decisions. As per CERC report published in June-2025, electricity traded through power exchanges accounted for 7.54% of electricity generation in its short-term market analysis. This includes exchange-based markets, the day-ahead market and real-time market. CERC explicitly differentiate power-exchange transactions from bilateral transactions and the broader short-term market. In June 2025, bilateral transactions accounted for 6.49%, while short-term transactions and deviation settlement mechanism (DSM) together represented 16.39% of electricity generation (CERC, 2025).

The economic question about renewable energy is now no longer simple. It is not just how much renewable is cheaper than conventional electricity, rather question is whether particular renewable energy portfolio can deliver a reliable solution at minimum total system cost. Shifting from generation to total system cost has a major implication for strategic thinkers like cost and management accountants. Increased penetration of solar and wind makes daytime pricing more volatile and require price cannibalisation, which eventually create financial risks for renewable generators (Saraswat and Sharma, 2026). Appropriate energy storage and revenue stacking can reduce the volatility and improve the financial viability of renewable projects through diversifying revenue streams. Therefore, Indian renewable energy transition and investment decisions increasingly require a comprehensive framework through integration of engineering, costing and energy marketing information. This is precisely area where big data analytics, management accounting and the professional expertise of CMAs can be strategically utilised.

Research gap: Although renewable energy transition in India was studied by previous researchers from theoretical and applied perspective, however the literature is largely fragmented and marginally explained how advanced technologies like BDA can be integrated to translate technical, operational and regulatory information into strategic financial and management decisions using a professional framework.

Objective statement: This article examines how renewable energy integration, big data analytics and data driven management accounting can strengthen

the financial evaluation and cost optimisation of India's evolving electricity system. The work further identifies the emerging strategic roles and competencies required for CMAs and proposes a professional framework for managerial analysis. The proposed professional framework can be utilised by the management accountants to connect the engineering data, electricity market data and operational data for converting the energy information into economic values.

Renewable energy integration, financial evaluation and cost optimisation

Besides technical complexities involved in renewable power integration, the economic value of renewables is determined through comprehensive framework considering the pure production cost and cost associated with integration of electricity system. For example, solar influx is available during daytime and fluctuates due to weather conditions, while electricity demand can remain high during evening periods. Likewise, wind generation depends on wind current, which again weather dependent. Such temporal differences may create imbalances between generation and consumption patterns and affects the pricing of available electricity. Due to merit-order dispatch effect, the renewable power generators with low marginal costs get priority over expensive conventional generators. With increased renewable share, corresponding expensive thermal utility may get displaced on the basis of variable purchase cost. Moderate renewable penetration contributes to economic and environmental goals. Jain and Shrimali (2022) demonstrated that wind generated mixing yields highest potential savings, followed by solar and hydro. However, marginal financial benefit depends on which conventional utilities are displaced. For example, a relatively low-variable-cost thermal generation replacement with additional renewable becomes less attractive and may yield smaller or adverse marginal financial benefit.

Therefore, investment in renewable projects cannot be evaluated in isolation. Incremental effect of renewable addition on the entire generation mix should be considered. A solar project with low LCOE may provide a smaller incremental benefit due to generation period clashes with low cost conventional generator. A higher LCOE renewable-storage project may yield greater benefits due to availability during peak-price periods. Saraswat and Sharma (2026) argued that price cannibalisation could be a

potential risk to renewable project viability. Increased penetration of renewable itself suppresses the pricing during higher renewable availability periods, resulting pressure on revenues. Renewable-storage projects even with higher LCOE can mitigate adverse price impact by storing renewable at low price time and supplying at higher demand and price. The appropriate financial profiles must incorporate risk-adjusted total system value and costs.

LCOE is calculated on the basis of discounted lifetime cost of power generation. However, relatively newer components of costs such as balancing, storage, curtailment and deviation must be incorporated in broader system-cost framework for financial evaluation of renewable projects. Theoretically, total cost of renewable integration can be represented by following equation:

$$TCRE = LCOE + CT + CB + CS + CD + CC$$

where Levelized cost of energy = LCOE,

CT = transmission cost (costs of connecting the project to the electricity grid and transmitting its output.)

CB = balancing cost (Costs of managing fluctuations in electricity supply and demand)

CS = storage cost (costs associated with batteries or other storage needed to integrate variable renewable energy)

CD = deviation cost (Cost incurred due to actual electricity generation or consumption differs from the schedule)

and CC = curtailment cost (Economic cost of electricity that could have been generated but is reduced or stopped due to grid or system constraints or cheaper alternative.)

Note # 1: The above conceptual representation proposed for managerial analysis only and not an established universally accepted accounting formula.

Likewise, the economic value should include energy revenue, capacity value and other potential revenue streams; theoretically

$$NEV = RE + RC + RA + RS - TCRE$$

Where RE = energy revenue (Revenue from electricity sales and energy-arbitrage activities, after deducting associated energy and operating costs),

RC = capacity related value (Economic value of storage contribution, distinct from actual capacity-market payments),

RA = ancillary revenue (Revenue generated through frequency regulation, reserves, balancing, and other ancillary grid-support services),

RS = storage revenue (Revenue from additional storage applications not already included in energy, capacity, or ancillary-service revenues),

TCRE = transient climate response to cumulative carbon emissions (associated cost).

Note # 2: Appropriate discounted may be applied on future revenues and costs to determine present economic value.

Note # 3: the above is only a suggestive Net Economic Value Framework.

The above distinction plays a crucial role in renewable investment appraisal, and management accountants should consider a comprehensive costing model including expenditure related to capital, operating, financing, replacement, asset degradation, transmission, forecasting, balancing, storage, carbon emission and regulatory compliances. Sensitivity and scenario analysis can further test the impact of changes in the variables like interest rates, generation yield, electricity prices, renewable penetration, storage costs and regulatory conditions. Thus, lifecycle costing provides a more appropriate picture than annual expenditure analysis. An initial capital incentive renewable asset but predictable operating expenditure may produce superior lifecycle economics compared to an apparently cheaper alternative that exposes the utility to higher fuel-price, carbon emission or balancing risks.

Renewable-energy optimisation through big data analytics, smart-grid, ToD tariff

Proliferation of intelligent sensing and digital measuring devices have created the new opportunities for data-driven smart-grid management (Tu et al., 2017). Big data analytics and artificial intelligence are increasingly becoming important technologies for predicting and forecasting electricity demand-generation patterns. Concurrent data acquisition and processing through BDA enable optimising storage, improving pricing decisions and enabling economic load dispatches. The digital electricity networks, smart meters, supervisory control and data acquisition systems, digital weather stations, satellite inputs, IoT sensors, electricity-marketing exchanges and digital distribution systems generate enormous data, which can be translated into exquisite business decision

through BDA application.

A well-placed BDA solution can effectively support grid stability, distributed-energy integration and optimum scheduling. In renewable-energy management, improved solar and wind forecasting can substantially reduce scheduling errors, while precise load forecasting optimises purchasing and load dispatch decisions. Efficient pricing forecast can assist wider market participation, while updated forecast on battery status can optimise the charging-discharging decisions. Therefore, BDA enabled energy management system creates a live connection between operational informatics and financial outcomes. Distribution companies (DISCOMs) can integrate historical load data, weather station information, grid connected rooftop-PV output, ToD tariffs and power-exchange prices for developing economic procurement and distribution decisions.

The Electricity (Rights of Consumers) Rules -2023 was amended in June-2023 introducing the ToD framework with prescribed timelines, consumer categories, smart metering and state regulatory arrangements. ToD provides an economic bridge between renewable generation and electricity demand. ToD pricing framework offers differentiated price of electricity for different time periods. It encourages consumers to optimise and reschedule consumption requirements from high-demand periods to relatively cheaper tariff periods. Tomar and Tiwari (2017) examined the economic relevance of ToD pricing for grid connected rooftop PV systems under net-metering and ToD arrangements in New Delhi. The finding of their work suggests that dynamic pricing structure materially influences techno-economic feasibility of renewable system and improve day time utilisation.

Regulatory framework and financial decision-making

The Electricity Act, 2003 provides a comprehensive regulatory framework for electricity generation, transmission and distribution. Electricity regulatory commissions in India work autonomously and determine many necessary economic conditions including tariff regulations, licensing, and inter and intra state transmission. Financial performance of renewable projects and its integration are inseparable from these regulations. Financial performance of renewable-projects depends on many factors such as renewable purchase obligations, renewable-energy certificates, tariff, grid codes and deviation-settlement. Grid Code - 2023 also recognise importance of system

flexibility and provides as conducive environment for renewable integration including provisions relevant to hybrid and energy storage. Deviation settlement creates a direct link between forecasting accuracy and financial performance. Deviation from loading schedule attracts additional adverse financial exposure for renewable generator. Therefore, investment in better forecasting technology alter the nature of IT expenditure from just IT expenditure to a strategic cost-control investment (CERC, 2026).

While appropriate regulatory commission determined tariffs in accordance with provision of section 62 of the Electricity Act, 2003, tariffs are discovered through a transparent competitive bidding process outlined in section 63 of the act and in accordance with the Central Government guidelines. (CERC, 2026; Government of India, 2003). Besides adhering regulatory mandates, the financial evaluation of renewable project must include the environmental dimension. The principle of sustainability accounting intended to connect environmental performance with financial performance and organisational strategies. An electricity-procurement having higher financial costs but lower carbon intensity, lower regulatory risk and greater renewable mix may generate superior long-term values.

Role of CMAs in renewable energy cost optimisation

The renewable penetration and integration with electricity system presents a structural transformation in energy economics and management accounting. Literature highlights that renewable generation can potentially reduce the electricity purchase costs, however corresponding financial value largely depend on penetration levels, generation mix, growth pattern, and timing of generation. The flexible system must consider engineering, marketing, regulatory and accounting information for addressing the price cannibalisation, intermittency, balancing, storage and demand problems. Advanced technology like BDA provides a technological foundation for cost optimisation and financial performance evaluation.

Big Data systems continuously collect structured, semi-structured and unstructured data related to electricity demand, renewable mix, weather conditions, energy exchange prices, storage and grid conditions. The forecasting models translate this data into predictions, connecting the operational dynamics with financial parameters. ToD tariffs encourage demand rescheduling to move towards economic

and environment friendly time periods. Optimised predictive models select the least-cost combination of power procurement, renewable mix, storage and demand response.

The BDA-enabled energy optimisation flow can be presented as: Data acquisition → Big data analytics → Forecasting → Optimisation → Dynamic operational decisions → Cost/revenue outcomes.

Approach and basis of analysis

On the basis of review of selected academic literature, professional analysis, Indian electricity-sector regulatory documents, renewable energy costing concepts, and management accounting principles, this work propose a logical flow which can be utilised by the CMAs' to convert operational results into financials. The responsibilities of CMAs go much beyond traditional cost determination, budgeting, variance analysis and investment appraisal. The role increasingly extends towards data analytics, sustainability, environmental management, statutory compliance and strategic decision-making. This can be represented as: Big data analytics → Predictive modelling → Forecasting → Optimisation → Cost management → Financial evaluation → Strategic decision making. In this flow, the management accountants are not just recipient of engineering information but also connect technical parameters of renewable performance with lifecycle costing, environmental costs, investment appraisal, regulatory risk, and sustainability performance. The management accountants stand as active participant in determining the optimum operational strategy to create higher economic value. CMAs' expertise in environmental costing, sustainability accounting and BDA enabled management accounting lays a strong foundation for technology driven professional transition.

Renewable energy management is not a simply technological transition from coal to solar, wind and battery storage, rather than it is a complete transformation from traditional cost accounting to data-driven predictive management accounting, which keeps the sustainability in centre. A successful renewable integration ultimately depends upon how swiftly organisations combine the engineering efficiency, regulatory prudence, big data analytics and comprehensive financial evaluation. In this journey, the CMAs are uniquely positioned to provide seamless interface between technical energy performance and financial management. While engineers determine the renewable capacity factor, degradation rate

and generation profiles, CMAs can translate these variables into financials such as LCOE, NPV, IRR, DSCR, lifecycle costing and risk-adjusted return. CMAs can further extend their expertise by utilising BDA capabilities coupled with smart metering and supervisory control and data acquisition (SCADA) into management accounting systems for predicting relationships between energy consumption and production cost. Industrial CMAs can optimise production schedule to take the advantage of favourable ToD periods. This may sometimes require business process reengineering. Likewise, a DISCOM CMA may think about BDA integration with energy procurement prices, demand forecasts, renewable generation, deviation costs and environmental risk in a predictive power-purchase-cost model.

From management accounting perspective, transition from historical cost accounting to predictive energy management accounting triggers an immediate need to combine historical financial information with BDA driven predictive and prescriptive analytics. ToD tariffs create an opportunity to calculate time

specific electricity cost. CMAs can determine if production schedule can be shifted between different time blocks for marginal electricity-cost saving. This equally applies on battery storage decisions. Batteries can be charged at relatively lower prices and discharge when prices are high. The economic values therefore should be evaluated on the basis of time dependent cost drivers. Deviation cost, renewable purchase obligation, carbon indicators and sustainability parameters should be incorporated into measurable financial KPIs, rather than treating them as purely legal matters. The renewable energy financial evaluation framework must consider system reliability and flexibility. CMAs can build a management dashboard to report electricity cost per unit, renewable mix, carbon intensity, peak demand cost, deviation exposure, adjusted risk, storage utilisation and avoided emissions at one place.

Conceptually central proposition and conceptual framework proposed by this this work can be presented as follows.



(Conceptual framework)

ICMAI's framework

ICMAI provides many important documents like 'Guidance Note on Environmental Costing', Sustainability Standards (SS-1 and SS-2), and Cost Accounting Standard, CAS-14 on pollution control cost (ICMAI, 2015a; ICMAI, 2015b; ICMAI, 2015c). For renewable energy integration, these guiding documents on environmental costing are particularly relevant as renewable energy decisions involve environmental costs and corresponding benefits cannot be appropriately captured through conventional financial accounting. Environmental management accounting allows managers to incorporate variables related to environmental expenditure, waste management costs and compliance costs in energy procurement and investment decisions. Such inclusion is necessary because stakeholders demand a more transparent disclosure on climate related risks and sustainable performance. The guidance notes and standards provide a professional framework through which CMAs can support renewable energy integration on total system cost concept, incorporating sustainability indicators as decision variables within the BDA enabled management accounting practices.

Practical implications

Besides improving theoretical understanding on renewable energy integration in Indian landscape, this work offers important practical implications. Now focus is to be shifted from just renewable energy capacity addition towards renewable energy integration. For management accountants, renewable transition creates a new field of energy cost management. Energy storage, flexible demand-supply mechanism, transmission, dispatch forecasting and IT infrastructure cost should be treated as complementary investments in integrated project appraisal. ToD tariffs creates a new window of consulting opportunity where management accountants can offer their expertise in business process reengineering and rescheduling production towards cheaper renewable availability. CMAs should utilise capabilities of big data analytics to acquire necessary data and information for coordinating these strategic decisions. CMAs should develop expertise in electricity markets, energy storage economics, renewable forecasting, ToD tariff analysis, environmental accounting, sustainability reporting and BDA-enabled financial analytics. ICMAI can continue institutional support in this

professional journey through strengthening education, professional development and capacity building in energy economics, big data analytics, AI, ESG and electricity regulations. The future CMAs must be in a position to answer the management accounting questions such as:

Marginal utility of adding another renewable megawatt?

Optimal battery charging-discharging and storage duration?

Cost of renewable curtailment?

Demand response that can be saved under ToD pricing mechanism?

How demand forecasting can be improved?

Financial value of improving such forecast accuracy?

Limitations of the study: While proposed professional framework with LCOE remains useful for comparing the average lifetime cost of projects, it cannot be treated as a comprehensive measure of whole system value. Complementary system-cost assessments are inherently context specific and largely depends on geographical location, network constraints, resource availability, demand patterns, regulatory conditions, and market structure. These context specific attributes can materially affect the overall project economics. Likewise, application of BDA in renewable energy integration require data quality, data governance, interoperability, cybersecurity, and the investment in digital infrastructure. Analytical capabilities of human resource within the organisation are another important consideration. Energy storage economics is again context specific and dependent on market design, revenue-stacking opportunities, operating conditions, and asset utilisation. Finally, the benefits associated with ToD tariffs are practically not available equally to all, rather than critically depends on consumers' ability and willingness to manage the load demand with best tariff structure. Accordingly, all these approaches are complementary and not universally applicable metrics. The effectiveness of each metrics should be evaluated within the specific technical, economic, institutional, geographical, and organisational context. MA

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