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Stochastic Multi-Objective for Optimal Dispatch of Renewable-Rich Power Systems Under Uncertainty: A Review and Future Directions

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PRESENTATION OUTLINE

01 INTRODUCTION
02 STATEMENT OF THE PROBLEM
03 AIM AND OBJECTIVES
04 SCOPE OF THE STUDY
05 LITERATURE REVIEW
06 FINDINGS AND DISCUSSION
07 IDENTIFIED CHALLENGES
08 FUTURE DIRECTIONS
09 CONTRIBUTIONS TO KNOWLEDGE
10 CONCLUSION
- REFERENCES

01 INTRODUCTION

- The integration of renewable energy resources into power network enhance green house gases (L. S. Paraschiv and S. Paraschiv, 2023). However, its variability changes the system operations (Swadi et al, 2024) which can lead to unsecure network if not well managed.

- Why the field is moving beyond deterministic economic dispatch toward stochastic, multi-objective and voltage-secure operation, renewable-rich grid need dispatch that plans for uncertainty.



02 STATEMENT OF THE PROBLEM

- Generation of renewable energy sources output mainly depend on weather (Swadi et al, 2024) .

- Variability in renewable generation affect voltage stability, transmission line losses and congestion (Maheshwari et al., 2023).

- The objectives are interdependent and often conflict (Katkar & Jadhav, 2025).

- This review therefore examines renewable uncertainty modelling, multi-objective dispatch formulations, and the integration of stochastic methods with multi-objective optimization.

03 AIM AND OBJECTIVES

AIM

- The aim of this study is to review the Stochastic multi-objective optimization methods for optimal dispatch in renewable-rich power networks under uncertainty.

OBJECTIVES

The objectives are to:

1. Examine renewables generation and load uncertainty modelling techniques.

2. Identify the economic, technical and environmental objectives of renewable dispatch.

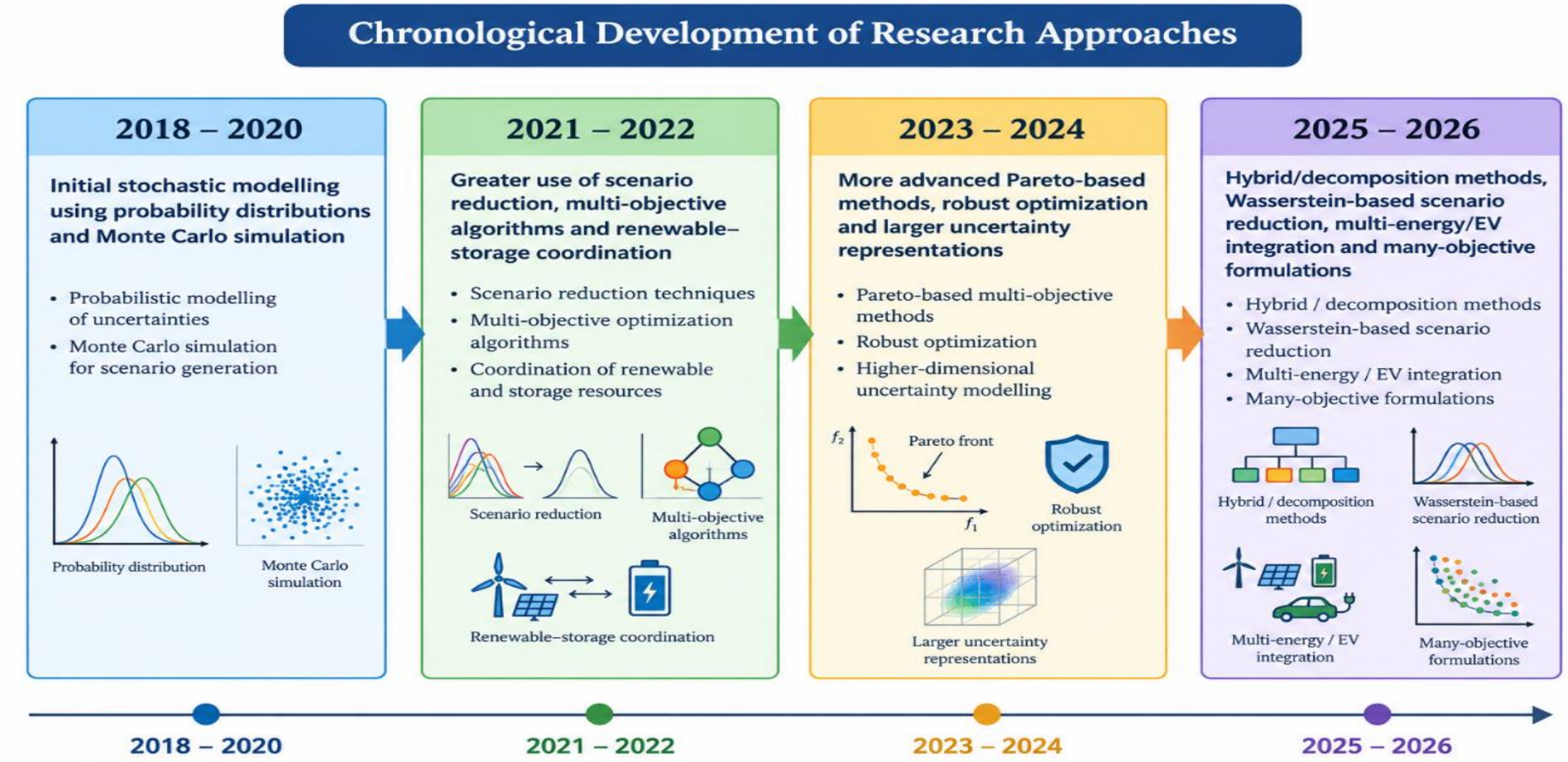
3. Investigate optimization used for stochastic modelling and multi-objective dispatch formulations.

4. Identify research gaps, methodological challenges and future research directions.

04 SCOPE OF THE STUDY

This work synthesizes relevant studies published between 2018 and 2026 linking uncertainty, Multi-Objective formulations, and optimization techniques.

05 LITERATURE REVIEW: Chronology



LITERATURE REVIEW CONT'D: How renewable uncertainty is represented?

The reviewed literature uses complementary analytical, scenario-based, robust and data-driven paradigms

PROBABILISTIC (Wang et al., 2020)

Weibull: wind
Beta: solar
Gaussian / Normal: load
Lognormal: solar in some studies

SCENARIO-BASED (Li et al., 2022)

Monte Carlo sampling
Scenario trees
Scenario generation & reduction
Moment matching / Wasserstein

ROBUST & CHANCE-CONSTRAINED (Lu et al., 2026)

Two-stage robust models
Distributionally robust methods
Chance constraints
Interval-based approaches

DATA-DRIVEN / INTELLIGENT (Katkar & Jadhav, 2025)

Forecast-error learning
Clustering and feature extraction
GAN-based generation
Spatio-temporal modelling

Key trade-off: wider uncertainty coverage versus computational burden and the risk of losing critical scenarios.

LITERATURE REVIEW CONT'D: Evolution of renewable dispatch frameworks

The literature reflects a shift from cost-centred dispatch toward integrated, uncertainty-aware formulations.

STAGE 01

CLASSICAL OPF / ED

Primarily fuel-cost minimization; limited treatment of variability and environmental effects (Lu et al., 2020).

STAGE 02

MULTI-OBJECTIVE DISPATCH

Cost, emissions and technical objectives; Pareto-based evolutionary and swarm algorithms. (Katkar & Jadhav, 2025)

STAGE 03

STOCHASTIC + FLEXIBLE DISPATCH

Scenario-based uncertainty, storage, EVs, demand response and dynamic coordination (Maheshwari., 2023).

Emerging direction: stochastic multi-objective ACOPF that jointly considers renewable and load uncerta voltage security, losses, congestion and renewable curtailment.

LITERATURE REVIEW CONT'D: What does optimal dispatch seek to balance?

Objectives are not independent: improving one performance measure can worsen another (Paraschiv et al., 2023).

ECONOMIC

Generation cost
Energy procurement cost

TECHNICAL

Power losses • voltage deviation
VSI / L-index • congestion

ENVIRONMENTAL

Emissions
Renewable utilization / curtailment

Pareto trade-offs → feasible compromise solutions

A robust formulation must preserve operational feasibility while exposing trade-offs among competing objectives.

LITERATURE REVIEW CONT'D: OPTIMIZATION METHODS

How stochastic modelling is combined with multi-objective optimization?

Three broad solution families recur across the reviewed studies.

MATHEMATICAL PROGRAMMING
(Biswas et al., 2018)

Stochastic MILP • SOCP
ε-constraint • Benders decomposition
Chance-constrained formulations

Strength: structured formulations
Concern: non-convex AC constraints and scenario growth

METAHEURISTICS (Bhurt et al., 2023)

MOPSO • NSGA-II • MOEA/D
Differential evolution • RIME
Hybrid and Pareto-based methods

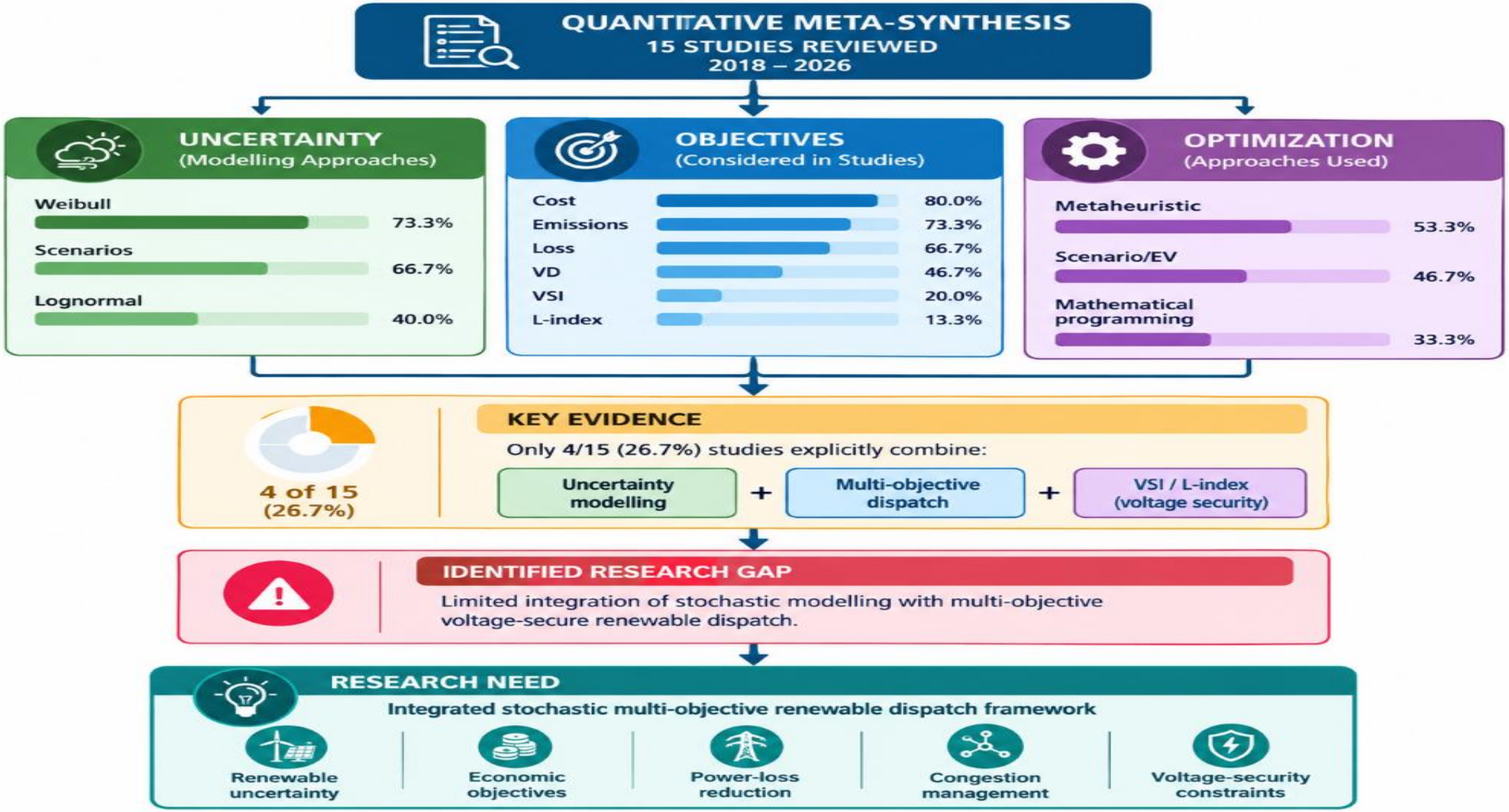
Strength: flexible search for complex trade-offs
Concern: convergence, diversity and parameter sensitivity

INTELLIGENT / DATA-DRIVEN (Katkar & Jadhav, 2025)

Machine-learning forecasting
GAN scenario generation
Clustering • MPC • learning-based control

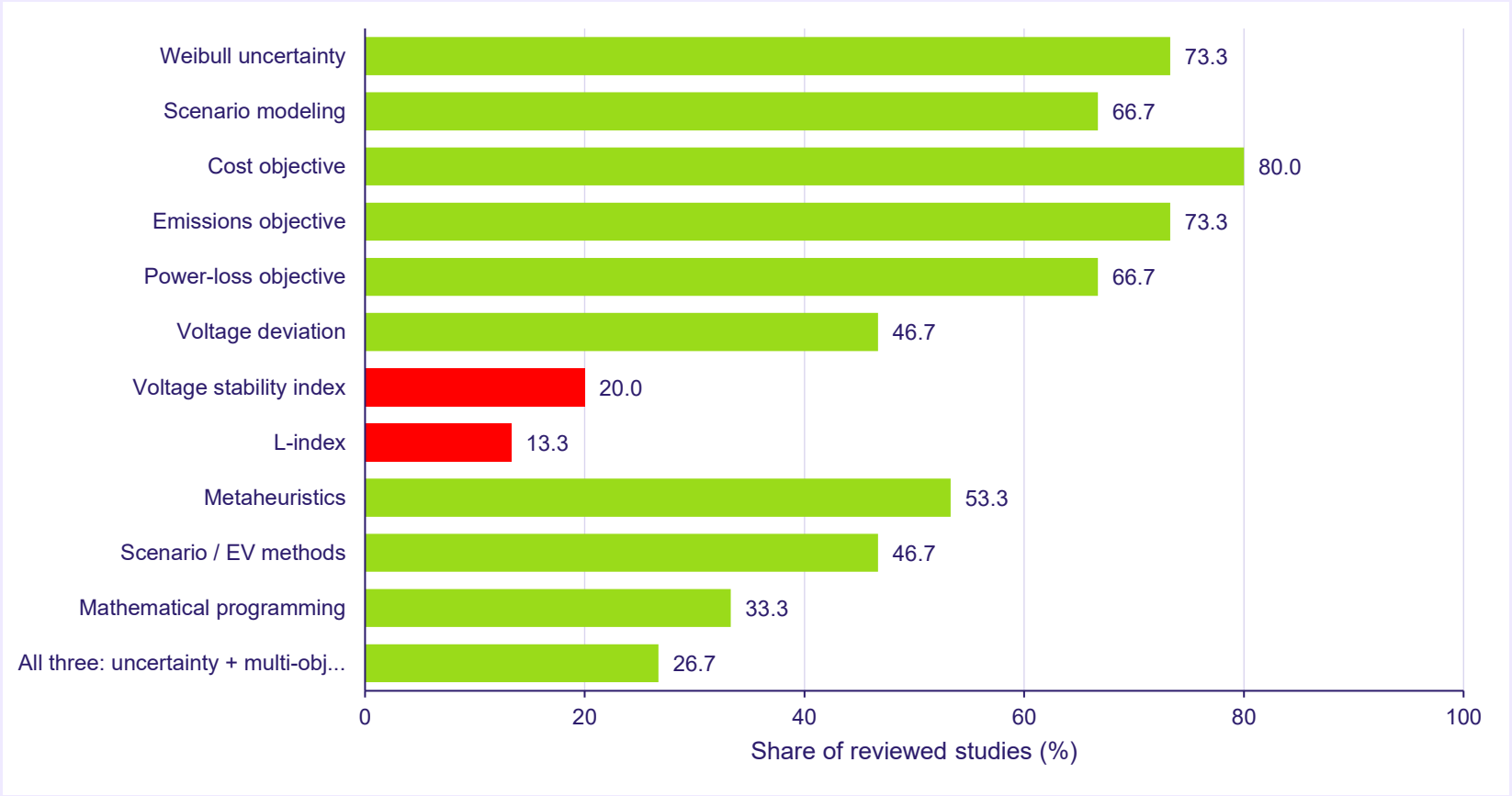
Strength: data adaptation and dynamic potential
Concern: data quality, validation and real-time reliability

06 FINDINGS AND DISCUSSION

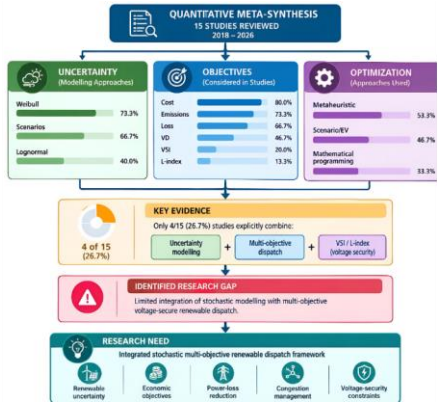


FINDINGS AND DISCUSSION CONT'D

The clearest gap is voltage-secure stochastic dispatch



Economic and emissions objectives are common, while voltage-security measures remain rare.



4 / 15

26.7% explicitly combine uncertainty modeling, multi-objective dispatch and voltage-security measures such as VSI or L-index.

FINDINGS AND DISCUSSION CONT'D

The comparison in the reviewed works show diversity in uncertainty models, objectives and solution strategies.

DIMENSION	COMMON PRACTICE	WHAT IT ENABLES	PERSISTING LIMITATION
Uncertainty	Distributions; Monte Carlo; scenarios	Represent variability and operating conditions	Correlations and extreme events may be lost
Objectives	Cost, emissions, losses, voltage indices	Expose competing system priorities	Holistic objective combinations remain rare
Optimization	MILP / SOCP; Pareto metaheuristics	Generate feasible or trade-off solutions	Scenario growth, scalability and diversity
Security	Voltage and line constraints; VSI / L-index	Account for network operating limits	Security requirements not consistently embedded

Overall finding: Integrated stochastic multi-objective dispatch is advancing, but voltage-security-aware and computationally scalable formulat remain underdeveloped.

07 IDENTIFIED RESEARCH GAPS

Four connected challenges remain

These limitations constrain the reliability and practical deployment of stochastic multi-objective dispatch.

01 Computational burden

Nonlinear, non-convex ACOPF + many scenarios; multi-period models increase dimensionality.

02 Uncertainty fidelity

Wind, solar and load correlations; temporal dependence; non-stationarity and extreme events.

03 Many-objective search

Conflicting objectives create complex Pareto fronts; convergence and diversity are difficult to maintain.

04 Voltage & network security

Enforcing AC power flow, voltage, thermal and stability requirements across scenarios is demanding.

Research gap: uncertainty, multiple objectives and voltage security are still not consistently addressed together.

08 FUTURE DIRECTIONS

The next framework should be correlation-aware, adaptive and voltage-secure

- Model spatial-temporal dependence
- Preserve critical tails
- Secure stochastic ACOPF
- Scale the framework
- Support practical selection

TAKE-HOME MESSAGE

The next generation of renewable dispatch must be:

Uncertainty-aware

Multi-objective

Voltage-security constrained

Computationally scalable

Secure renewable integration requires coordinated treatment of uncertainty, trade-offs and network constraints.

09 CONTRIBUTIONS TO KNOWLEDGE

- This study gave attention to comparative assessment of renewable uncertainty modelling, multi-objective formulations and methods for optimized renewable energy dispatch.

- The study was able to classified how multi-criteria objectives were combined which is currently in trend for renewable dispatch.

- Identification of methodological gaps for future directions.

- The results will be relevant from an academic, technical, and practical standpoint, providing theoretical insights for the planning and operation of future power systems sustainability.

10CONCLUSION

From renewable variability to secure, multi-objective dispatch

- Stochastic modelling is essential when renewable output defers from forecasts.
- Economic, technical and environmental objectives must be optimized together.
- Scenario management, computational scalability and voltage-security integration are priority research nee

Thank you

Questions & discussion

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