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TEN YEARS OF RENEWABLE ENERGY INTEGRATION IN SENEGAL RETROSPECTIVE VALIDATION OF 2015 GRID PRIORITIES USING 2025 OPERATING DATA AND A PLANNING FRAMEWORK FOR 2026–2030

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ABSTRACT

A decade after the first wave of renewable integration studies in Senegal, this paper re-examines whether their stated priorities remain aligned with current operational realities. Recommendations from the 2015 Senelec–Tractebel study and the 2017–2035 PATRP are compared with the 2025 Energy Information System (SIE) report and Senelec's 2025 operating report. The SIE records, for 2024, 1,903.81 MW of installed capacity and a peak of 1,159 MW, including 267.01 MW of grid-connected photovoltaic capacity, 159 MW of wind and 127 MW of hydropower. For 2025, Senelec reports 2,310.5 MW of installed capacity, a peak demand of 1,261 MW, the commissioning of the Walo battery system rated at 10 MW and 20 MWh, and 1,040 GWh of cross-border exchanges. The accumulated evidence confirms the continuing salience of variability management, operating reserves, N−1 security, dynamic stability and interconnection planning. Their evaluation must now explicitly incorporate battery storage, inverter-based resources and the implications of control parameterization. A retrospective validation matrix and monitoring indicators are proposed, together with a planning framework for 2026–2030 structured around adequacy, network performance, flexibility, stability and regional resilience. An illustrative reserve computation examines sensitivity to additional photovoltaic capacity. Its role is methodological; it does not constitute an operator forecast..

KEYWORDS: renewable integration; power-system stability; transmission; reserve; battery storage; inverter-based resources; interconnections; Senegal.

Nomenclature and Abbreviations

The table below defines the abbreviations, symbols and units used in the text, equations and tables. MW denotes power, whereas MWp denotes nominal peak photovoltaic power. Energy is expressed in MWh or GWh.

Abbreviation or symbol	Meaning	Unit or clarification
RE	Renewable energy	—
PV	Photovoltaic	—
BESS	Battery Energy Storage System	—
IBR	Inverter-Based Resources	—
GFL	Grid-following control	—
GFM	Grid-forming control	—
LVRT	Low-Voltage Ride-Through	—
HVRT	High-Voltage Ride-Through	—
SCR	Short-Circuit Ratio at the connection point	Dimensionless

SOC	State of Charge of storage	%
RoCoF	Rate of Change of Frequency	Hz/s
CCT	Critical Clearing Time of a fault	s
ENS	Energy Not Served	MWh or GWh

Abbreviation or symbol	Meaning	Unit or clarification
KPI	Key Performance Indicator	Indicator-dependent
CAGR	Compound Annual Growth Rate	%/year
VRE	Variable Renewable Energy	—
SIE	Energy Information System (French acronym retained)	—
PATRP	Power Africa Transactions and Reforms Program	—
JET	Just Energy Transition	—
OMVS	Senegal River Basin Development Organisation	—
OMVG	Gambia River Basin Development Organisation	—
N	Reference network state with its elements in service	—
N−1	Security criterion following the loss of one network element	—
t	Time instant considered	Time-series dependent
j	Index of a historical priority	Dimensionless
R_req(t)	Reserve requirement at time t in expression (2)	MW
C_max(t)	Largest generation contingency at time t	MW
R_VRE(t)	Reserve requirement associated with renewable ramps	MW
C_interco(t)	Credible loss of imports at time t	MW
R_ext,firm(t)	Firm external support available at time t	MW
Vmin / Vmax	Minimum and maximum voltage values	Model-base dependent
Q	Reactive power	MVAr
Δf	Frequency deviation	Hz
V0–V6	Identifiers of the minimum validation scenarios	—
MW	Megawatt; unit of active power	1 MW = 10^6 W
MWp	Megawatt-peak; nominal peak photovoltaic power	1 MWp = 10^6 Wp
MWh	Megawatthour; unit of energy	1 MWh = 10^6 Wh
GWh	Gigawatthour; unit of energy	1 GWh = 10^3 MWh
MVAr	Megavoltampere reactive; unit of reactive power	1 MVAr = 10^6 VAr
Hz	Hertz; unit of frequency	1 Hz = 1 s^{-1}
s	Second; unit of time	—

1. INTRODUCTION

Integration studies for solar and wind generation assess, in advance, the operational constraints that new resources may impose on a power system. A decade of operating experience now enables a retrospective appraisal of those assessments: which risks remain pertinent, and which require reframing. Senegal's trajectory over 2015–2025 provides a suitable basis for this comparison. Peak demand increased, solar and wind capacity scaled up, the transmission network expanded, and regional exchanges assumed a larger role. Grid-connected battery storage has also emerged as a distinct operational and planning resource.

1.1. Contributions

The study keeps historical projections distinct from recent observations. It consolidates the quantitative evidence available for 2019–2025 and employs a comparison matrix to track the evolution of technical priorities. These results inform a 2026–2030 planning framework that connects resource adequacy with network security, operational flexibility, dynamic stability and regional resilience.

2. Sources, Scope and Method

The principal references are the 2015 Senelec–Tractebel study[1], the 2017–2035 PATRP[2], the 2025 Energy Information System (SIE) report, which is primarily an energy balance for 2024[3], and the 2025 Annual Energy Flows Report.[4] The Just Energy Transition Investment Plan[5] and technical literature on inverter-based resources[6–16] provide additional context. Quantitative comparisons are performed only where definitions and reporting boundaries are sufficiently congruent. In particular, PATRP values are preserved as historical benchmarks rather than interpreted as estimates of current requirements.

Source	Period	Contribution	Interpretation rule
Senelec–Tractebel	2015	Variability, adequacy, static/dynamic studies	Ex ante reference
PATRP / Tetra Tech	2017–2035	N−1, reserve, stability, interconnections	Historical benchmarks
SIE 2025	2024 balance	Peak demand, generation fleet, RE, off-grid PV	Statistical observation
Senelec 2025	2025	Peak demand, generation fleet, BESS, exchanges, operation	Operator observation
JET Plan / ENERCAP	2025–2030	Solar + BESS pathway	Prospective, not confirmed delivery

2.1. Retrospective Validation Approach

For each historical priority j, the analysis verifies whether the associated risk or mechanism is observable in the recent record. The priority is then classified as persistent, transformed or strengthened, or as a new dimension. These categories serve to test the ongoing applicability of earlier concerns. They do not attribute causality: a present-day observation that resembles an anticipated risk is not, by itself, evidence of a causal relationship.

3. Findings of the 2015–2017 Studies

The 2015–2017 studies already addressed variability from solar and wind, generation adequacy, and power flows both under normal conditions and under N−1 contingencies. They further considered transient and frequency stability, spinning reserve, and support from neighboring systems. Among the benchmarks used by PATRP were a 115 MW loss at Sendou, a 41 MW intra-hour solar fluctuation and a 54 MW wind fluctuation. For one 2022 case, PATRP estimated a reserve of approximately 70 MW to cover the Sendou loss. These values document the assumptions of the period. They cannot be transferred to current operations without re-evaluation.

Dimension	Historical benchmark	2024–2025 observation	Retrospective assessment
Variability	PV/wind scenarios	PV and wind in operation	Persistent
Reserve	Loss + fluctuations	Reserve and exchanges remain central	Persistent / transformed
Network	N and N−1	Reinforced network and substations	Persistent
Stability	Voltage, transient, frequency	IBR and protection more critical	Strengthened
Interconnections	OMVS/OMVG support	Significant regional exchanges	Strengthened
Storage	Secondary dimension	Walo 10 MW/20 MWh	New operational dimension

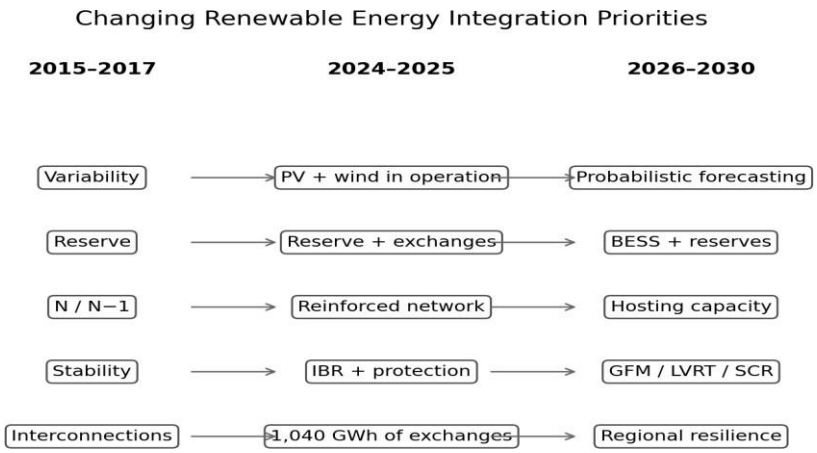


Figure 1: Evolution of integration priorities from the earlier studies through recent operation to the proposed 2026–2030 framework.

4. Quantitative Changes in the System

SIE reports that peak demand rose from 672 MW in 2019 to 1,159 MW in 2024, with Senelec subsequently reporting a 2025 maximum of 1,261 MW. The difference between the published 2019 and 2025 peaks is 589 MW, or roughly 87.6 percent of the 2019 level. This is a descriptive comparison, as reporting scopes may differ. The compound annual growth rate for 2019–2024 is approximately 11.5 percent; the increase from 2024 to 2025 is approximately 8.8 percent.

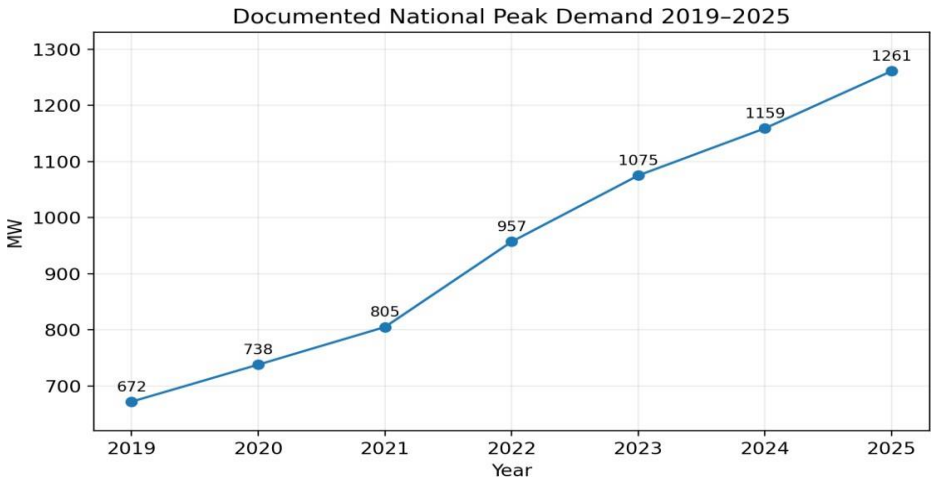


Figure 2: Reported peak demand from SIE for 2019–2024 and Senelec for 2025.

CAGR2019–2024 = (1159/672)^(1/5) − 1 ≈ 11.5% per year (1)

For 2024, SIE lists 267.01 MW of grid-connected solar and 159 MW of wind, totaling 426.01 MW, which corresponds to about 22.4 percent of the 1,903.81 MW of installed capacity. This share pertains to installed capacity rather than energy produced. The report also identifies 288.66 MW of off-grid photovoltaic capacity and 366.65 GWh of generation under a separate category. The scope of each category must therefore be verified before combining or comparing figures.

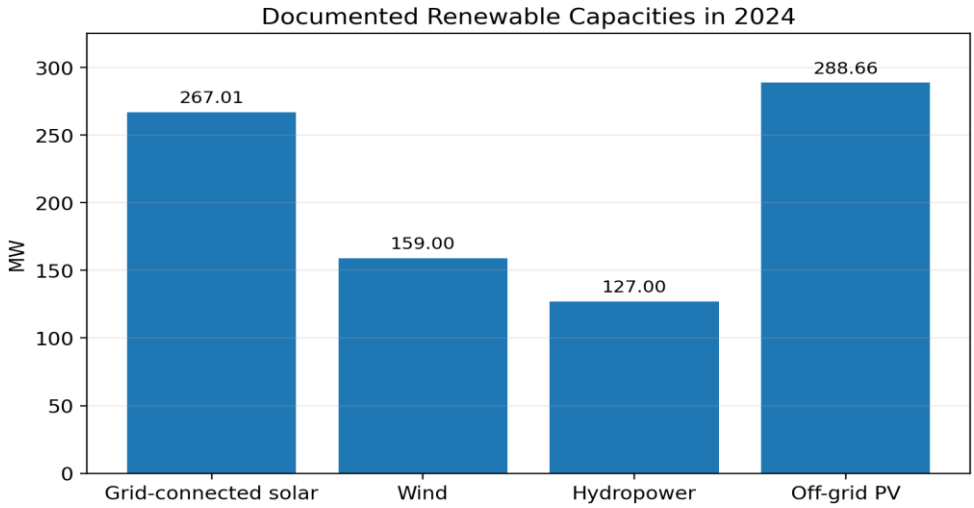


Figure 3: Documented renewable capacities in 2024.

Indicator	2019 / 2024	2025	Analytical use
Peak demand	672 MW (2019); 1,159 MW (2024)	1,261 MW	Demand scale
Installed capacity	1,903.81 MW (2024)	2,310.5 MW	Generation fleet scale
Grid-connected solar	267.01 MW (2024)	—	PV exposure
Wind	159 MW (2024)	—	Wind exposure
Hydropower	127 MW (2024)	—	Dispatchable/regional renewable resource
Off-grid PV	288.66 MW; 366.65 GWh	—	Distinct category
Grid-connected BESS	—	Walo 10 MW/20 MWh	New flexibility
Cross-border exchanges	—	1,040 GWh	Regional dimension

5. Reserve Frequency and Interconnections

Reserve needs are driven by several classes of events, including the outage of a generating unit, renewable generation ramps and the loss of an interconnection. When available, regional support can reduce the local response required; the potential unavailability of that support is itself a contingency to be evaluated. The following expression specifies the quantities needed for an initial screening calculation.

Rreq(t) ≥ max{Cmax(t), RVRE(t), Cinterco(t)} −

Rext,firm(t) (2)

Here, Cmax denotes the largest single generating contingency, RVRE the requirement induced by renewable ramps, Cinterco a credible import loss, and R_ext,firm firm external support available at the time t. The expression identifies inputs for screening and is not intended as an operator's real-time rule.

5.1. Exploratory Sensitivity

Analysis The illustrative exercise retains the historical 115 MW contingency and considers photovoltaic ramps of 5, 10 and 15 percent applied to a capacity block increasing to 700 MWp. Under these suppositions, incremental PV capacity does not mechanically translate into a one-for-one increase in reserve. The result depends on the assumed ramp rate and the dominant contingency, and also on storage capability, synchronous unit commitment and regional support. The resulting curves show this sensitivity within the confines of the illustration; they do not constitute a 2030 forecast or a prescriptive reserve target.

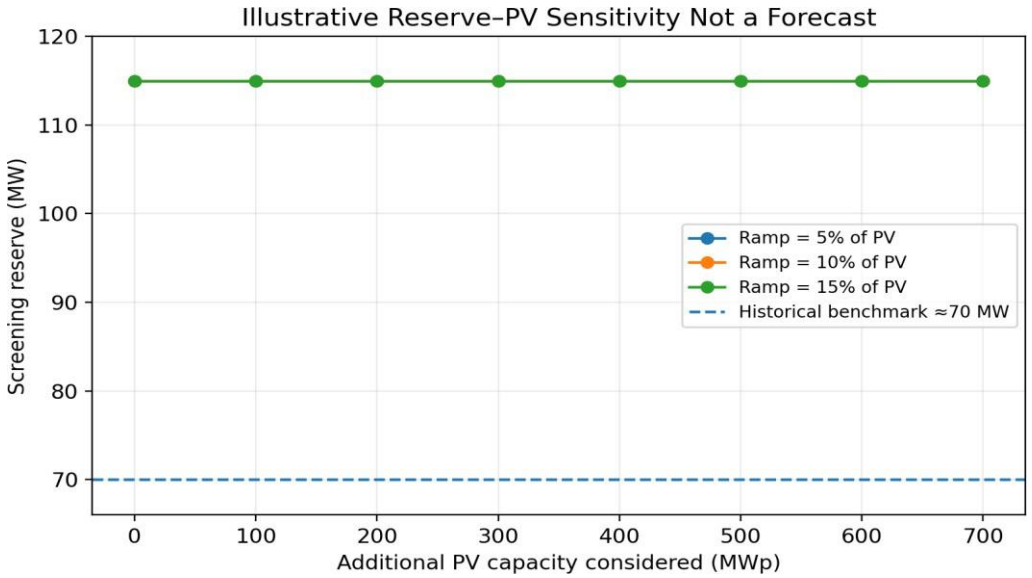


Figure 4: Illustrative reserve sensitivity to an additional PV capacity block. The calculation uses synthetic assumptions and does not represent an official reserve requirement.

6. Inverter Based Resources and Storage Changing the Nature of the Problem

As inverter-based resources account for a larger fraction of generation, system security becomes increasingly dependent on their dynamic response to faults and other disturbances. Installed capacity and annual energy output do not describe these dynamics adequately. Robust evaluation must include control parameterization, low- and high-voltage ride-through capability, reactive power and voltage support, current limiting behavior, and active power–frequency response. The local short-circuit strength, often expressed as SCR, together with the design and coordination of protection systems, materially conditions the same analysis. Battery energy storage can deliver rapid support, but the effective contribution is constrained by power and energy ratings, state of charge, and the adopted dispatch or control policy. Grid-following and grid-forming modes must be explicitly defined and consistently represented in the validation models.

Function	Indicator	Validation question
Frequency	RoCoF, nadir, recovery time	Sufficient response after a loss or ramps?
Voltage	Vmin/Vmax, Q, LVRT/HVRT	Does the inverter remain connected?
Grid strength	SCR / equivalent impedance	Robust control in a weak grid?
BESS	MW, MWh, SOC, availability	Sufficient energy and power headroom?
Protection	Timing, selectivity, ride-through	Unwanted trips avoided?

7. Five Layer Planning Framework for 2026–2030

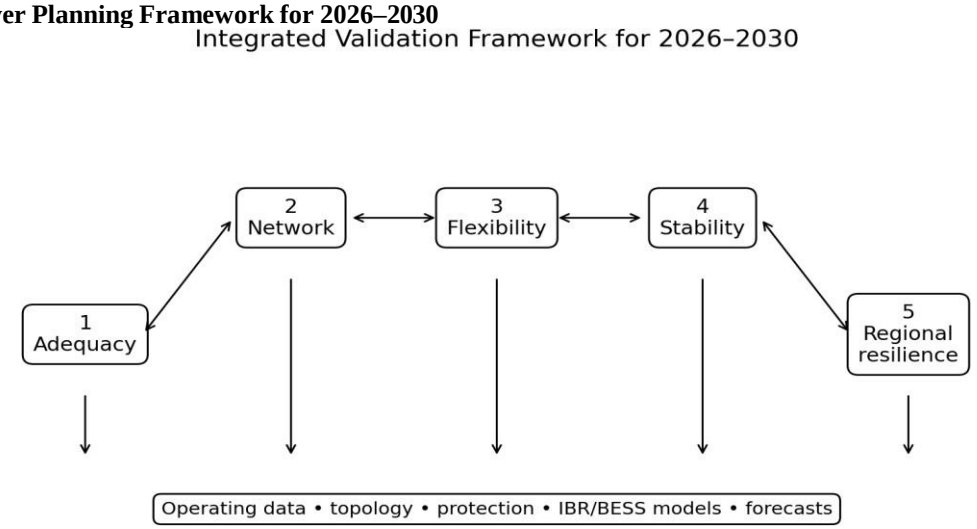


Figure 5: Proposed five-layer framework for integration studies in 2026–2030. Source: author's elaboration.

Layer	Question	Indicators / simulations
1. Adequacy	Sufficient energy and capacity?	Peak demand, margin, ENS, chronology
2. Network	Secure flows in N and N−1?	Line/transformer loading, voltage, losses
3. Flexibility	Can variability be accommodated?	Reserve, ramps, curtailment, SOC
4. Stability	Acceptable dynamic response?	RoCoF, nadir, CCT, LVRT, SCR
5. Regional resilience	Can interconnection loss be managed?	Imports, local reserve, islanding/fallback

7.1. Minimum Validation Scenarios

Case	System state	Disturbance	Main KPIs
V0	Reference	None	Power flows, voltage, reserve
V1	High load / low RE	Loss of largest unit	Nadir, RoCoF, reserve
V2	Low load / high PV	Network N−1	Voltage, congestion, SCR
V3	High PV/wind	Renewable ramp	Δf, reserve, BESS SOC
V4	High interconnection flows	Loss of interconnection	Frequency, replaceable imports
V5	High IBR share	Critical fault cleared	LVRT, current, CCT
V6	BESS in use	Repeated events	SOC, availability, cycling

8. Alignment with the 2030 Pathway

The Just Energy Transition Investment Plan allocates financing for an additional 700 MWp of solar capacity. It also identifies three Quick Win priorities, each integrating 100 MWp of photovoltaics with 60 MW and 180 MWh of battery storage.[5] These items indicate a forward-looking investment trajectory rather than a set of assets that will be in service by 2025. Updated models should be applied to every interconnection stage and assessed across all five layers of the proposed framework.

Prospective element	Published value	Implication for studies
Additional solar	700 MWp	Hosting capacity and chronology
3 PV Quick Wins	300 MWp in total	Coordinated connection studies
Quick Wins BESS	180 MW / 540 MWh in total	Co-optimise reserve, energy, stability
RE target	40% of installed capacity by 2030	Test several synchronous unit commitment states

9. DISCUSSION

The retrospective analysis shows that the fundamental physical challenges remain: variability, credible contingencies, power flow management, voltage regulation, provision of reserves, and overall stability. The salient shift from 2015 to 2025 lies in the scale of the system and in the breadth of resources available to address these challenges. Interregional exchanges play a more significant role, grid-connected battery storage is now a documented component of the resource mix, and inverter-based resources have become markedly more prominent. Accordingly, planning must determine the volume of capacity that can be interconnected without compromising security and specify the suite of system services required to operate the system reliably.

9.1. What Is Validated and What Is Not

Statement	Level of support
The 2015–2017 risk categories remain relevant	Strong documentary support
The 2025 system is larger and more interconnected	Recent quantitative support
Storage becomes an operational variable	Supported by Walo Storage
Exact reserve requirements for 2030 are known	No: an updated model is required
A single national hosting capacity can be stated	No: it depends on location, network state and time
Optimal GFM parameters are known	No: specifications and simulations are required

9.2. Limitations

The underlying sources apply heterogeneous reporting boundaries, definitions, and temporal scopes. Comprehensive specifications for protection schemes, power electronic converters, dispatch practices, and interconnection configurations are only partially accessible. As a result, the evidence base cannot rigorously quantify the accuracy of each 2015 projection, nor can it support the reconstruction of a consistent time series from nonpublic records. The reserve screening example is presented solely to illustrate an analytical method. Sound operational and investment decisions must instead rely on chronological, dynamic simulations calibrated with operator datasets.

10. Methodological Recommendations

Future analyses should employ a network model that is refreshed annually to reflect the realized topology and observed operational time series. Establishing a shared repository of recorded contingencies would enable systematic validation against operating experience, while transparent, well-documented dynamic parameters would strengthen the modeling of inverter-based resources. Storage should be represented explicitly in adequacy, reserve, and stability assessments. The system should also be stress-tested for the loss of an interconnection. For new photovoltaic connections, hosting capacity should be quantified at the point of interconnection across a spectrum of system states. A shared dashboard could track peak demand, synchronous unit commitment, solar and wind output, reserve margins, cross-border exchanges, curtailment, voltage and frequency events, and storage availability.

11. Conclusion

A decade of transformation in Senegal's power system indicates that renewable integration still hinges on adequacy, network capability, reserve provision, dynamic stability, and interconnection performance. The concerns formulated prior to large-scale solar and wind deployment remain pertinent, but they now require updated operating assumptions and modeling techniques. System expansion, a higher share of inverter-based resources, increased regional exchanges, and the integration of battery storage all reshape the assessment. The proposed 2026–2030 framework consolidates these issues into five analytical layers and evaluates them under a unified scenario set. Its objective is to specify the conditions under which additional renewable capacity can be connected and operated with the system services it requires.

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