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INVESTMENT SEQUENCING FOR A JUST ENERGY TRANSITION IN SENEGAL GRID SOLAR STORAGE ACCESS AND CAPITAL MOBILISATION

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ABSTRACT

Senegal's Just Energy Transition Investment Plan estimates power-sector capital needs at about EUR 9.531 billion and sets a 2030 objective of renewables representing 40% of installed capacity. Achieving this objective depends critically on temporal coordination. A photovoltaic plant will not deliver its intended output at commissioning if the interconnection, flexibility assets, or operating protocols are not in place. This paper develops a sequencing methodology that structures investments around these interdependencies. The approach treats separately the effective renewable contribution, system security, project maturity, socio-economic impacts, and financing. Evidence is drawn from the 2025 JET Investment Plan, the 2025 Energy Information System, the 2025 Annual Energy Flows Report, the 2017–2035 PATRP analysis, and a least-cost integrated planning framework. The JET portfolio foresees 700 MWp of additional solar capacity. Three Quick Wins comprise 300 MWp of PV paired with 180 MW/540 MWh of battery energy storage systems. Constraints documented by PATRP specify the pre-connection checks for further variable generation, including reserve sufficiency, compliance with the N−1 criterion, interconnection availability, and dynamic stability margins. A dependency map links investment packages to stress-test scenarios and financing instruments. The resulting protocol enables assessment of the feasibility of alternative build sequences as conditions evolve. The contribution is methodological; the current evidence base does not justify a definitive project ranking or an optimal investment timetable.

KEYWORDS: just energy transition; integrated planning; investment sequencing; solar photovoltaics; BESS; grid; universal access; financing; Senegal.

ABSTRACT

Nomenclature and Abbreviations

The abbreviations, symbols and units below follow the terminology used in the text, tables and equations. Normalised project characteristics are dimensionless; this paper does not specify a numerical normalisation scale.

Abbreviation or symbol	Definition	Unit or convention
BESS	Battery energy storage system	—
EE	Energy efficiency	—
EMS	Energy management system	—
RE	Renewable energy	—
ESCO	Energy service company	—
IPP	Independent power producer	—
JET	Just energy transition	—
KPI	Key performance indicator	Depends on indicator
LPDSEM	Energy and Mining Sector Development Policy Letter (French acronym)	—

M&V	Measurement and verification	—
OMVG	Gambia River Basin Development Organisation (French acronym)	—
OMVS	Senegal River Basin Development Organisation (French acronym)	—
Abbreviation or symbol	**Definition**	**Unit or convention**
PATRP	Power Africa Transactions and Reforms Program	—
PIMC	Least-Cost Integrated Plan (French acronym)	—
PPA	Power purchase agreement	—
PV	Photovoltaic	—
R&D	Research and development	—
SIE	Energy Information System (French acronym)	—
GIS	Geographic information system	—
SOC	Storage state of charge; meaning used in the scenarios	Fraction or %
NPV	Net present value	Monetary unit
x_i	Vector of the five normalised characteristics of project i, Equation (1)	Dimensionless
RE_i	Useful renewable contribution of project i	Dimensionless
SEC_i	Contribution of project i to system security and robustness	Dimensionless
MAT_i	Technical and contractual maturity of project i	Dimensionless
SOC_i	Documented socio-economic effects of project i; distinct from state of charge SOC	Dimensionless
FIN_i	Ability of project i to secure financing	Dimensionless
i	Index of the project considered	—
k	Index of a project prerequisite	—
t	Date at which prerequisite availability is assessed	Selected time unit
z_i□ (t)	Availability of prerequisite k for project i at date t, Equation (2)	Binary: 0 or 1
Feasible(i,t)	Feasibility indicator for project i at date t, Equation (2)	Binary: 0 or 1
seq	Investment sequence under assessment	—
R(seq)	Share of tested scenarios in which the sequence remains feasible, Equation (3)	Fraction from 0 to 1
N_feasible	Number of scenarios in which the sequence is feasible	Count
N_scenarios_tested	Total number of scenarios tested	Count
N and N−1	Operation with all elements in service and following the loss of one element; N is distinct from scenario counters	—
S0 to S3	Base case; high demand; grid delay; reduced interconnection availability	—
EUR million	Million euros	10^6 EUR
MW	Megawatt, unit of power	10^6 W
MWp	Megawatt-peak; equivalent to the French notation MWc	10^6 W peak
MWh	Megawatt-hour, unit of energy	10^6 Wh
GWh	Gigawatt-hour, unit of energy	10^9 Wh
kWh	Kilowatt-hour, unit of energy	10^3 Wh

Abbreviation or symbol	**Definition**	**Unit or convention**
p.u.	Value expressed relative to a base quantity (per unit), particularly for voltage	Dimensionless

Reading convention: a dash indicates that no unit is associated with the abbreviation. Calculations must use a consistent time unit and monetary basis.

1. INTRODUCTION

Generation facilities are often commissioned before the grid-side infrastructure needed for safe interconnection and operation is in place. Substations may still be under construction, protection schemes may not yet have regulatory clearance, and metering systems may be only partially installed. The converse pattern also occurs: network reinforcements can remain underutilized when the associated generation or load materializes later than expected. In both cases, the temporal coordination of works determines the quality of service delivered and the productivity of capital already deployed. Intertemporal investment sequencing manages these interdependencies by specifying the readiness dates of projects and the enabling conditions they require.[12,15,22,30]

1.1. Research Question and Contributions

The core question is how to determine, in a transparent manner, whether a proposed investment sequence remains technically attainable and capable of attracting financing when realized demand or infrastructure readiness deviates from the forecast. The paper addresses

this problem using the JET portfolio as a case study. It links documented historical grid constraints to observations for 2024–2025, constructs a dependency map across projects, and formulates stress scenarios to evaluate alternative sequencing options. A financing matrix complements the technical assessment by aligning asset categories with their contractual cash flow structures and the set of feasible financing instruments.

2. Sources and Method

The analysis relies on six principal sources: the 2025 JET Investment Plan[1], the 2025 Energy Information System (SIE) report[2], the 2025 Annual Energy Flows Report[3], the 2017–2035 PATRP study[4], the least-cost integrated planning framework (PIMC)[5], and the Energy and Mining Sector Development Policy Letter for 2025–2029 (LPDSEM).[6] Because these documents span different time horizons and serve distinct purposes, figures from PATRP are used as historical reference points rather than as forecasts of grid conditions in 2026. Investment amounts are taken verbatim from the published JET plan. The robustness exercises indicate how the method would be implemented once contractual schedules, power system models, and project finance parameters become available.

Source	Reference year	Information used	Qualification
JET plan / ENERCAP	2025	Portfolio, strategic areas, 700 MWp, Quick Wins, instruments	Published amounts, not recalculated
Senegal SIE	2025 (2024 balance)	Fleet, peak demand, solar, wind, hydro	2024 statistics
Senelec Annual Energy Flows	2025	2025 fleet, peak demand, Walo Storage, exchanges	2025 operating status
PATRP / Tetra Tech	2017–2035	N−1, reserves, stability, OMVS/OMVG	Historical benchmarks
PIMC / LPDSEM	2024–2029	Consistency of sector planning	Institutional framework

3. Quantitative Assessment of the JET Portfolio

The JET plan places total financing needs at EUR 9,531 million. The largest expenditure blocks are green mobility and universal access, amounting to EUR 3,372 million and EUR 3,255 million, respectively. Investments in renewables integrated within a modernised and interconnected grid total EUR 1,515 million. The residual components comprise coal phase-out (EUR 212 million), modern household fuels (EUR 117.6 million), demand management (EUR 603.2 million), industrial energy efficiency (EUR 49.5 million), green industries (EUR 42 million), and the water–energy–agriculture nexus (EUR 365 million).[1] This composition clarifies where financing pressures are concentrated. That said, the magnitude of an allocation does not, by itself, dictate implementation timing or sequencing.

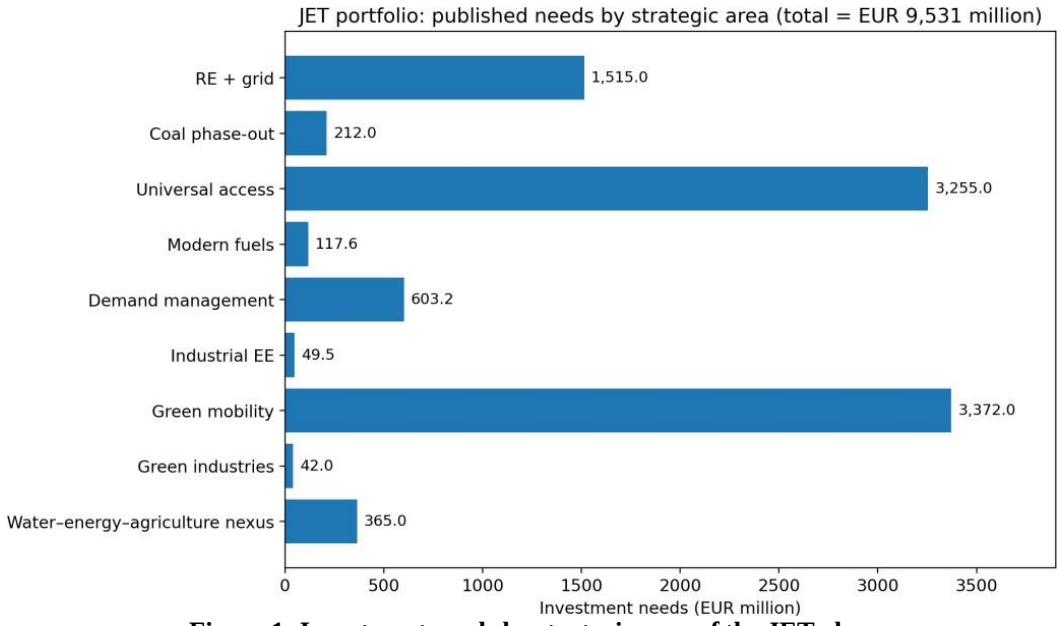


Figure 1: Investment needs by strategic area of the JET plan.

Strategic area	Published amount (EUR million)	Indicative share of total
RE + grid	1,515.0	15.9%
Coal phase-out	212.0	2.2%
Universal access	3,255.0	34.2%
Modern fuels	117.6	1.2%
Demand management	603.2	6.3%
Industrial EE	49.5	0.5%
Green mobility	3,372.0	35.4%
Green industries	42.0	0.4%
Water–energy–agriculture nexus	365.0	3.8%

3.1. Renewables and Grid Investment

According to the plan's detailed table, approximately EUR 1,514.4 million is assigned to Strategic Area 1. This envelope covers three 100 MWp Quick Wins and an additional 400 MWp of solar PV paired with storage still to be developed. A further EUR 30 million is reserved for grid reinforcement and modernisation, and EUR 10 million for capacity building, research and development, and renewable energy promotion.[1] Each Quick Win integrates a 60 MW/180 MWh battery energy storage system. In total, the three projects comprise 300 MWp of PV, 180 MW of storage power, and 540 MWh of storage energy. The difference between power and energy capacity is critical when appraising the services the storage can deliver.

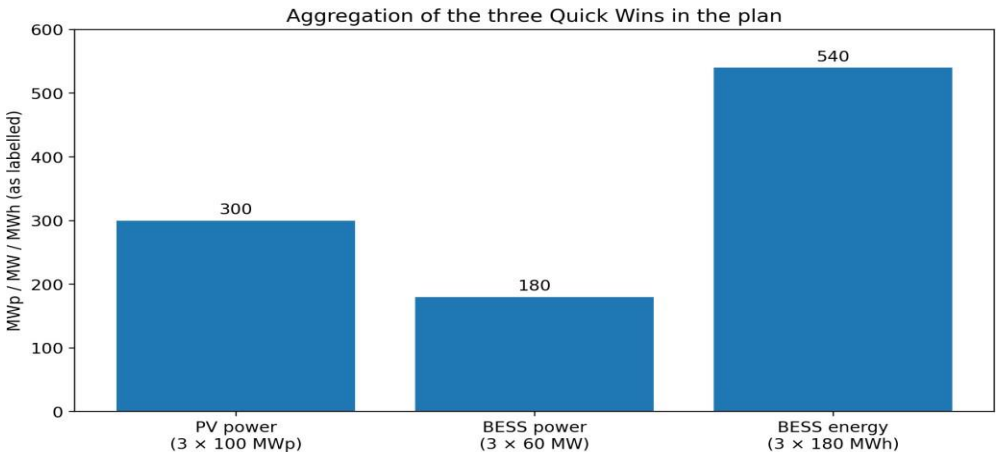


Figure 2: Aggregated published technical specifications of the three Quick Wins.

4. Power System Developments and Coordination Needs

The 2025 SIE reports an installed capacity of 1,903.81 MW for 2024 and a system peak of 1,159 MW. The portfolio comprises 267.01 MW of grid-connected solar, 159 MW of wind, and 127 MW of hydropower.[2] For 2025, Senelec indicates 2,310.5 MW of installed capacity and a maximum peak of 1,261 MW, and lists the Walo Storage facility with a rating of 10 MW/20 MWh.[3] Analytical work on investment pathways must be continuously aligned with these updates. Any sequencing assessment should therefore adopt generation and demand assumptions that correspond to the decision period under consideration.

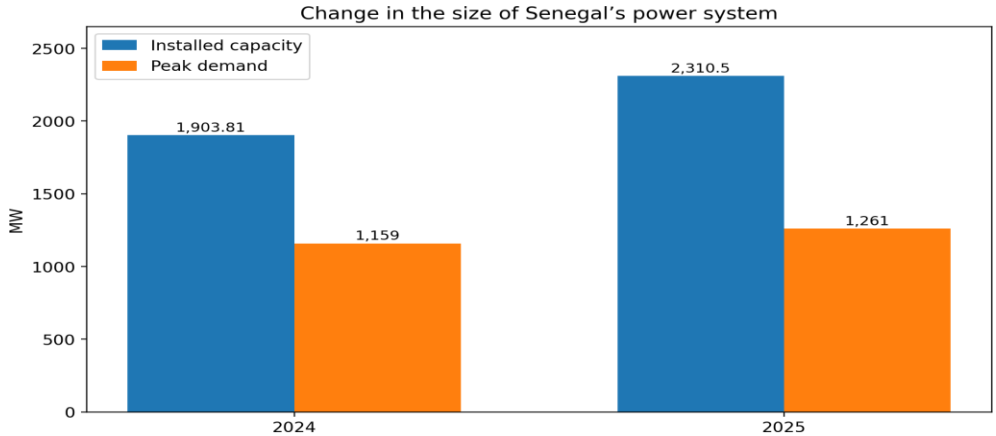


Figure 3: System size indicators in 2024 and 2025.

Indicator	2024	2025 / recent benchmark	Implication for sequencing
Installed capacity	1,903.81 MW	2,310.5 MW	Recalibrate adequacy studies
Peak demand	1,159 MW	1,261 MW	Test high demand
Grid-connected solar	267.01 MW	—	Existing source of variability
Grid-connected wind	159 MW	—	Additional variability
Walo Storage	—	10 MW / 20 MWh	Use BESS operating experience

5. Grid Constraints and Technical Dependencies

The PATRP analysis identifies constraints that merit re-examination in an updated assessment: performance of lines and substations under N−1 contingencies, thermal ratings, voltage profiles, dynamic stability margins, spinning reserve adequacy, and the availability of interconnections. As historical disturbance magnitudes, it cites a 115 MW generation loss event, solar variability of 41 MW, and wind variability of 54 MW.[4] Transposing these benchmarks to the 2026 system would require recalibration. They remain informative, however, as indicative stressors that a system must tolerate as additional variable generation is integrated.

PATRP benchmark	Historical value	Current methodological use
Reference generation loss	115 MW	Update generation contingency
Solar fluctuation	41 MW	Ramping/reserve scenario
Wind fluctuation	54 MW	Fast reserve scenario
Grid security	N and N−1	Test lines, substations, voltages and protection
OMVS / OMVG	Support + contingencies	Test interconnection availability and loss

6. Formal Sequencing Framework

Each project i is characterised by a vector of five normalised attributes, retained separately to preserve the visibility of distinct implications. Aggregation into a single index would necessitate explicit weights that reflect policy preferences; this choice lies outside the remit of technical analysis.[28,30]

$x_i = [RE_i, SEC_i, MAT_i, SOC_i, FIN_i]$ (1)

In Equation (1), RE_i denotes the project's useful renewable contribution, SEC_i its contribution to system security and robustness, MAT_i its technical and contractual maturity, SOC_i its documented socio-economic effects, and FIN_i its ability to secure financing.

Feasibility at a given date is tested separately by verifying the availability of all prerequisites.

$Feasible(i,t) = 1$ if $\prod z_{ik}(t) = 1$; otherwise 0 (2)

Here $z_{ik}(t)$ is a binary indicator that equals 1 if prerequisite k for project i is available at time t, and 0 otherwise. If any prerequisite is missing, the product is zero and the project fails the feasibility test. Prerequisites may comprise physical assets such as substations, as well as studies, permits, power purchase agreements, protection schemes, dispatch rules, or confirmed financing. The test renders these requirements explicit rather than presuming timely availability.

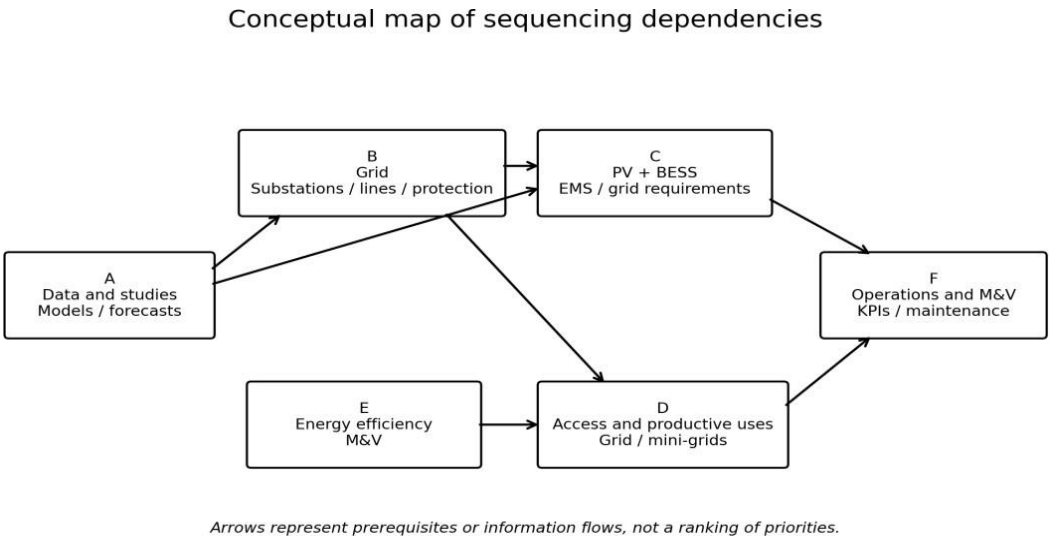


Figure 4: Conceptual map of dependencies between investment packages.

6.1. Coherent Investment Packages

Package	Content	Dependencies to check	Expected output
A — Data and studies	Forecasts, network models, stability, GIS, M&V	Data access, governance	Validated base case
B — Grid	Substations, lines, compensation, protection	A + N−1 studies	Power evacuation capacity
C — PV + BESS	Generation, storage, EMS, grid requirements	A + B + operating rules	Integrable MW/MWh
D — Access / uses	Grid, mini-grids, productive-use equipment	Local capacity + solvent demand	Service and useful demand
E — Energy efficiency	Buildings, industry, losses, demand management	Measurement and verification	Avoided peak demand/energy
F — Operations / M&V	Dispatch, KPIs, maintenance, data	A–E	Operational feedback loop

7. Scenario-Based Robustness Analysis

Each candidate sequence is evaluated against four conditions: S0 as the base case; S1 with demand above the central forecast; S2 with delayed grid reinforcement; and S3 with reduced availability of a regional interconnection. The verification covers power evacuation capability, reserve sufficiency, voltage compliance, curtailment volumes, storage state of charge, and N−1 criteria. In this section, SOC refers to the battery state of charge and should not be confused with SOC_i in Equation (1), which denotes socio-economic effects.[15,18,20–22,28]

$$R(seq) = Nfeasible / Nscenarios_tested \quad (3)$$

R measures the proportion of tested scenarios under which the sequence remains feasible. Its meaning is conditional on the chosen scenarios; it indicates robustness within that set and is not a probability of success. Figure 5 illustrates a possible reporting format. The entries shown as "feasible" and "requires revalidation" serve only to explain the method and are not simulation outcomes for the Senegalese system. Public authorities must still weigh broader considerations when selecting a sequence.

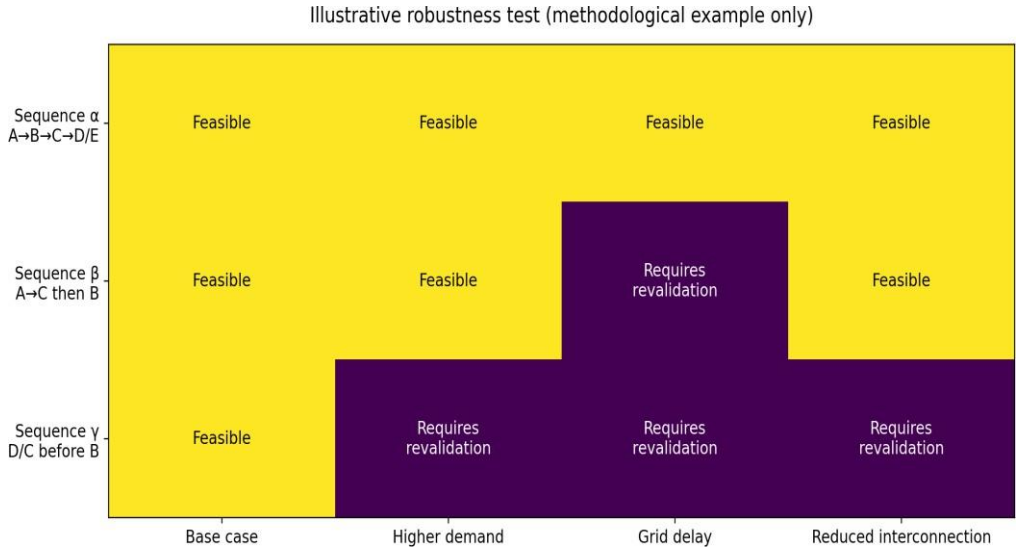


Figure 5: Illustrative robustness matrix. Values are methodological examples only and support no conclusion about an actual project.

8. Capital Mobilisation and Financial Synchronisation

Financing must be sequenced to match construction and commissioning schedules. The JET plan enumerates concessional loans, grants, technical assistance, guarantees, market-rate loans, and private participation.[1] The appropriate instrument depends in part on the asset's revenue model and risk allocation. Power plants with energy sales agreements can generate direct cash flows, whereas studies, data, and certain network reinforcements primarily yield system-wide benefits. The financing matrix highlights these distinctions. Final structuring for each project should be agreed by authorities, development partners, and investors in light of project-specific conditions.

Asset type	Potential cash flows	Risk to document	Instruments to consider
PV IPP	PPA / energy sales	Offtaker, connection, resource	Debt, equity, guarantee
BESS	Availability, energy, services	Revenue stacking, degradation, dispatch	Service contract, debt, guarantee
Grid	Regulated tariff / budget	Long recovery period, execution	Public, concessional
Data / studies	Indirect benefit	Underfunding, coordination	Grant, technical assistance
Universal access	Tariff + social impact	Ability to pay, density	Blended finance, targeted subsidy
Energy efficiency	Measured savings	Baseline, M&V, performance risk	ESCO, debt, guarantee

9. Quantitative Application Protocol

Implementing the framework begins with a consolidated register of projects that includes expected completion dates. An updated network model and an explicit mapping of physical and institutional dependencies are then required to formulate alternative sequences. These sequences are tested under the stress scenarios and compared using disaggregated indicators. Maintaining separate results enables decision-makers to scrutinise trade-offs among security, service quality, financing, and timing. Any composite score would require decision-makers to define and accept the weighting scheme explicitly.[28,30]

Domain	Minimum indicator	Unit	Assessment criterion
Adequacy	Power/energy margin	MW / GWh	Demand served
Grid	Maximum loading / voltage	% / p.u.	N and N−1
Flexibility	Reserve / available BESS	MW / MWh	Contingencies and ramps
RE	Evacuated / curtailed energy	GWh / %	Effective use of installed MW
Access	New services + productive uses	Households/sites/kWh	Service actually delivered
Finance	Secured financing / requirement	%	Disbursement aligned with schedule
Execution	Actual / planned date deviation	Months	Dependency synchronisation

10. RESULTS AND INTERPRETATION

The materials reviewed surface three sequencing challenges. First, the EUR 9,531 million portfolio spans far more than power generation, which implies that decisions on new capacity must internalize implications for access, mobility, energy efficiency and the water-energy-agriculture nexus. Second, the planned 700 MWp of additional solar, including Quick Wins paired with BESS, requires joint evaluation of generation and system flexibility. Storage must be treated as a co-requisite with network studies, reinforcements and operating protocols for secure integration. Third, the revisions documented for 2024–2025 highlight the necessity of updating model assumptions. While PATRP offers a useful taxonomy of constraints, the parameter values themselves now warrant recalibration.[1, 4,18,20, 22]

The framework is designed to pinpoint where sequencing could stall and to test whether a given order of actions remains viable under credible shifts in conditions. Practically, the analysis should flag missing preconditions, specify the data required to reduce key uncertainties and identify the scenarios that merit deeper investigation prior to commitment. The results are intended to guide rather than predetermine the choice of sequence.

11. DISCUSSION

The JET plan specifies projects, investment envelopes, indicative timelines and financing instruments. In parallel, the PIMC and network studies address the system question of whether the proposed expansion can be integrated while meeting demand and preserving evacuation capacity, reserves, stability and acceptable operating conditions. Mapping dependencies aligns these perspectives by showing how a stand-alone “ready” project may still hinge on another asset or on a pending institutional decision.[1,4,5,15,22]

11.1. Limitations

An operationally credible simulation would require inputs not fully available in the current evidence base, including complete contractual schedules, 2026 power-flow models, granular costs of capital, hourly demand profiles, interconnection availability and dispatch parameters. Consequently, the study does not quantify portfolio net present value, substation-level hosting capacity, delay probabilities or an optimal schedule. The matrices instead establish a protocol that can be populated and stress-tested once the requisite data are

assembled.

12. Methodological Recommendations for Applying the Framework

For institutional deployment, the project register should maintain an auditable history of versions and changes to scheduled dates. Planning and operations should work from a common network model, share agreed maturity milestones and retain a documented record of grid connection risks. Financial tracking needs to differentiate committed amounts from actual disbursements. PV and BESS projects should be evaluated jointly with their evacuation infrastructure, protection schemes, reserve needs and dispatch rules. Demand forecasting should integrate access and energy efficiency programs so that investment assumptions can be revised as observed uses become clearer.[15,18,20,22,27,28,30]

13. CONCLUSION

The timing of investments, no less than their magnitude, is decisive for Senegal's just energy transition. The reviewed documents present substantial renewable additions and parallel access and mobility priorities, all constrained by grid conditions that evolve with the system. The proposed framework links dependencies among data, grid infrastructure, solar generation, storage, access, energy efficiency and finance. It supports ex ante testing of whether alternative sequences hold under demand variability or infrastructure slippage. Its principal contribution is to render prerequisites and trade-offs visible before commitments are made. Quantitative application will require refreshed project datasets and network models.[1, 6,12,15,18,22,28,30]

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