Squeeze the Line or Build Another? Grid-Technology Capital Allocation

A portfolio framework for utilities and regulators choosing between digital, asset and new-build capacity

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Abstract

Power-system planners can add capacity through software, sensors, power electronics, advanced conductors, substations, storage, flexible demand or new transmission. These options differ in service, duration, delivery time, capital intensity, operating risk and residual value. A rapid digital intervention may unlock capacity within an existing corridor, while a new line can provide durable topology and strategic headroom. Comparing headline megawatts or upfront capital alone can produce the wrong portfolio.

This paper develops the Grid-Technology Capital Allocation Framework. It begins with the system need, counterfactual, binding constraint and common service requirement. It then compares ambient-adjusted and dynamic ratings, topology optimisation, advanced power-flow control, reconductoring, voltage upgrades, parallel circuits, substations, storage, flexible demand, overhead lines, cables and HVDC. The model evaluates dependable transfer, delivery speed, capital and operating cost, congestion, connections, reliability, losses, land, supply chain, maturity, interoperability, modularity, reversibility and residual value.

FERC Order 1920 requires regional planners to consider dynamic line ratings, advanced power-flow control, advanced conductors and transmission switching where they may meet needs more efficiently or cost-effectively [1]-[3]. FERC Order 881 establishes ambient-adjusted rating requirements for specified near-term uses [4]. The US Department of Energy's advanced-conductor work and REFA tool support lifecycle comparison of reconductoring and rebuild options [5]-[7]. DOE also recognises grid-enhancing technologies, reconductoring, HVDC and storage as tools for expanding effective grid capacity [8]-[9]. Ofgem's current price-control approach emphasises staged investment and maximising existing capacity under uncertainty [10].

The central conclusion is that utilities should finance a sequenced portfolio of bridge and enduring capacity rather than choose a single technology category. Four tables and three figures translate the framework into a decision method. Numerical examples are hypothetical management assumptions used solely to demonstrate the method; they are not observations, forecasts, valuation conclusions or investment recommendations.

JEL Classification: G31, G32, H54, L51, L94, O32, Q40, Q48

Keywords: grid capital allocation, dynamic line rating, advanced conductors, reconductoring, power-flow control, topology optimisation, transmission investment, real options

1. DEFINE THE CAPITAL-ALLOCATION DECISION

Utilities and regulators must choose among operational technology, asset upgrades and new infrastructure under uncertain demand. The decision should compare equivalent system service, timing, risk and lifecycle value.

The evidence file should identify the system model, asset data, option scope, cost estimate, delivery schedule, benefit method, regulatory treatment and accountable owner. Each comparison needs a common base date and controlled assumptions.

A practical capital review asks which option meets the need, by when, for how long, with which downside and at what whole-life value. The answer should support board and regulatory approval using comparable evidence.

2. DEFINE THE SYSTEM NEED

The need may be reliability, congestion relief, connection capacity, resilience, loss reduction or market integration. A precise need statement prevents technology selection from preceding problem definition.

The assessment should distinguish measured performance, vendor claims, scenario outputs and policy judgement. Capacity, cost and delivery conclusions should retain confidence ranges and record dependencies on other network investments.

The implementation plan should translate the option set into engineering, procurement, financing, operating and governance actions. Capital release should follow decision gates and preserve alternatives where uncertainty remains material.

3. SET THE COMMON SERVICE REQUIREMENT

Each option should meet the same transfer, duration, contingency, availability and commissioning requirements. Comparisons based only on nameplate capacity can favour solutions that provide different service.

The working model should reconcile technical service, timing, lifecycle cost, financing and system benefit under common scenarios. Option-specific benefits should remain separate from transfers between customers, owners, vendors and public authorities.

The board and regulator should see the distribution of capacity, value and risk across scenarios. The preferred portfolio should remain deliverable and economically defensible under delay, escalation, lower benefits and technology underperformance.

4. BUILD THE COUNTERFACTUAL

The counterfactual should represent credible system operation without the investment or with the next-best programme. It should include demand, generation, retirements, outages, constraints and policy.

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5. MAP THE COMPLETE CONSTRAINT CHAIN

Conductors, towers, clearances, transformers, breakers, substations, stability, voltage and downstream circuits can each bind. Investment should target the system constraint rather than its most visible symptom.

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Table 1. Grid-capacity technology benchmark

Option	Typical role	Delivery profile	Capacity characteristic	Principal risk
Dynamic line rating	Unlock weather-dependent headroom	Fast after integration	Variable and corridor-specific	Forecast, systems and downstream constraints
Topology and power-flow control	Redirect power to spare paths	Fast to medium	Network-state dependent	Protection, control and device placement
Advanced reconductoring	Increase existing-corridor capacity	Medium	Structural and long-lived	Tower, clearance, outage and conductor risk
Storage or flexible demand	Relieve time-bound constraints	Medium	Duration and contract dependent	Degradation, performance and concentration
New AC or HVDC transmission	Add durable capacity and topology	Long	Structural and strategic	Route, permits, supply chain and capital

Ranges are qualitative and project-specific; detailed engineering and current market evidence remain required.

6. CREATE THE OPTION UNIVERSE

The option set should include dynamic ratings, ambient-adjusted ratings, topology optimisation, power-flow control, advanced conductors, conventional reconductoring, substation upgrades, storage, demand flexibility and new lines.

The working model should reconcile technical service, timing, lifecycle cost, financing and system benefit under common scenarios. Option-specific benefits should remain separate from transfers between customers, owners, vendors and public authorities.

The board and regulator should see the distribution of capacity, value and risk across scenarios. The preferred portfolio should remain deliverable and economically defensible under delay, escalation, lower benefits and technology underperformance.

7. SCREEN NO-BUILD AND OPERATIONAL ACTIONS

Dispatch changes, outage coordination and operating procedures may create near-term relief. Their recurring cost, reliability effect and sustainability should remain visible.

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8. EVALUATE DYNAMIC LINE RATINGS

DLR can unlock weather-dependent headroom quickly on suitable overhead lines. Value depends on limiting spans, forecast confidence, system integration and usable congestion relief.

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9. EVALUATE TOPOLOGY OPTIMISATION

Software can identify network configurations that relieve constraints. Switching feasibility, protection, operator workload, maintenance and contingency security determine dependable value.

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10. EVALUATE ADVANCED POWER-FLOW CONTROL

Modular or conventional devices can redirect power toward available capacity. Location, range, losses, failure mode, maintenance and coordination with dispatch shape economics.

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11. EVALUATE AMBIENT-ADJUSTED RATINGS

Temperature-sensitive ratings can improve near-term accuracy with less instrumentation than full DLR. The comparison should identify incremental value from additional variables and sensing.

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12. EVALUATE ADVANCED RECONDUCTORING

Advanced conductors can increase capacity using existing rights of way and structures where mechanical and clearance limits permit. The study should include tower assessment, outage and conductor lifecycle.

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13. EVALUATE CONVENTIONAL RECONDUCTORING

Conventional conductors can be efficient where moderate capacity is sufficient and towers have compatible loading. Lower material cost may be offset by future capacity limits.

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14. EVALUATE VOLTAGE UPGRADE

A voltage conversion can increase transfer capacity and reduce losses but may require insulation, substation, protection and clearance changes. System compatibility and outage sequencing are central.

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15. EVALUATE PARALLEL CIRCUIT ADDITION

An additional circuit on existing structures or corridor can provide structural capacity. Tower, right-of-way, foundation, outage and electromagnetic constraints should be tested.

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16. EVALUATE SUBSTATION AND TERMINAL UPGRADES

Transformers, breakers, buswork, compensation and protection can constrain otherwise adequate lines. Targeted terminal investment may unlock the corridor at lower cost.

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17. EVALUATE STORAGE

Storage can relieve a constraint for defined hours and provide ancillary services. Energy duration, cycling, degradation, location and charging constraints affect equivalence with transmission.

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18. EVALUATE FLEXIBLE DEMAND

Managed load can reduce peaks or shift consumption. Contract duration, response performance, customer concentration and rebound should be modelled.

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19. EVALUATE NEW OVERHEAD TRANSMISSION

A new line can provide durable capacity and topology change. Development time, route, permits, land, community impact and supply chain create material execution risk.

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20. EVALUATE UNDERGROUND AND SUBSEA CABLES

Cable solutions can address route or environmental constraints with different cost, repair, thermal and reactive-power characteristics. Comparisons should include terminal equipment and outage recovery.

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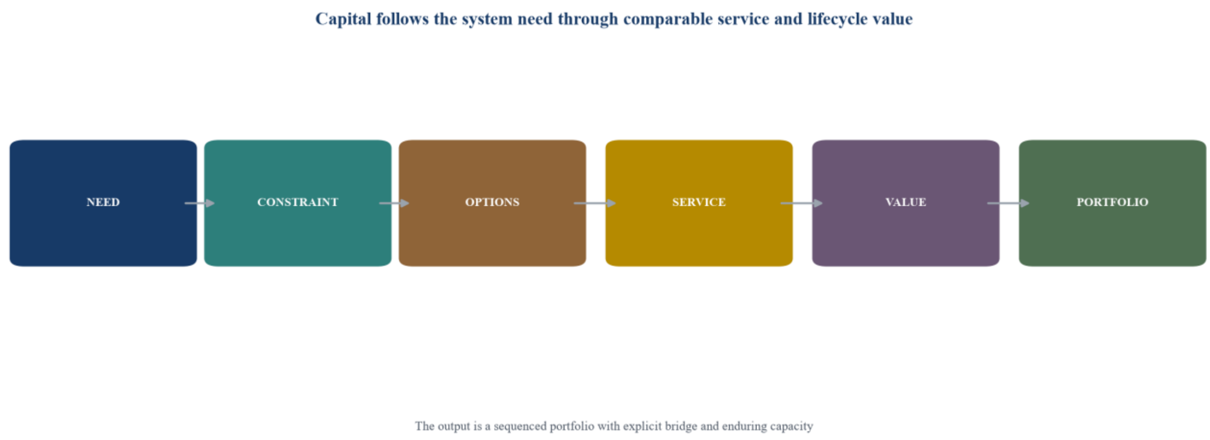

Figure 1. Grid-capacity option architecture

Options should be compared against one system need and common service requirement.

21. EVALUATE HVDC

HVDC can move large power volumes over long distances and control flows. Converter cost, losses, multi-terminal complexity, fault behaviour and system strength belong in the case.

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22. BUILD TECHNOLOGY COMBINATIONS

A portfolio can pair near-term grid-enhancing technologies with later reconductoring or new build. Sequencing should avoid stranded digital or physical expenditure.

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23. DEFINE BRIDGE AND ENDURING CAPACITY

Bridge capacity addresses a temporary timing gap; enduring capacity serves long-term need. The investment horizon and residual value should match that role.

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The implementation plan should translate the option set into engineering, procurement, financing, operating and governance actions. Capital release should follow decision gates and preserve alternatives where uncertainty remains material.

24. MEASURE DEPENDABLE TRANSFER

Dependable transfer should reflect contingencies, weather, outages and other network limits. The model should distinguish average, percentile and firm capability.

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The board and regulator should see the distribution of capacity, value and risk across scenarios. The preferred portfolio should remain deliverable and economically defensible under delay, escalation, lower benefits and technology underperformance.

25. MEASURE DELIVERY SPEED

Lead time should include studies, approvals, procurement, outages, construction, commissioning and integration. Software speed claims should include operational and cyber readiness.

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26. MEASURE CAPITAL COST

Capital cost should cover development, land, equipment, construction, integration, financing, owner cost, contingency and escalation. Option scope should be consistently defined.

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The implementation plan should translate the option set into engineering, procurement, financing, operating and governance actions. Capital release should follow decision gates and preserve alternatives where uncertainty remains material.

27. MEASURE OPERATING COST

Licences, communications, maintenance, inspections, energy losses, cyber operations, data services, staffing and replacement cycles belong in lifecycle cost.

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The board and regulator should see the distribution of capacity, value and risk across scenarios. The preferred portfolio should remain deliverable and economically defensible under delay, escalation, lower benefits and technology underperformance.

28. MEASURE CONGESTION AND CURTAILMENT VALUE

Chronological dispatch modelling can estimate avoided redispatch and renewable curtailment. Benefits should reflect how often the investment changes the binding constraint.

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29. MEASURE CONNECTION VALUE

Earlier capacity may accelerate generation, industrial or data-centre connections. Value should use credible project readiness and avoid assuming every queued project proceeds.

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The implementation plan should translate the option set into engineering, procurement, financing, operating and governance actions. Capital release should follow decision gates and preserve alternatives where uncertainty remains material.

30. MEASURE RELIABILITY AND RESILIENCE

Options provide different redundancy, visibility, control and restoration benefits. Engineering studies should quantify service under relevant contingencies and extreme events.

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Table 2. Option-risk allocation matrix

Risk	Digital and operating options	Asset upgrades	New build	Core control
Service underperformance	Vendor and utility integration	Designer, supplier and owner	Developer and contractors	Measured acceptance against common service
Delivery delay	Systems and data interfaces	Outage and supply chain	Route, permits and construction	Stage gates and schedule contingency
Cost escalation	Licence and integration scope	Materials and outage scope	Civil works and financing	Controlled baseline and procurement evidence
Technology obsolescence	High for proprietary platforms	Moderate by conductor or device	Lower for core civil assets	Standards, data rights and upgrade path
Demand changes	Modular deployment can adapt	Phasing depends on corridor	High committed-capital exposure	Triggers, staging and residual-value plan
Regulatory recovery	Output and incentive evidence	Prudence and used-useful tests	Need, cost and delivery approval	Early regulatory treatment and reporting

Risk ownership should follow controllability and the governing regulatory and contractual framework.

31. MEASURE LOSSES

Conductors, voltage levels, power electronics and storage change losses. Energy value and thermal implications should be calculated under expected flows.

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32. MEASURE LAND AND PERMITTING IMPACT

Use of existing corridors can reduce land and approval requirements. New works may provide greater strategic capacity while carrying longer development risk.

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The implementation plan should translate the option set into engineering, procurement, financing, operating and governance actions. Capital release should follow decision gates and preserve alternatives where uncertainty remains material.

33. MEASURE SUPPLY-CHAIN EXPOSURE

Transformers, conductors, cables, power electronics, sensors and specialist labour have different lead-time and concentration risks. The schedule should reflect current procurement evidence.

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The board and regulator should see the distribution of capacity, value and risk across scenarios. The preferred portfolio should remain deliverable and economically defensible under delay, escalation, lower benefits and technology underperformance.

34. MEASURE TECHNOLOGY MATURITY

Commercial deployment, standards, warranties, service capability and performance history inform execution risk. Maturity should be assessed for the specific use case and environment.

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35. MEASURE INTEROPERABILITY AND DATA RIGHTS

Digital options can create proprietary interfaces and vendor dependence. Open standards, data access, model transparency and transition rights affect lifecycle value.

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36. MODEL MODULARITY

Modular options can stage capital and respond to uncertainty. The model should value the option to add, relocate, expand, retire or combine modules.

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37. MODEL REVERSIBILITY

Some investments can be redeployed or cancelled with limited loss; others commit the route and capital. Reversibility has value when demand timing is uncertain.

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38. MODEL RESIDUAL VALUE

Residual value depends on remaining life, alternative use, redeployment, regulated treatment and salvage. It should be consistent with the asset and decision horizon.

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39. USE REAL-OPTIONS LOGIC

Uncertainty can justify staging, learning and conditional commitment. Real-options logic should identify the information gained and the cost of waiting.

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40. BUILD THE LEAST-REGRETS PORTFOLIO

A least-regrets portfolio performs acceptably across demand, generation, technology and cost scenarios. It may combine early low-capital measures with protected pathways for larger assets.

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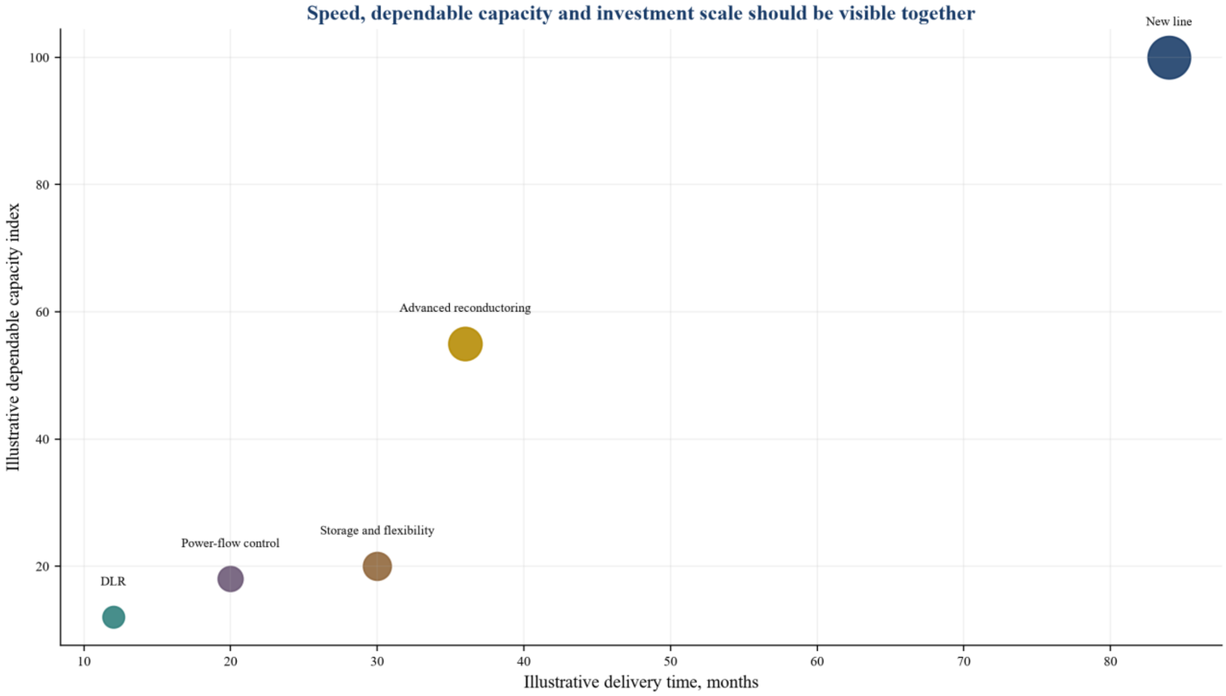

Figure 2. Hypothetical option comparison on speed and dependable capacity

Values are hypothetical management assumptions used solely to demonstrate the framework.

41. APPLY FERC ORDER 1920

Order 1920 requires planners to consider dynamic ratings, power-flow control, advanced conductors and transmission switching when they may meet needs more efficiently or cost-effectively.

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The implementation plan should translate the option set into engineering, procurement, financing, operating and governance actions. Capital release should follow decision gates and preserve alternatives where uncertainty remains material.

42. APPLY FERC ORDER 881

Order 881 establishes ambient-adjusted rating requirements for specified near-term transmission uses. Its implementation affects the incremental case for full DLR.

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43. USE DOE RECONDUCTORING EVIDENCE

DOE's advanced-conductor work and REFA tool support lifecycle comparison of conductor options, full rebuild and reconductoring under technical and economic constraints.

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44. USE GREAT BRITAIN PRICE-CONTROL LOGIC

Ofgem's price-control approach combines need, uncertainty, incentives and consumer protection. Current decisions emphasise maximising existing capacity before committing additional grid investment.

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The implementation plan should translate the option set into engineering, procurement, financing, operating and governance actions. Capital release should follow decision gates and preserve alternatives where uncertainty remains material.

45. ADDRESS HOT-CLIMATE GRIDS

High ambient temperature and cooling load can reduce weather-dependent headroom during peaks. Advanced conductors, substations and new lines may provide firmer capacity.

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The board and regulator should see the distribution of capacity, value and risk across scenarios. The preferred portfolio should remain deliverable and economically defensible under delay, escalation, lower benefits and technology underperformance.

46. ADDRESS RENEWABLE CORRIDORS

Output and cooling conditions can support DLR while curtailment creates value. Longer-term renewable build may still require reconductoring or new transmission.

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47. ADDRESS DATA-CENTRE CLUSTERS

Large, fast connections require credible energisation dates and high reliability. A staged technology portfolio can bridge capacity while permanent works progress.

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The implementation plan should translate the option set into engineering, procurement, financing, operating and governance actions. Capital release should follow decision gates and preserve alternatives where uncertainty remains material.

48. ADDRESS INDUSTRIAL ELECTRIFICATION

Industrial loads can be concentrated, inflexible and economically material. Connection agreements, flexibility and reinforcement should be co-designed.

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The board and regulator should see the distribution of capacity, value and risk across scenarios. The preferred portfolio should remain deliverable and economically defensible under delay, escalation, lower benefits and technology underperformance.

49. BUILD THE CAPITAL STACK

Regulated expenditure, user contributions, public grants, project finance and vendor finance may support different assets. Recovery and risk should follow the approved service.

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A practical capital review asks which option meets the need, by when, for how long, with which downside and at what whole-life value. The answer should support board and regulatory approval using comparable evidence.

50. COMPARE REVENUE CERTAINTY

Regulated allowance, shared savings, congestion value, connection payments and availability revenue have different certainty. Debt sizing should use enforceable cash flows.

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The implementation plan should translate the option set into engineering, procurement, financing, operating and governance actions. Capital release should follow decision gates and preserve alternatives where uncertainty remains material.

Table 3. Hypothetical capital-allocation sensitivity

Portfolio	Initial capex, USD m	Dependable capacity index	Earliest service	Benefit-cost ratio	Decision implication
Digital bridge only	25	15	Year 1	2.8x	Useful bridge with limited enduring capacity
Reconductoring only	220	55	Year 3	2.2x	Strong corridor option where towers permit
New line only	900	100	Year 7	1.6x	Strategic capacity with high delay exposure
Bridge plus staged reconductoring	245	62	Year 1	2.7x	Preserves speed and structural capacity
Bridge plus protected new-line pathway	80 then 900	115	Years 1 and 7	2.1x	Highest optionality under uncertain demand

All values are hypothetical management assumptions and do not represent an actual project or forecast.

51. BUILD THE NPV MODEL

The model should compare lifecycle cost, benefits, taxes, financing, residual value and timing under a common discount basis. Transfers between stakeholders should remain separate from system value.

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The board and regulator should see the distribution of capacity, value and risk across scenarios. The preferred portfolio should remain deliverable and economically defensible under delay, escalation, lower benefits and technology underperformance.

52. BUILD THE COST-OF-DELAY MODEL

Delayed capacity can create congestion, curtailment, connection delay and reliability exposure. The cost should be measured against credible delivery schedules.

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53. BUILD DOWNSIDE CASES

Cases should include lower demand, higher demand, cost escalation, permit delay, technology underperformance, vendor failure, outage constraints and changed market conditions.

The assessment should distinguish measured performance, vendor claims, scenario outputs and policy judgement. Capacity, cost and delivery conclusions should retain confidence ranges and record dependencies on other network investments.

The implementation plan should translate the option set into engineering, procurement, financing, operating and governance actions. Capital release should follow decision gates and preserve alternatives where uncertainty remains material.

54. SET THE DECISION THRESHOLDS

Thresholds can include benefit-cost ratio, NPV, dependable capacity, delivery date, reliability, consumer impact and optionality. Trade-offs should be documented explicitly.

The working model should reconcile technical service, timing, lifecycle cost, financing and system benefit under common scenarios. Option-specific benefits should remain separate from transfers between customers, owners, vendors and public authorities.

The board and regulator should see the distribution of capacity, value and risk across scenarios. The preferred portfolio should remain deliverable and economically defensible under delay, escalation, lower benefits and technology underperformance.

55. DESIGN PROCUREMENT BY OPTION CLASS

Software, sensors, conductors, power electronics and civil works need different specifications and risk terms. Procurement should support fair comparison and future competition.

The evidence file should identify the system model, asset data, option scope, cost estimate, delivery schedule, benefit method, regulatory treatment and accountable owner. Each comparison needs a common base date and controlled assumptions.

A practical capital review asks which option meets the need, by when, for how long, with which downside and at what whole-life value. The answer should support board and regulatory approval using comparable evidence.

56. DESIGN PROGRAMME GOVERNANCE

Planning, engineering, operations, markets, cyber, finance, regulation and procurement need shared data and decision rights. Governance should control assumptions and change.

The assessment should distinguish measured performance, vendor claims, scenario outputs and policy judgement. Capacity, cost and delivery conclusions should retain confidence ranges and record dependencies on other network investments.

The implementation plan should translate the option set into engineering, procurement, financing, operating and governance actions. Capital release should follow decision gates and preserve alternatives where uncertainty remains material.

57. CREATE THE INVESTMENT SCORECARD

The scorecard should show service, speed, capacity, capex, opex, benefit, risk, maturity, modularity and residual value. Scores should be traceable to evidence.

The working model should reconcile technical service, timing, lifecycle cost, financing and system benefit under common scenarios. Option-specific benefits should remain separate from transfers between customers, owners, vendors and public authorities.

The board and regulator should see the distribution of capacity, value and risk across scenarios. The preferred portfolio should remain deliverable and economically defensible under delay, escalation, lower benefits and technology underperformance.

58. RUN THE NEED AND CONSTRAINT GATE

This gate confirms the system need, counterfactual, binding constraints and common service requirement. It prevents premature technology selection.

The evidence file should identify the system model, asset data, option scope, cost estimate, delivery schedule, benefit method, regulatory treatment and accountable owner. Each comparison needs a common base date and controlled assumptions.

A practical capital review asks which option meets the need, by when, for how long, with which downside and at what whole-life value. The answer should support board and regulatory approval using comparable evidence.

59. RUN THE OPTION AND ECONOMICS GATE

This gate validates the option universe, technical feasibility, lifecycle economics, uncertainty and combinations. It identifies the preferred portfolio.

The assessment should distinguish measured performance, vendor claims, scenario outputs and policy judgement. Capacity, cost and delivery conclusions should retain confidence ranges and record dependencies on other network investments.

The implementation plan should translate the option set into engineering, procurement, financing, operating and governance actions. Capital release should follow decision gates and preserve alternatives where uncertainty remains material.

60. ADOPT THE DECISION RECORD AND 90-DAY PLAN

The final record states need, options, economics, risk, capital, procurement, owners and triggers. The first 90 days should close the evidence gaps that could change the preferred portfolio.

The working model should reconcile technical service, timing, lifecycle cost, financing and system benefit under common scenarios. Option-specific benefits should remain separate from transfers between customers, owners, vendors and public authorities.

The board and regulator should see the distribution of capacity, value and risk across scenarios. The preferred portfolio should remain deliverable and economically defensible under delay, escalation, lower benefits and technology underperformance.

Table 4. Illustrative 90-day grid-capital programme

Period	Workstream	Core actions	Decision output	Accountable owner
Days 1-15	Need and constraints	Confirm system need, counterfactual, binding elements and common service	Approved problem definition	System planner
Days 16-30	Option engineering	Screen digital, conductor, substation, flexibility and new-build options	Feasible option set	Transmission engineer
Days 31-45	Lifecycle economics	Model capex, opex, delivery, benefits, residual value and cost of delay	Comparable financial model	Financial adviser
Days 46-60	Risk and scenarios	Test demand, escalation, permits, technology, outages and vendor failure	Risk-adjusted portfolio	Programme director
Days 61-75	Procurement and recovery	Define commercial route, incentives, regulatory treatment and financing	Executable capital plan	Commercial and regulatory leads
Days 76-90	Decision record	Approve sequence, triggers, owners, evidence and monitoring	Authorised investment portfolio	Utility board and regulator

Timing is indicative and should be adapted to utility governance and the regulatory process.

Figure 3. Five gates for grid-technology capital allocation

Each gate requires documented evidence before the next capital commitment.

The framework converts a technology menu into an auditable capital-allocation process. It compares options against one need, one service requirement and one lifecycle value model before sequencing bridge and enduring capacity.

Execution quality depends on preserving option value while evidence develops. Demand, technology, delivery and regulation should update the same controlled decision model and trigger pre-agreed changes to the portfolio.

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