

The Route Defines the Return: Whole-Life Valuation of Transmission Options

A decision framework for route evidence, service boundaries and whole-life capital commitments

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Abstract

Transmission routes commit capital to distinct service calendars, installation packages and lifecycle obligations. This paper develops a conditional whole-life valuation method that defines the required receiving-end service before ranking capital alternatives. Sixteen primary sources inform the technical, planning and appraisal discussion within their stated jurisdictions and documentary limits.

A fictional 300 MW requirement by year 4 compares overhead, underground, subsea/HVDC, reconductoring and an early grid-enhancing technology stage followed by a line. At an assumed 7% real system discount rate, base net present values are USD 377.473 million for overhead and USD 282.865 million for underground. Partial-service packages fail the stipulated full-capacity deadline. A two-year overhead delay changes the higher-value eligible choice to on-time underground; its separate economic crossing occurs at four years.

Ten numerical exhibits and five figures reconcile useful delivery, sent-energy losses, construction, renewals, closure and conditional switching values. The proposed implementation method carries the calculation into evidence gates and bounded capital commitments. All model inputs are fictional; engineering equivalence, permissions, operator receipts and financing remain unresolved. The fixed year-30 stop is an analytical boundary requiring further whole-life review for an actual investment.

JEL Classification: D61, G31, L94, Q41

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1. Put a dated service obligation at the centre of the investment decision

A transmission route commits capital to a particular service calendar. The endpoints, usable capacity and service deadline shape the choice before construction quotations can be meaningfully ranked. This paper develops a conditional whole-life decision method for that commitment. It combines a source-bounded technical and policy discussion with a deliberately fictional, reproducible resource account. The objective is to expose the assumptions that make one route preferable, the conditions that invalidate a comparison and the evidence needed before a further capital release.

The worked decision is an additional 300 MW of receiving-end transfer-equivalent capacity required by the beginning of year 4. Five mutually exclusive packages represent overhead, underground, a particular subsea/HVDC design, reconductoring and an early grid-enhancing

technology stage followed by an overhead line. The name of a package supplies no engineering certification. All service quantities, costs, operating assumptions and delivery dates are stipulated for this example. Engineering feasibility, permissions and contractual recovery remain open for every candidate.

Under the base assumptions, overhead has the highest calculated system value among the three packages meeting the stipulated capacity and deadline. Its real net present value is USD 377.473 million at an assumed 7% system discount rate. Underground yields USD 282.865 million and subsea/HVDC USD 74.950 million. Reconductoring and the staged package create positive partial-service value, while their assumed designs fail the original full-capacity deadline. This distinction is material to the recommendation. An unrestricted numerical ranking cannot discharge a fixed service obligation that a candidate does not meet.

The comparison is sufficiently explicit to support conditional changes. A two-year overhead delay moves its service start to year 5 and removes it from the deadline-compliant shortlist. With the other candidates held on time, underground then has the highest calculated eligible value. The economic crossing against on-time underground occurs only at four years of overhead delay. These are separate thresholds with different meanings. The earlier threshold controls the stipulated delivery obligation; the later threshold identifies a value comparison between calendars that no longer all satisfy that obligation.

The proposed output is consequently a route preference accompanied by a service gate, a dated resource ledger and a bounded next decision. A preferred candidate can remain conditional on route investigations or permissions. A committee can approve additional evidence gathering without approving the full investment. Any actual funding commitment requires an additional owner-cash and financing case, because the benefits calculated here are system resource savings. The calculation identifies no entity entitled to receive the benefit amount in cash.

2. Specify the service before comparing routes

This paper proposes a whole-life comparison that begins with an explicit service specification. Each candidate should identify the same sending and receiving boundaries, the useful transfer required at the receiving boundary, the hours in which that service matters and the permitted interruption conditions. The appraisal should record the date by which service is needed and the treatment of demand that arrives earlier or later. A candidate with an incomplete engineering case may remain in a screening exercise, provided its assumed service is visible and the unresolved feasibility question accompanies every ranking.

The United States Department of Energy's National Transmission Planning Study was developed with the National Renewable Energy Laboratory and Pacific Northwest National Laboratory. Its published framework connects capacity-expansion and resource-adequacy analysis with nodal production-cost modelling, alternating-current power-flow and contingency analysis, and stress analysis for selected scenarios. These are distinct analytical stages with different representations of the network. The chapter provides a useful example of the evidence layers behind a transmission comparison. It supplies no engineering certification for the fictional packages considered here. [6]

For the proposed comparison, functional equivalence should be expressed as a vector of requirements. Receiving-end power, annual useful energy, timing, ordinary availability, renewal

interruptions and permitted operating conditions should occupy separate fields. A shared nameplate rating would leave important differences unresolved. An option that meets the annual energy requirement while missing a critical delivery window should have that shortfall shown separately. Where the required service itself is uncertain, the decision record should preserve several service cases and identify which options remain feasible in each case.

Ofgem's 15 April 2026 decision conditionally approved NESO's Centralised Strategic Network Plan methodology, subject to two conditions seeking further detail in limited areas. The published description covers identification of system needs, option development, appraisal and recommendations for delivery across Great Britain's relevant energy networks. The decision concerns a planning methodology. Its conditional status and scope should accompany its use; this paper has not verified satisfaction of those conditions or a project-specific approval arising from them. [2]

The proposed investment record should therefore distinguish the planning need, the assumed technical response and the subsequent permissions required to execute that response. A financial ranking can be calculated while one of these records remains provisional. Its decision status should remain provisional as well. An accountable reviewer should be able to trace every claimed service back to a study boundary, a dated assumption or a project-specific acceptance document.

3. Define the complete electrical and installation package

The comparison should describe each route as a complete package of assets and interfaces. Overhead and underground identify installation arrangements. Subsea describes an installation environment. High-voltage direct current identifies an electrical transmission arrangement with terminal equipment. A hypothetical subsea/HVDC candidate should consequently include the assumed cable route, terminal conversion, onshore connections and associated works. The package definition should identify these interfaces explicitly. The worked comparison uses deliberately assumed packages; an engineering study would determine their suitability for a particular network. [5]

DOE's February 2022 electric-grid supply-chain assessment treats HVDC converter stations as systems containing converters, DC switchgear, filters and AC switchyards, with further component and transformer interfaces. It also states that a general minimum distance favouring HVDC cannot be specified through a universal rule of thumb. This dated technical description supports a complete scope boundary. Its historical supply-chain statistics and illustrative equipment quantities are excluded from the valuation assumptions in this paper. [5]

National Grid's undergrounding guide explains that cable heat dissipation depends on the surrounding environment and installation method. It describes route-specific influences including ground conditions, terrain, power, voltage and length, together with transition arrangements between overhead lines and cables. The guide is issue 4, dated January 2015. Its technical categories are used here to identify questions for investigation; its historical cost comparisons, indicative dimensions and repair statistics are excluded. [4]

For each candidate, the proposed scope reconciliation should pair the route drawing with an equipment register and a cost ledger. Connections, protection, control, communications, reactive requirements where applicable, access and temporary works should receive explicit inclusions or exclusions. A supplier's boundary should be reconciled with the network owner's boundary before

the estimate is compared with another candidate. An exclusion is acceptable for screening when its consequence is stated and the same treatment is applied consistently.

This perimeter also determines the interpretation of later sensitivities. A loss assumption that includes converter losses in one candidate and excludes them in another would compare different services. A capital estimate that omits a terminal connection would have a similar problem. The proposed review should identify these mismatches before applying a discount rate. Unresolved interfaces can be represented as separate scenarios, with the ranking reported conditional on the assumed completion of each package. No route in this paper is represented as electrically interchangeable through its label alone.

4. Treat land, landscape and marine interfaces as route decisions

A route comparison should retain the geography behind each cost. The proposed route register would divide a candidate into segments with separate access, land, construction and environmental assumptions. A marine segment should identify its assumed landing interfaces and the investigations still required. An onshore segment should identify the rights and construction access included in the estimate. These are proposed diligence fields. Their presence in a model establishes neither a legal right nor an accepted environmental case for any actual site.

DESNZ's EN-5, carrying the 2025 edition title and published on 6 January 2026, has defined England-and-Wales planning scope. Its route-assessment provisions address feasible alternatives and environmental explanations. The general presumption favouring overhead lines is reversed in nationally designated landscapes, subject to the policy's engineering and impact qualifications. Elsewhere, undergrounding remains a case-specific assessment where significant landscape or visual effects arise. These provisions support a geographically explicit comparison; they establish no universal UK route permission or numerical cost multiplier. [3]

The proposed valuation should separate mitigation already included in the design from mitigation contingent on a later route decision. If the screening case assumes undergrounding through one segment, the cost, loss, construction date and maintenance-access assumptions should all refer to that same segment. A later change in the planning case should update these linked fields together. Keeping only the original capital premium would leave the comparison internally incomplete. The decision record should preserve the previous route version so that the effect of the changed requirement can be examined.

NESO's current Beyond 2030 Electricity Transmission Update page describes advice for Ofgem reflecting updated policy, scenarios, connections reform and transmission-owner proposals. It recommends a greater share of offshore cabling and onshore upgrades where possible. The page distinguishes near-term options recommended for early investment from longer-term options requiring further development and assessment. These are published recommendations with different maturity levels. The webpage supplies no evidence that every recommended route has received consent, funding or commissioning acceptance. [13]

For an actual investment decision, the proposed analysis should attach the source and date of the route assumption to the model version. A planning preference, an owner's proposal, a consent requirement and an executed land instrument should have different evidence statuses. Where the route remains open, a scenario tree can preserve the alternatives without assigning unsupported

probabilities. A committee could then identify which expenditure remains reversible and which commitment would expose capital to a specific unresolved route outcome.

5. Test existing-corridor alternatives against the same need

The proposed shortlist should give reconductoring and grid-enhancing technologies a service-specific entry test. It should ask which constraint the intervention is assumed to address, how long that benefit is required and what further investment follows. A staged GET-now/line-later package should include both stages and their interactions. Its early service should be limited to the explicitly assumed operating envelope. Its later line should retain its own construction cost, completion date and replacement assumptions. This approach permits a fair comparison with a new route while preserving the different evidence requirements.

FERC Order 1920-A requires consideration of dynamic line ratings, advanced power-flow control, advanced conductors and transmission switching in the specified regional planning processes, including new facilities and upgrades. Paragraphs 598-600 preserve engineering judgment in identifying suitable elements, require supported determinations and decline a presumption favouring these technologies. The cited order establishes a bounded planning obligation. It supplies no blanket procurement requirement, selected project, approved tariff recovery or guaranteed technical substitution for a new line. [8]

INL's 10 October 2024 account of advanced-conductor research identifies testing and evaluation involving mechanical and material integrity, environmental exposure, aging, creep, fatigue and installation handling. The account describes research activities and testing plans at its publication date. It supports questions about qualification evidence for a conductor package. It establishes no completed qualification, achieved transfer capacity or economic result for a candidate evaluated in this paper. [7]

Current primary announcements illustrate different evidence stages. DOE's 24 September 2026 SPARK release announced selected projects and an intention to help fund reconductoring and other advanced-transmission investments. The announced funding intentions and expected results are excluded from this paper's assumed cash receipts and measured operating benefits. Each selected project would require its own subsequent funding and delivery evidence before those outcomes could enter an actual investment model. [10]

SSEN Transmission reported on 23 September 2026 that its north-of-Beaulieu DLR project had become fully operational. Its account describes environmental data used to adjust circuit ratings up or down. This is a dated operator-reported deployment milestone for a particular network area. The paper uses no reported consumer-saving amount as a project cash flow and makes no independent measurement claim about the deployment's incremental benefit or investment return. [12]

The proposed screen should therefore retain separate columns for technical suitability, demonstrated operation and financial capture. A successful deployment elsewhere can inform diligence questions. Its operating envelope, topology and contractual setting would still need comparison with the candidate under review. Any unsupported transfer of performance should remain outside the base case.

6. Reconcile useful delivery, losses and the beneficiary ledger

The proposed energy ledger begins at the receiving boundary. Required useful delivery should be stated independently of the energy sent. Where a fictional loss fraction is defined on sent energy, the energy required at the sending boundary should be calculated using that denominator consistently. A receiving-end percentage would require a different calculation. The analysis should also state which equipment contributes to the assumed losses and whether the annual figure represents a simplified average or an output from a time-resolved network study.

ENTSO-E's fourth cost-benefit guideline assesses changes in system losses through network studies with and without the investment. Its B5 methodology connects loss quantities with energy valuation and recognises that changed transfers and dispatch can increase total system losses, including where a new asset has lower resistance. The methodology supports a network and counterfactual boundary. It gives no universal loss advantage to a route category and supplies no loss factor for the fictional alternatives here. [11]

For the proposed cash analysis, the quantity of lost energy and the responsibility for paying for it should occupy separate records. An energy purchaser, network owner and end user may be represented differently depending on the hypothetical contractual case. The model should state whose expense is being valued and the assumed price basis. A system-wide production-cost benefit should be reconciled with any narrower loss-purchase saving before totals are added. The same physical improvement should have one defined place in each ledger.

ACER's 18 May 2026 policy article distinguishes congestion-income distribution, inter-TSO compensation for hosting cross-border flows and cross-border cost allocation based on expected benefits of new infrastructure. It describes gaps and overlaps and introduces policy exploration about improving the mechanisms. The article supports separating benefit geography from cost responsibility. It establishes no adopted reform, project-specific allocation, merchant entitlement or private funding commitment for the route comparison in this paper. [16]

The proposed decision record should present at least two perspectives when both are relevant: whole-system value and owner cash requirements. A welfare benefit can be material even when a separate recovery agreement remains unresolved. Owner cash analysis can reveal a funding gap despite a favourable system comparison. Each conclusion should name its beneficiary perimeter and timing. A transfer payment between parties should be recorded as a transfer in the wider analysis and as a receipt or expense in the appropriate narrower account, with the reconciliation visible.

7. Price access, maintenance and renewal over the assessment period

The proposed whole-life ledger should date maintenance spending, planned renewal and any assumed decommissioning obligation. Routine availability and discrete renewal interruptions should be represented separately. If an annual availability assumption already includes a particular maintenance window, adding the same lost service through a second outage deduction would duplicate its effect. Conversely, a major renewal excluded from ordinary availability needs its own dated service and cost entry. The chosen convention should remain identical across all candidate routes.

NESO's April 2026 CSNP methodology appendices assess system access through construction outage plans, their duration, mitigation, interacting options and potential effects on constraints

and security of supply. The appendices also distinguish strategic environmental assessment from the project-level investigation subsequently required for delivery. These provisions support explicit outage and investigation records. The methodology supplies no accepted outage booking, site survey or project-specific engineering conclusion for the fictional routes. [1]

National Grid's dated undergrounding guide describes inspection, testing, ancillary-equipment refurbishment and access to joint bays for maintenance and repair. The paper draws only on those qualitative activities. Its historical asset-life and fault-duration estimates are excluded from assumptions about current cable systems. A candidate-specific maintenance plan and evidence of access would be required before assigning actual renewal dates, repair durations or expenditure. [4]

ENTSO-E's cost categories separate inception capital expenditure, sustaining capital expenditure and annual operation and maintenance. Sustaining expenditure includes relevant mid-life interventions and replacements within the assessment period. Dismantling enters where relevant within that period. Its operating-cost category excludes system losses because they have a dedicated indicator. These boundaries inform the proposed reconciliation of the cost ledger; the guideline's assessment conventions do not establish the physical life or terminal value of an individual asset. [11]

The fictional comparison adopts a fixed analytical cutoff and states its terminal treatment. A production appraisal should test residual service, remaining obligations and any expenditure falling beyond that cutoff under its applicable methodology. Disposal proceeds should have an explicit basis before inclusion. A zero terminal entry should be explained as a modelling boundary, with sensitivity where material. Renewal expenditure should preserve the function for which it is assumed; any additional service should receive a separately defined increment. This distinction makes the cost comparison traceable as asset scope changes over time.

8. Make delivery timing and risk allocation visible

The proposed route schedule should connect expenditure to an assumed service date through identifiable milestones. Early design, route investigation, permissions, procurement, access and testing can be represented as separate dependencies. The purpose is to locate the consequence of delay. A single commissioning-date sensitivity may show its financial significance, while a more detailed schedule can reveal the affected contracts and temporary arrangements. Neither representation establishes a probability of delay without supporting evidence.

FERC's Order 1920 compliance schedule, last updated on 19 August 2026 when accessed, distinguishes initial regional-planning filings from later interregional-coordination filings and records region-specific extensions. It links Orders 1920, 1920-A and 1920-B. The published schedule is used here as current procedural context. A listed filing deadline establishes no Commission acceptance, completed regional implementation, individual-project selection or resolution of litigation. Those matters require separate documentary checks. [9]

Ofgem's 2 July 2025 Early Competition commercial-framework decision illustrates explicit treatment of post-selection cost risk. Its discussion of the preliminary-works cost assessment addresses a cap to be finalised for the first tender during market engagement, specified high-impact low-probability events and further implementation consultation. It also discusses incentives concerning design and consentability. This paper relies on that dated framework

discussion alone; it asserts no current tender price, final project-specific cap or universal cost-recovery right. [15]

For the proposed valuation, each route-change event should have three linked consequences: revised cost, revised service date and the assumed party bearing the change. A contractual entitlement should enter cash analysis only under an expressly hypothetical contract or verified executed provision. A modelled compensation assumption should identify payment timing and collection conditions. The underlying cost should remain in the system ledger even where a particular owner is assumed to recover it from another party.

The proposed sensitivity programme should combine selected risks when their joint occurrence is decision-relevant. A route change might be tested alongside a later service date and revised maintenance access. The analyst should state that this is an author-selected scenario with no statistically estimated dependency. Results can identify a break-even condition for additional investigation. They cannot demonstrate that an actual design, regulator or contractor would deliver the assumed response. A decision should carry the unresolved conditions into the next approval stage and identify the expenditure exposed before those conditions are settled.

9. Keep the whole-life recommendation conditional and auditable

HM Treasury's Green Book 2026 frames appraisal around objectives, alternative options, social costs, benefits and risks. It describes an assessment horizon extending through development, operation and winding-down or decommissioning, and distinguishes social impacts from public-sector financial costs. Its guidance has its own applicable time horizons and appraisal conventions. These principles support an explicit whole-life boundary. The fictional analytical cutoff and proposed owner-cash analysis remain separate assumptions requiring adaptation for any actual public appraisal. [14]

The proposed recommendation should bring together four records: service equivalence, dated resource costs, beneficiary and payer accounts, and unresolved delivery conditions. The ranking should identify the perspective used, the price basis, the discount convention and the timing of service. Capital cost alone can remain a useful screening field. Its interpretation should be limited to that field whenever operating costs, lost delivery, renewals or material unmonetised effects have been omitted.

A useful decision statement would explain which candidate performs best under the stated assumptions, which condition could reverse the ranking and what evidence is needed next. Where a service-equivalence test remains open, the committee could approve further investigation with a defined expenditure limit. Where a contract or recovery mechanism remains hypothetical, the investment case should retain that qualification. The decision can then be revisited when engineering, route or commercial evidence changes, without representing an earlier screening result as a completed investment approval.

Monitoring should be designed around the assumptions most capable of changing the choice. Candidate-specific milestones, package boundaries, energy-loss conventions and renewal events should be retained with dated evidence. Actual expenditure and accepted service could subsequently be compared with the approved case using the same definitions. Differences should be allocated to scope, quantities, prices, timing and operating conditions where the evidence supports that decomposition. Unexplained differences should remain visible in the record.

This framework offers a disciplined way to investigate competing transmission routes and staged upgrades. Its numerical applications are hypothetical, and its source examples retain their own jurisdictions, dates and documentary maturity. The paper provides no site investigation, consent opinion, technical feasibility finding, live procurement quotation or regulated-return forecast. An actual recommendation would require project-specific engineering, environmental, contractual and financial review using the relevant authorities and current instruments.

10. Construct an auditable comparison from quantities and dated consequences

The analytical contribution is a linked decision record with four components. First, a service specification states the required receiving-end transfer, timing and operating conditions. Second, a package register maps the scope needed to deliver that service. Third, a dated account converts useful delivery, losses and lifecycle obligations into resource value. Fourth, a decision record separates case-assumed eligibility, actual unresolved engineering conditions and the evidence required for the next capital commitment. A change in one component should carry its consequences through the others.

For the worked model, useful delivery in each operating year equals the lower of installed transfer-equivalent capacity and assumed demand, multiplied by useful hours and ordinary availability, then adjusted for the separately stated renewal outage. Gross benefit attaches to that delivered quantity. Losses use a sent-energy denominator: additional lost MWh equal delivered MWh multiplied by the loss fraction and divided by one minus that fraction. Replacement energy is priced once. The annual ledger preserves ordinary delivery, renewal interruption, useful delivery, sent energy and loss energy as separate quantities.

The resource-cost account dates construction, holding costs, routine O&M, loss-energy purchases, renewals, interim removal and final closure. A renewal can change both cash expenditure and useful delivery. Each consequence has its own entry. When useful delivery has already fallen for a renewal window, an additional lost-benefit payment would duplicate the same consequence. Similarly, a terminal amount defined net of closure must replace the final closure entry. Explicit quantity and cash identities make these conventions reviewable before a result is rounded for presentation.

The fixed analytical calendar runs from immediate time-zero expenditure through end-year 30. Service begins at the start of the specified year; its benefit and annual operating costs enter at that year's end. A delay shifts the uncommitted construction calendar and the start of useful service, and adds the separately stipulated holding resource cost. The model does not move payments already irreversibly spent, because none are assumed. A real project with deposits, enabling works or termination obligations would require those dates and conditions to be added explicitly.

No probability distribution, observed quote or market-calibrated discount rate enters this constructed case. Sensitivities change identified assumptions while retaining the rest. This permits a reader to reproduce conditional rankings without interpreting them as expected returns. The table values and figures are rounded displays of the underlying dated account. A numerical comparison is acceptable for this paper only when its service definition, cost perimeter, timing and terminal treatment can be traced to that account.

11. Define the service that each route must deliver

The constructed case asks which mutually exclusive package supplies an additional 300 MW of receiving-end transfer-equivalent capacity by the beginning of year 4. All capacities, costs, service dates and availability assumptions are fictional. The packages are an overhead line, an underground route, a particular subsea/HVDC package, reconductoring and an early grid-enhancing technology package followed by an overhead line. Their common receiving-end definition is a modelling convention. Actual comparison requires route-specific network, terminal, converter, security, environmental and consenting studies. The calculation supplies no finding that these physical solutions are interchangeable.

The overhead and underground packages each provide the assumed 300 MW from year 3. Their construction payments total USD 210 million and USD 330 million respectively, spread across time zero and end-years 1 and 2. The subsea/HVDC package costs USD 430 million over time zero through end-year 3 and begins service in year 4. Reconductoring costs USD 115 million and provides 220 MW from year 2. The staged package spends USD 32 million on 120 MW of assumed GET service from year 2, followed by USD 220 million of line expenditure in years 4 to 6. Its full 300 MW begins in year 7.

The capacity timeline exposes two exclusions before ranking values. Reconductoring never reaches the required 300 MW in the analysed calendar. The staged package reaches it after the stated deadline. Their partial-service benefits remain useful to compare; their base designs fail the case requirement. A buyer could consider changing the requirement or adding a complementary investment only through a newly specified case. The present results contain no assumed purchase of the missing capacity, temporary supply contract or emergency reliability remedy.

Ordinary accepted-service availability is stipulated separately for each package, from 94% for GET to 98.5% for underground. It scales expected useful energy and excludes the separately modelled renewal outage windows. This bookkeeping convention contains no hourly chronology, disturbance coincidence or probability distribution. It cannot demonstrate firm capacity or security under a particular contingency. A capacity gate labelled pass means only that the case-assumed receiving-end equivalent is present by the deadline. Actual engineering eligibility remains unresolved for every package.

The no-new-investment counterfactual has zero incremental spending and zero incremental service benefit in this account. Existing assets, their book value and already sunk costs stay outside it. This permits a consistent comparison of new decisions. A negative incremental value would call for reconsideration of the assumptions or scope; the zero-cost counterfactual itself leaves the specified new service requirement unmet.

Table 1. Assumed service and lifecycle parameters

Package	MW / start year	Ordinary availability %	Sent-energy loss %	Annual O&M	Renewal / interval
Overhead	300 / 3	97.00	2.500	2.5	20 / 15 years
Underground	300 / 3	98.500	1.500	2	30 / 18 years
Subsea / HVDC	300 / 4	96.00	3.500	5	75 / 12 years
Reconductoring	220 / 2	96.500	3.00	1.5	18 / 12 years

Package	MW / start year	Ordinary availability %	Sent-energy loss %	Annual O&M	Renewal / interval
GET then overhead	120 / 2; 300 / 7	94.00; 97.00	1.00; 2.500	1.2; 2.5	8 / 4 years; 20 / 15 years

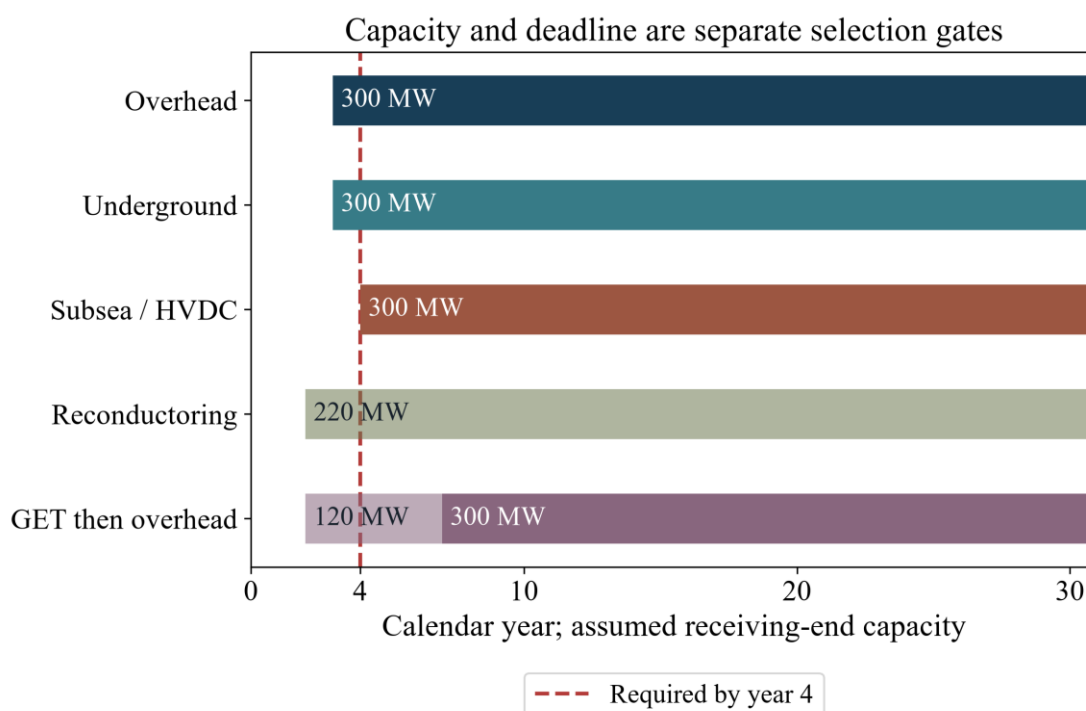
Fictional receiving-end equivalents. Staged entries show GET then overhead. O&M and renewal amounts are USD million; renewal outages are 8%, 12%, 15%, 10%, and staged 5% then 8%. Ordinary availability excludes these windows. Engineering equivalence is unresolved.

Table 2. Construction timing and final closure

Package	Dated construction cash	Total construction	First full year	Closure at year 30
Overhead	0: 42; 1: 84; 2: 84	210.000	3	15.000
Underground	0: 66; 1: 132; 2: 132	330.000	3	22.000
Subsea / HVDC	0: 43; 1: 129; 2: 129; 3: 129	430.000	4	35.000
Reconductoring	0: 46; 1: 69	115.000	Not reached	10.000
GET then overhead	0: 16; 1: 16; 4: 44; 5: 88; 6: 88	252.000	7	15.000

Fictional USD million, with year 0 paid immediately and later payments at year end. Staged GET removal costs 2 in year 7. No existing book value or sunk expenditure is charged. Thirty years is the analytical boundary, not asset life.

Figure 1. Receiving-end capacity and the assumed delivery deadline



Fictional transfer-equivalent inputs, with the same 300 MW requirement by year 4. Reconductoring and the early GET stage provide partial service. Actual power-flow, security, environmental and consenting feasibility remain unresolved; the diagram certifies no engineering equivalence.

12. Reconcile useful service, losses and resource costs

The base demand is 300 MW for 2,500 useful hours annually. In each operating year, useful receiving-end MWh equal the smaller of demand and installed capacity, multiplied by hours, ordinary availability and the fraction remaining after any renewal outage. Gross system benefit is that useful quantity multiplied by a stipulated USD 80/MWh avoided resource cost. No benefit is assigned before service or after year 30. The constructed value measure excludes additional reliability, environmental and distributional benefits that would require separate evidence and boundaries.

Losses use a different denominator. Each stated loss fraction is a fraction of sent energy. Consequently, loss MWh equal delivered MWh multiplied by the loss fraction and divided by one minus that fraction. Sent MWh equal delivered MWh plus loss MWh. Replacement energy for those losses costs an assumed USD 50/MWh. The benefit price is defined before this incremental loss-energy adjustment. This construction charges the extra energy resource once and leaves the useful receiving-end quantity intact. It contains no second loss haircut to already delivered benefits.

For example, the overhead package delivers 727,500 useful MWh in an ordinary base operating year. Its 2.5% sent-energy loss fraction produces 18,653.846 additional loss MWh and USD 0.933 million of replacement-energy cost. Gross benefit is USD 58.200 million. Annual O&M is USD 2.500 million. In renewal year 18, a separate 8% outage removes 58,200 useful MWh from that year's ordinary amount. Both gross benefit and associated loss energy follow the reduced quantity. A separate foregone-benefit payment is absent.

All monetary amounts are real USD million. Payments at time zero are undiscounted, and subsequent cash flows occur at year end. At the assumed 7% real system discount, overhead has benefit PV of USD 615.602 million and total resource-cost PV of USD 238.129 million. Its net system value is USD 377.473 million. Underground yields USD 282.865 million, subsea/HVDC USD 74.950 million, reconductoring USD 336.365 million and the staged package USD 299.121 million. The cost-account exhibit separates construction, O&M, loss energy, renewals and closure so that each difference has an identifiable driver.

These values describe system resource effects. They supply no tariff, availability payment, merchant receipt or regulated asset recovery. The 7% assumption is a system valuation input with no claim to represent an observed investor cost of capital. An investable case would require a separately evidenced payer, eligible expenditure, collection schedule and financing structure. Debt service cannot be sized from the gross system-benefit series in this model.

Table 3. Base discounted system value

Package	Benefit PV	Construction PV	Other cost PV	Net system PV	Assumed gate
Overhead	615.602	193.874	44.256	377.473	Pass
Underground	624.808	304.658	37.284	282.865	Pass
Subsea / HVDC	559.374	381.537	102.887	74.950	Pass
Reconductoring	484.828	110.486	37.977	336.365	Fail
GET then overhead	529.440	185.902	44.418	299.121	Fail

USD million at 7% real discount. The case gate requires 300 MW by year 4. Positive partial-service value does not satisfy that gate. System benefit is not operator revenue.

Table 4. Resource-cost account by package

Package	O&M PV	Loss-energy PV	Renewal PV	Closure PV	Useful MWh million
Overhead	26.503	9.865	5.917	1.971	20.312
Underground	21.202	5.947	7.245	2.890	20.596
Subsea / HVDC	48.924	12.680	36.685	4.598	19.224
Reconductoring	17.212	9.372	10.080	1.314	15.286
GET then overhead	23.705	7.652	9.845	3.216	18.798

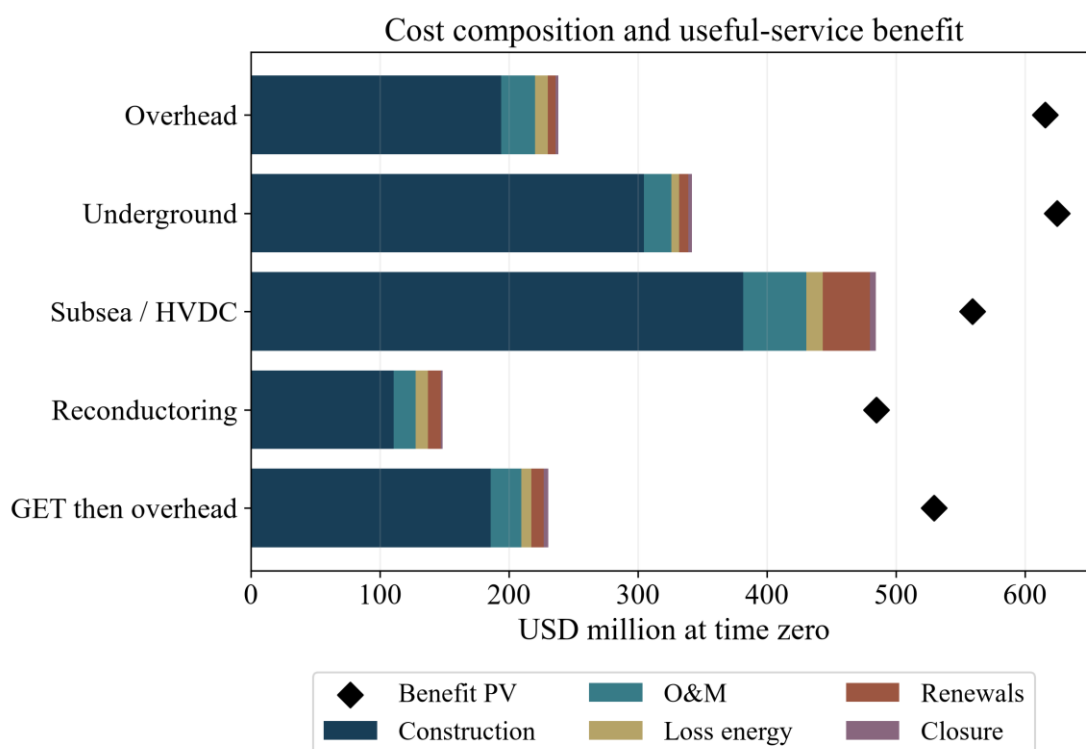
Costs are USD million present values. Useful receiving-end MWh are undiscounted expected-state quantities. Loss MWh = delivered MWh times loss fraction divided by one minus loss fraction; replacement energy costs USD 50/MWh once.

Table 5. Annual service and cost reconciliation

Package / year	Useful MWh	Loss MWh	Benefit cash	Resource cost	Net system cash
Overhead / 0	0.000	0.000	0.000	42.000	-42.000
Overhead / 3	727,500.000	18,653.846	58.200	3.433	54.767
Overhead / 18	669,300.000	17,161.538	53.544	23.358	30.186
Overhead / 30	727,500.000	18,653.846	58.200	18.433	39.767
Subsea / HVDC / 4	720,000.000	26,113.990	57.600	6.306	51.294
Subsea / HVDC / 16	612,000.000	22,196.891	48.960	81.110	-32.150
Subsea / HVDC / 28	612,000.000	22,196.891	48.960	81.110	-32.150
GET then overhead / 2	282,000.000	2,848.485	22.560	1.342	21.218
GET then overhead / 6	267,900.000	2,706.061	21.432	97.335	-75.903
GET then overhead / 7	727,500.000	18,653.846	58.200	5.433	52.767
GET then overhead / 22	669,300.000	17,161.538	53.544	23.358	30.186
GET then overhead / 30	727,500.000	18,653.846	58.200	18.433	39.767

Monetary cash is fictional USD million at the stated year. Renewal downtime reduces useful benefit and associated loss energy together. No separate lost-benefit cash charge is added.

Figure 2. Discounted resource costs and useful-service benefits



Author-created USD million at 7% real discount, fixed years 0-30. Sent-energy loss fractions generate replacement-energy costs once. Benefits are system resource savings, with no operator receipt, allowed revenue or financing entitlement assumed.

13. Make delay change the actual calendar

The whole-package delay cases move every uncommitted construction payment, service start and renewal clock by the same integer number of years. The analytical stop remains end-year 30. An assumed resource holding cost of USD 1.500 million is paid at the end of each waiting year.

Construction postponement therefore reduces its discounted cost while later service removes useful years from the fixed calendar. Both effects enter the same dated account. No separate lost-benefit charge is added to the missing operating receipts in the system-benefit calculation.

This treatment describes a decision taken before construction commitments. It supplies no cancellation payment or sunk-construction recovery. If a real consent delay occurs after deposits or enabling works have been paid, those expenditures would need their own fixed dates and termination terms. Moving them automatically would overstate deferral flexibility. The model's schedule is deliberately explicit about which payments move, allowing that distinction to be tested in a subsequent transaction-specific case.

For overhead, one year of delay reduces net system PV from USD 377.473 million to USD 344.524 million. Two years reduce it to USD 313.730 million and three years to USD 284.951 million. The first whole-year delay that puts overhead below the on-time underground package is four years, when overhead falls to USD 258.054 million. This economic crossing does not determine the earlier feasibility decision. Overhead begins in year 5 after a two-year delay and already fails the year-4 requirement. With other base assumptions retained, on-time underground becomes the higher-value eligible alternative to the on-time subsea/HVDC package.

The staged schedule also has a separate line-only delay calculation. GET remains in service until the later line starts, and its recurring renewals continue while it is active. Its benefit ends when the 300 MW line takes over. The model never adds 120 MW to that line's 300 MW or retains both benefit streams after the transition. GET removal costs USD 2 million at the handover. A one-year line-only delay reduces staged value to USD 287.875 million; a three-year delay reduces it to USD 267.542 million. These cases still fail the original deadline.

The delay chart can show uneven changes when a renewal moves outside the fixed horizon. For subsea/HVDC, a scheduled late renewal that reaches year 30 is excluded under the explicit closure convention, which allows operation in the final year followed by closure. That creates a boundary effect, not an engineering forecast of maintenance need. The terminal sensitivity and the annual ledger expose this limitation for review.

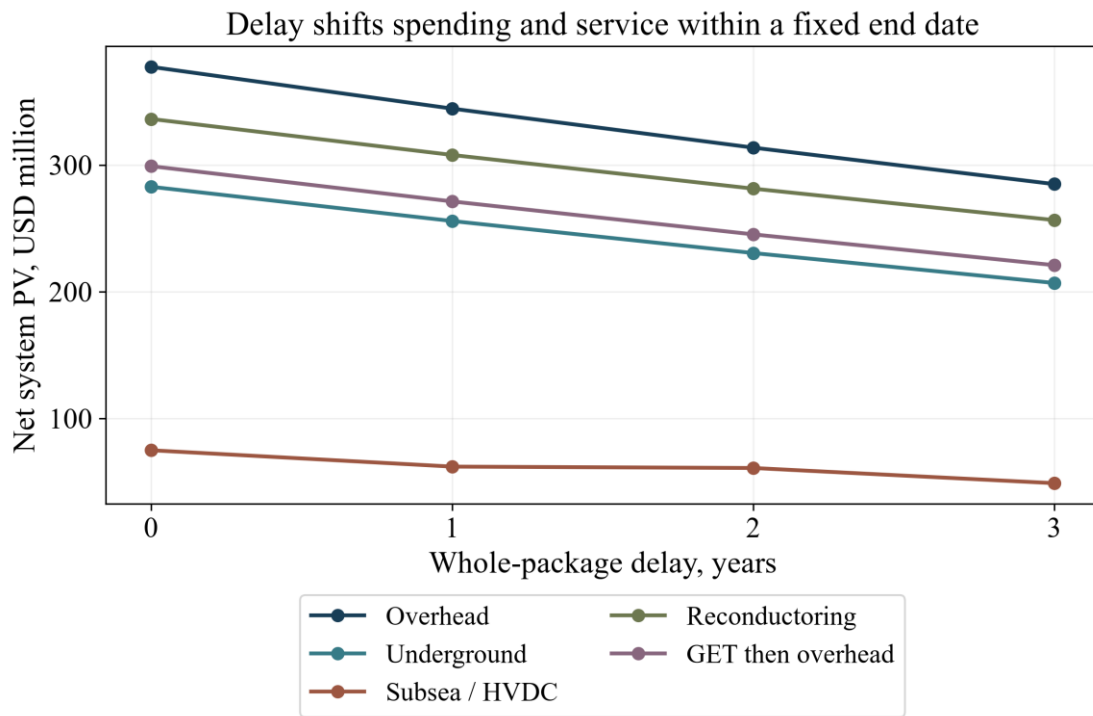
Table 6. Whole-package consenting delay

Package	Delay years	First service	Net system PV	Holding PV	Assumed gate
Overhead	0	3	377.473	0.000	Pass
Overhead	1	4	344.524	1.402	Pass
Overhead	2	5	313.730	2.712	Fail
Overhead	3	6	284.951	3.936	Fail
Underground	0	3	282.865	0.000	Pass
Underground	1	4	255.828	1.402	Pass
Underground	2	5	230.559	2.712	Fail
Underground	3	6	206.943	3.936	Fail
Subsea / HVDC	0	4	74.950	0.000	Pass
Subsea / HVDC	1	5	62.047	1.402	Fail
Subsea / HVDC	2	6	60.949	2.712	Fail
Subsea / HVDC	3	7	48.962	3.936	Fail
Reconductoring	0	2	336.365	0.000	Fail
Reconductoring	1	3	307.944	1.402	Fail
Reconductoring	2	4	281.382	2.712	Fail
Reconductoring	3	5	256.558	3.936	Fail
GET then overhead	0	2	299.121	0.000	Fail

Package	Delay years	First service	Net system PV	Holding PV	Assumed gate
GET then overhead	1	3	271.297	1.402	Fail
GET then overhead	2	4	245.294	2.712	Fail
GET then overhead	3	5	220.992	3.936	Fail

USD million. All uncommitted construction, start dates and renewal clocks move together. Holding resource cost is 1.5 per waiting year. Final year 30 is fixed; no separate foregone-benefit penalty. Staged line-only delay is separately retained in the full results.

Figure 3. Consenting delay shifts construction, service and renewal dates



Each curve delays the whole package by the stated integer years, adds stipulated holding resource costs and retains the fixed year-30 stop. No separate foregone-benefit charge is added. Gate compliance and actual permissions require separate consideration; late renewals can move beyond the analytical boundary.

14. Test the demand case and the fixed end boundary

Demand sensitivities change useful service while preserving the assumed 300 MW functional requirement. At 200 MW demand and USD 80/MWh gross benefit, overhead value falls to USD 175.561 million and reconductoring value is USD 293.141 million. The smaller package supplies the assumed demand more cheaply in that economic scenario, yet its 220 MW capacity still fails the unchanged functional gate. Selecting it would require an explicit revision of the service requirement and supporting engineering evidence. The sensitivity does not silently redefine the obligation.

At 300 MW and USD 40/MWh, reconductoring also has the higher unrestricted value: USD 93.951 million against overhead's USD 69.672 million. At the base USD 80/MWh, overhead leads by USD 41.108 million. The demand-value figure displays this difference directly. Increasing assumed demand to 400 MW produces no additional value for these two packages because each is already capped by its modelled capacity. The excess demand receives no fictitious service benefit. At 200 MW and USD 40/MWh, even the highest-value gate-passing

option, overhead, has negative value of USD 29.640 million; that result requires a review of the need, scope and omitted benefits before committing resources.

Discount and capital-cost cases retain the same service calendars and separately test 4%, 7% and 10% discount rates and construction at 75% or 125% of the base amounts. Renewal sensitivities distinguish a 50% increase in renewal cash from removing the assumed renewal downtime while retaining its cost. These are deterministic changes, with no probabilities or market calibration. They identify evidence that could change the decision. Each favourable combination remains an explicitly assumed scenario with no forecast probability attached.

End-year 30 is a chosen analytical boundary. Each base package operates within that period, pays its stated final closure cost and receives no salvage or later cash. This convention makes the case a bounded lifecycle comparison; it establishes no physical service life. Three separate sensitivities replace the final closure payment with net terminal cash of minus USD 100 million, zero or plus USD 100 million. Interim GET removal remains. Final closure is removed in those cases so that the net terminal amount cannot double-count it.

Applying the same terminal scenario to every package does not reverse the base ranking in the tested range. Underground alone would require approximately USD 698.178 million of net terminal cash in year 30, replacing its USD 22 million closure cost, to equal unchanged base overhead value. That switching amount is a conditional calculation with no assertion that an asset could realise it. A credible continuation assessment would need additional operating costs, renewals and service evidence beyond this model's horizon.

Table 7. Demand and benefit-value decision tests

Demand MW	Benefit USD/MWh	Best assumed-feasible package	Net system PV	Best unrestricted package	Net system PV
200	40	Overhead	-29.640	Reconductoring	72.765
200	80	Overhead	175.561	Reconductoring	293.141
200	120	Overhead	380.761	Reconductoring	513.518
300	40	Overhead	69.672	Reconductoring	93.951
300	80	Overhead	377.473	Overhead	377.473
300	120	Overhead	685.274	Overhead	685.274
400	40	Overhead	69.672	Reconductoring	93.951
400	80	Overhead	377.473	Overhead	377.473
400	120	Overhead	685.274	Overhead	685.274

USD million present value at 7%. Demand is capped by installed transfer-equivalent capacity; the functional 300 MW deadline gate stays fixed even in low-demand valuation cases. Ranking is conditional on fictional inputs and unresolved engineering.

Table 8. Discount and capital-cost sensitivity

Package	PV at 4%	PV at 7%	PV at 10%	PV at 75% capex	PV at 125% capex
Overhead	626.551	377.473	228.170	425.941	329.004
Underground	533.018	282.865	133.496	359.030	206.700
Subsea / HVDC	260.480	74.950	-33.770	170.335	-20.434
Reconductoring	519.271	336.365	224.903	363.986	308.743
GET then overhead	516.166	299.121	175.913	345.596	252.645

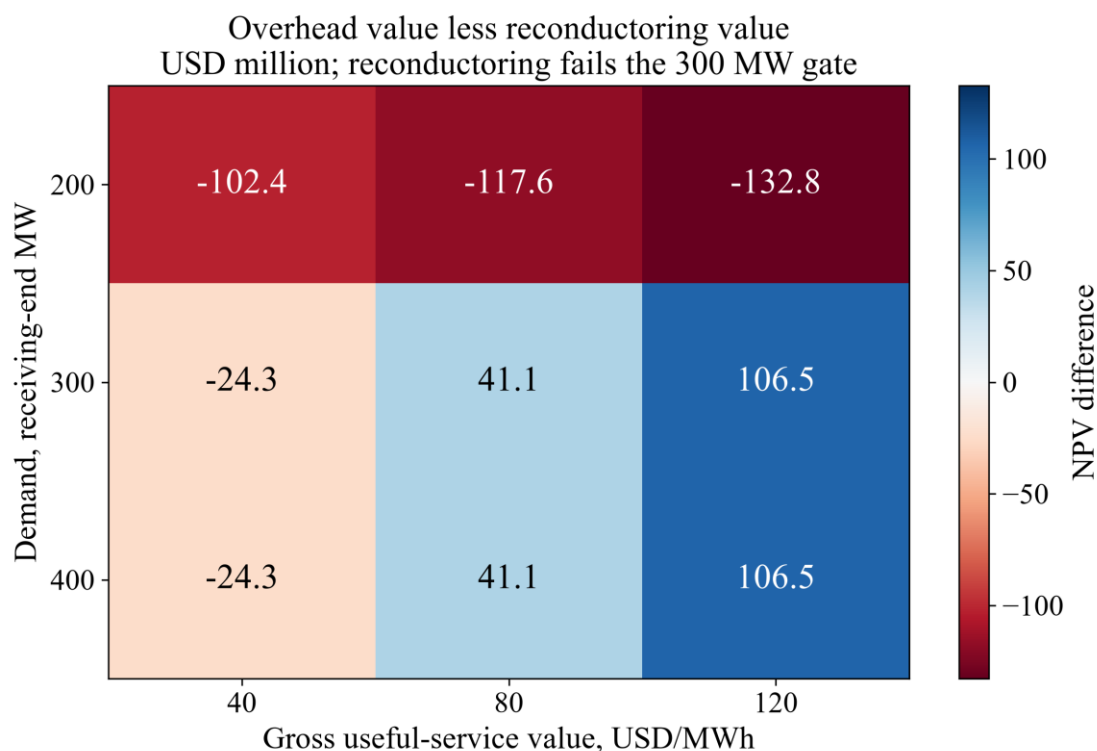
USD million. Capital-cost cases hold the base 7% discount and all service assumptions fixed. The discount is a stipulated system valuation rate, not an observed cost of capital.

Table 9. Renewal and final-boundary sensitivity

Package	No renewal outage	150% renewal cost	Net terminal - 100	Net terminal 0	Net terminal +100
Overhead	378.828	374.514	366.307	379.443	392.580
Underground	284.561	279.242	272.618	285.755	298.892
Subsea / HVDC	79.081	56.608	66.412	79.548	92.685
Reconductoring	338.696	331.324	324.542	337.678	350.815
GET then overhead	300.902	294.198	287.954	301.091	314.228

USD million NPV. Each terminal sensitivity substitutes a signed net cash amount at year 30 for the final closure cost. Interim GET removal remains. No simultaneous closure deduction or physical-life claim; no benefit after year 30.

Figure 4. Demand and service value change the overhead-reconductoring comparison



Fictional net system NPV difference in USD million at 7%. Negative cells favour the partial-capacity reconductoring package economically; that package still fails the unchanged 300 MW deadline gate. Demand above the modelled capacity produces no extra benefit.

15. Turn switching values into conditional decisions

The underground package has assumed advantages in availability, loss energy and annual O&M, with different renewal and closure costs. Together, its benefit and nonconstruction-cost differences support a maximum extra construction PV of USD 16.177 million over overhead at the base service dates. The actual extra construction PV is USD 110.785 million. The resulting value difference is USD 94.608 million. The switching figure represents that difference as a time-zero capital adjustment: underground would need an upfront reduction of that amount to equal overhead while all other assumptions remain fixed.

This boundary creates a specific diligence question. A proposed underground premium could become supportable through a lower quoted capital schedule, demonstrably different service benefits, a constrained overhead permission path or another explicit change. Each proposed change should enter the dated calculation once and retain the same service and cost perimeter. Combining a revised capital quote with the old scope, or adding an undated amenity benefit

without evidence, would weaken the comparison. Any actual environmental or community effects require their own assessment before their treatment in an economic case is settled.

The integrated base decision is conditional: overhead has the highest calculated system value among the three packages passing the stipulated capacity and deadline tests. A two-year overhead delay changes that eligible choice to on-time underground under the remaining assumptions. A lower demand case strengthens the economic appeal of reconductoring but requires reconsidering the fixed capacity requirement. The staged option demonstrates the value and cost of early partial service while exposing its late full-service date. None of these outcomes establishes a procurement award, permission, regulated recovery or lender commitment.

Reproducibility comes from retaining the full time-zero and thirty annual rows for every specified case. The deterministic calculation uses fifty-digit decimal arithmetic before exporting numerical data for display. Its checks reconcile useful service and renewal downtime, sent and delivered energy, the resource-cost sum and discounted net value. Additional directly expressed calculations test the overhead loss denominator, construction PV and staged handover. Displayed values are rounded; underlying schedules retain computational precision. These checks document the calculation process and do not replace engineering review or independent arithmetic review.

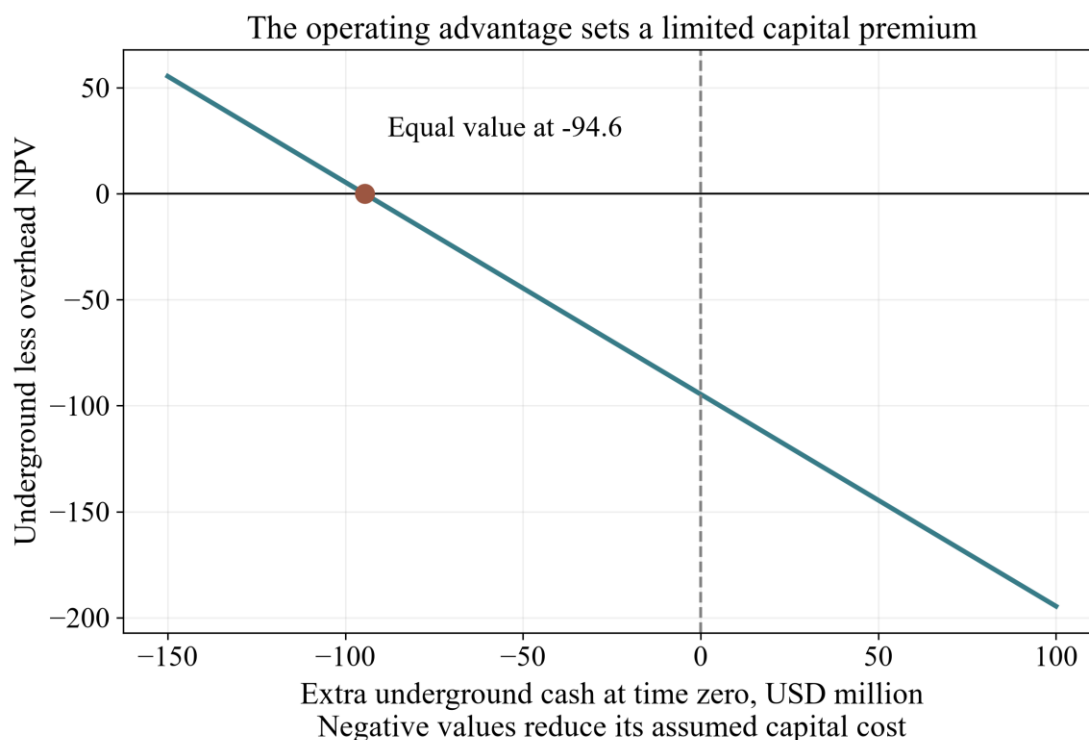
An implementation decision would therefore maintain two further accounts outside this example. The owner account identifies actual allowed or contracted receipts, collection risk and eligible cost recovery. The financing account identifies dated debt and equity contributions, interest, reserves, covenants and distributions. Their relationship to the system account requires evidence for each transfer and condition. Keeping those accounts explicit allows a system-attractive route to be assessed for affordability and deliverability without treating its calculated social value as cash already available to its operator.

Table 10. Conditional switching boundaries

Decision test	Value	Unit	Meaning
Maximum extra underground capex PV	16.177	USD million	Operational advantage at base service dates
Actual extra underground capex PV	110.785	USD million	Base construction schedule difference
Underground additional upfront headroom	-94.608	USD million	Negative value means reduction required
First whole-year overhead delay below underground	4.000	Years	Economic crossing; deadline gate already fails
Underground net terminal cash to match overhead	698.178	USD million in year 30	Replaces underground closure; overhead stays base

These are conditional system-value comparisons, not investment offers or compensation entitlements. Integer delays 0-10 are searched without interpolation. Required permissions, power-flow feasibility and owner cash recovery remain outside this model.

Figure 5. The conditional capital adjustment that equalises two route values



Underground value less overhead value under unchanged service assumptions, USD million. A negative extra payment is a reduction in time-zero capital cost. The crossing is a system-economic condition, with no actual bid, regulated recovery or owner financing commitment implied.

16. Define the route decision through an evidence perimeter

The proposed route appraisal begins with a service specification that every candidate must address. The sponsor should identify the connection points, the intended service, the period over which that service is required and the operating conditions under which it will be assessed. Candidate descriptions should distinguish physical installation from electrical configuration and include the associated interfaces. A route register would give each option a stable identifier and list the substations, terminal equipment, connection works and access arrangements included in its scope. An alternative whose boundary remains incomplete should retain that qualification throughout the comparison. The investment committee would then see which proposals address the same decision and which require further engineering definition.

For each route, the evidence pack should connect drawings and quantities to dated surveys, design assumptions and the parties responsible for checking them. The recommended register records surveyed segments separately from desktop assumptions and unresolved crossings. It would identify where the alignment depends on access that has yet to be agreed, on another party's works or on a design choice that remains open. A length estimate should carry its alignment version and inclusions; quantities derived from another version should be reconciled before they enter a cost schedule. This method provides a practical way to investigate a cost change without treating an early route sketch as a completed design.

The analyst should establish a comparable service boundary before calculating an economic preference. Where an existing-corridor intervention is proposed alongside a new route, the engineering reviewer would explain the service each can supply under the agreed conditions and identify any supplementary works. The financial reviewer would then price those defined

packages and their dates. A candidate requiring an unresolved interface should carry a separately identified condition and a conditional cash case. The proposed control is to withhold a definitive ranking where the alternatives have materially different, unexplained service obligations. Preliminary screening can continue, provided its narrower question and outstanding evidence are visible.

Table 11. Define comparable route packages

Evidence item	Record requested	Open condition	Decision supported
Service boundary	Endpoints and agreed operating conditions	Engineering review incomplete	Admit option to comparison
Physical scope	Alignment and terminal/interface schedule	Excluded works unresolved	Compare whole package cost
Evidence maturity	Survey and design version register	Desktop assumption remains	Authorise further investigation
Alternative scope	Supplementary works and dependencies	Different service requirement	Revise comparison boundary

Proposed evidence matrix; no technical equivalence between candidates is assumed.

17. Connect land, construction and repair obligations

The proposed contracting review follows the route through its whole operating period. For every segment, the sponsor should identify the evidence supporting construction access, operating access and access needed for inspection, repair or removal. The review would record the relevant parcel or corridor reference, counterparty, document status, duration and any unresolved condition. Legal advisers should determine the meaning and enforceability of the actual instruments. The valuation team should use their documented conclusions to specify cash consequences and timing assumptions. A generic allowance for land expenditure cannot establish that all required access is available, particularly when the proposed maintenance method needs space outside the construction footprint.

The interface schedule should connect each physical boundary to an accountable contractual party. For example, an illustrative package might separate civil works, equipment supply, installation, terminal integration and testing. Its schedule would identify who supplies design information, who confirms compatibility, who accepts the completed interface and who bears the cost while a discrepancy is resolved. The commercial review should compare those responsibilities with the programme's assumed sequence. If one supplier can complete its contract while another interface remains unavailable, the model should retain the resulting exposure explicitly. Contract summaries should preserve exclusions and limitations that affect these assumed remedies.

Repair planning deserves a separate contractual and cash review. The sponsor should request a route-specific description of fault location, safe access, replacement materials, specialist services, reinstatement and return to service. Any timing assumption should identify its evidence and dependencies, including the availability of the people and equipment required. The appraisal could then distinguish routine expenditure from a conditional major intervention and state who funds each. No standard repair duration or recovery payment is presumed here. Where repair rights, spares ownership or responsibility for reinstatement remain unresolved, the investment memorandum should show the open decision and its consequence for the selected route's whole-life cost.

Table 12. Allocate route access and repair interfaces

Interface	Evidence requested	Cash exposure to examine	Responsible review
Construction access	Parcel and access instruments	Payments before conditions resolved	Legal and delivery
Terminal integration	Scope and acceptance responsibilities	Uncompleted interface expenditure	Engineering and commercial
Repair access	Route-specific intervention plan	Access and reinstatement costs	Operations and legal
Spares and services	Ownership and availability arrangements	Replacement and mobilisation funding	Procurement and finance

Proposed diligence questions; actual rights, timing and liabilities depend on the relevant documents.

18. Release capital through conditional procurement stages

The proposed procurement method separates information expenditure from irreversible delivery commitments. Early spending could obtain surveys, design development or comparable supplier responses where those activities resolve a material uncertainty in the route decision. Each proposed commitment should state the question it will answer, the amount exposed and the later decision it enables. The sponsor should identify expenditure that becomes unusable if the alignment changes and distinguish it from work that remains useful across candidates. A stage is complete when the stated evidence has been obtained and reviewed. Spending the budget allocated to that stage supplies no equivalent confirmation.

Supplier comparisons should use a common scope schedule and a transparent treatment of exclusions. The recommended comparison records the delivery boundary, price basis, validity period, assumed quantities, programme conditions and acceptance obligations for each offer. A low quoted amount can enter the comparison only with the costs and responsibilities left outside it identified. The buyer should ask how a route amendment changes quantities, engineering effort, cancellation exposure and delivery commitments. Where a supplier response is indicative, the appraisal should preserve that status and test a conditional amount. This paper proposes no general entitlement to hold a quoted price or reserve a manufacturing slot.

Before a major order, the committee should receive a dated capital-release memorandum linking the procurement decision to the latest route evidence. It should show payments due before access or approvals are resolved, the conditions under which those payments can be recovered, and the amount still exposed if the programme stops. A proposed alternative procurement sequence should be evaluated against the same service requirement and decision horizon. The sponsor should also explain whether an earlier commitment reduces a particular uncertainty or merely transfers cash sooner. The resulting recommendation would identify the next authorised commitment and the evidence required before further capital is released.

Table 13. Release procurement capital against evidence

Commitment stage	Evidence gate	Exposure to retain	Approval requested
Investigation	Defined uncertainty and work scope	Unusable work if route changes	Limited study expenditure
Supplier comparison	Comparable inclusions and exclusions	Indicative price and quantity changes	Negotiation authority
Major order	Current access and design conditions	Cancellation and advance payments	Bounded procurement commitment
Further release	Verified milestone and remaining conditions	Cash due before service starts	Next authorised payment

Author-proposed stage controls; no supplier reservation, price protection or refund right is presumed.

19. Give the investment committee a decision it can execute

The proposed committee paper should distinguish the economic preference from the authority to proceed. A route can compare favourably under a stated set of assumptions while remaining dependent on access, design, procurement or funding conditions. The recommendation should identify which decision is requested: additional investigation, negotiation of a defined package, a limited commitment or approval of the complete programme. Each request should have an expenditure boundary and named dependencies. The committee should be able to approve a bounded next step without inadvertently authorising the full route or accepting every assumption used in a preliminary valuation.

The comparison should keep system-level effects and owner cash in separately labelled schedules. A claimed reduction in system cost should identify its measurement boundary and assumptions. An owner receipt should identify the instrument and conditions under which payment is assumed. A financing schedule should identify the entity that pays construction invoices and the source of funds available on those dates. The committee would review the connections between these schedules explicitly. A proposed economic benefit can support a planning argument while its allocation to an investor remains unresolved. Any assumed payment or recovery mechanism should remain conditional until the supporting evidence is established.

The recommendation should also explain how robust the preferred route is to the uncertainties that could change the choice. The analyst should identify the assumptions that move the ranking, the evidence needed to narrow them and the point at which the committee would reconsider its decision. An alternative should remain available only to the extent that its access, design and procurement conditions support that claim. The decision record would retain the rejected options and the reasons for rejection, including scope differences and unresolved evidence. This creates an auditable basis for revisiting the choice when a condition changes, without presenting the initial preference as an unconditional investment conclusion.

Table 14. Separate economic preference from commitment authority

Decision account	Question	Evidence required	Conditional outcome
Service comparison	Do packages meet the defined need?	Engineering scope assessment	Comparable candidates
System economics	Which effects enter the comparison?	Consistent baseline and horizon	Scenario preference
Owner cash	Which receipts can the owner receive?	Applicable instrument and conditions	Conditional cash schedule
Funding authority	Who pays and when?	Dated funds and expenditure authority	Executable next commitment

Proposed investment-committee structure; economic benefits and private receipts retain distinct boundaries.

20. Turn the selected route into an implementation baseline

After conditional approval, the proposed implementation roadmap starts with reconciliation of the selected option's boundaries. The delivery team should receive the exact alignment version, included interfaces, service specification, cost schedule and assumptions on which the approval was based. The handover should identify open matters and assign each to an owner with authority to obtain the necessary decision. A contract award should be mapped back to those approved boundaries. Any difference in scope, dates or allocation of responsibility should be recorded before the approved financial case is used as the delivery baseline.

The roadmap should connect milestones through actual dependencies. A work package may require access, design information, a preceding installation or an available testing interface before it can proceed. The sponsor should ask each responsible party to identify these prerequisites and the evidence that will demonstrate completion. The programme should preserve the distinction between physical progress, contractual acceptance and availability of the intended service. Payment milestones should be reconciled with each state so that cash commitments remain visible even where an operating milestone moves. A combined programme can then show the financial consequence of a delay without presuming that every contractual date shifts automatically.

Change control should begin from the approved route package and retain both the original and revised case. The proposed change memorandum records the reason, affected segments, revised service assumptions, incremental expenditure, timing effects and contractual consequences. It should identify whether the change also alters future inspection, repair or removal obligations. The committee's delegated authority should specify which changes the delivery team can approve and which require renewed investment review. The purpose is a traceable sequence of decisions linking the selected route to the asset delivered. A change should enter the forecast only when its status and supporting authority are explicit.

Table 15. Control the approved route through implementation

Control point	Baseline record	Change to reconcile	Owner to identify
Delivery handover	Approved alignment and scope	Contract boundary differs	Sponsor and delivery lead
Interface milestone	Prerequisites and acceptance record	Preceding work unavailable	Interface coordinator
Payment milestone	Dated commitment and cash schedule	Service date moves	Commercial and finance lead
Scope amendment	Original and revised cases	Future repair obligation changes	Delegated investment authority

Proposed implementation controls; roles must be assigned within the actual project organisation.

21. Monitor performance against the assumptions that drove selection

The proposed monitoring plan should be designed alongside the appraisal so that the later review can test the assumptions that mattered. The sponsor should define the measures, observation periods, data owners and comparison basis before using operating results to claim that the selected route performed as expected. Measures could concern expenditure, service availability, operating costs or restoration events, where relevant to the approved case. Their definitions should be consistent with the valuation boundary. A result recorded under a different operating condition should carry that qualification and should enter the comparison through a documented adjustment or a separate observation.

An evidence ledger would connect each material assumption to its latest supporting record and subsequent result. For expenditure, it should reconcile approved scope with commitments, invoices and cash paid. For an operating assumption, it should identify the measurement record and any exclusions or interruptions. For a conditional receipt, it should distinguish the assumed amount from invoicing, collection and any dispute. This paper recommends keeping revisions visible so that a changed forecast can be explained. Retrospectively changing the original assumption to match the outcome would remove information needed to evaluate the quality of the investment decision.

Periodic review should focus on decisions that remain available. If a repair dependency, access condition or operating cost changes, the sponsor should identify which future commitments can still be revised and the cost of doing so. A review of the original selection should distinguish information available at the time from information learned later. The whole-life calculation remains bounded by its stated horizon, included costs and assumed service; omitted renewal, removal or residual obligations need explicit treatment before practical use. The proposed method therefore ends with a maintained decision record, a schedule of unresolved conditions and an accountable process for updating the route's economic and delivery case.

Table 16. Maintain a whole-life evidence ledger

Assumption	Baseline to retain	Subsequent observation	Decision affected
Capital expenditure	Approved quantities and price basis	Commitments, invoices and payments	Remaining funding
Operating service	Defined conditions and measurement basis	Qualified operating records	Future service assumption
Repair exposure	Access and intervention dependencies	Actual event and restoration evidence	Spares or maintenance decision
Owner receipt	Assumed payment conditions	Invoice, collection and dispute status	Cash forecast revision

Proposed monitoring ledger; observations should preserve their operating context and do not establish a general route-performance claim.

22. Interpret the switching conditions as specific diligence questions

The underground premium illustrates how the framework directs diligence. Under the assumed service dates, its availability, loss-energy, O&M, renewal and closure differences support USD 16.177 million of additional construction present value over overhead. The stipulated construction difference is USD 110.785 million. The resulting USD 94.608 million value shortfall gives a precise conditional question: which evidenced change could close that gap while retaining the same service obligation and resource boundary?

An upfront reduction of USD 94.608 million in underground capital cost would equalise the two values under unchanged operating assumptions. That is a mathematical switching condition. It establishes no supplier willingness, regulated payment or available subsidy. A change in the dated bid schedule would require a fresh present-value comparison; the same total reduction paid at another date has a different time-zero value. Additional useful service, a changed overhead calendar or a properly evidenced effect outside the current boundary would also require a revised ledger.

The timing result supplies a second focused inquiry. Overhead loses deadline eligibility after a two-year delay, before its economic value falls below on-time underground. Evidence about the earliest achievable service date therefore has a direct consequence for the shortlist even where a broad valuation range still favours overhead. A sponsor should investigate permissions, access, supplier commitments and construction dependencies capable of moving that date. This paper assigns no probability to any such event. The relevance of a study follows from its possible decision consequence and the cost of obtaining it.

Demand provides a third inquiry. At 200 MW of assumed demand and USD 80 per useful MWh, reconductoring has higher unrestricted economic value than overhead, while its 220 MW package still fails the unchanged 300 MW requirement. A lower economic demand case does not itself authorise a smaller service obligation. The sponsor would need to establish whether the 300 MW

condition remains required, whether another intervention supplies the balance and whether the combined package meets the same deadline. Any complementary investment would bring its own cash, losses, operating and interface entries.

The model supplies no expected value of perfect information or study-budget optimum. Those calculations would need probabilities, possible findings and decision responses that have not been established. It does support a bounded evidence agenda: state the assumption capable of changing eligibility or value, identify an investigation that can resolve it, record its cost and decision date, and explain which further commitment depends on its result. That agenda connects the appraisal to an executable next step without presenting an assumed scenario as a forecast.

23. Examine the horizon before assigning a continuation or recovery value

The year-30 boundary is part of the calculation's meaning. It permits service in the final year, charges the stipulated base closure amount at its end and assigns no subsequent benefit. Renewals scheduled in year 30 are excluded under this convention. Those choices do not establish a physical asset life, an acceptable maintenance interval or an engineering ability to operate without the excluded renewal. They define a finite analytical account whose sensitivity must be visible.

This boundary explains an irregularity in the subsea/HVDC delay response. Postponing service also postpones renewal dates. A late renewal can move to the excluded final year, reducing a cost and removing an assumed outage inside the account. The resulting change in value contains a horizon effect. An appraisal used for an actual investment would need to examine the continuing service requirement, the maintenance work necessary to support it and the obligations that survive the selected calculation date. A longer or differently closed horizon could change the comparison.

The three net-terminal sensitivities replace final closure with minus USD 100 million, zero or plus USD 100 million at year 30. Interim GET removal remains in the staged package. Applying the same terminal scenario to all packages preserves the base ranking over the tested range. Underground alone would need approximately USD 698.178 million of net terminal cash in year 30, replacing its USD 22 million closure cost, to match unchanged overhead value. This amount is a conditional threshold with no asserted sale, recovery mechanism or continuation entitlement.

A credible continuation case would specify residual useful service, routine costs, renewal spending, eventual closure and the price or benefit basis over the added period. A residual-value line unsupported by those quantities would conceal the mechanism producing value. If a narrower owner account is used, the continuing cash must also have a documented payer and eligibility conditions. If a system account is used, transfers between parties need a consistent treatment. The current case deliberately leaves that extension unvalued.

The proposed terminal review should identify which obligations are already included, which remain outside the period and which depend on the route design. It should explain whether the final entry represents closure, a sale, net continuation value or another explicit convention. The review then tests the ranking under that convention and retains the original calculation for comparison. This preserves the distinction between a bounded calculation and a whole-life decision that may require further evidence beyond the chosen horizon.

24. Carry the route result into owner affordability and capital execution

The system account answers a defined resource-allocation question. Its positive value does not identify the cash available to the network owner. An owner-affordability case would need the actual entity, eligible expenditure, allowed or contracted receipts, payment timing, collection conditions and costs that fall to that entity. The financing case would then date debt and equity contributions, interest, reserves, covenants and distributions. These are proposed extensions to the framework; no such owner receipts or financing terms are calculated in the worked example.

A practical reconciliation would assign each resource item an economic consequence and a separately documented owner-cash treatment. A payment recovered from another party remains a resource cost in the wider account where the resource is consumed. Its recovery can be a receipt in the owner's account. The matching payer treatment depends on the wider boundary. This paired record can expose an owner funding gap alongside a favourable system result without assigning social benefits to an unsupported private revenue stream.

Capital release should follow the decision's actual maturity. A route study, land investigation, supplier negotiation and major construction order expose different amounts and reversibility. The proposed committee record identifies the purpose of each commitment, the evidence already accepted, the unresolved condition, cancellation or change exposure, and the authority required for the following step. An assumed benefit from further investigation should remain a hypothesis until its evidence is obtained. The original route comparison should be retained when a later design or quotation changes it.

The worked case supports a specific conditional recommendation: progress overhead as the highest-value package meeting the stipulated base service gate, subject to actual engineering, route, environmental and commercial review. Preserve underground as the higher-value deadline-compliant alternative when the assumed overhead delay reaches two years and other candidates remain on time. Investigate partial-service options against a revised or complemented requirement only through a newly specified package. No candidate receives a permission, procurement award or financing commitment through this calculation.

Subsequent performance review should reconcile accepted service and expenditure to the approved definitions. Changes in quantities, scope, prices, timing and ordinary or renewal availability can be examined separately when records permit. An unexplained difference should remain open until evidence supports its attribution. The value of this decision architecture lies in the traceability of its conditional choices: a reader can identify the required service, reproduce the dated calculation, locate the assumption that changes the result and determine what evidence the next commitment requires.

Public sources accessed 9 October 2026. Model inputs, calculated examples and proposed decision records are author-created illustrations. The route comparisons represent author-created system-economic scenarios, with project-specific service requirements and engineering qualification left conditional. They establish no actual route feasibility, owner revenue, tariff, regulatory recovery or financing commitment. The model horizon, cash boundaries and residual treatment are stated with the calculations. Calculated table values are displayed to three decimal places using round-half-up; floating-point noise is removed at twelve decimal places before display rounding. Calculations retain their underlying precision.

Frequently Asked Questions

What must be comparable before transmission routes are ranked?

The comparison defines endpoints, receiving-end service, the delivery deadline, operating conditions and included interfaces. The worked case assumes 300 MW by year 4. Reconductoring and the staged package have positive partial-service value but fail that fixed gate. Actual engineering equivalence remains unresolved for every package.

How should uncertain access enter the appraisal?

The route register should identify the relevant segment, document status, required access period and unresolved condition. The cash case should show expenditure exposed before that condition is resolved. Legal advisers must establish the actual rights; an assumed land allowance supplies no equivalent evidence.

Why can delay change eligibility before it changes the value ranking?

In the fictional case, two years of overhead delay move service to year 5 and fail the year-4 requirement. Overhead falls below on-time underground in economic value at four years of delay. The earlier service gate and later value crossing answer different questions; both remain conditional on the stipulated assumptions.

Can a system benefit be treated as an investor receipt?

The framework keeps system effects and owner cash in separately labelled schedules. An assumed owner receipt needs an identified payment mechanism and its conditions. Funding also requires a dated account of the entity that pays and the funds available to it.

How are losses and the final analytical boundary treated?

A sent-energy loss fraction gives loss MWh equal to delivered MWh times that fraction divided by one minus it. The model charges replacement energy once. Base service stops after year 30 with the stated closure cost; terminal scenarios replace that cost with net terminal cash. These conventions establish no physical asset life or residual-value entitlement.

How should the investment decision be updated after approval?

The sponsor should retain the original alignment, scope, cash case and decision conditions. A change record should explain revised assumptions, expenditure, timing and future obligations, with the required authority identified. Monitoring should compare qualified observations with the original assumptions and show which future commitments remain adjustable.

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