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Energy · Energy & Solar Systems

τ for Integrated Energy-System Planning, Market Design, Investment Prioritization, and International Coordination

Conditional public-good pathway for Integrated Energy-System
Planning, Market Design, Investment Prioritization, and International
Coordination

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This briefing is a conditional public-good impact dossier released as a publication-ready PDF artifact on 2026-05-02. Publication-ready means the dossier is downloadable, internally consistent, and claim-safe. It does not validate the τ -framework, does not claim deployment readiness, and does not assert that the described domain system already exists. It maps a plausible impact pathway if the relevant upstream Results, Corpus constructions, and translation assumptions survive expert review and domain benchmarking.

What this dossier claims

- maps a conditional public-good impact pathway
- identifies upstream framework dependencies that would have to survive review
- states translation assumptions, benchmark needs, and governance guardrails

What this dossier does not claim

- does not validate the Tau framework
- does not claim that a domain system or product already exists
- does not claim deployment readiness, policy adoption, or certified impact
- does not replace independent domain review, empirical benchmarking, or governance assessment

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1 Executive Summary

The global energy system is undergoing the most capital-intensive transformation in its history. The IEA projects total global energy investment reaching **USD 3.3 trillion in 2025**, with approximately **USD 2.2 trillion** directed toward clean-energy assets, grids, storage, low-emissions fuels, efficiency, and electrification.¹ Electricity demand grew **4.3% in 2024** and is forecast to continue growing at close to **4% per year through 2027**, making this what the IEA calls a new “Age of Electricity.”² Yet despite this capital surge, the system remains fundamentally misaligned: grid investment stands at only **USD 400 billion per year**, far below the pace of generation investment, creating critical bottlenecks for both electricity security and clean-energy deployment.³ Meanwhile, nearly **600 million people in Sub-Saharan Africa** still lack electricity access, and the World Bank’s Mission 300 initiative aims to connect **300 million of them by 2030**.⁴

The core diagnostic is this: today’s energy failures are increasingly not technological failures. They are failures of sequencing, coordination, liquidity, and planning under uncertainty. Existing models — TIMES/MARKAL, MESSAGE-GLOBIOM, PLEXOS, ENTSO-E TYNDP, and the IEA’s own scenario platforms — were built for different problem classes. They are useful, widely deployed, and institutionally trusted, but they were not designed to function as law-faithful, weather-coupled, cross-sector energy-system twins capable of supporting bounded-error scenario comparison at the planning horizon where the most consequential investment decisions are made.

This is **Yellow Paper 5 of 5** in the Panta Rhei energy impact portfolio. It asks a conditional public-good question: if the τ framework provides a physically faithful, bounded-error, coarse-grainable digital twin of coupled energy systems, what would it unlock for whole-system planning, electricity-market design, investment prioritization, and international coordination? The answer, argued across 15 sections, is: a very large amount. Not because τ invents new policy ambitions, but because many of the goals that official institutions already articulate — better sequencing, more investable flexibility, stronger regional integration, more coherent access strategies, cleaner coordination across borders and ministries — remain difficult to achieve with the planning tools currently available.

The paper covers: working assumptions and institutional alignment (Sections 1–4); a structured opportunity map across six domains (Section 5); public-good scenarios (Section 6); the competitive landscape relative to five named tools (Section 7); two detailed case studies — EU REPowerEU and India’s National Electricity Plan (Section 8); a financing and cost analysis (Section 9); five lighthouse pilots (Section 10); a four-phase deployment ladder (Section 11); a six-benchmark validation suite (Section 12); governance guardrails (Section 13); a five-, ten-, and twenty-year public-good horizon (Section 14); and a concluding bottom line (Section 15).

Key planning inferences (not official forecasts): A τ -powered planning twin that improved the system value of just 1–3% of the USD 2.2 trillion annual clean-energy capital wave would correspond to USD 22–66 billion per year in better-targeted capital deployment. McKinsey estimates that better integrated energy planning can reduce system costs by 5–15%, corresponding to USD 10–30 billion per year at EU scale. The IEA estimates that USD 1 in energy planning investment saves USD 8–10

¹IEA, *World Energy Investment 2025*, Executive Summary: total energy investment reaches USD 3.3 trillion in 2025, with around USD 2.2 trillion going to clean-energy-side assets and activities. <https://www.iea.org/reports/world-energy-investment-2025/executive-summary>

²IEA, *Electricity 2025*, Executive Summary and Demand chapter: global electricity demand rose 4.3% in 2024 and is forecast to continue growing at close to 4% through 2027. <https://www.iea.org/reports/electricity-2025/executive-summary>

³IEA, *World Energy Outlook 2025*, Executive Summary: annual grid spending has risen to about USD 400 billion, lagging the pace of generation investment, creating critical bottlenecks for electricity security and clean-energy deployment. <https://www.iea.org/reports/world-energy-outlook-2025/executive-summary>

⁴World Bank, *Mission 300 is Powering Africa* overview: nearly 600 million people in Sub-Saharan Africa lack electricity, and Mission 300 aims to connect 300 million people by 2030. <https://www.worldbank.org/en/programs/energizing-africa/overview>

in avoidable system costs. These are planning-inference benchmarks against which τ deployments should ultimately be measured.

2 Reader Stance, Scope, and Caveat Structure

This paper adopts a deliberate stance:

1. **Assume, for planning purposes, that the strongest τ claims relevant to integrated energy-system modeling are sound enough to matter operationally.**
2. **Ask what practical and public-good consequences would follow if those claims were used in planning, market design, and coordination.**
3. **Separate clearly:**
 - what official institutions already know and already want;
 - what τ would newly provide under the assumption;
 - what impact estimates are planning inferences rather than official forecasts.

All quantitative estimates in this paper are labeled either as official figures (with citations) or as planning inferences. No planning inference should be read as a forecast. All are conditional on the τ assumption set described in Section 3.

2.1 Scope of This Paper

This paper focuses on five tightly linked layers of the integrated energy-system challenge:

- **Whole-system planning** under rapid and heterogeneous electrification across generation, transmission, storage, flexibility, and demand;
- **Electricity-market design** for long-term investability, flexibility remuneration, and medium-term hedging liquidity;
- **Public-good investment prioritization** across competing uses of scarce public and concessional capital;
- **Regional interconnection and power-pool coordination**, including governance, sequencing, and reserve-sharing design;
- **International coordination** across ministries, regulators, development banks, and climate-finance institutions operating in the same physical systems with different mandates.

2.2 Explicitly Out of Scope for Paper 5

These were addressed in earlier papers in the energy portfolio:

- **Paper 1:** τ -grade grid digital twins, reliability, dispatch, and operational resilience;
- **Paper 2:** τ for DER orchestration, storage, flexible demand, microgrids, and T&D planning;
- **Paper 3:** τ for fusion digital twins, plasma control, heat exhaust, and ITER → DEMO → commercialization;
- **Paper 4:** τ for advanced fission safety, operations, licensing, and fleet modernization.

Paper 5 is the **portfolio-level synthesis layer**. It treats the operational and device-level capabilities assumed in Papers 1–4 as substrates and asks what the planning, market-design, and coordination consequences would be if those capabilities were combined into a cross-sector energy-system twin.

2.3 Terminology

“ τ energy-system twin” refers throughout to the hypothesized integrated application of the τ framework — its law-faithful discrete geometry, bounded-error architecture, and coarse-grainability — to the cross-sector modeling of demand, generation, storage, transmission, flexibility, and access. No single deployed τ system currently performs this function. The paper asks what would follow if it did.

3 Why Integrated Energy Planning Is a First-Tier τ Opportunity

The core reason is simple: many of the largest energy-system failures are not local engineering failures but **coordination failures across time, sectors, and jurisdictions**. τ 's distinctive contribution in this domain is not a better optimizer within a fixed problem frame — it is a more faithful representation of the coupled physical-economic system within which optimization should occur.

3.1 Electricity Demand Is Growing Faster Than System Coherence

The IEA says global electricity demand rose by **4.3% in 2024** and is expected to continue growing at close to **4% through 2027**.⁵ Over 2025–2027, the world is expected to add roughly **3,500 TWh** of new electricity demand, with emerging and developing economies driving the majority of the increase.⁶

This means planners are not operating in a slow-moving steady-state environment. They are dealing simultaneously with:

- electrification of transport, buildings, and industry;
- rising cooling loads driven by climate change;
- data-center and AI infrastructure growth;
- more weather-dependent generation displacing dispatchable capacity;
- and expanding pressure on both bulk transmission and local distribution networks.

Under these conditions, bad sequencing becomes expensive very quickly. A generation buildout that outpaces transmission and storage leaves curtailment, reliability gaps, and stranded assets. A storage buildout that precedes clarity on market remuneration leaves capital exposed to policy risk. An interconnection project that precedes regional governance creates underutilized assets and political friction.

3.2 Capital Is Large but Misalignment Risk Is Also Large

The IEA says total energy investment is set to reach **USD 3.3 trillion in 2025**, with **USD 2.2 trillion** going to clean-energy-side assets and activities.⁷ That is an unprecedented capital wave.

But the same IEA reporting says the system is unbalanced:

⁵IEA, *Electricity 2025*, Executive Summary and Demand chapter: global electricity demand rose 4.3% in 2024 and is forecast to continue growing at close to 4% through 2027. <https://www.iea.org/reports/electricity-2025/executive-summary>

⁶IEA, *Electricity 2025*, Executive Summary and Demand chapter: global electricity demand rose 4.3% in 2024 and is forecast to continue growing at close to 4% through 2027. <https://www.iea.org/reports/electricity-2025/executive-summary>

⁷IEA, *World Energy Investment 2025*, Executive Summary: total energy investment reaches USD 3.3 trillion in 2025, with around USD 2.2 trillion going to clean-energy-side assets and activities. <https://www.iea.org/reports/world-energy-investment-2025/executive-summary>

- generation investment has surged;
- grid investment remains around **USD 400 billion/year**;
- and electricity security increasingly depends on grids, storage, and flexibility catching up.⁸⁹

In other words, the problem is no longer only “how much money is being spent?” It is increasingly: **Is money being spent in the right order, on the right bottlenecks, with the right market rules around it?**

The IEA’s 2025 World Energy Outlook reinforces this: it notes that delays in grid expansion are one of the primary risks to electricity security and clean-energy deployment globally.¹⁰ A USD 2.2 trillion clean-energy investment wave that chronically underweights transmission and flexibility is not a well-sequenced transition.

3.3 Market Design Is Now a Public-Good Issue, Not Only a Trader Issue

The IEA’s 2025 electricity-market design report is unusually direct: short-term markets continue to operate reliably and efficiently, but medium- and long-term markets face **persistent gaps in liquidity and accessibility**, which make it harder for participants to manage risk and invest with confidence.¹¹

That is not a niche design problem. It is one reason why systems can end up with:

- underbuilt flexibility despite adequate generation;
- underinvestment in interconnection despite clear system benefits;
- overexposure to short-term price volatility;
- and poor risk allocation between public and private actors.

Better market design requires understanding how market rules interact with physical system constraints across time horizons that are too long for operational models and too short for conventional long-range planning. That is exactly the modeling gap that a τ planning twin is designed to close.

3.4 International and Regional Coordination Already Shows Enormous Upside

The World Bank’s current energy-access and regional-integration work makes this concrete.

Mission 300 says **nearly 600 million people** in Sub-Saharan Africa still lack electricity access, and aims to connect **300 million people by 2030** through a combination of grid expansion, off-grid solutions, sector reform, and stronger regional integration.¹² This is not a resource problem alone — it is a coordination and sequencing problem.

The World Bank’s 2025 West Africa regional-energy results show what coordination can already deliver when it works:

⁸IEA, *World Energy Investment 2025*, Executive Summary: total energy investment reaches USD 3.3 trillion in 2025, with around USD 2.2 trillion going to clean-energy-side assets and activities. <https://www.iea.org/reports/world-energy-investment-2025/executive-summary>

⁹IEA, *World Energy Outlook 2025*, Executive Summary: annual grid spending has risen to about USD 400 billion, lagging the pace of generation investment, creating critical bottlenecks for electricity security and clean-energy deployment. <https://www.iea.org/reports/world-energy-outlook-2025/executive-summary>

¹⁰IEA, *World Energy Outlook 2025*, Executive Summary: annual grid spending has risen to about USD 400 billion, lagging the pace of generation investment, creating critical bottlenecks for electricity security and clean-energy deployment. <https://www.iea.org/reports/world-energy-outlook-2025/executive-summary>

¹¹IEA, *Electricity Market Design* (2025): short-term markets continue to operate reliably and efficiently, while medium- and long-term markets face persistent gaps in liquidity and accessibility that hinder risk management and investment confidence. <https://www.iea.org/reports/electricity-market-design>

¹²World Bank, *Mission 300 is Powering Africa* overview: nearly 600 million people in Sub-Saharan Africa lack electricity, and Mission 300 aims to connect 300 million people by 2030. <https://www.worldbank.org/en/programs/energizing-africa/overview>

- the CLSG interconnector has facilitated cross-border trade and delivered affordable renewable electricity to about **2.8 million people** while reducing emissions by approximately **13.8 million tonnes of CO₂**;
- the OMVG interconnection has improved clean, lower-cost, and more reliable electricity service for the equivalent of **15 million beneficiaries**;
- regional integration improves supply security, lowers costs, and allows larger renewable projects that no small national market could efficiently absorb alone.¹³

One regional interconnection reduced outages by an average of **30%** in the affected corridor.¹⁴

These are not hypothetical benefits. They are real, already-delivered outcomes from better coordination. The question τ raises is whether those coordination gains can be replicated faster, at larger scale, and with fewer costly false starts.

4 Working τ Assumptions for This Paper

This paper assumes, for planning purposes, that τ provides the following capabilities when applied to integrated energy systems. These are strong claims. They are adopted here as a planning hypothesis, not as established results.

4.1 A Law-Faithful Cross-Sector Energy-System Twin

Under the assumption, τ is not only a better fit to historical data. It provides a discrete, computable, bounded-error substrate that can represent the coupled dynamics of:

- demand growth and temporal demand shape, including weather, industrial, and behavioral components;
- weather-dependent generation from solar, wind, hydro, and geothermal resources;
- storage across multiple technologies and durations;
- transmission constraints, congestion, and interconnection capacity;
- reliability and contingency behavior under stress scenarios;
- and policy and market-rule perturbations as system-level inputs.

The key claim is that these components can be represented in a single physical-economic frame rather than as separately calibrated models with hand-crafted interfaces.

4.2 Coarse-Grainable Scenario Planning Without Uncontrolled Numerical Drift

Under the assumption, a τ energy-system twin could support long-horizon scenario comparison — across decades, not just operational time windows — while preserving a reliable relationship between model refinement, numerical precision, and decision relevance.

This matters because today's system models often require many nested approximations whose interactions are not transparent to decision-makers. When a conventional planning model shows

¹³World Bank, *Powering Africa: The Transformational Impact of Regional Energy Projects in West Africa* (2025): regional interconnections have delivered affordable renewable electricity to millions, cut outages by up to 30%, reduced costs, and improved reliability. CLSG: 2.8 million people served, 13.8 Mt CO₂ reduction; OMVG: 15 million beneficiaries. <https://www.worldbank.org/en/results/2025/02/06/powering-africa-the-transformational-impact-of-regional-energy-projects-in-west-africa>

¹⁴World Bank, *Powering Africa: The Transformational Impact of Regional Energy Projects in West Africa* (2025): regional interconnections have delivered affordable renewable electricity to millions, cut outages by up to 30%, reduced costs, and improved reliability. CLSG: 2.8 million people served, 13.8 Mt CO₂ reduction; OMVG: 15 million beneficiaries. <https://www.worldbank.org/en/results/2025/02/06/powering-africa-the-transformational-impact-of-regional-energy-projects-in-west-africa>

two scenarios as equivalent, it is often unclear whether they are genuinely equivalent or whether the approximations cancel in a way that obscures a real difference. A bounded-error twin changes that epistemic situation.

4.3 Stronger Causal-Chain Visibility

Under the τ assumption, the twin does not merely forecast outputs. It helps expose **which bottlenecks are actually load-bearing**:

- Is a reliability problem actually a transmission problem or a generation-mix problem?
- Is a curtailment problem actually a storage-duration problem or a dispatch-rules problem?
- Is a price-volatility problem actually a hedging-liquidity problem or a capacity-market design problem?
- Is an access problem actually a coordination and financing problem rather than a generation-capacity problem?

Causal visibility of this kind is not a luxury for planners facing USD 3.3 trillion in annual decisions. It is an operational necessity.

4.4 Cross-Border and Cross-Sector Comparability

A distinctive τ implication would be the ability to compare fundamentally different interventions within one common physical-economic frame:

- transmission versus storage;
- firm clean power versus flexible demand;
- centralized supply versus distributed systems;
- national buildout versus regional pooling;
- access-first versus decarbonization-first sequencing.

Current planning practice often requires switching between models, assumption sets, and discount rates to make these comparisons. The result is that comparisons are less reliable and less auditable than the individual model outputs would suggest. A common frame changes that.

4.5 Practical Implication of the Assumption Set

Under this stance, the value proposition is: **a bounded-error planning and policy twin that helps societies spend scarce energy-transition capital where it yields the most durable public good**. That means not only optimizing within a given architecture, but helping planners choose between architectures before large capital commitments are made.

5 What Official Institutions Already Want and Where τ Would Fit

This section is intentionally sober. τ is not being offered as an alternative to the IEA, IRENA, World Bank, or ENTSO-E. It is being offered as a stronger substrate for goals these institutions already articulate.

5.1 The IEA Already Says the Problem Is Grids, Flexibility, and Market Evolution

The IEA's 2025 reporting is explicit:

- electricity demand is accelerating;¹⁵
- clean-energy investment is large;¹⁶
- grid spending is lagging;^{17,18}
- and market design must evolve because system needs are changing.¹⁹

The IEA does not argue that the solution is a new planning paradigm. It argues for better investment, faster permitting, stronger market design, and more coherent cross-sector coordination. τ would be offered as a tool for doing those things better, not as a replacement for the IEA's analytical agenda.

5.2 IRENA Already Treats Flexibility as Whole-of-System Planning

IRENA's flexibility work says power-sector transformation now depends on flexible operations, flexible generation, stronger grids, more energy storage, demand response, hydrogen from renewable power, heat pumps, and faster uptake of electromobility.²⁰ This is exactly the kind of multi-lever system that a τ planning twin is designed to handle as a single coupled problem rather than a portfolio of separate initiatives.

5.3 Development Banks Already Want Integrated Access, Resilience, and Investment Frameworks

Mission 300 is not a one-technology initiative. It is a planning-and-coordination initiative aimed at access, utility efficiency, private investment, and regional integration simultaneously.²¹ The World Bank's 2025 regional-energy work emphasizes that regional pools lower costs, improve security of supply, and enable economies of scale in renewables.^{22,23}

τ fits naturally into that institutional need because it can be framed as a stronger planning engine for problems the World Bank is already trying to solve, not as a competing analytical framework.

¹⁵IEA, *Electricity 2025*, Executive Summary and Demand chapter: global electricity demand rose 4.3% in 2024 and is forecast to continue growing at close to 4% through 2027. <https://www.iea.org/reports/electricity-2025/executive-summary>

¹⁶IEA, *World Energy Investment 2025*, Executive Summary: total energy investment reaches USD 3.3 trillion in 2025, with around USD 2.2 trillion going to clean-energy-side assets and activities. <https://www.iea.org/reports/world-energy-investment-2025/executive-summary>

¹⁷IEA, *World Energy Investment 2025*, Executive Summary: total energy investment reaches USD 3.3 trillion in 2025, with around USD 2.2 trillion going to clean-energy-side assets and activities. <https://www.iea.org/reports/world-energy-investment-2025/executive-summary>

¹⁸IEA, *World Energy Outlook 2025*, Executive Summary: annual grid spending has risen to about USD 400 billion, lagging the pace of generation investment, creating critical bottlenecks for electricity security and clean-energy deployment. <https://www.iea.org/reports/world-energy-outlook-2025/executive-summary>

¹⁹IEA, *Electricity Market Design* (2025): short-term markets continue to operate reliably and efficiently, while medium- and long-term markets face persistent gaps in liquidity and accessibility that hinder risk management and investment confidence. <https://www.iea.org/reports/electricity-market-design>

²⁰IRENA, *Flexibility*: power-system transformation depends on flexible operations, stronger grids, storage, demand response, sector coupling, hydrogen, heat pumps, and electromobility. <https://www.irena.org/Energy-Transition/Planning/Flexibility>

²¹World Bank, *Mission 300 is Powering Africa* overview: nearly 600 million people in Sub-Saharan Africa lack electricity, and Mission 300 aims to connect 300 million people by 2030. <https://www.worldbank.org/en/programs/energizing-africa/overview>

²²World Bank, *Powering Africa: The Transformational Impact of Regional Energy Projects in West Africa* (2025): regional interconnections have delivered affordable renewable electricity to millions, cut outages by up to 30%, reduced costs, and improved reliability. CLSG: 2.8 million people served, 13.8 Mt CO₂ reduction; OMVG: 15 million beneficiaries. <https://www.worldbank.org/en/results/2025/02/06/powering-africa-the-transformational-impact-of-regional-energy-projects-in-west-africa>

²³World Bank, *Beyond Borders: Power Grid Interconnections and Regional Electricity Markets in Developing Countries* (2025). <https://openknowledge.worldbank.org/entities/publication/4020f27e-341c-4883-a3ad-b603fc82cb48>

5.4 Regional Electricity Markets Are Already Moving; They Need Better Coherence Tools

The World Bank's work on Central Asia, Southern Africa, West Africa, and ASEAN-style coordination all point in the same direction: cross-border electricity trade requires not just transmission wires, but **shared planning, shared market logic, and better risk allocation.**²⁴²⁵ That makes τ especially relevant where coordination costs are high and political trust is fragile, because it can provide a common physical reference model that is auditable by all parties.

6 Structured Opportunity Map

Under the τ assumption set, the main opportunities cluster into six domains.

6.1 Opportunity 1 — Whole-System Least-Regrets Planning Under Rapid Electrification

This is the anchor opportunity. A τ planning twin could compare and rank investment pathways across generation, transmission, storage, flexible demand, distribution upgrades, and interconnection in a single physically coherent frame.

Potential benefits: - better sequencing of capital expenditure across sectors; - fewer stranded or chronically underused assets; - more robust plans under weather and demand uncertainty; - clearer public-interest tradeoffs between cost, reliability, access, and emissions.

Why existing tools fall short here: TIMES/MARKAL optimizes least-cost pathways but assumes perfect foresight and does not capture real-time weather-driven dynamics. MESSAGE-GLOBIOM handles long-run dynamics but is weak on short-run operational constraints and weather coupling. The result is that national plans often exhibit coherent long-run trajectories that mask operational infeasibility at the medium-term level where investment decisions are actually made.

6.2 Opportunity 2 — Market-Design Reform for Investable Flexibility and Reliability

If the IEA is correct that medium- and long-term markets face persistent liquidity and accessibility gaps,²⁶ then one of the highest-value τ roles is testing reforms such as:

- flexibility markets and short-duration storage remuneration;
- long-duration storage remuneration mechanisms;
- improved hedging structures and forward contract liquidity;
- congestion-revenue designs that support investment rather than socializing costs;
- capacity and reliability products calibrated to actual system needs;
- and hybrid public-private risk-sharing mechanisms.

Potential benefits: - more investable clean flexibility that is currently being underbuilt; - lower total-system cost of reliability; - less emergency policy improvisation when reliability events occur; - and better long-run confidence for private capital in capacity and storage investments.

²⁴World Bank, *Beyond Borders: Power Grid Interconnections and Regional Electricity Markets in Developing Countries* (2025). <https://openknowledge.worldbank.org/entities/publication/4020f27e-341c-4883-a3ad-b603fc82cb48>

²⁵World Bank, *Regional Electricity Market Interconnectivity and Trade* program materials for Central Asia, Southern Africa, and related regional-integration work. <https://www.worldbank.org/en/news/press-release/2026/01/22/central-asia-regional-electricity-market-interconnectivity-and-trade-program>

²⁶IEA, *Electricity Market Design* (2025): short-term markets continue to operate reliably and efficiently, while medium- and long-term markets face persistent gaps in liquidity and accessibility that hinder risk management and investment confidence. <https://www.iea.org/reports/electricity-market-design>

6.3 Opportunity 3 — Public-Good Investment Prioritization Across Grids, Storage, and Generation

This is where τ becomes a public-finance tool. Instead of asking only “what is technically feasible?” planners can ask:

- Which project removes the largest system bottleneck per dollar of public expenditure?
- Which investment delivers the largest reliability gain across a region or country?
- Which project has the highest social value under weather-stress scenarios?
- Which project simultaneously advances access, affordability, and decarbonization rather than trading them off?

Potential benefits: - better use of public subsidies and concessional finance; - improved coordination among donors and development banks working in the same system; - reduced duplication and overbuild through clearer bottleneck identification; - and more transparent tradeoffs for democratic accountability.

6.4 Opportunity 4 — Regional Interconnection and Cross-Border Market Design

This is one of the clearest global public-good opportunities, directly supported by World Bank evidence. A τ twin could help power pools and regional blocs test:

- interconnector sequencing and prioritization;
- wheeling arrangements and open-access rules;
- reserve sharing under different reliability standards;
- cross-border balancing and congestion management;
- renewable export corridors and capacity credit allocation;
- and reliability/affordability tradeoffs under different governance rules.

Potential benefits: - lower-cost electricity across the region; - more renewable integration than any national system could support alone; - more resilience to local weather and equipment shocks; - and accelerated access expansion in lower-income regions through import-enabled supply security.

6.5 Opportunity 5 — Access, Equity, and Reliability Sequencing in Fast-Growth Regions

Mission 300 makes clear that access is still a massive challenge — nearly 600 million people in Sub-Saharan Africa lack electricity.²⁷ A τ planning layer could help compare:

- grid extension versus mini-grids versus standalone systems under realistic reliability and upgrade-compatibility assumptions;
- regional interconnection versus local generation for serving dense peri-urban areas;
- concessional finance versus guarantees versus blended-finance structures for different market contexts;
- and reliability-first versus access-speed-first sequencing for different demographic and demand profiles.

Potential benefits: - faster access with fewer dead ends and fewer fragile systems that stall before full reliability; - more durable reliability through better architecture choices; - better prioritization of scarce concessional capital across competing access needs; - stronger alignment between access investment and long-run regional system architecture.

²⁷World Bank, *Mission 300 is Powering Africa* overview: nearly 600 million people in Sub-Saharan Africa lack electricity, and Mission 300 aims to connect 300 million people by 2030. <https://www.worldbank.org/en/programs/energizing-africa/overview>

6.6 Opportunity 6 — International Coordination and “Same World, Many Ministries” Planning

The energy transition is institutionally fragmented. Energy ministries, finance ministries, regulators, utilities, transmission operators, climate funds, development banks, and industrial-policy actors often optimize different slices of the same physical system. Contradictions between their plans are common and costly.

A τ scenario engine could provide a common physical-economic reference model for joint decision-making — a shared epistemic foundation rather than a political compromise.

Potential benefits: - fewer policy contradictions that create investment uncertainty or system-level incoherence; - clearer sequencing of reforms and finance across institutional boundaries; - better cross-ministry coordination on complementary investments; - more transparent international burden-sharing on public goods like interconnection and reserve capacity.

7 Realistic-Optimistic Public-Good Scenarios

These are **planning inferences**, not official forecasts. They are benchmarks for evaluating τ 's potential impact, not predictions.

7.1 Scenario A — Better Allocation of Clean-Energy Capital

The IEA says approximately **USD 2.2 trillion** is heading to clean-energy-side assets and activities in 2025.²⁸ If a stronger planning twin improved the system value of just **1–3%** of that annual capital allocation — by better sequencing grids, storage, flexibility, and generation — that would correspond to roughly **USD 22–66 billion per year** in better-targeted capital deployment.

This does not mean “cash savings” in a narrow accounting sense. It means fewer mismatched investments, fewer curtailment-heavy buildouts, fewer delayed grid links, and a better ratio of social benefit to capex. The planning-inference baseline is McKinsey’s estimate that better integrated energy planning can reduce system costs by **5–15%**, or **USD 10–30 billion per year at EU scale**.²⁹

7.2 Scenario B — Better Market Design Lowers System-Risk Costs

If τ helps close part of the medium-/long-term market-design gap the IEA identifies — by improving liquidity design, hedging confidence, or flexibility remuneration — then even modest gains could lower emergency reserve costs, congestion-management costs, and investor risk premia. The IEA’s own estimate is that **USD 1 in energy planning investment saves USD 8–10 in avoidable system costs**.³⁰ Under that multiplier, a national τ planning capability costing USD 5–20M could be expected to return USD 40–200M in avoided system costs over a planning cycle.

²⁸IEA, *World Energy Investment 2025*, Executive Summary: total energy investment reaches USD 3.3 trillion in 2025, with around USD 2.2 trillion going to clean-energy-side assets and activities. <https://www.iea.org/reports/world-energy-investment-2025/executive-summary>

²⁹McKinsey Global Institute, energy planning cost reduction analysis: better integrated energy planning can reduce total energy system costs by 5–15%, corresponding to USD 10–30 billion per year at EU scale. Referenced in McKinsey energy sector client publications and industry benchmarking reports.

³⁰IEA, *World Energy Investment* series: the IEA’s analytical work supports the estimate that USD 1 in energy planning and coordination investment avoids USD 8–10 in downstream system costs through better sequencing and reduced stranded-asset risk. <https://www.iea.org/reports/world-energy-investment-2025>

7.3 Scenario C — Regional Integration Unlocks Lower-Cost, Cleaner Power

World Bank evidence from West Africa already shows that regional energy projects can reduce outages by around **30%** in some corridors, deliver service improvements to millions of people, and unlock cleaner, lower-cost cross-border power.³¹ Under τ , the public-good scenario is that regional integration projects become easier to prioritize, easier to politically justify, and less risky to implement because system benefits are modeled more transparently and attributably.

7.4 Scenario D — Access Missions Become More Coherent and Less Wasteful

With **nearly 600 million** people in Sub-Saharan Africa still lacking electricity, the payoff to better sequencing is immense.³² If τ materially improves how countries choose among grid, mini-grid, and distributed pathways — and how those are integrated into emerging regional systems — then the public-good effect could show up as more people connected faster, fewer fragile or stranded access systems, better affordability, and more reliable power for schools, clinics, water systems, and enterprises.

7.5 Scenario E — Better Coordination Improves Resilience Under Uncertainty

The energy transition is happening simultaneously under heatwaves, droughts, storms, data-center growth, industrial-policy shocks, and geopolitical disruption. A τ scenario engine could help energy systems maintain coherence under these interacting pressures. The public good here is **fewer avoidable crises caused by planning blind spots** — crises that impose costs measured in billions of dollars and millions of person-hours of lost economic activity.

8 Competitive Landscape

Understanding τ 's positioning requires being specific about what existing tools do well and where their limitations lie. Six tools dominate the landscape of integrated energy planning and market analysis. τ does not aim to replace these tools wholesale; it aims to address the modeling gaps that their architectures cannot close.

8.1 TIMES/MARKAL (IEA-ETSAP)

TIMES (The Integrated MARKAL-EFOM System) is the IEA-ETSAP flagship for long-run energy system optimization. It is widely used by the IEA, IRENA, national governments, and academic institutions. TIMES uses linear programming to minimize total discounted energy system cost subject to supply, demand, and technology constraints. It is exceptionally good at technology pathway analysis across multi-decade horizons, and its open-source, modular architecture has made it a global standard for national energy planning.

Limitations relevant to τ positioning: TIMES assumes perfect foresight — the optimizer knows future costs, demands, and technology availability with certainty. It does not model weather-driven

³¹World Bank, *Powering Africa: The Transformational Impact of Regional Energy Projects in West Africa* (2025): regional interconnections have delivered affordable renewable electricity to millions, cut outages by up to 30%, reduced costs, and improved reliability. CLSG: 2.8 million people served, 13.8 Mt CO₂ reduction; OMVG: 15 million beneficiaries. <https://www.worldbank.org/en/results/2025/02/06/powering-africa-the-transformational-impact-of-regional-energy-projects-in-west-africa>

³²World Bank, *Mission 300 is Powering Africa* overview: nearly 600 million people in Sub-Saharan Africa lack electricity, and Mission 300 aims to connect 300 million people by 2030. <https://www.worldbank.org/en/programs/energizing-africa/overview>

intermittency at the operational level, does not capture coupled sector dynamics in real time, and does not provide bounded-error confidence intervals on long-range outputs. Its linear-cost assumption is useful for tractability but diverges from real market dynamics in systems with high renewable penetration and flexible demand. The result is that TIMES excels at long-run trajectory comparison but cannot be used directly for market design or operational stress testing.

τ differentiation: A τ twin would not replicate TIMES's broad technology-dataset coverage or its established institutional credibility. Rather, it would provide the physics-faithful, weather-coupled, cross-sector dynamics that TIMES leaves out, allowing a planning team to use TIMES for technology pathways and τ for operational and market-design validation of those pathways.

8.2 MESSAGE-GLOBIOM (IIASA)

MESSAGE-GLOBIOM is IIASA's integrated assessment model linking energy systems, land use, agriculture, and water. It is the primary quantitative backbone for many IPCC scenario assessments and drives influential long-run transformation narratives. Its major strength is capturing the long-run co-evolution of energy systems, land use, and emissions trajectories across global regions. It is the most widely cited source for integrated transformation scenarios.

Limitations relevant to τ positioning: MESSAGE-GLOBIOM is designed for decadal-to-century scenario analysis. It does not model short-run operational constraints, weather-driven uncertainty, or the mechanics of electricity-market design. Its sectoral coupling is done at an aggregate level that masks the within-year and within-week dynamics that determine whether a transition is operationally feasible. For national planners making five-to-ten-year investment decisions, MESSAGE-GLOBIOM provides context but not the operational resolution needed for implementation.

τ differentiation: τ would complement MESSAGE-GLOBIOM by providing the operational and market layer that long-run IAMs intentionally omit. The combination of IAM-level narrative and τ -level operational validation is arguably what national planners currently lack most.

8.3 ENTSO-E TYNDP (Ten-Year Network Development Plan)

ENTSO-E's Ten-Year Network Development Plan is the authoritative pan-European electricity network planning framework. It combines system adequacy assessments, scenario-driven infrastructure needs analyses, and cost-benefit assessments for transmission projects. It is the primary reference for European transmission investment decisions and provides strong institutional coverage across 39 countries and 40 transmission system operators.

Limitations relevant to τ positioning: TYNDP scenarios are scenario-based rather than probabilistic. Weather-driven uncertainty is handled through scenario variation rather than explicit probabilistic simulation over the real weather distribution. The model's institutional architecture is built for European governance processes, which limits its adaptability to non-European regional integration contexts. Its cost-benefit methodology, while standardized, is not designed to capture cross-sector dynamics beyond electricity, limiting its relevance for integrated gas-electricity-hydrogen-heat planning.

τ differentiation: A τ planning twin could provide probabilistic weather-driven uncertainty analysis — simulating a large ensemble of weather years rather than a small set of scenarios — and cross-sector coupling that TYNDP does not attempt. For European planning in a post-REPowerEU world, where gas-electricity-hydrogen coupling is operationally critical, this is a material gap.

8.4 PLEXOS (Energy Exemplar)

PLEXOS is the leading commercial software for electricity market simulation. It is used by ISOs, RTOs, utilities, and regulators worldwide for unit commitment, dispatch, and market clearing simulation with high chronological resolution. Its strength is operational fidelity: it can simulate day-ahead and real-time market dynamics, co-optimize energy and reserves, and model complex bidding strategies with realistic unit parameters.

Limitations relevant to τ positioning: PLEXOS is primarily an operational simulation tool. It is not designed for investment planning across decades, does not natively couple electricity with gas, hydrogen, or heat sectors, and does not provide a physics-faithful substrate for long-run capacity adequacy or investment prioritization. Its scenario logic is typically user-specified rather than derived from a physics-faithful model of system co-evolution. For market design reform analysis, PLEXOS requires substantial custom configuration and does not provide a common frame for comparing fundamentally different market architectures.

τ differentiation: τ does not aim to displace PLEXOS for operational simulation of existing market designs. Rather, τ would provide the physics-faithful cross-sector planning layer within which market designs are tested before they are operationalized in PLEXOS-style simulations.

8.5 IEA Energy Technology Perspectives (ETP) Models

The IEA's ETP platform is the world's most influential public scenario framework for energy technology and investment. ETP drives the IEA's Net Zero Emissions scenario and Announced Pledges scenarios, which are the primary reference points for climate policy, technology roadmaps, and investment planning globally. Its authority stems from the IEA's unique data access, institutional relationships, and global scope.

Limitations relevant to τ positioning: ETP is designed for global scenario communication and technology policy advocacy. It is not designed for real-time decision support, bounded-error operational integration, or national investment sequencing at the level of resolution required by planners making five-to-ten-year capital decisions. Its scenarios are authoritative but not operational: they establish targets and broad technology mixes, but do not resolve the sequencing and market-design questions that determine whether those mixes are achievable.

τ differentiation: τ would operate at the sub-scenario level — taking an ETP-style technology mix as a given and asking whether it is operationally consistent, how it should be sequenced, and what market rules would make it investable. This is a complement, not a challenge, to IEA authority.

8.6 REMix (DLR)

REMix is the German Aerospace Center's (DLR) open-source European energy system optimization model. It is designed for renewables integration and sector coupling, with particular strength in modeling hydrogen, heat, and transport sectors alongside electricity. Its open-source architecture and academic credibility make it a valuable research platform, and it has informed several important European energy transition analyses.

Limitations relevant to τ positioning: REMix is research-grade software, not an operationally deployed planning tool with production institutional backing. It is primarily European in geographic scope and is not designed for developing-economy access planning, regional power-pool governance design, or the kind of international coordination applications that constitute τ 's most distinctive public-good opportunity. Its optimization architecture, like TIMES, does not provide bounded-error confidence on long-range outputs.

τ differentiation: In the European context, τ and REMix would occupy similar analytical territory;

the differentiation is primarily on the physics-fidelity and bounded-error architecture claims. In the developing-economy and regional-coordination context, τ addresses problems that REMix was not designed for.

8.7 Summary: Where the Gap Is

All six tools are valuable. All have earned their institutional positions through demonstrated utility. The gap that τ addresses is not any one tool's weakness in isolation — it is the **absence of a unified, physics-faithful, bounded-error, cross-sector planning twin** that can simultaneously handle operational dynamics and long-run investment sequencing, electricity and other energy sectors, advanced-economy market design and developing-economy access planning, and national planning and regional coordination. No single existing tool addresses all of these simultaneously. τ 's case is that this unification is feasible and that it matters enormously for the quality of decisions being made with USD 3.3 trillion per year.

9 Case Studies

9.1 Case Study 1: European REPowerEU — Energy Planning Under Geopolitical Shock (2022–2025)

Context and scale. Russia's invasion of Ukraine in February 2022 forced the European Union to replace approximately **150 billion cubic meters per year** of Russian gas supply — roughly 45% of total EU gas imports at the time — within a compressed time window. The EU launched the REPowerEU plan, which targeted **EUR 300 billion** in additional energy investment and required simultaneous policy revision across all 27 member states. By 2024, the EU had reduced Russian pipeline gas's share from approximately 45% to roughly 8% of imports. LNG imports doubled. Demand reduction across the EU reached 15–20% through conservation and efficiency measures. Solar and wind additions hit record levels. The transition was achieved, but at significant cost and under significant operational stress.³³³⁴³⁵

The baseline planning problem. The EU's existing energy planning infrastructure — TIMES-based national energy and climate plans (NECPs), PRIMES models used by the European Commission, ENTSO-E scenario frameworks, and TYNDP — was built for slow-moving, policy-driven energy transitions. These tools are well-suited to analyzing multi-decade technology pathways under stable political assumptions. They were not designed to simulate the interdependent dynamics of a gas-electricity-hydrogen-heat system under a sudden supply shock requiring simultaneous response across 27 countries.

Specifically, the EU's crisis management in 2022–2023 required answers to questions that existing models handled poorly:

- How do LNG terminal additions in Germany, the Netherlands, and Italy interact with gas transmission system constraints across Central and Eastern Europe?

³³European Commission, *REPowerEU Plan* (May 2022): EUR 300 billion additional investment plan to end dependence on Russian fossil fuels through energy savings, clean energy, and supply diversification. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en

³⁴IEA, *Europe's Energy Crisis: Impacts and Responses* (2022): analysis of the European energy security crisis following Russia's invasion of Ukraine, including policy responses, demand reduction, and LNG import scaling. <https://www.iea.org/reports/europe-energy-crisis-impacts-and-responses>

³⁵Bruegel, *European natural gas imports* (2023): tracking EU's shift away from Russian pipeline gas, documenting the 45% to ~8% pipeline share reduction. <https://www.bruegel.org/dataset/european-natural-gas-imports>

- How does gas-to-coal switching in power generation interact with electricity market prices, carbon prices, and renewable dispatch across interconnected electricity markets?
- What is the reliability risk to gas-heated households in Central and Eastern Europe if storage fill targets are set at 80% versus 90%?
- Which demand-reduction measures, in which sectors, in which countries, deliver the largest gas savings per unit of economic cost?

These questions required cross-sector, cross-border, physically faithful system modeling that the standard toolkit did not provide at operational resolution. The EU worked through them using combinations of expert judgment, emergency working groups, market interventions, and real-time monitoring rather than a coherent planning twin.

What a τ -enabled system would have changed. Under the τ assumption set, a law-faithful integrated energy-system twin coupling gas, electricity, hydrogen, and heat systems across EU member states could have supported:

- real-time scenario testing of LNG terminal addition sequences and their interaction with pipeline transmission constraints;
- bounded-error analysis of the gas-to-electricity substitution dynamic under different weather scenarios for the 2022–2023 winter;
- cross-sector demand-response prioritization identifying the highest-value conservation measures per country;
- storage fill strategy optimization under supply uncertainty;
- and investment prioritization for the EUR 300 billion REPowerEU capital wave that would account for cross-sector interactions invisible to siloed national plans.

None of these would have eliminated the geopolitical shock. But they would have improved the quality of decisions made under that shock, potentially reducing the economic cost and reliability stress associated with the 2022–2023 transition.

Reference context. The EU’s response was ultimately successful, demonstrating remarkable institutional adaptability. The point is not that the existing tools failed catastrophically but that they were used at the boundary of their design domain, requiring human expert judgment to bridge gaps that a τ twin could have filled systematically.³⁶³⁷³⁸³⁹

9.2 Case Study 2: India National Electricity Plan 2022–2032 and G20 Energy Transition

Context and scale. India is executing one of the largest energy transitions in history. By 2023, India had added more than **100 GW of renewable capacity**; the government’s stated goal is **500 GW of non-fossil capacity by 2030**. Peak electricity demand is expected to reach **335 GW by 2030**, up from approximately 223 GW in 2022. The Central Electricity Authority’s (CEA) National Electricity Plan 2022–2032 estimates required investment of over **USD 300 billion** in generation,

³⁶European Commission, *REPowerEU Plan* (May 2022): EUR 300 billion additional investment plan to end dependence on Russian fossil fuels through energy savings, clean energy, and supply diversification. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en

³⁷IEA, *Europe’s Energy Crisis: Impacts and Responses* (2022): analysis of the European energy security crisis following Russia’s invasion of Ukraine, including policy responses, demand reduction, and LNG import scaling. <https://www.iea.org/reports/europe-energy-crisis-impacts-and-responses>

³⁸Bruegel, *European natural gas imports* (2023): tracking EU’s shift away from Russian pipeline gas, documenting the 45% to ~8% pipeline share reduction. <https://www.bruegel.org/dataset/european-natural-gas-imports>

³⁹ENTSO-G / ENTSO-E, *Winter Outlook 2022–2023*: joint assessment of European gas and electricity system adequacy under high-uncertainty conditions following Russian supply reduction. <https://www.entsog.eu/winter-outlook>

transmission, and storage to meet this target.⁴⁰⁴¹

India's energy planning challenge is structurally more complex than most, for several interacting reasons:

- **Monsoon-linked demand and supply:** air-conditioning loads peak in the pre-monsoon hot season; hydropower output fluctuates dramatically with monsoon performance; both are strongly coupled to interannual climate variability.
- **Cooling water constraints:** India's thermal power fleet — still a major reliability backstop — faces cooling-water stress during heat waves and droughts, precisely when demand peaks.
- **Cross-state grid congestion:** India's inter-regional transmission system has historically been congested in ways that prevent surplus renewable generation in western and southern states from serving deficits in northern and eastern states.
- **Industrial demand growth:** India's industrial sector, a major and growing electricity consumer, has demand patterns that interact with grid reliability in ways that neither demand models nor supply models capture well in isolation.
- **Multi-tier access challenge:** India has nominally achieved near-universal household electrification under SAUBHAGYA but quality of supply — measured in hours per day and voltage reliability — remains a major problem in rural areas.

The baseline planning problem. The CEA's National Electricity Plan uses deterministic demand projections calibrated to historical growth rates with scenario adjustments. It does not natively represent weather-driven intermittency across the full annual cycle, cooling-water constraints on thermal plants as a function of monsoon performance, or cross-state transmission dynamics as an endogenous part of capacity planning. The result is a plan that is coherent in its overall technology mix and trajectory but has limited operational resolution for the sequencing and reliability questions that actually determine whether the 500 GW target is achievable without creating new reliability risks.

India's experience during the **summer 2022 heat wave** illustrated this gap: a combination of abnormally high cooling demand, below-expected hydro output due to weak snowpack, and supply chain disruptions in coal imports created a reliability crisis that the national planning framework had not anticipated because its scenario logic was not designed to represent the joint probability distribution of interacting weather and supply-chain shocks.

What a τ -enabled system would change. Under the τ assumption set, a cross-sector planning twin coupling renewable intermittency, monsoon weather patterns, thermal plant cooling constraints, transmission expansion, and demand growth could support:

- investment sequencing for the USD 300 billion grid modernization program that accounts for weather-driven reliability risk;
- transmission expansion prioritization that accounts for the east-west renewable-deficit asymmetry as an endogenous constraint rather than an exogenous input;
- reliability stress testing under joint weather scenarios combining heatwave, drought, and monsoon delay;
- and sub-national access-quality improvement planning that connects supply-side adequacy to distribution-level reliability.

As India's energy system grows more complex and more weather-dependent, the gap between deterministic planning and physics-faithful scenario modeling will widen. The USD 300 billion investment at stake makes better planning economics straightforward to justify.

⁴⁰Central Electricity Authority of India, *National Electricity Plan 2022–2032*, Volume I (Generation): projections for 500 GW non-fossil capacity by 2030, 335 GW peak demand, and USD 300B+ investment requirement. <https://cea.nic.in/national-electricity-plan/>

⁴¹IEA, *India Energy Outlook 2021*: analysis of India's energy system, including renewables growth, coal transition, grid modernization, and electrification trajectory. <https://www.iea.org/reports/india-energy-outlook-2021>

G20 energy-transition relevance. India’s G20 presidency in 2023 placed energy transition planning prominently on the international agenda. The G20 Energy Transitions Working Group’s output documents note the importance of integrated system planning and just transition frameworks.⁴² A τ planning capability deployed in India would be directly relevant to India’s role as a model for large-economy energy transitions in the developing world.

Reference context. The CEA National Electricity Plan is a serious, detailed planning document produced by technically capable institutions. The argument is not that India lacks planning capacity but that the planning tools available do not match the complexity of the system being planned. A τ twin would augment existing Indian planning institutions, not replace them.^{43,44}

10 Financing and Cost Analysis

10.1 Institutional Financing Landscape

World Bank Energy Sector Management Assistance Program (ESMAP). ESMAP is the World Bank’s global knowledge and technical assistance program for energy. It provides analytical work, technical assistance, and seed financing for energy sector planning in developing countries. ESMAP has funded national energy access strategies, renewable energy resource assessments, and energy system planning capacity-building in dozens of countries. A τ -based national energy planning capability would be a natural candidate for ESMAP co-financing in fast-growing developing economies where the planning infrastructure is thinnest relative to the investment decisions being made.

Asian Development Bank (ADB). The ADB provides energy sector lending of more than **USD 4 billion per year**, primarily in Southeast Asia and South Asia — two of the world’s fastest-growing electricity demand regions. ADB’s energy strategy emphasizes grid modernization, regional interconnection, clean energy, and energy access. A τ regional planning twin for ASEAN-level coordination or South Asian cross-border market design would be directly aligned with ADB’s lending priorities and its institutional ambition for regional integration.

IEA Just Transition Finance Facility (JTFF). The IEA’s Just Transition Finance Facility focuses on coal-to-clean transition planning support, particularly for major coal economies in Asia and Eastern Europe. The facility’s central challenge is planning technically and financially credible pathways that retire coal assets while maintaining system reliability and protecting affected workers and communities. A τ planning twin that can model the system-reliability consequences of coal retirement sequencing under different renewable buildout and storage scenarios would directly support JTFF’s operational mandate.

IRENA Global Renewables Outlook Financial Mobilization Framework. IRENA’s financial mobilization work on the Global Renewables Outlook emphasizes the role of de-risking instruments, blended finance, and planning credibility in attracting private capital to renewable energy in developing economies. Better planning — with bounded-error scenarios rather than point estimates — is a de-risking instrument in itself, because it reduces the policy uncertainty that inflates risk premia on renewable investment in frontier markets.

⁴²G20 India 2023, *Energy Transitions Working Group (ETWG)* outcomes: integrated energy planning, just transition frameworks, and technology cooperation as priorities for G20 energy coordination. <https://www.g20.in/en/g20-india/tracks/sherpa-track/energy-transitions-working-group.html>

⁴³Central Electricity Authority of India, *National Electricity Plan 2022–2032*, Volume I (Generation): projections for 500 GW non-fossil capacity by 2030, 335 GW peak demand, and USD 300B+ investment requirement. <https://cea.nic.in/national-electricity-plan/>

⁴⁴IEA, *India Energy Outlook 2021*: analysis of India’s energy system, including renewables growth, coal transition, grid modernization, and electrification trajectory. <https://www.iea.org/reports/india-energy-outlook-2021>

10.2 Cost Scenarios

Scenario 1: National energy planning capability for one country. A τ -powered national energy planning capability — covering whole-system scenario modeling, investment sequencing, and market-design testing for one country with USD 10–100 billion in annual energy investment — is estimated at **USD 5–20 million** over a three-to-five-year initial deployment. This supports a full five-to-ten-year investment planning cycle. Institutions with relevant precedents include ESMAP national energy modeling projects and IEA-sponsored national TIMES-model deployments.

Scenario 2: Regional energy coordination platform. A τ -powered regional planning and coordination platform serving 10+ countries in a regional power pool — for example ASEAN, the East African Power Pool (EAPP), or the South Asian Association for Regional Cooperation (SAARC) energy initiative — is estimated at **USD 30–80 million**, supporting coordination of more than **USD 100 billion** in regionally coordinated investment. This scale is consistent with World Bank and ADB regional energy integration programs and with ENTSO-E’s institutional model in Europe.

10.3 Benefit-Cost Benchmarks

The planning-inference benchmarks are:

- **McKinsey global benchmark:** Better integrated energy planning can reduce system costs by **5–15%**. At EU scale (approximately USD 200–300 billion in annual energy investment), this corresponds to **USD 10–30 billion per year** in avoidable system costs.⁴⁵
- **IEA planning multiplier:** USD 1 in energy planning investment saves **USD 8–10** in avoidable system costs.⁴⁶ Applied to a USD 5–20 million national planning deployment, this implies USD 40–200 million in expected avoided system costs per planning cycle.
- **World Bank regional integration evidence:** The CLSG interconnection project delivered avoided emissions of approximately **13.8 million tonnes of CO₂** and service improvements to **2.8 million people**.⁴⁷ If better planning had enabled earlier or more optimal deployment of such projects, the public-good gains compound over multiple investment cycles.

These benchmarks should be used to set performance expectations for τ deployments, not as assured returns. The IEA planning multiplier in particular reflects the general value of planning quality improvements and should be interpreted as a rough order of magnitude rather than a precise estimate.

11 Lighthouse Pilots

To make the paper concrete and testable, five plausible lighthouse pilots are proposed. Each is designed to be completable within a two-to-three-year window, with clear success criteria and institutional sponsors.

⁴⁵McKinsey Global Institute, energy planning cost reduction analysis: better integrated energy planning can reduce total energy system costs by 5–15%, corresponding to USD 10–30 billion per year at EU scale. Referenced in McKinsey energy sector client publications and industry benchmarking reports.

⁴⁶IEA, *World Energy Investment* series: the IEA’s analytical work supports the estimate that USD 1 in energy planning and coordination investment avoids USD 8–10 in downstream system costs through better sequencing and reduced stranded-asset risk. <https://www.iea.org/reports/world-energy-investment-2025>

⁴⁷World Bank, *Powering Africa: The Transformational Impact of Regional Energy Projects in West Africa* (2025): regional interconnections have delivered affordable renewable electricity to millions, cut outages by up to 30%, reduced costs, and improved reliability. CLSG: 2.8 million people served, 13.8 Mt CO₂ reduction; OMVG: 15 million beneficiaries. <https://www.worldbank.org/en/results/2025/02/06/powering-africa-the-transformational-impact-of-regional-energy-projects-in-west-africa>

11.1 Pilot 1 — National “Grid vs. Generation vs. Flexibility” Planning Twin

Objective: Build a τ decision twin for one fast-electrifying country or region that compares three spending strategies under a common physical frame: generation-heavy, balanced generation and grid, and flexibility-first.

Measurement: Effects on reliability, curtailment, reserve needs, and public cost across a ten-year investment horizon under a realistic distribution of weather scenarios.

Institutional sponsor: IEA, World Bank ESMAP, or national energy ministry in a country with high renewable growth and grid-bottleneck challenges (India, Brazil, or Vietnam are plausible candidates).

Success criterion: τ 's scenario ranking differs from the conventional model's ranking in at least one material investment decision, and the τ reasoning is auditable and communicable to non-technical decision-makers.

11.2 Pilot 2 — Regional Power-Pool Interconnector and Trade Design Twin

Objective: Apply τ to one real regional integration context — for example a West African, Southern African, or Central Asian market-expansion pathway — to compare interconnector sequencing, reserve sharing, renewable integration, and social benefit under different market-rule packages.

Measurement: Cost per beneficiary served, reliability improvement, renewable integration share, and congestion reduction under five alternative governance rule packages.

Institutional sponsor: World Bank regional energy program, African Development Bank, or ADB for Asia.

Success criterion: The pilot identifies a market-rule package that is both more reliable and cheaper than the current default, with a clear political economy pathway for adoption.

11.3 Pilot 3 — Market-Design Reform Test Bench

Objective: Use τ to compare alternative designs for flexibility markets, capacity or reliability products, long-duration storage remuneration, and congestion pricing or hedging structures in a real electricity market context.

Measurement: Liquidity, reliability, and investment outcomes under multiple medium- and long-term market designs using the same physical system constraints.

Institutional sponsor: ISO/RTO, national regulator, or the IEA Electricity Market Design team.⁴⁸

Success criterion: The test bench identifies a design change that improves both reliability and investability, as measured by reduced expected unserved energy and improved forward-contract liquidity, without increasing total system cost.

11.4 Pilot 4 — Mission-300-Style Access Sequencing Engine

Objective: Build a planning layer that compares access pathways across main-grid expansion, regional imports, mini-grids, and standalone systems, while explicitly scoring access speed, affordability, resilience, and upgrade compatibility.

⁴⁸IEA, *Electricity Market Design* (2025): short-term markets continue to operate reliably and efficiently, while medium- and long-term markets face persistent gaps in liquidity and accessibility that hinder risk management and investment confidence. <https://www.iea.org/reports/electricity-market-design>

Measurement: People served per dollar of concessional capital, reliability hours per day at five years and ten years, and upgrade-pathway compatibility with emerging national grid architecture.

Institutional sponsor: World Bank Mission 300 program, African Development Bank, or IRENA Access and Equity program.

Success criterion: The engine changes the recommended access pathway in at least two of five test districts relative to conventional planning tools, and the change is accepted as operationally valid by the local planning authority.

11.5 Pilot 5 — Cross-Ministry Energy-Transition Dashboard

Objective: Create a τ scenario tool for finance, energy, and planning ministries in one country that enables comparison of the same investment package through multiple lenses simultaneously: power-system adequacy, social value, emissions impact, access gain, and resilience.

Measurement: Improvement in inter-ministry agreement on investment sequencing, as measured by reduction in formal inter-ministerial conflicts over energy investment prioritization in the two-year period following pilot deployment.

Institutional sponsor: National government with active energy transition planning, supported by IEA or World Bank advisory capacity.

Success criterion: The dashboard becomes a standing part of the inter-ministerial energy planning process, with use by at least three ministries in annual investment review.

12 Evidence and Translation Ladder

12.1 Phase 1 — Shadow-Planning Mode

τ is used in parallel with existing planning tools, not yet integrated into official decision processes.

Goals: - benchmark against official planning models in retrospective and prospective cases; - identify where τ changes ranking or sequencing of investment priorities; - validate causal-chain claims against real cases with known outcomes.

Duration: 12–24 months. **Key output:** A documented track record of cases where τ and conventional models agree and disagree, with auditable reasoning for disagreements.

12.2 Phase 2 — Decision-Support Mode

τ enters planning and market-design workflows as an advisory engine, providing scenario analysis that complements but does not replace existing tools.

Use cases: - investment prioritization for national or regional energy plans; - interconnector design and sequencing; - flexibility-market design testing; - access sequencing under Mission-300-style programs; - and public-finance allocation across competing energy investments.

Duration: 24–48 months post Phase 1. **Key output:** Documented cases where τ advisory input changed a planning decision, with subsequent outcome tracking.

12.3 Phase 3 — Portfolio-Governance Mode

τ becomes part of the formal evidence layer for major energy planning decisions.

Use cases: - national system plans submitted to regulators and development banks; - development-bank project pipelines and portfolio review; - regional pool master plans and interconnection sequencing; - and climate/energy coordination platform scenario analysis.

Duration: 3–7 years post initial deployment. **Key output:** Integration into institutional planning processes with defined governance roles, data standards, and audit procedures.

12.4 Phase 4 — International Coordination Mode

τ supports joint scenario exercises across ministries, regulators, system operators, and financing institutions, functioning as a shared coordination technology.

Use cases: - joint energy security analysis for regional power pools; - G20 or COP energy-transition coordination platforms; - cross-border investment co-financing due diligence; - and shared resilience standards for interconnected systems.

Duration: Long-run institutional evolution, extending beyond any single project timeline. **Key output:** A τ -based scenario platform that is recognized as a neutral, auditable, shared reference for cross-border energy planning — analogous to the role ENTSO-E’s TYNDP plays in Europe but globally applicable and physics-faithful.

13 Benchmark Suite

A serious Paper 5 deployment path must be held to specific, auditable benchmarks. Six benchmarks are proposed.

13.1 Benchmark 1 — Reproduce Official Demand-Growth Baselines

Can the τ planning twin reproduce and stress-test official electricity-demand scenarios of the sort published by the IEA, including the 4.3% growth in 2024 and forecast continuation through 2027?⁴⁹ The success criterion is matching IEA baselines within a specified bounded error and identifying the weather and policy conditions under which the baseline is most sensitive.

13.2 Benchmark 2 — Grid-vs-Generation-vs-Storage Sequencing

Given a realistic national budget and ten-year investment horizon, can τ rank investment packages more effectively than conventional siloed models — where “more effectively” means lower expected curtailment, lower expected unserved energy, and lower total system cost at end of horizon, evaluated ex post against actual system outcomes?

13.3 Benchmark 3 — Market-Design Sensitivity

Can τ compare liquidity, reliability, and investment outcomes under multiple medium- and long-term market designs using the same physical system constraints, in a way that is auditable against the IEA’s electricity-market design evidence base?⁵⁰

⁴⁹IEA, *Electricity 2025*, Executive Summary and Demand chapter: global electricity demand rose 4.3% in 2024 and is forecast to continue growing at close to 4% through 2027. <https://www.iea.org/reports/electricity-2025/executive-summary>

⁵⁰IEA, *Electricity Market Design* (2025): short-term markets continue to operate reliably and efficiently, while medium- and long-term markets face persistent gaps in liquidity and accessibility that hinder risk management and investment confidence. <https://www.iea.org/reports/electricity-market-design>

13.4 Benchmark 4 — Regional Trade and Interconnection Value

Can τ quantify — with bounded error — when regional integration lowers cost, improves resilience, and increases renewable integration, and under which governance assumptions? The success criterion is reproducing World Bank-documented outcomes from existing West Africa regional interconnection projects⁵¹ in a retrospective validation, then extending forward.

13.5 Benchmark 5 — Access Architecture Comparison

Can τ compare electrification pathways in a way that is useful for Mission-300-style programs and national access compacts — providing rankings that differ from conventional tools in at least a minority of cases and are validated by subsequent deployment outcomes?

13.6 Benchmark 6 — Public-Good Dashboard Quality

Does τ improve decisions when judged not only on cost but on affordability, reliability, access, resilience, emissions, and equity simultaneously? The success criterion is that decision-makers using τ identify tradeoffs that pure cost-minimization approaches miss, and that those tradeoffs are confirmed as real by subsequent system evolution.

14 Governance Guardrails

If τ is ever used in high-level energy planning at national or regional scale, it should be deployed with strong governance guardrails. The tool's value depends entirely on it being used as a neutral, auditable planning aid and not as a technocratic authority that displaces legitimate political deliberation.

14.1 It Should Clarify Politics, Not Pretend to Replace Politics

Many energy choices are political by nature. Grid expansion in one region versus another is a distributional choice. Flexibility market design determines who bears the cost of transition risk. Regional integration creates interdependencies that affect national sovereignty. τ should help clarify the consequences of these choices with greater physical fidelity, not claim to dissolve the choices themselves. Any deployment that presents τ outputs as politically neutral technical conclusions rather than as evidence to inform political deliberation is misusing the tool.

14.2 Public-Good Metrics Should Be First-Class

Planning should be scored not only in cost and emissions terms but also in electricity access, affordability, outage burden, service continuity, and distributional equity. These metrics are often excluded from conventional optimization because they are harder to monetize. A τ deployment that reproduces conventional optimization's cost-centric framing without adding public-good dimensions has not achieved its purpose.

⁵¹World Bank, *Powering Africa: The Transformational Impact of Regional Energy Projects in West Africa* (2025): regional interconnections have delivered affordable renewable electricity to millions, cut outages by up to 30%, reduced costs, and improved reliability. CLSG: 2.8 million people served, 13.8 Mt CO₂ reduction; OMVG: 15 million beneficiaries. <https://www.worldbank.org/en/results/2025/02/06/powering-africa-the-transformational-impact-of-regional-energy-projects-in-west-africa>

14.3 Open or Auditable Benchmark Culture Is Essential

Because the claims are strong, the benchmark culture should be correspondingly strong. τ deployments should be held to documented, retrospective validation exercises before being used for forward-looking planning decisions. The validation record should be publicly accessible to the extent possible within confidentiality constraints.

14.4 Cross-Border Use Requires Governance Trust

Regional coordination tools should be designed with institutional transparency and data-sovereignty guardrails. Countries sharing a regional power pool must be able to audit how their national data is used in the joint planning model. A τ regional platform should have an explicit governance architecture — clear data-sharing agreements, defined roles for national system operators, and transparent update and validation procedures.

14.5 Development Use Should Avoid Extractive Asymmetry

In lower-income contexts, τ should not become a new technocratic gatekeeping layer imposed by donors or development banks on national planning processes. It should support local planning capability, public-interest accountability, and fair financing structures. Deployment models that build local analytical capacity — training national planners, establishing open or shared model architectures, and connecting τ outputs to locally understandable planning questions — are preferable to black-box licensing arrangements.

15 Five-, Ten-, and Twenty-Year Public-Good Horizon

15.1 5-Year Horizon (2026–2031)

The most realistic gains in a five-year window are at the national planning and early regional coordination level:

- better national energy-planning prioritization in five to ten countries with τ -enabled planning twins;
- clearer grid-versus-generation sequencing for the USD 400 billion per year grid investment bottleneck;
- stronger evidence for flexibility-market reforms in at least three major electricity markets;
- and better donor and public-finance coordination on energy access in Sub-Saharan Africa and South Asia.

The social signature would be **better-targeted energy spending and fewer obvious sequencing mistakes** — fewer overbuilt solar parks without grid connections, fewer under-served grid extensions into areas better served by mini-grids, fewer market-design reforms that create new investment uncertainty rather than resolving existing uncertainty.

15.2 10-Year Horizon (2031–2036)

The larger gains in a ten-year window accumulate through institutional adoption and regional scale:

- stronger regional market coordination in at least two major developing-world regional power pools;

- more reliable scaling of renewables and storage through better sequencing and market design;
- more coherent access strategies in the countries targeted by Mission 300;
- and better integration of demand flexibility into system planning in major markets.

The social signature would be **cleaner growth, more reliable electrification, and fewer access/reliability tradeoffs** — a demonstrable narrowing of the gap between access expansion speed and access quality.

15.3 20-Year Horizon (2036–2046)

The best-case structural gain in a twenty-year window is a qualitative change in how the energy transition is governed:

- energy-system planning becomes less fragmented and more anticipatory, reducing the frequency of crisis-driven improvisation;
- public and private capital are allocated with higher social efficiency, measured in lives improved per billion dollars spent;
- and regional cooperation becomes more durable because the benefits and tradeoffs of cooperation are made legible to political stakeholders rather than remaining opaque inside planning models.

The social signature would be **a more governable energy transition** — one in which the enormous capital wave already underway delivers its full potential public value rather than being partly absorbed by sequencing errors, coordination failures, and avoidable market-design inefficiencies.

16 Bottom Line

Under the τ assumptions, integrated energy planning is one of the most important public-policy layers in the entire framework.

Why? Because even when great technologies exist and sufficient capital is mobilized, societies still fail the energy transition if they:

- build in the wrong order, creating curtailment before storage and grid extensions before local generation;
- underfund grids while overbuilding generation, creating the bottleneck the IEA has already identified;⁵²
- misprice flexibility, leaving the system brittle against the weather-driven intermittency that defines the renewable era;
- fail to coordinate across borders, forgoing the public goods that only regional integration can deliver;^{53,54}
- or neglect access and resilience while optimizing for narrow cost metrics, leaving hundreds of millions of people behind.

⁵²IEA, *World Energy Outlook 2025*, Executive Summary: annual grid spending has risen to about USD 400 billion, lagging the pace of generation investment, creating critical bottlenecks for electricity security and clean-energy deployment. <https://www.iea.org/reports/world-energy-outlook-2025/executive-summary>

⁵³World Bank, *Powering Africa: The Transformational Impact of Regional Energy Projects in West Africa* (2025): regional interconnections have delivered affordable renewable electricity to millions, cut outages by up to 30%, reduced costs, and improved reliability. CLSG: 2.8 million people served, 13.8 Mt CO₂ reduction; OMVG: 15 million beneficiaries. <https://www.worldbank.org/en/results/2025/02/06/powering-africa-the-transformational-impact-of-regional-energy-projects-in-west-africa>

⁵⁴World Bank, *Beyond Borders: Power Grid Interconnections and Regional Electricity Markets in Developing Countries* (2025). <https://openknowledge.worldbank.org/entities/publication/4020f27e-341c-4883-a3ad-b603fc82cb48>

Paper 5 matters because it is the layer where τ could help answer the most consequential planning question in the energy transition:

What should be built first, where, with what market rules, with whose money, and for whose benefit?

That is not a marginal technical question. It is the heart of whether the energy transition becomes orderly, equitable, and resilient — or fragmented, bottlenecked, and crisis-prone.

The core public-good idea is simple: if τ can make whole energy systems more faithfully knowable and more coherently plannable, then it can help societies spend scarce energy-transition capital where it delivers the greatest durable public benefit. At USD 3.3 trillion per year in total energy investment — with USD 400 billion per year chronically under-allocated to the grid bottleneck, 600 million people still lacking electricity, and medium-term electricity markets persistently illiquid — that is a very large public good.

17 References

This dossier is Paper 5 of 5 in the Panta Rhei energy impact portfolio. It draws on official IEA, World Bank, IRENA, and institutional sources for all quantitative baselines. Planning-inference estimates are labeled as such and should not be read as forecasts. The τ framework is the subject of the Panta Rhei book series (7 volumes, 2nd Edition, 2026); its mathematical foundations are developed in Books I–III and its physical applications in Books IV–V.

18 Dossier accountability addendum

The following addendum records the release-facing accountability layer for this dossier: claim boundaries, baseline evidence, upstream dependencies, translation assumptions, scenario bands, scorecard rationales, benchmark requirements, governance guardrails, and related Panta Rhei surfaces. It is intentionally downstream of the full source argument above.

Impact thesis

A Public-Good Briefing on how τ could improve integrated energy-system planning, electricity market design, investment prioritization, and international energy coordination. The v3 impact thesis is conditional: a Tau-grade integrated energy-system planning, market-design, and investment-coordination twin would become valuable if it improves benchmarked public decisions while preserving transparent uncertainty, reviewability, and governance control.

18.1 Public-good burden and baseline evidence

A Public-Good Briefing on how τ could improve integrated energy-system planning, electricity market design, investment prioritization, and international energy coordination. The public-good burden is treated here as an institutional decision problem: existing agencies already monitor parts of the domain, but the operational handoff from data to timely, auditable action remains incomplete.

18.1.1 External evidence baseline

- **IEA**, Electricity 2025, Executive Summary and Demand chapter: global electricity demand rose 4.3% in 2024 and is forecast to continue growing at close to 4% through 2027 [2]: source-page evidence item.
- **IEA**, World Energy Investment 2025, Executive Summary: total energy investment reaches USD 3.3 trillion in 2025, with around USD 2.2 trillion going to clean-energy-side assets and activi [4]: source-page evidence item.
- **IEA**, World Energy Outlook 2025, Executive Summary: annual grid spending has risen to about USD 400 billion, lagging the pace of generation investment, creating critical bottlenecks for [5]: source-page evidence item.
- **IEA**, Electricity Market Design (2025): short-term markets continue to operate reliably and efficiently, while medium- and long-term markets face persistent gaps in liquidity and accessi [3]: source-page evidence item.
- **World Bank**, Mission 300 is Powering Africa overview: nearly 600 million people in Sub-Saharan Africa lack electricity, and Mission 300 aims to connect 300 million people by 2030 [10]: source-page evidence item.
- **World Bank**, Powering Africa: The Transformational Impact of Regional Energy Projects in West Africa (2025): regional interconnections have delivered affordable renewable electricity to million [11]: source-page evidence item.
- **IRENA**, Flexibility: power-system transformation depends on flexible operations, stronger grids, storage, demand response, sector coupling, hydrogen, heat pumps, and electromobility [7]: source-page evidence item.
- **World Bank**, Beyond Borders: Power Grid Interconnections and Regional Electricity Markets in Developing Countries (2025) [9]: source-page evidence item.

- **World Bank**, Regional Electricity Market Interconnectivity and Trade program materials for Central Asia, Southern Africa, and related regional-integration work [12]: source-page evidence item.
- **IEA-ETSAP**, TIMES Model Documentation [6]: The Integrated MARKAL-EFOM System: long-run energy system optimization model using linear programming under perfect foresight.

18.2 Current institutional landscape

The relevant landscape includes public agencies, research infrastructures, standards bodies, development-finance channels, and domain review communities represented in the evidence base, including IEA, World Bank. These references are evidence and adoption surfaces, not endorsements or deployment partners.

18.3 Capability gap

The practical gap is a benchmarkable translation gap: current systems expose useful data or partial models, but they do not yet provide a single law-faithful, bounded-error decision layer for integrated energy-system planning, market-design, and investment-coordination twin.

18.4 Tau framework dependency map

Surface	Role in this dossier
Build the Tau-Kernel	finite address and scalar foundation
Recover Core Mathematics	mathematical bridge and model interface
Derive Physics	physical readout and domain translation candidate
Results lane	upstream consequences to be mapped precisely during release preparation
direct-registry-mapping-withheld	no direct Registry object is asserted until a substantive Corpus mapping is available
public-docs-mapping-withheld	TauLib module links are asserted only where public documentation exposes a clear surface
Release Manifest	release baseline
Predictions and Falsification	empirical accountability route

18.5 Translation assumptions and missing engineering

Required domain model: **integrated energy-system planning, market-design, and investment-coordination twin.**

First benchmarkable test: capacity expansion, flexibility, reliability, and market-design outputs against official energy-system planning scenarios.

- domain-specific model construction
- data ingestion and validation
- benchmark harness
- pilot protocol
- independent review workflow


18.6 Impact mechanism chain

Public-good burden → external evidence baseline → τ capability hypothesis → upstream Results / Corpus / Verify dependency → translation assumptions → benchmarked pilot → governed adoption pathway.

18.7 Scenario bands

Band	Scenario summary	Confidence
Conservative	A narrow shadow-mode pilot improves one bounded decision task for Integrated Energy-System Planning, Market Design, Investment Prioritization, and International Coordination without operational authority.	medium
Realistic	A reviewed prototype strengthens several public-sector workflows for Integrated Energy-System Planning, Market Design, Investment Prioritization, and International Coordination after benchmark comparison with incumbent systems.	medium-low
Optimistic	A reusable public-good intelligence layer becomes plausible for Integrated Energy-System Planning, Market Design, Investment Prioritization, and International Coordination after external validation and transparent governance review.	low

18.8 Impact scorecard

Public-good scale	 5/5	The affected public-good burden is large or institutionally significant within the portfolio.
Tau fit	 3/5	The proposed pathway depends on coupled state, bounded uncertainty, and compositional modelling rather than isolated prediction alone.
Evidence proximity	 5/5	The evidence base is anchored in public institutions, official monitoring systems, or established scientific reviews.
Measurability	 3/5	A first benchmark can be framed against incumbent public datasets, institutional records, or operational decision metrics.
Adoption readiness	 2/5	Adoption remains conditional on domain review, governance fit, data access, and institutional integration.
Equity leverage	 4/5	The pathway can prioritize underserved or vulnerable populations where public access and safeguards are built in.

18.9 Candidate pilot pathways

national or regional energy-transition stress test with a planning authority and independent modelling comparison

18.10 Benchmark suite and success metrics

Type	Incumbent base-line	Required benchmark	Tau	Success metric	Validator
translation benchmark	current public or institutional systems in the domain	capacity expansion, flexibility, reliability, and market-design outputs against official energy-system planning scenarios	pre-registered	accuracy, latency, uncertainty, or decision-quality metric	independent domain reviewers
governance benchmark	existing audit, disclosure, and reporting practice	transparent and failure-mode disclosure	assumption, data, model, and outcome protocol	reviewable evidence and adverse-outcome protocol	public-sector or expert governance panel
equity benchmark	current service-quality, or exposure disparities	access, documented way for underserved or vulnerable without exclusion	path-hidden	distributional benefit and risk review before pilot expansion	equity, community, or public-interest review process

18.11 Governance and risk guardrails

- Human oversight for any operational use.
- Public benchmark disclosure before institutional adoption.
- Equity access review for underserved or vulnerable communities.
- Data-rights and privacy controls for operational datasets.
- Misuse-prevention and adverse-outcome monitoring.
- Adverse-outcome monitoring with a documented escalation path.
- External domain review before pilot expansion.

18.12 Related Results / Corpus / Verify / Publications

This dossier is downstream of Results, Corpus, Verify, and Publications surfaces. It is not a Registry object. Direct Registry or TauLib links are asserted only where the mapping is substantive rather than decorative.

18.13 Bibliography and external evidence

References

[1] Thorsten Fuchs and Anna-Sophie Fuchs. τ for integrated energy-system planning, market design, investment prioritization, and international coordination. <https://panta-rhei.site/impact/>

- [papers/integrated-energy-system-planning-market-design-investment-coordination/, 2026](#). Current public full-text source for dossier [integrated-energy-system-planning-market-design-investment-coordination](#).
- [2] IEA. Electricity 2025, executive summary and demand chapter: global electricity demand rose 4.3% in 2024 and is forecast to continue growing at close to 4% through 2027. <https://www.iea.org/reports/electricity-2025/executive-summary>, 2026. source-page evidence item.
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Panta Rhei Research Program

Public-Good Impact Dossier

**τ for Integrated Energy-System Planning, Market Design,
Investment Prioritization, and International Coordination**

Dossier ID: PGID-ENER-05 Portfolio: Energy Release: May 2026
publication-ready release

Conditional scenario map. Domain review pending. Deployment, product,
validation, certified-impact, and policy-commitment claims are not made.

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