Foundations of Integrated Planning

Defining a Framework for Comprehensive Energy System Planning

ESIG
ENERGY SYSTEMS INTEGRATION GROUP

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Foundation paper components

Sets the foundations for the why/what/how of integrated planning

- **Why** do integrated planning? → Key drivers + blind spots of siloed approach
- **What** is integrated planning? → IP definition
- **How** to do integrated planning? → 4 part "framework" + key information flows

Key drivers of integrated planning

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Rapidly accelerating load growth

Aging infrastructure

Decarbonization policies

Evolving extreme weather events

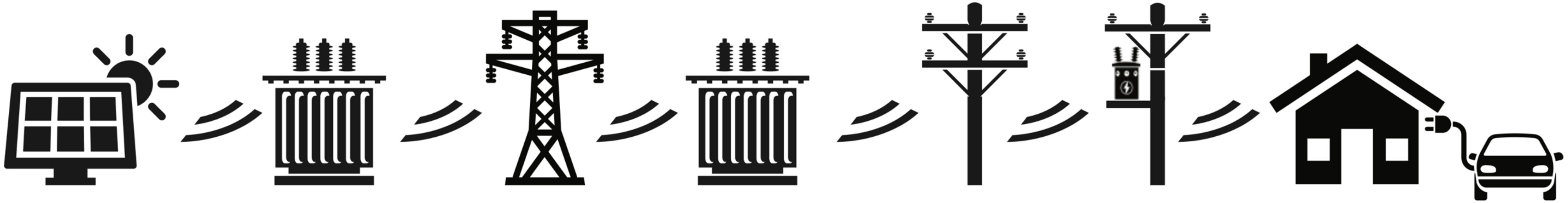
Technology evolution

Inverter-based resources

Inter-sectoral coupling

Advances in modeling + cloud computing

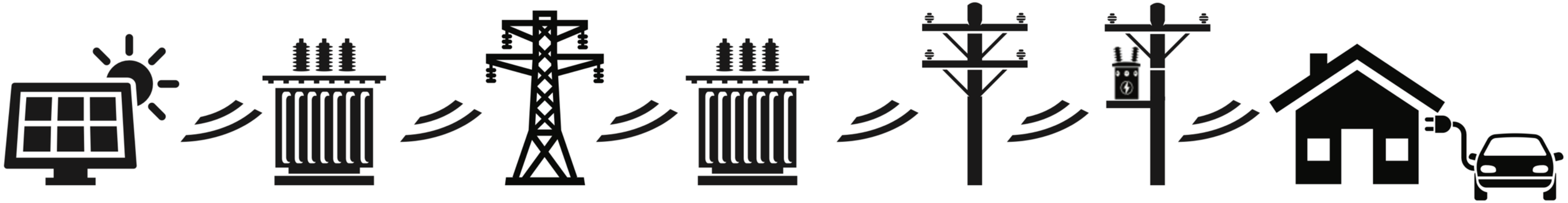
Electricity planning is historically siloed



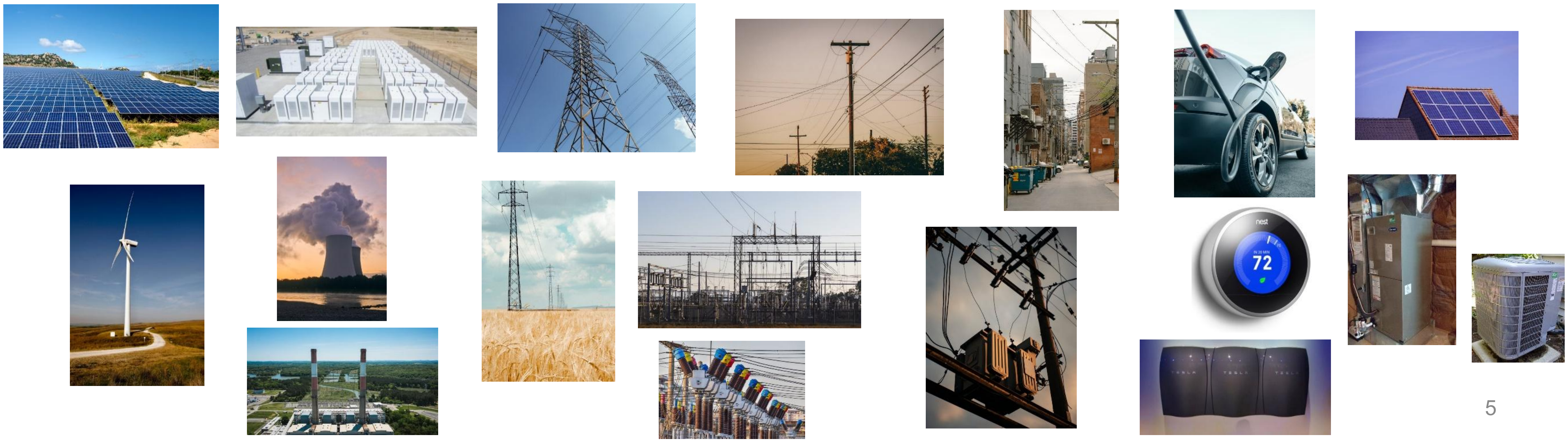
Generation	Transmission	Distribution	Customer Programs & DERs
• 10-20+ year IRP • Requests for proposals	• 5-15 year horizon • Interconnection studies	• 3- to 10-year studies	• Simple, coarse forecast • Cost-effective programs evaluation

Siloed planning worked when investments in one planning domain had limited impact on other planning needs – this is no longer the case

New investments like batteries, EVs, and remote renewables have impacts across planning domains



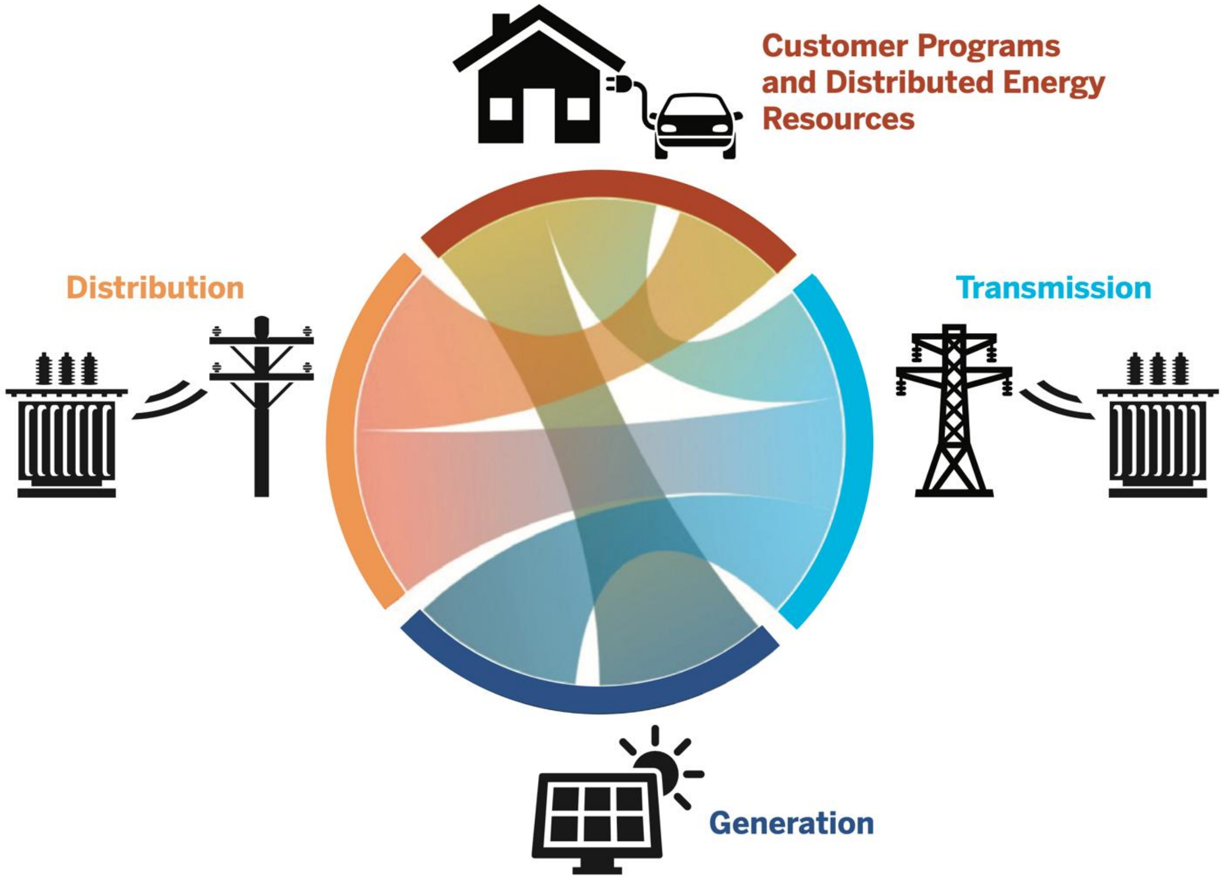
Generation	Transmission	Distribution	Customer Programs & DERs



Defining integrated planning

Integrated planning is a comprehensive energy system planning approach that coordinates across systems to develop affordable, reliable, and robust investment plans.

Integrated planning coordinates across electricity generation, transmission, and distribution, and customer loads and DERs, and may also consider interactions between the electricity system and other energy systems.



Source: A. Burdick, J. Hooker, L. Alagappan, M. Levine, and A. Olson, *Integrated System Planning: Holistic Planning for the Energy Transition*, Energy and Environmental Economics, Inc. (2024), https://www.ethree.com/wp-content/uploads/2024/10/E3-ISP-Whitepaper.pdf.

Key outcomes from integrated planning

	Examples
Right investments...	• Optimal mix of dispatchable thermal, renewable, and storage resources to meet reliability and policy goals • Investments in load flexibility versus utility storage • Grid investments versus non-wires alternatives
...in the **right places**...	• Geospatial forecasting of load growth, distributed energy resources, and resource potential • Optimal siting of storage resources on the bulk grid, distributed in-front-of-meter or distributed behind-the-meter • Where to build new transmission infrastructure to support reliability, economic, and policy objectives
...at the **right times**	• Proactive grid build-out to support electrification or new large loads • Consistent investment signals for the marginal hourly value of generation between bulk grid planning, customer program and distributed energy resource valuation, and retail rate design

Integrated solutions for grid needs

Lower total system costs

Identification and validation of "value-stacking" opportunities

Source: Energy Systems Integration Group.

Four pillars of ESIG's integrated planning framework

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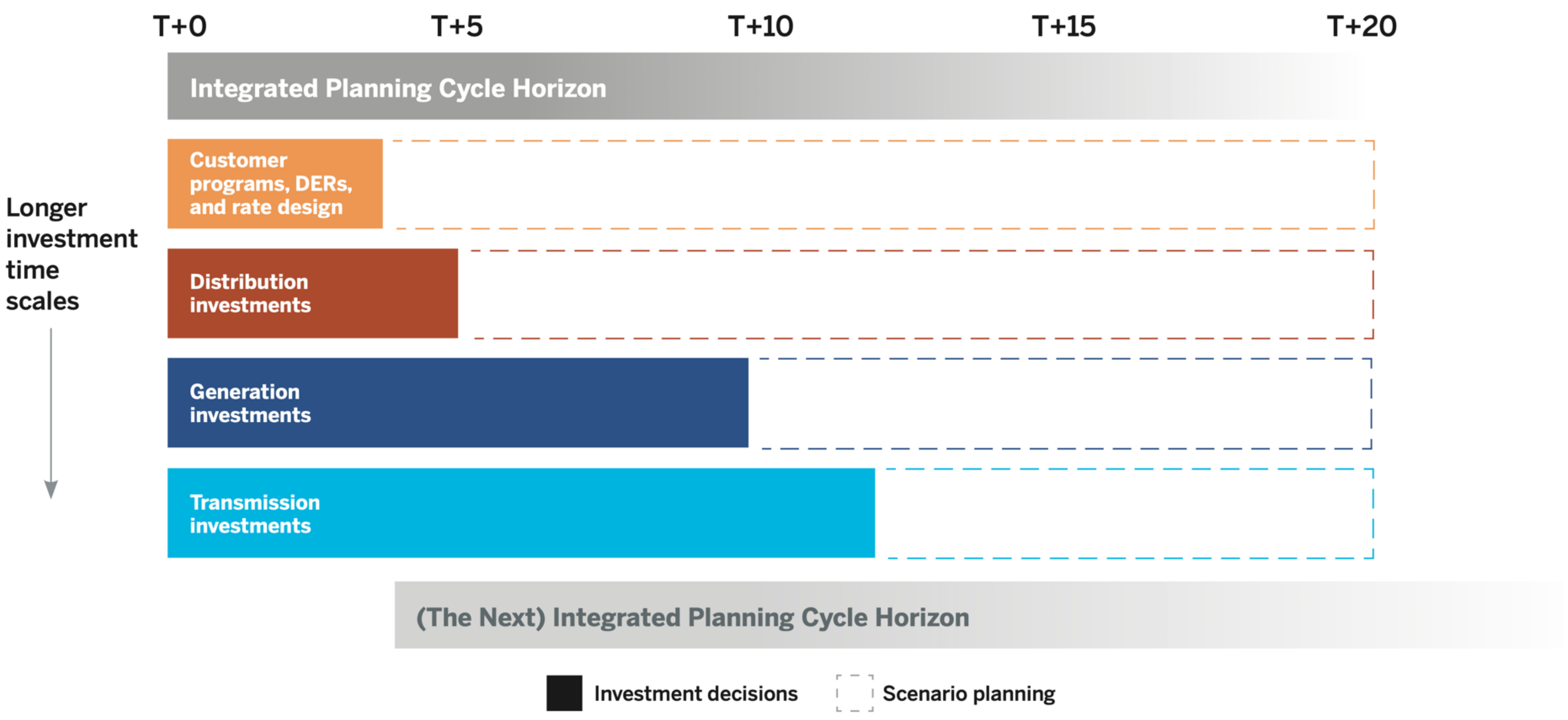
Integration of Inputs	Integration of Analysis	Integration of Actions	Integration with Decision-Making
Aligning inputs, modeling assumptions, scenarios, and data formats and structures across planning processes to set a common foundation across all planning processes	Determining the key data flows between both economic and physical planning analyses needed to reach a compre-hensive solution	Leveraging integrated planning analyses to determine a coordinated set of near-term proposed investments across all planning domains	Ensuring that these proposed near-term action plans fit within existing infrastructure decision-making structures or that those decision-making structures evolve to support regulatory approval and implementation of compre-hensive planning solutions

Source: Energy Systems Integration Group.

Integration of Inputs

- Develop integrated scenarios across all planning process
- Align key inputs and assumptions (loads, load shapes, etc.)
- Define common data structures to facilitate transfers between models
- Align planning horizons

A Sample Integrated Planning Horizon



Horizons for generation, transmission, distribution, and customer programs and DERs in an integrated planning process, segregated by the investment decision time frame in the current cycle and the scenario planning time frame beyond near-term investment decisions.

Source: Energy Systems Integration Group.

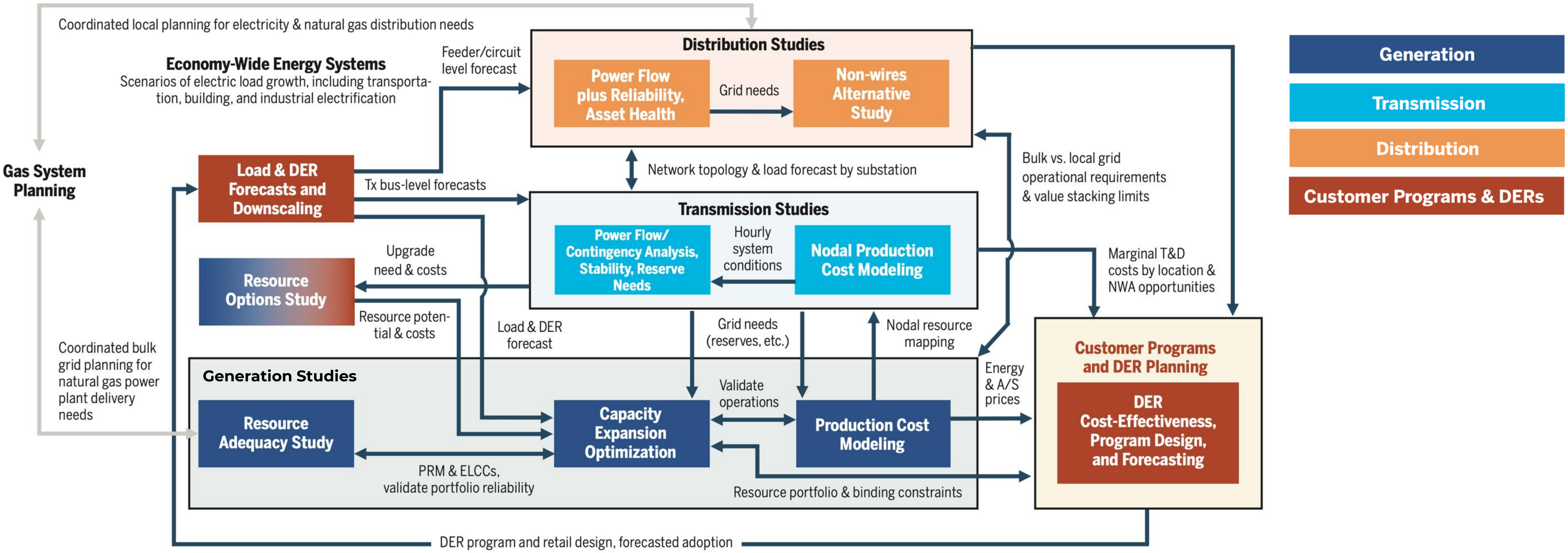
Integration of analysis

- **There is no "one-size-fits-all" analytical approach** for integrated planning
  - E.g., small island grid vs. RTO wide study, a vertically integrated utility vs planning across organizations in deregulated markets, etc.

- The **key focus should be on implementing the necessary data linkages** between planning models/decisions to ensure an integrated solution that meets all planning objectives

- Integrated analysis may use:
  - Co-optimization (where feasible)
  - Coordinated modeling processes with iterative feedback loops

Electricity system planning integrations: key data flows



Notes: A/S = ancillary service; DER = distributed energy resource; ELCC = effective load-carrying capability; NWA = non-wires alternative; PRM = planning reserve margin; Tx = transmission; T&D = transmission and distribution

Source: Energy Systems Integration Group, adapted from A. Burdick, J. Hooker, L. Alagappan, M. Levine, and A. Olson, *Integrated System Planning: Holistic Planning for the Energy Transition*, Energy and Environmental Economics, Inc. (2024), https://www.ethree.com/wp-content/uploads/2024/10/E3-ISP-Whitepaper.pdf.

Mapping information flows between planning domains

Necessary integrated planning studies are defined as is the required information flows between them

Connections Between Electricity System Analytical Processes in an Integrated Planning Process

Generation Planning	Transmission Planning
Generation Planning	Customer Program and DER Planning
Distribution Planning	Customer Program and DER Planning
Transmission Planning	Customer Program and DER Planning
Transmission Planning	Distribution Planning
Generation Planning	Distribution Planning

Examples

Resource options study *incorporates transmission upgrades options for deliverability or congestion relief*

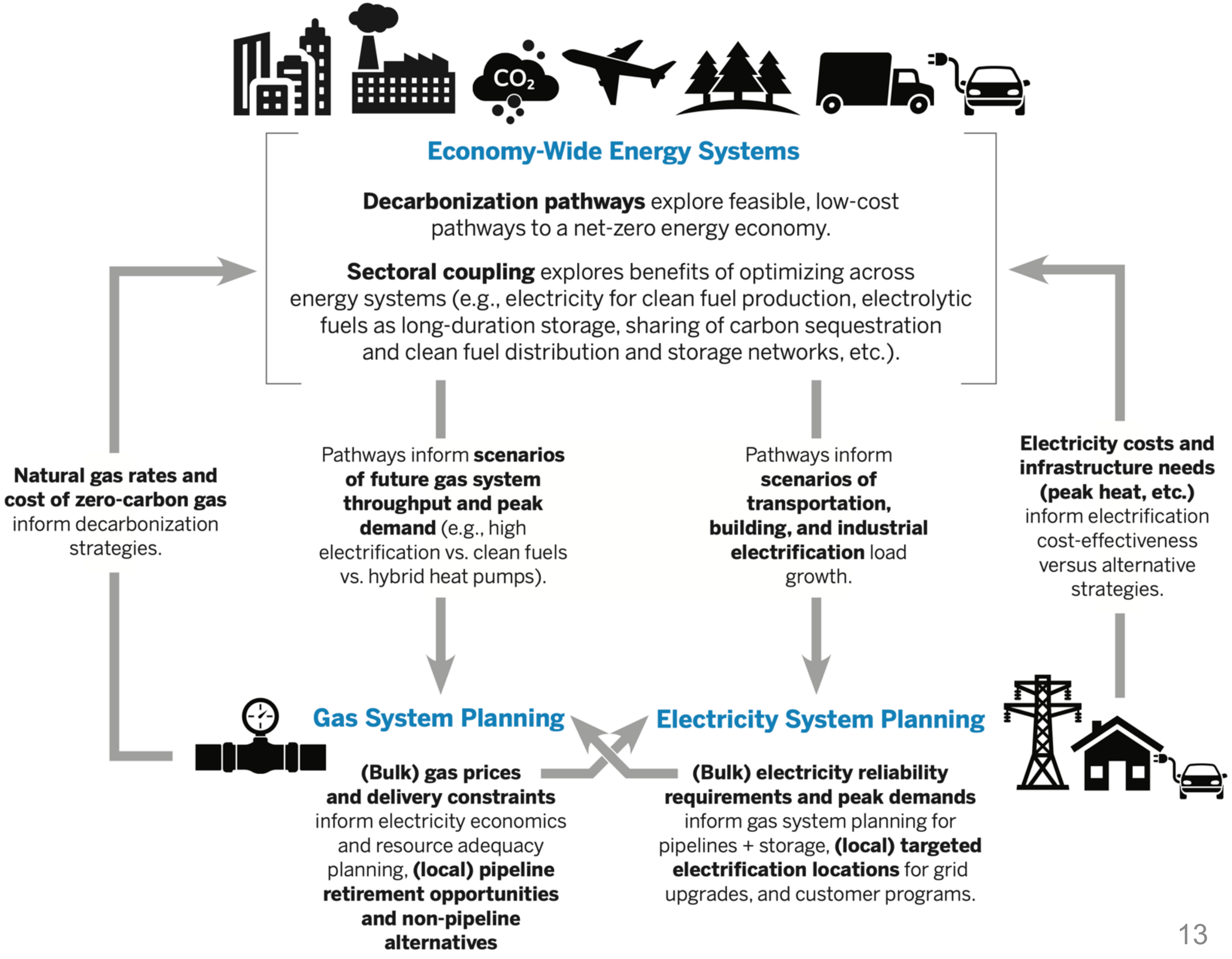
Load forecasts *are informed by* ***economywide energy system studies*** *and are aligned across G/T/D planning with appropriate levels of* ***geospatial allocation***

Distribution studies *identify investment needs for grid expansion and modernization, while* ***non-wires alternative studies*** *explore how DERs can meet those needs*

The ability to value stack is validated*, such as providing bulk grid services (like RA) and local grid services (like distribution deferral)*

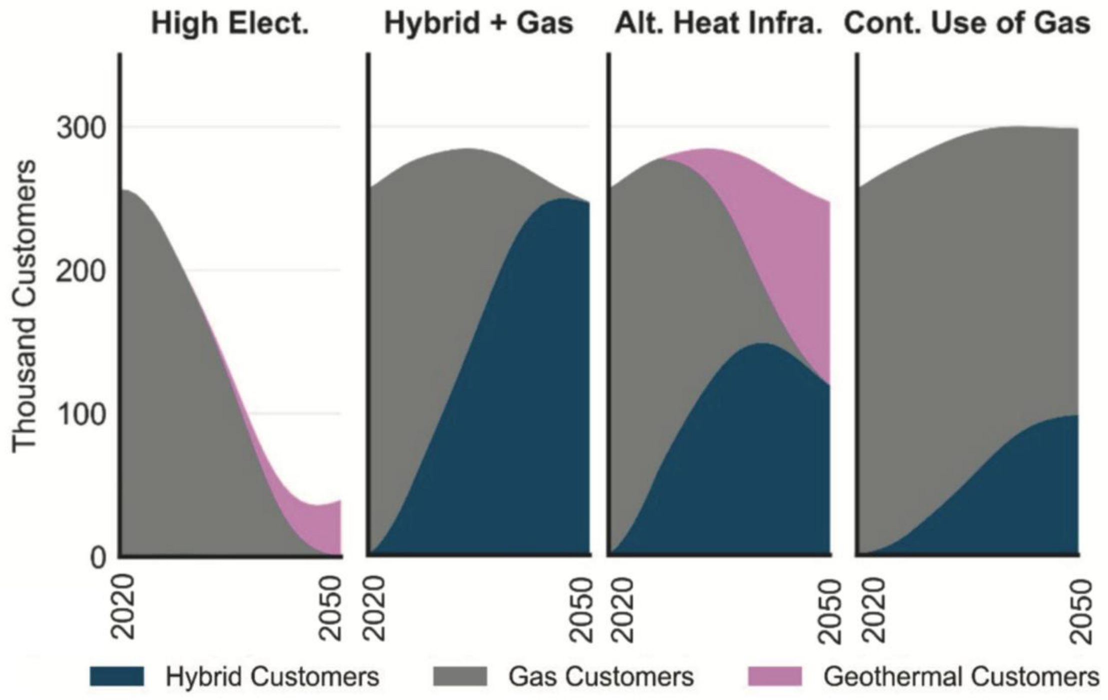
Expanding beyond electricity

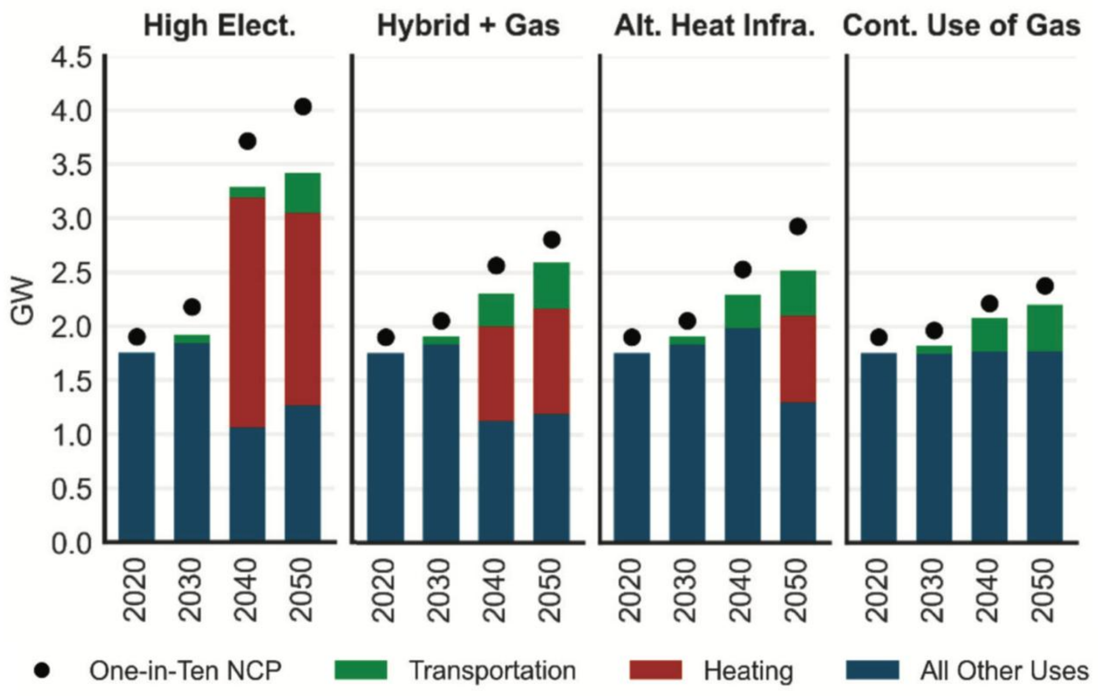
- **Electricity <> Economywide Energy Systems**
  - Electrification scenarios
  - Electricity system costs
- **Electricity <> Gas**
  - Gas delivery needs
  - Non-pipeline alternatives
- **Gas <> Economywide Energy Systems**
  - Gas demand scenarios
  - Gas system costs



Source: Energy Systems Integration Group.

Integrated scenario planning for decarbonizing regions supports electricity and gas infrastructure planning





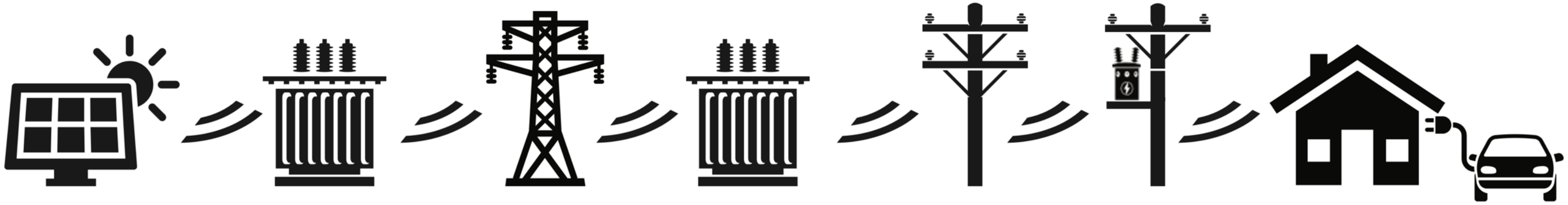
Decarbonization pathways scenarios inform future gas system demand…

…and electricity peak demand needs for generation, transmission, and distribution infrastructure

Source: N. Lintmeijer, T. Clark, S. Kinser, M. Bertolacini, K.enzie Schwartz, B. Wheatle, C. Li, D. Aas, and S. Smillie, "Rhode Island Investigation into the Future of the Regulated Gas Distribution Business. Technical Analysis Report. Docket 22-01-NATURAL GAS," Energy & Environmental Economics, Inc. (2024), https://www.ethree.com/wp-content/uploads/2024/06/Docket-22-01-NG-E3-Technical-Analysis-Report.pdf.

Integration of actions

Components of an Action Plan Resulting from an Integrated Planning Process



Generation	Transmission	Distribution	Customer Programs & DERs

Action plans are consistent with integrated planning and require coordination across teams

Generation resource action plan

- Recource investments and/or procurement need
- All-source request for propos-als
- Requests for proposals tar-geted by location

Transmission action plan

- Transmission asset invest-ments
- Storage providing transmission service
- Regional transmission project participation

Distribution action plan

- Investments in substation/ lines/grid modernization
- Development of targeted DER/customer programs
- Non-wires alternatives solici-tations

Customer/DER programs and rates action plan

- Customer program evaluation and design for efficieincy and equity
- Rate design updates

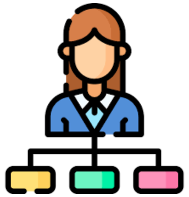
Plus pilot programs to validate planning assumptions (technology pilots, commercial pilots, operational pilots, etc.)

Source: Energy Systems Integration Group, adapted from A. Olson, J. Hooker, A. Burdick, and L. Alagappan, "Integrated System Planning: From Vision to Reality," Energy and Environmental Economics, Inc., ISP Webinar Series presented September 26, 2024.

Integration into decision making

- There is a wide variety of potential decision makers, which may differ for G/T/D/C
- Integrated planning processes should be designed in the context of decision-making processes
- Key questions:
  - What are the key planning objectives?
  - What decisions will be made in this planning cycle?
  - Who are the decision makers?
  - Who are the stakeholders and how will they be engaged?
  - When will decisions be made?
  - How can decisions be adaptive/robust?

Policymakers + Regulators create policy and ensure prudent investments



Utility Leaders provide safe, reliable, affordable, and clean power; new asset approval + cost recovery

Stakeholders meaningfully participate in the planning process

Economic Modelers optimize to ensure least-cost investment + operations

Grid Planning Engineers model grid physics to ensure reliable grid operations

Developers understand where and when their products provide value

Getting started

- Determine integrated planning objectives
- Perform a gap assessment for existing planning processes
- Align key inputs and develop integrated scenarios
- Better connect existing analytical processes
- Adapt stakeholder engagement plans to support an integrated planning process
- Consider organizational re-alignment and/or formalized agreements between planning organizations
- Consider new opportunities for co-optimization or co-simulation methods across planning domains
- Develop new analytical methods and tools to facilitate planning integrations

Optimization for Integrated Electricity System Planning

Opportunities for Integrated Planning in Capacity Expansion Models

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Optimization paper components

Explores the opportunities and current challenges for using capacity expansion optimization tools for integrated planning

- **Capacity expansion modeling** → Current optimization approaches, tradeoffs
- **"Full system" modeling** → Opportunities and challenges
- **Bulk grid** co-optimization → Bulk G + T + storage optimization methods
- **Bulk + local** co-optimization → Challenges + currently tractable methods
- **Conclusions** and how to get started → Walk/jog/run for integrated optimization

Traditional generation capacity expansion

Key Inputs

- Load/distributed energy resource forecasts
- Load/distributed energy resource shapes
- Baseline resources
- Planned additions and retirements
- Capital, operations and maintenance, and fuel costs
- Resource potential
- Resource operating characteristics
- Reliability need and resource contributions

Objective Function: Minimize Costs

Fixed resource costs

- Generation capacity (thermal, hydro, renewables, etc.)
- Energy storage
- Demand response, energy efficiency, etc.
- Transmission (if modeled)

+

Variable operating costs

- Fuel and variable operations and maintenance costs
- Start Costs
- Carbon costs
- Etc.

Constraints

Reliability/operations

- Hourly load/resource balance
- Operating reserves/flexibility
- Resource adequacy
- Resource build limits
- Resource operating limits
- Transmission flow limits

Policy

- Renewable portfolio standard targets
- Greenhouse gas limit and/or carbon price

Key Outputs

- Generation capacity additions and retirements
- Generation by resource
- Achieved renewable portfolio standard
- Achieved greenhouse gas emissions targets
- Costs
  - Modeled costs (annual and net present value)
  - Shadow prices (energy, reserves, capacity, renewable portfolio standard or green-house gas emissions targets, etc.

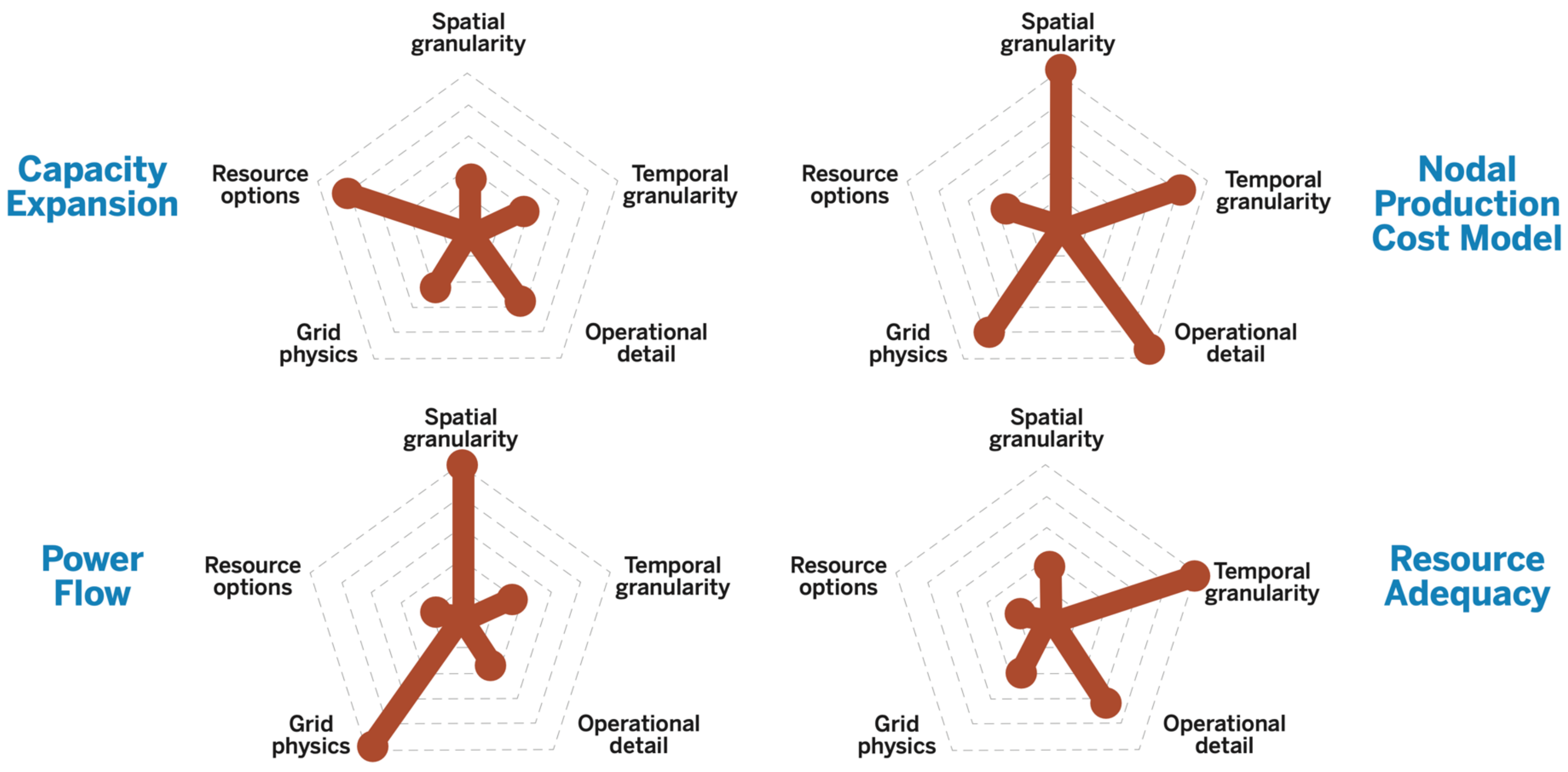
Source: Energy Systems Integration Group.

- Capacity expansion optimization modeling is used in IRP generation planning processes
- Typically set up as a **least-cost** optimization problem
- Generation portfolio outputs meet **reliability, operational, and policy constraints**

Capacity expansion modeling already requires tradeoffs for computational tractability

- **Spatial granularity**: typically zonal, nodal siting addressed in downstream models
- **Temporal granularity**: representative days or weeks from broader datasets
- **Operational detail**: approximations of economic dispatch
- **Grid physics**: limited detail, simple zone-to-zone transfers limits
- **Resource options**: multiple candidate resource technologies (some aggregation, often linear not integer variables)

Level of Detail Captured Across Five Key Dimensions in Various Power System Planning Models

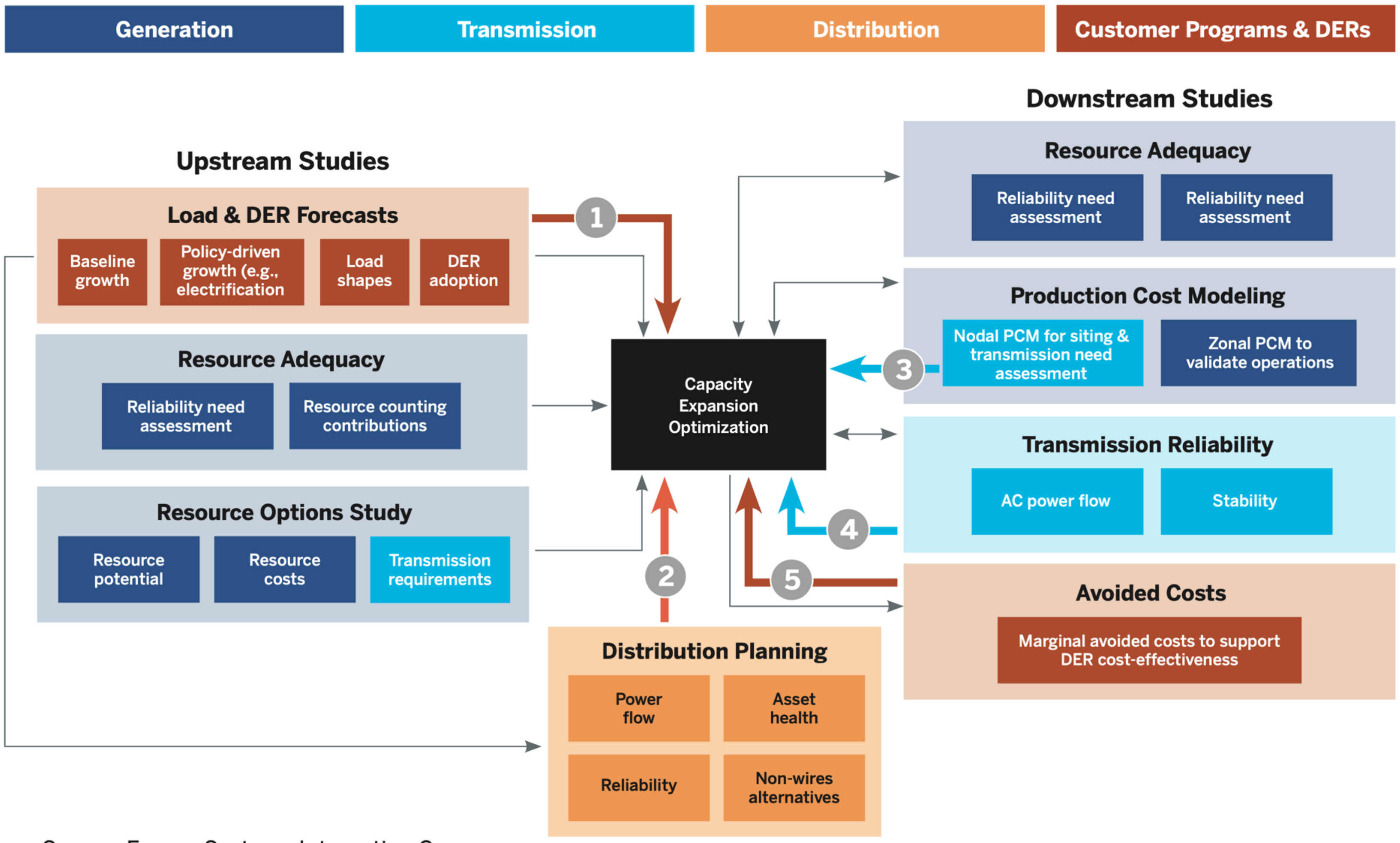


Source: Energy Systems Integration Group.

Integrated planning will require expanding detail in these areas

A broader optimization presents key opportunities

Upstream and Downstream Processes That Inform a Full-System Capacity Expansion Optimization



Source: Energy Systems Integration Group.

1. DERs as resource options
2. Local grid constraints to capture full DER values
3. Bulk grid locational constraints and congestion solutions
4. Transmission reliability needs
5. Consistent valuation of supply + demand side resource options

A broader optimization also presents key challenges

Computational challenges

- Tradeoffs in spatial granularity vs model runtime
- Capturing full distribution system detail is generally intractable in system optimization

Data challenges

- Significant new data development is required, with varying degrees of difficulty, such as:
  - Geospatial load allocation
  - Geospatial resource potential
  - Grid upgrade options and costs
  - DER program “bundling”

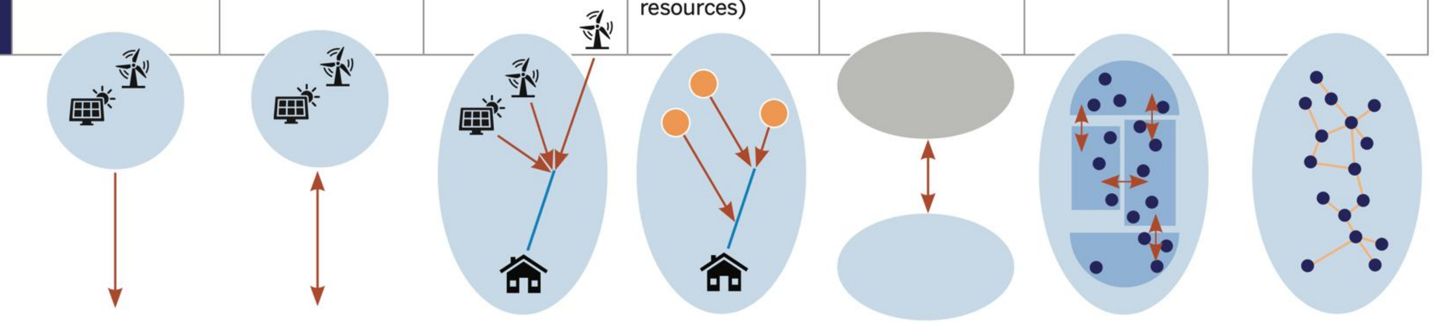
Process challenges

- Overconfidence in specific outcomes
- Real world validation requires additional considerations (risk, uncertainty, feasibility, equity, etc.)
- Multiple decision-making venues for optimal investments

Capacity expansion models are well positioned to co-optimized bulk-grid generation, transmission, and storage

- Resource / transmission zone limits
- Hourly flow constraints
  - Inter- and intra-zonal
  - Nodal

		Integrated Planning Approaches					
			Co-optimization Approaches				
	No integration	Iteration	Resource or transmission zone limits		Hourly flow constraints (pipe and bubble representation)		
	One-way flow	G ⟷ T Iterative Process	Resource-specific constraints	Transmission zones	Inter-zonal	Intra-zonal (aggregated nodes)	Nodal
Capacity expansion model dispatch	Zonal	Zonal	Zonal	Zonal	Inter-zonal	Intra-zonal (aggregation of full network nodes)	Nodal
Capacity expansion model transmission limits	None	None	Resource-level	Transmission zone level (across resources)	Inter-zonal hourly flow	Intra-zonal hourly flow	Nodal hourly flow



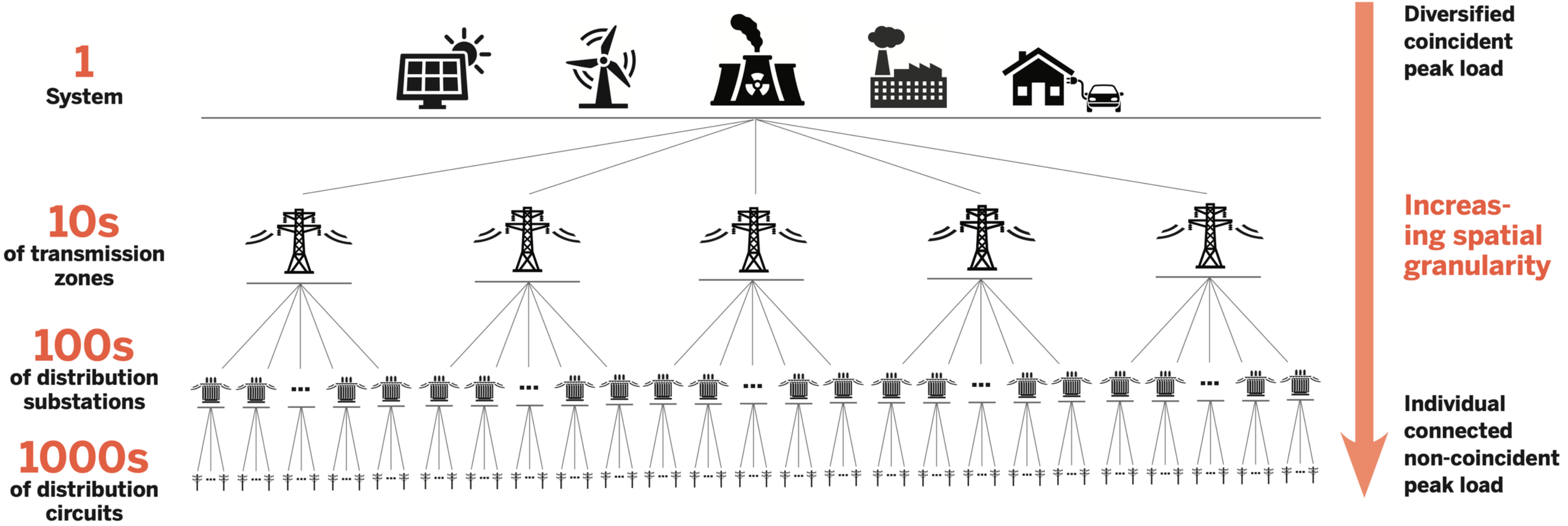
Downstream studies address all transmission needs from capacity expansion resource additions	Downstream studies address all transmission needs from capacity expansion resource additions, but include feedbacks to adjust the generation mix (or siting) based on results	Resource-level limits can vary from interconnection to new tie-lines and are useful for connecting a single resource type	Transmission zone-level limits allow for diversity to maximize utilization (e.g., adding solar, wind, storage together) and transmission studies for major renewable energy	Inter-zonal limits allow for study of large-scale interregional upgrades, including impact on investment and production costs	Intra-zonal limits capture intra-zonal constraints but aggregates nodes to limit data needs and runtime impacts	Nodal representation captures full network model nodal constraints; requires modeling nodal-level dispatch, which vastly increases runtime

Investment Zone — Transmission Investments Options — Transmission Zone — Neighboring Zone — Zones Defined — Node

Source: Energy Systems Integration Group.

The challenge of capturing granular DER location values

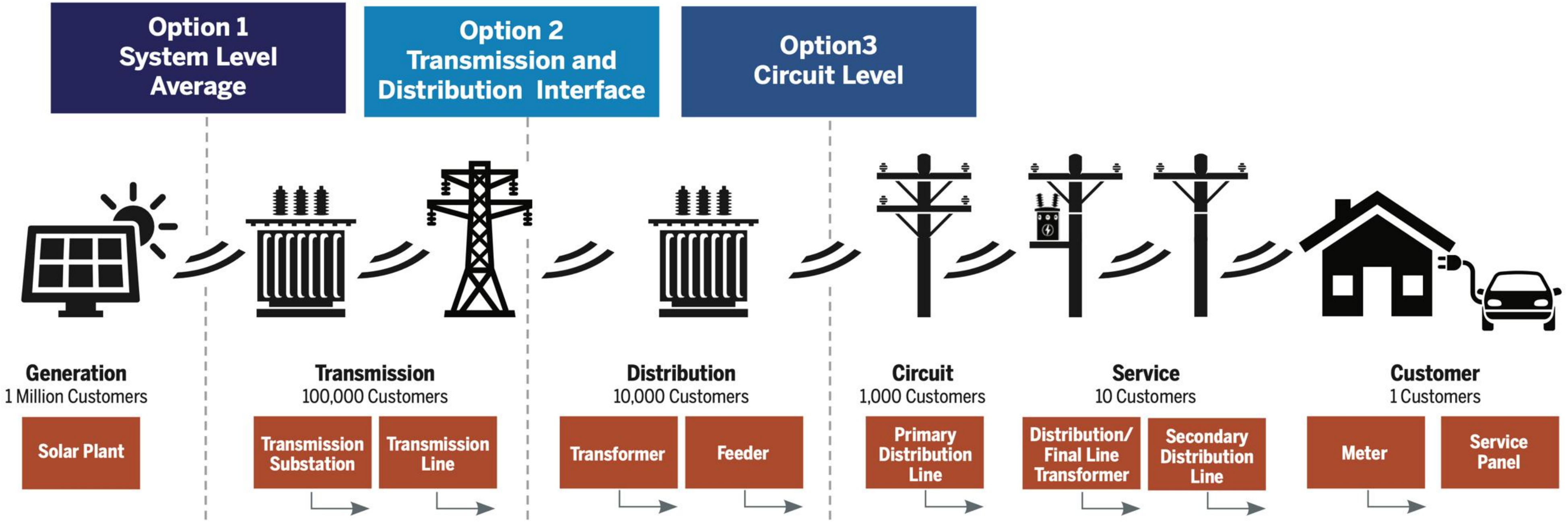
An Example of Relative Scales of a System-Wide Zonal Expansion Problem Versus a Granular Distribution-Level Expansion Problem



It is currently computationally intractable to model detailed distribution grid topology in a system-level optimization because it requires hundreds to thousands of load forecasts and resource zones to model.

Source: Energy Systems Integration Group.

There is a tradeoff between computational tractability and spatial granularity



- Low granularity
- Highly imprecise measure of locational value
- Computationally tractable

e.g., "peanut buttering" of average distribution values

- Medium granularity
- Imprecise measure of locational value
- May be computationally tractable

e.g., transmission and distribution interface L/R dispatch or distribution planning area parameterized locational supply curve.

- High granularity
- Precise measure of locational value
- Computationally intractable

e.g., circuit level L/R dispatch of parameterized locational supply curve

Other potential methods may exist between options 2 and 3, such as grouping of feeders into archetypes

Good/Tractable
Okay/Partially Tractable
Something or Other
Not good/Intractable

Source: Energy Systems Integration Group.

Alternative 1: Marginal hourly avoided costs

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Forecasted Loads and DERs

Capacity Expansion

- **Generation**
- **Transmission**
- **Optimized DER***

Resource portfolio

Production Cost Modeling

Hourly avoided energy and ancillary services

Resource adequacy capacity

Policy value (renewable portfolio standard, greenhouse gas reduction, etc.)

Avoided transmission value

Transmission

- Nodal PCM
- Power flow/stability

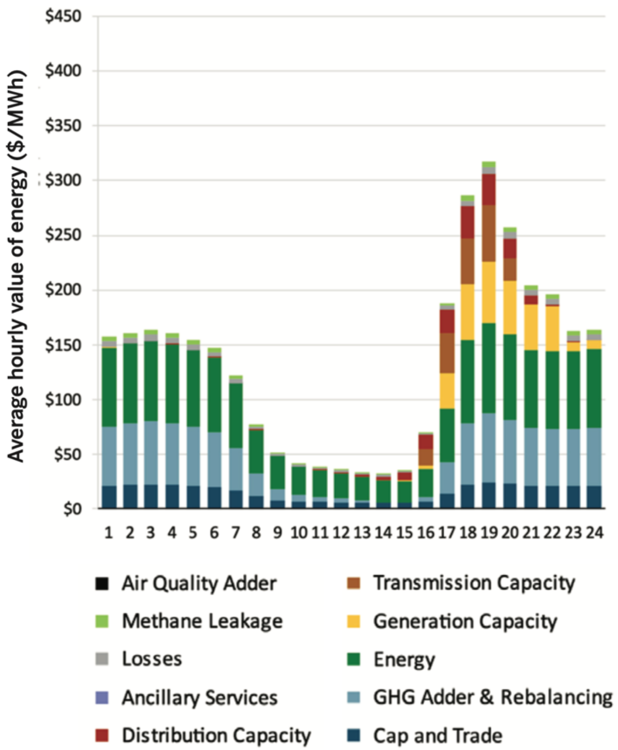
Avoided transmission value (avoidable investments, time periods, marginal costs)

Distribution

- Power flow/reliability
- Non-wires alternatives

Avoided distribution value (avoidable investments, time periods, marginal costs)

Hourly Avoided Costs



DER Cost-Effectiveness and Adoption Models

- Energy efficiency cost-effective portfolio goals
- Distributed generation adoption
- Demand response and flexible load programs

Source: Energy Systems Integration Group.

Alternative 2: Local-grid optimization with bulk-grid avoided costs

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Initial bulk-grid resource plan

Capacity Expansion

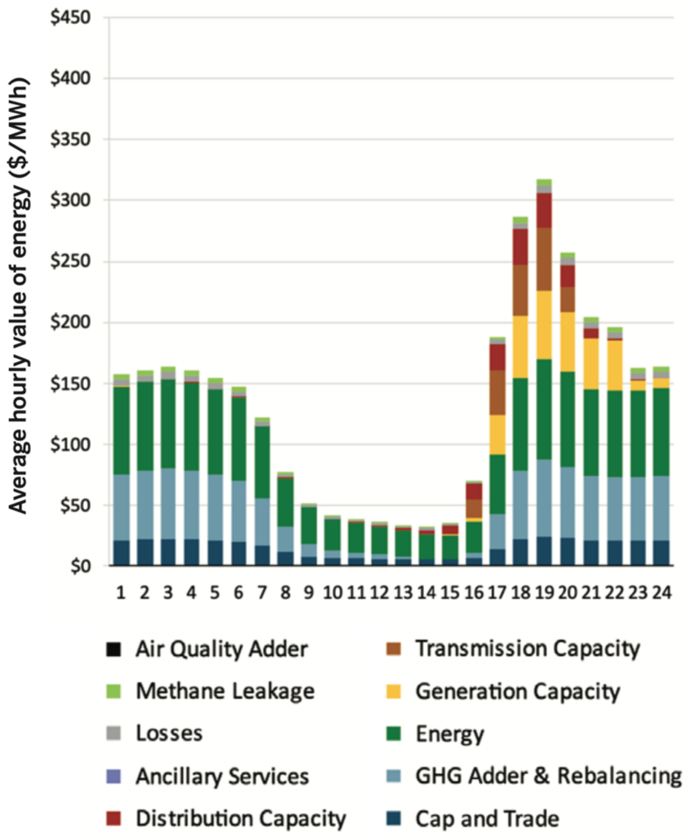
Generation

Transmission

Forecasted and/or Optimized DER

Bulk-grid values and performance requirements, resource adequacy, etc.

Hourly Avoided Costs



Local grid and resource plan

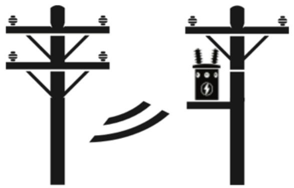
Integrated Distribution System Planning

Substation- or feeder-level economic optimization

Distribution grid investments vs. incremental DER investment or operational changes

Incremental DERs

Distribution



Final bulk-grid resource plan

Final G+T Capacity Expansion

Including initial and incremental DER forecast

Source: Energy Systems Integration Group.

Alternative 3: Bulk-grid + DER optimization with parameterized distribution values

Iterate to converge on balance of distribution grid upgrades and DERs

Forecasted Loads and DERs

Distribution

- Capacity needs assessment
- Non-wires alternatives

Distribution studies identify capacity upgrades that can be deferred by DERs

Can use reduced form analysis, e.g., simplified hourly load/resource balance vs. full power flow modeling.

Calculate Marginal Distribution Grid Value

Step 1. Calculate hourly distribution grid overloads

Step 2. Determine marginal costs to address overloads

Step 3. From 1 and 2, calculate hourly marginal distribution grid avoided costs

Parameterize Distribution Grid Value for DERs

Step 4. Use hourly DER shapes (and/or load flexibility potential) to estimate marginal DER distribution grid values

Step 5. Parameterize DER distribution grid values into tractable capacity expansion inputs, adjusting bulk grid availability accordingly

Parameterization options include aggregation of feeder-level values, creating DER tranches with and without distribution grid value, etc.

Capacity Expansion

- **Generation**
- **Transmission**
- **DERs**

Source: Energy Systems Integration Group.

Designing integrated planning processes to complement decision-making processes

1. **Process alignment**
   - Align planning and decision making
2. **Process consolidation**
   - Combine processes or regulatory proceedings to increase efficiency for planners, stakeholders, and decision makers
3. **Organizational restructuring**
   - Ensure business structure aligns with efficient planning and decision-making
4. **Use of pilot projects to validate novel approaches**
   - Between planning processes validate value stacking and other new opportunities with real-world data

> Even if a comprehensive value-stacked solution is identified in an integrated planning process, there can be important real-world barriers to feasibly implementing that solution. Without solutions to overcome some of the decision-making barriers, integrated planning analyses may be limited in the scope of investments they can ultimately secure.

Moving towards a more integrated analytical approach

Walk

The *Walk* Phase of Full-System Capacity Expansion Modeling of the Electricity System
Convene the leaders of all involved planning organizations to align objectives and determine the overall goals of an integrated planning process
Review existing planning processes to identify existing gaps within—or between—processes
Align key inputs, assumptions, and scenarios across planning processes

Jog

The *Jog* Phase of Full-System Capacity Expansion Modeling of the Electricity System
Data and Model Development
Create new data needed for integrated planning including enhanced spatial granularity of load and DER forecasts, enhanced spatial resolution of candidate resource options, and candidate grid upgrades as investment options
Build new modeling capabilities including making generation and transmission co-optimization a standard practice
Process Refinement
Create an integrated planning process through which these new data can be incorporated into expanded models and decision-making processes
Carefully examine and potentially refine planning and decision-making processes
Increase the planning horizon of distribution planning processes, identify locationally defined grid needs, use hourly data to identify hourly overload amounts, and identify marginal distribution system costs

Run

The *Run* Phase of Full-System Capacity Expansion Modeling of the Electricity System
Consider DER co-optimization or iterative processes for DER and customer program planning that ensure consistent valuation of supply- and demand-side resources
Consider locational grid needs and related DER investment opportunities, such as distribution deferral
Use a comprehensive avoided-cost framework to inform retail rate design and align customer incentives with grid needs