Foundations of Integrated Planning

Defining a Framework for Comprehensive Energy System Planning

ESIG
ENERGY SYSTEMS
INTEGRATION GROUP

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Foundation paper components

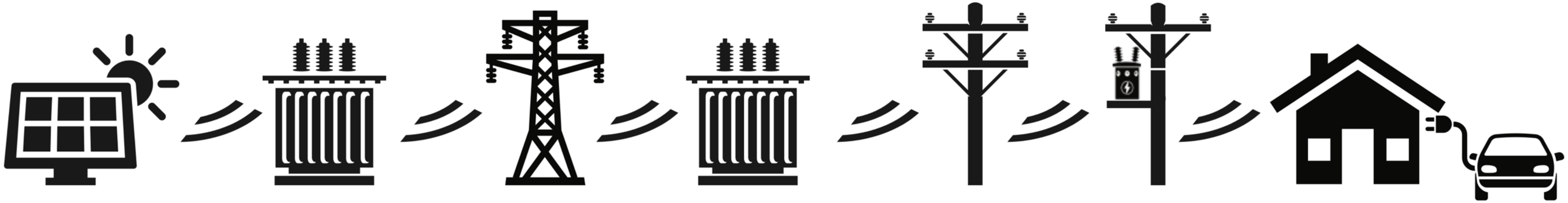
Sets the foundations for the why/what/how of integrated planning

- **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

- 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

- 10-20+ year IRP
- Requests for proposals

Transmission

- 5-15 year horizon
- Interconnection studies

Distribution

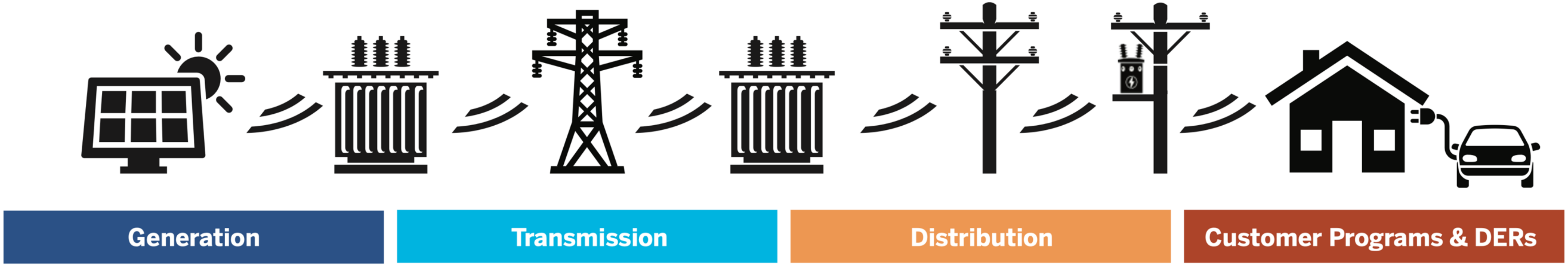
- 3- to 10-year studies

Customer Programs & DERs

- 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

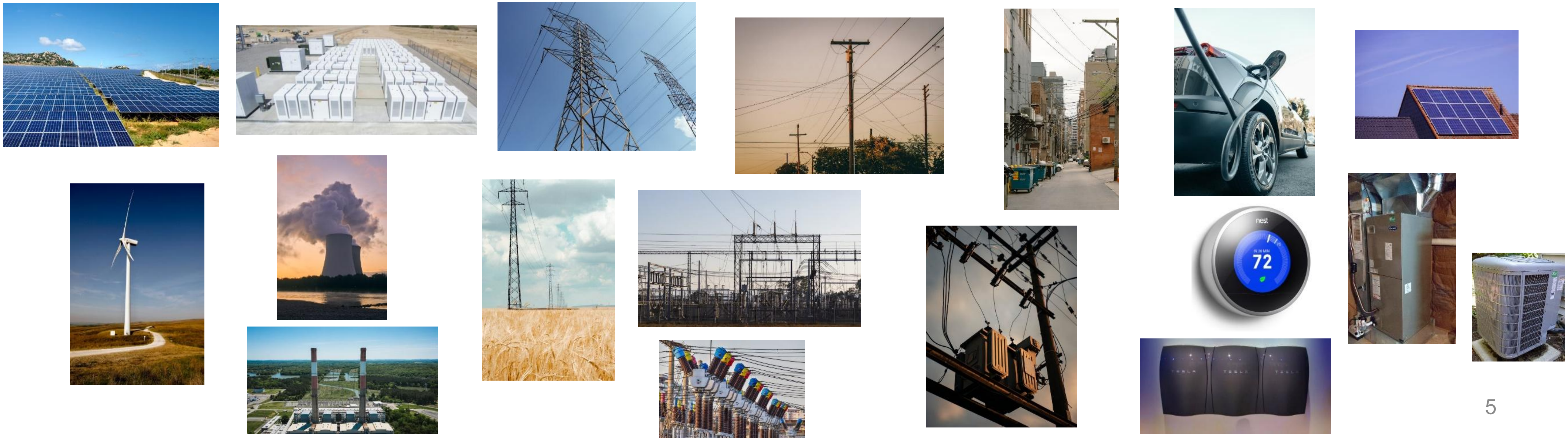


Generation

Transmission

Distribution

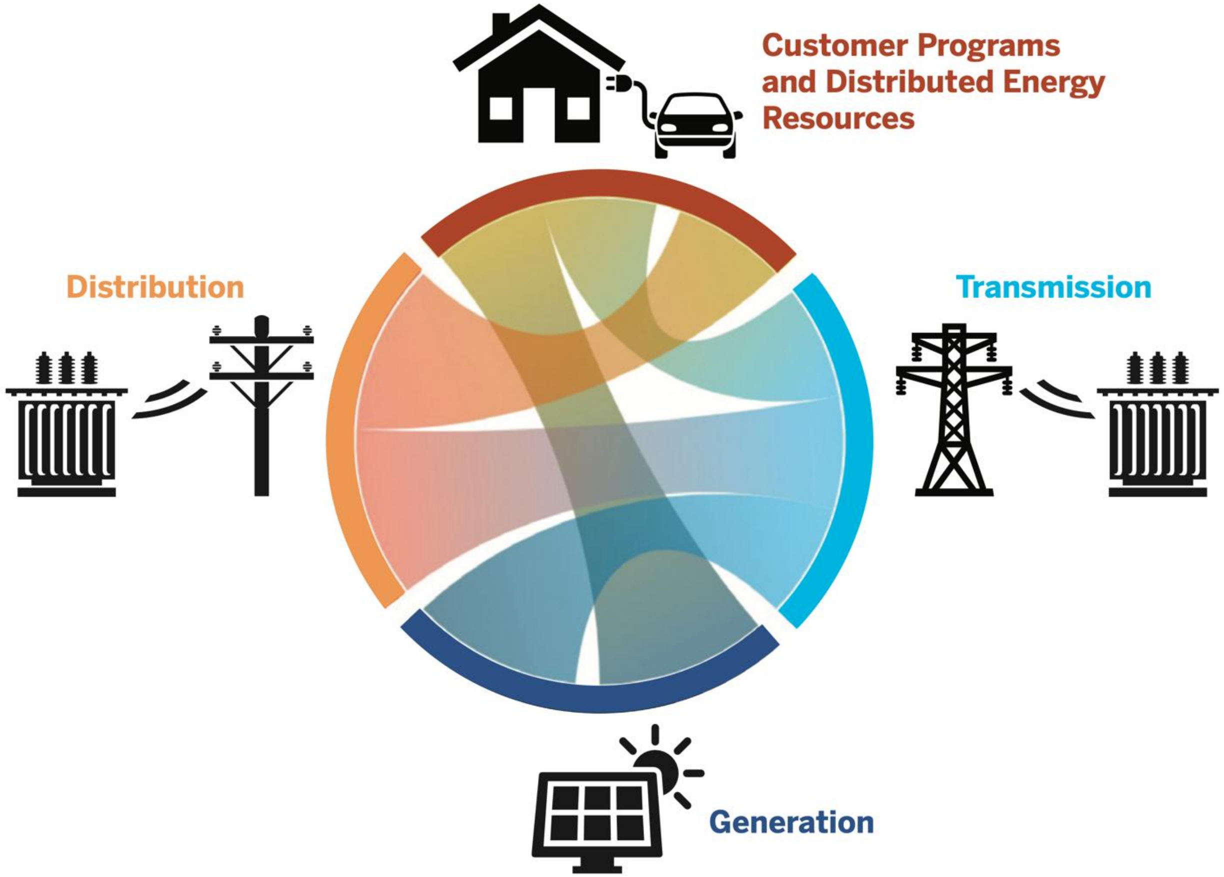
Customer Programs & DERs



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

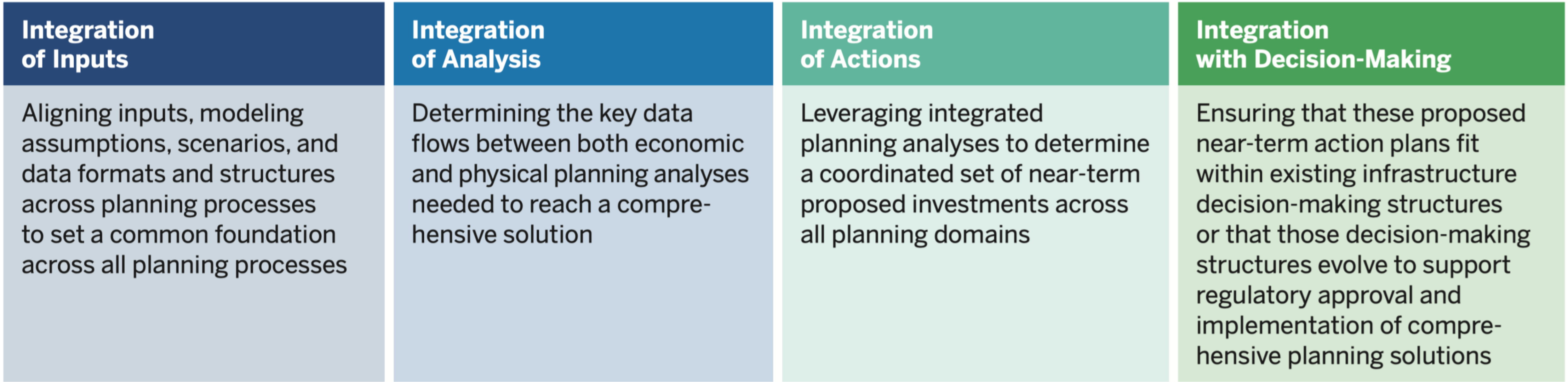
Integrated solutions for grid needs

Lower total system costs

Identification and validation of “value-stacking” opportunities

Source: Energy Systems Integration Group.

Four pillars of ESIG's integrated planning framework



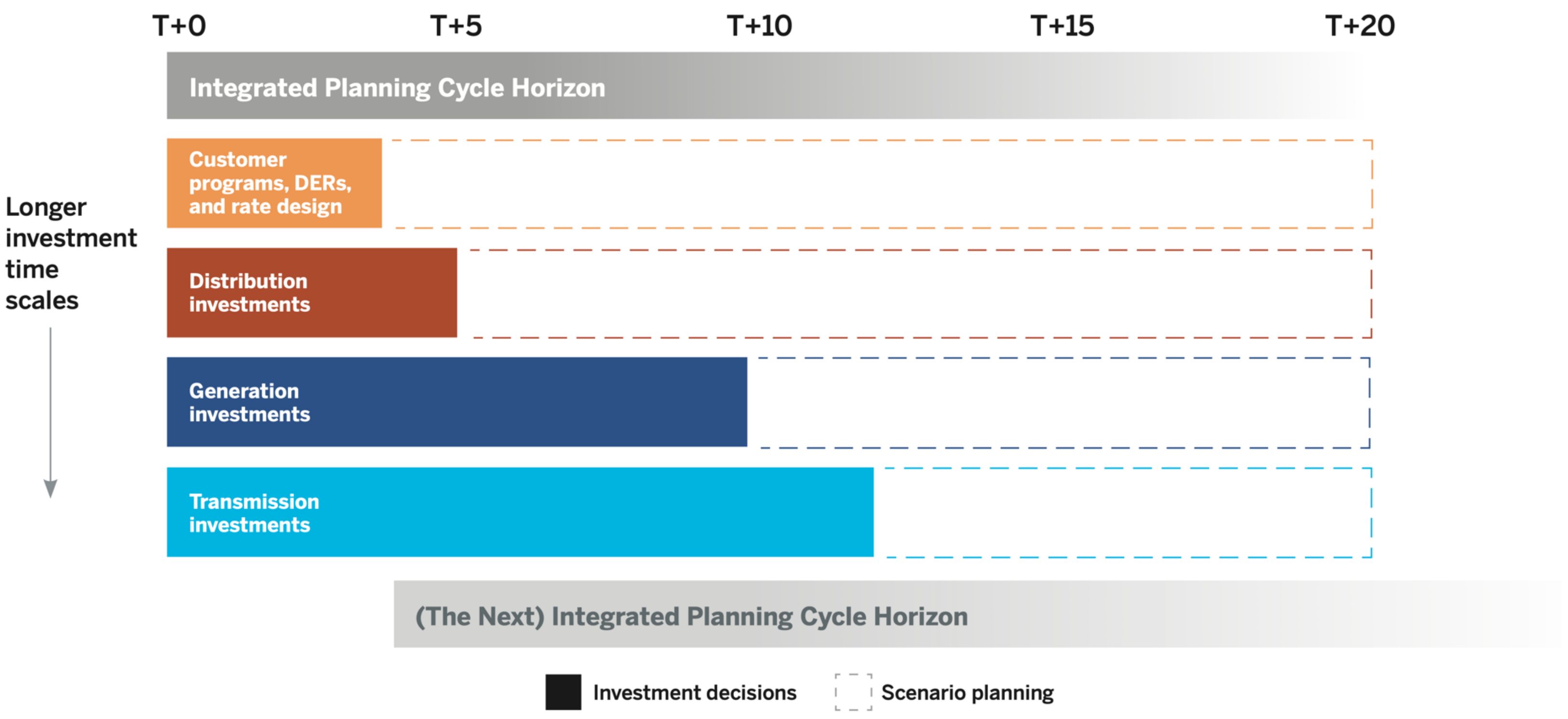
Integration of Inputs	Integration of Analysis	Integration of Actions	Integration with Decision-Making
Aligning inputs, modeling assumptions, scenarios, and data formats and structures across planning processes to set a common foundation across all planning processes	Determining the key data flows between both economic and physical planning analyses needed to reach a comprehensive 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 comprehensive 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



T+0 T+5 T+10 T+15 T+20

Integrated Planning Cycle Horizon

Longer investment time scales

Customer programs, DERs, and rate design

Distribution investments

Generation investments

Transmission investments

(The Next) Integrated Planning Cycle Horizon

■ Investment decisions ⬚ Scenario planning

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.

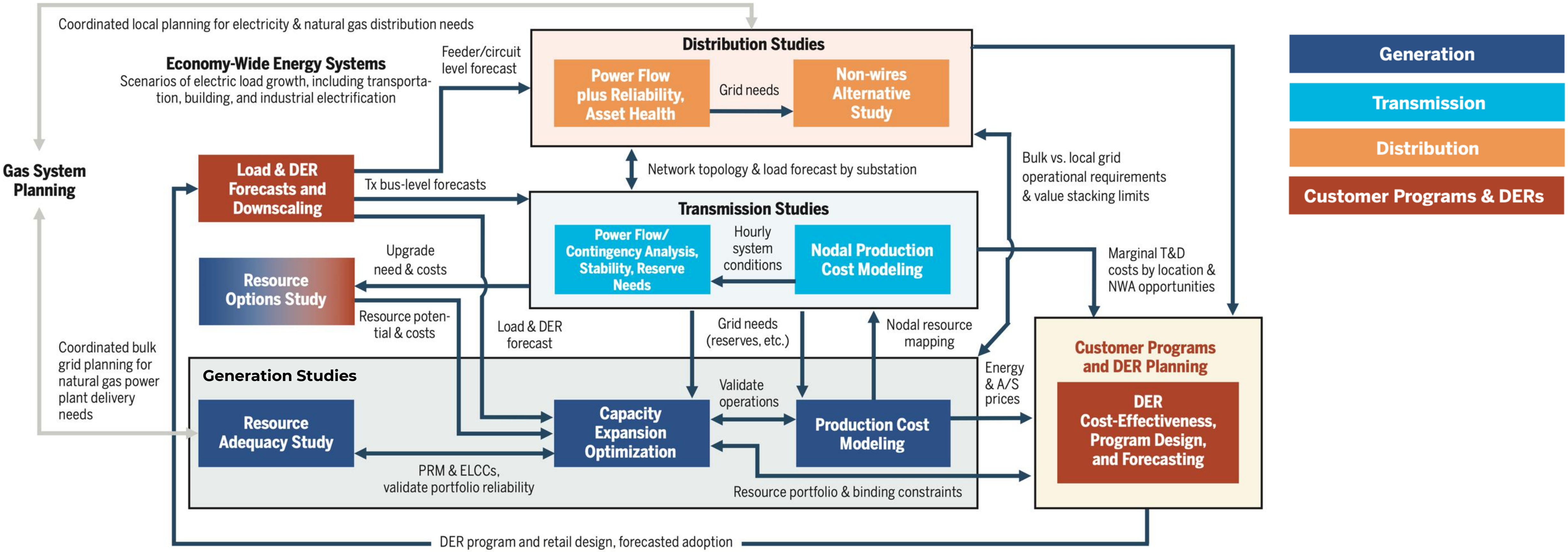
Integration of analysis

- **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



Coordinated local planning for electricity & natural gas distribution needs

Economy-Wide Energy Systems
Scenarios of electric load growth, including transportation, building, and industrial electrification

Feeder/circuit level forecast

Distribution Studies

Power Flow plus Reliability, Asset Health

Grid needs

Non-wires Alternative Study

Gas System Planning

Load & DER Forecasts and Downscaling

Tx bus-level forecasts

Network topology & load forecast by substation

Bulk vs. local grid operational requirements & value stacking limits

Transmission Studies

Power Flow/ Contingency Analysis, Stability, Reserve Needs

Hourly system conditions

Nodal Production Cost Modeling

Marginal T&D costs by location & NWA opportunities

Upgrade need & costs

Resource Options Study

Resource potential & costs

Load & DER forecast

Grid needs (reserves, etc.)

Nodal resource mapping

Coordinated bulk grid planning for natural gas power plant delivery needs

Generation Studies

Resource Adequacy Study

Capacity Expansion Optimization

Validate operations

Production Cost Modeling

Energy & A/S prices

Customer Programs and DER Planning

DER Cost-Effectiveness, Program Design, and Forecasting

PRM & ELCCs, validate portfolio reliability

Resource portfolio & binding constraints

DER program and retail design, forecasted adoption

Generation

Transmission

Distribution

Customer Programs & DERs

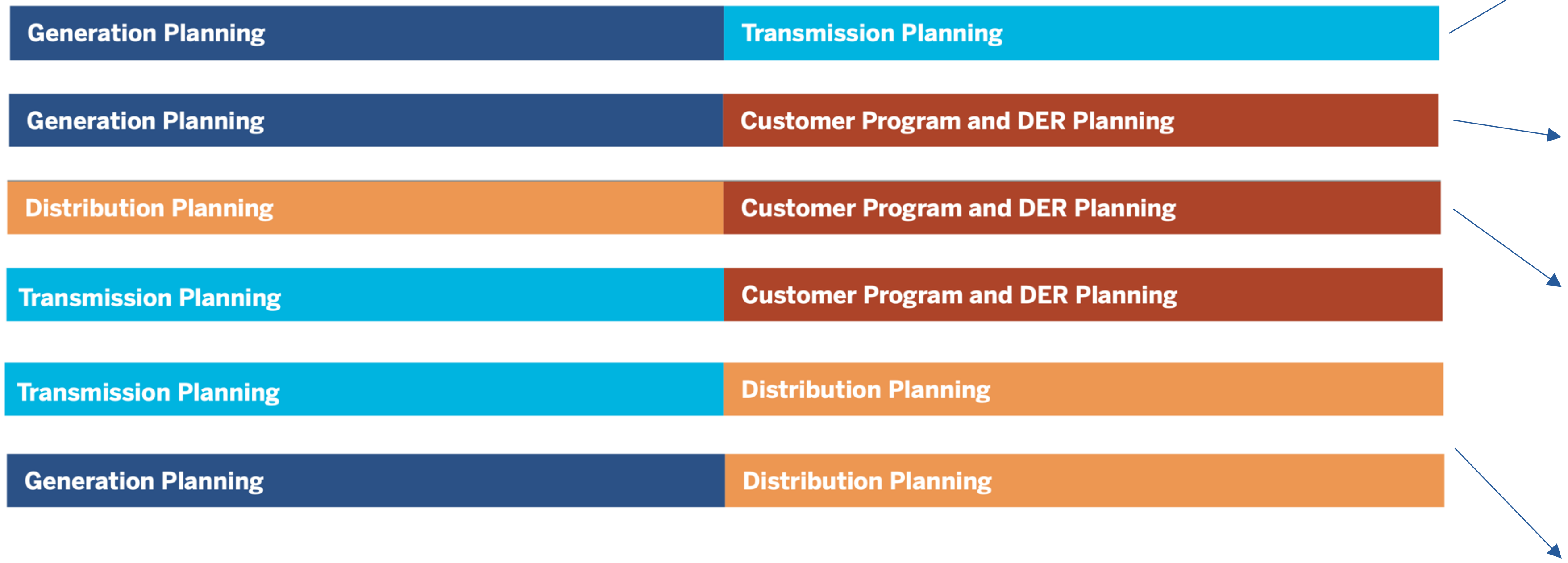
Notes: A/S = ancillary service; DER = distributed energy resource; ELCC = effective load-carrying capability; NWA = non-wires alternative; PRM = planning reserve margin; Tx = transmission; T&D = transmission and distribution

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



Examples

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

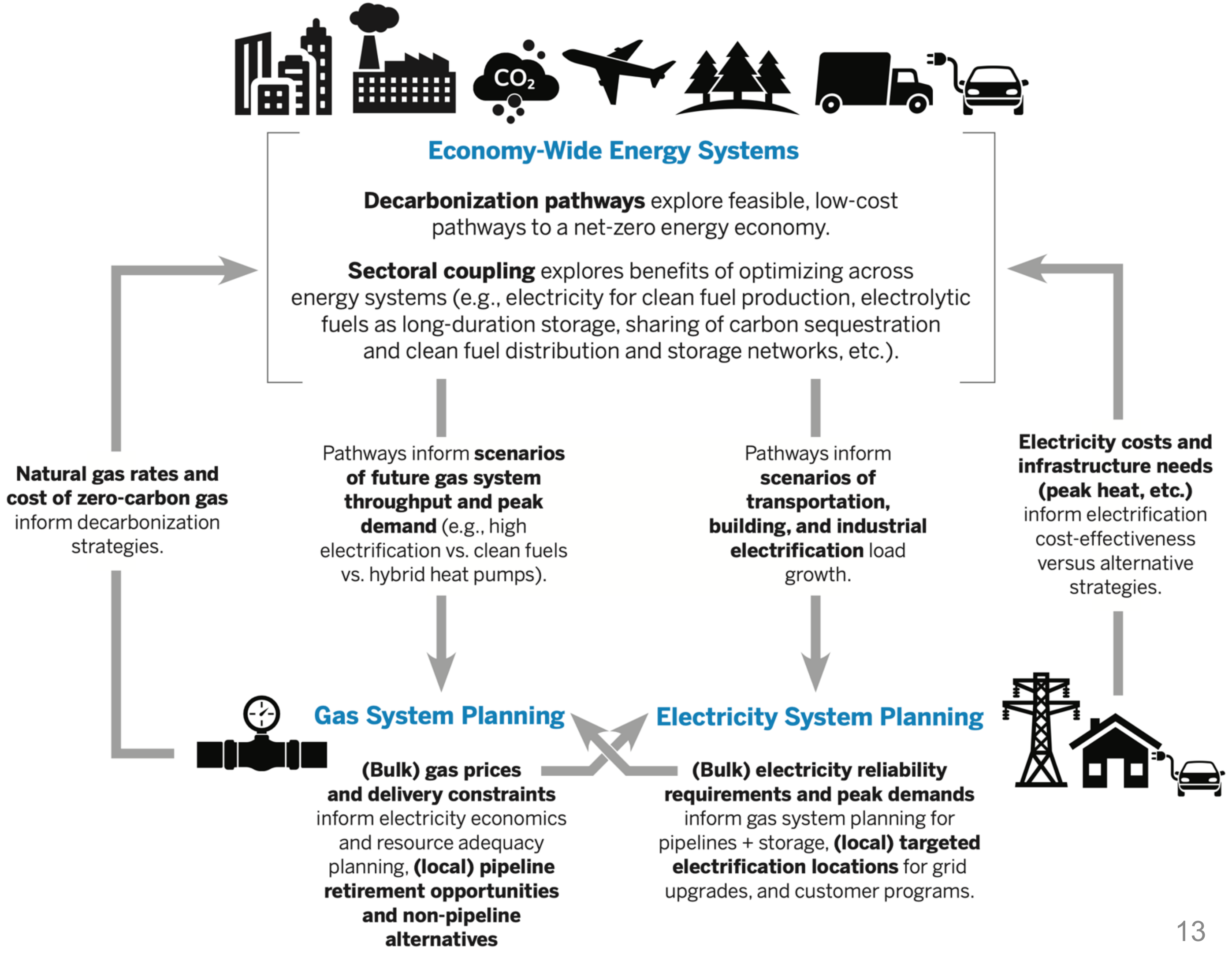
Load forecasts** are informed by **economywide energy system studies** and are aligned across G/T/D planning with appropriate levels of **geospatial allocation

***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



Economy-Wide Energy Systems

Decarbonization pathways explore feasible, low-cost pathways to a net-zero energy economy.

Sectoral coupling explores benefits of optimizing across energy systems (e.g., electricity for clean fuel production, electrolytic fuels as long-duration storage, sharing of carbon sequestration and clean fuel distribution and storage networks, etc.).

Natural gas rates and cost of zero-carbon gas inform decarbonization strategies.

Pathways inform **scenarios of future gas system throughput and peak demand** (e.g., high electrification vs. clean fuels vs. hybrid heat pumps).

Pathways inform **scenarios of transportation, building, and industrial electrification** load growth.

Electricity costs and infrastructure needs (peak heat, etc.) inform electrification cost-effectiveness versus alternative strategies.

Gas System Planning

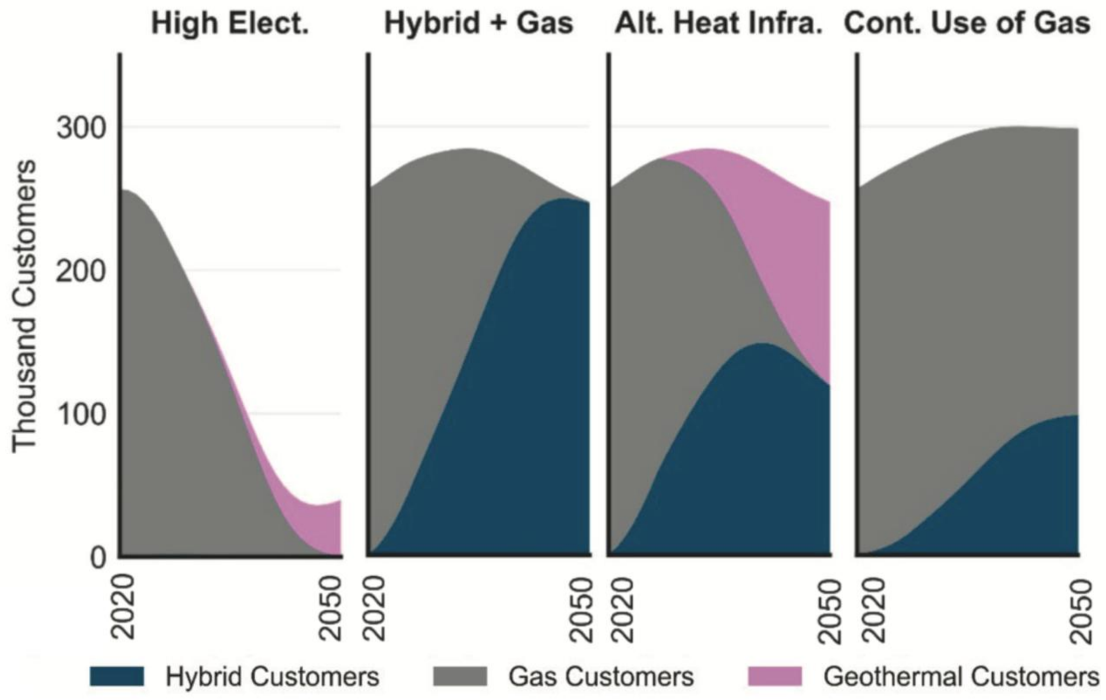
(Bulk) gas prices and delivery constraints inform electricity economics and resource adequacy planning, **(local) pipeline retirement opportunities and non-pipeline alternatives**

Electricity System Planning

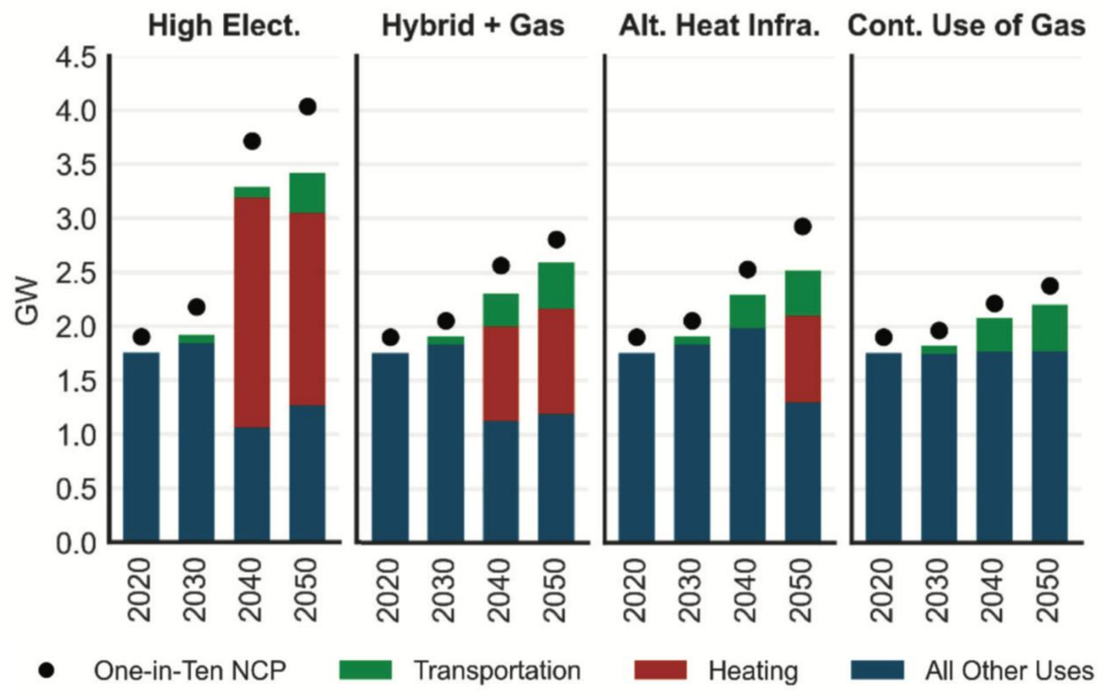
(Bulk) electricity reliability requirements and peak demands inform gas system planning for pipelines + storage, **(local) targeted electrification locations** for grid upgrades, and customer programs.

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…

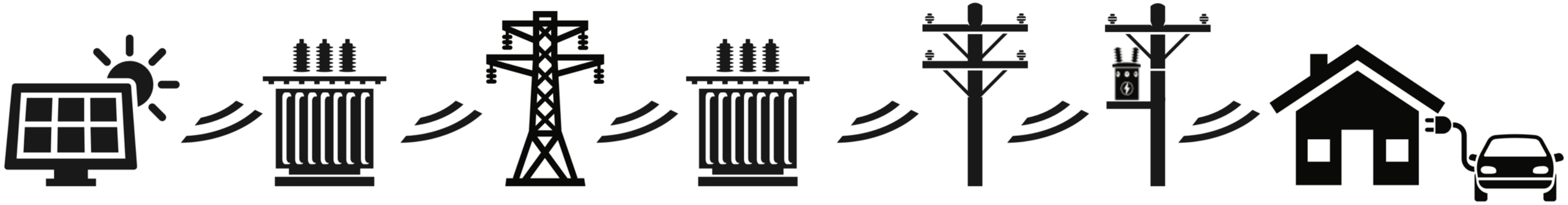


…and electricity peak demand needs for generation, transmission, and distribution infrastructure

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 proposals
- Requests for proposals targeted by location

Transmission action plan

- Transmission asset investments
- 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 solicitations

Customer/DER programs and rates action plan

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

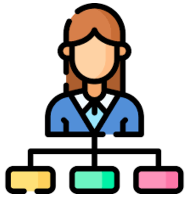
Plus pilot programs to validate planning assumptions (technology pilots, commercial pilots, operational pilots, etc.)

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

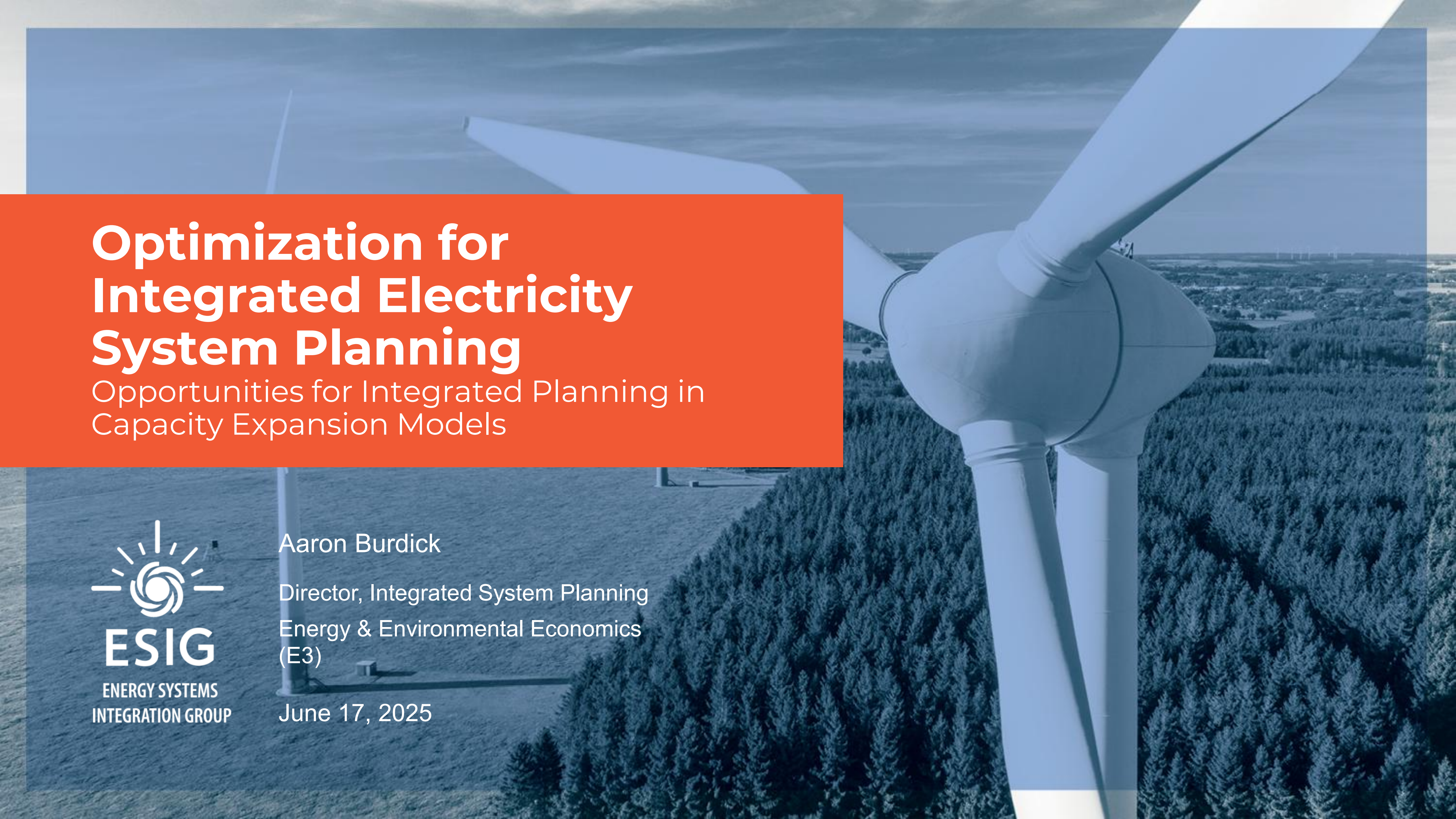
Getting started

Walk

Jog

Run

- 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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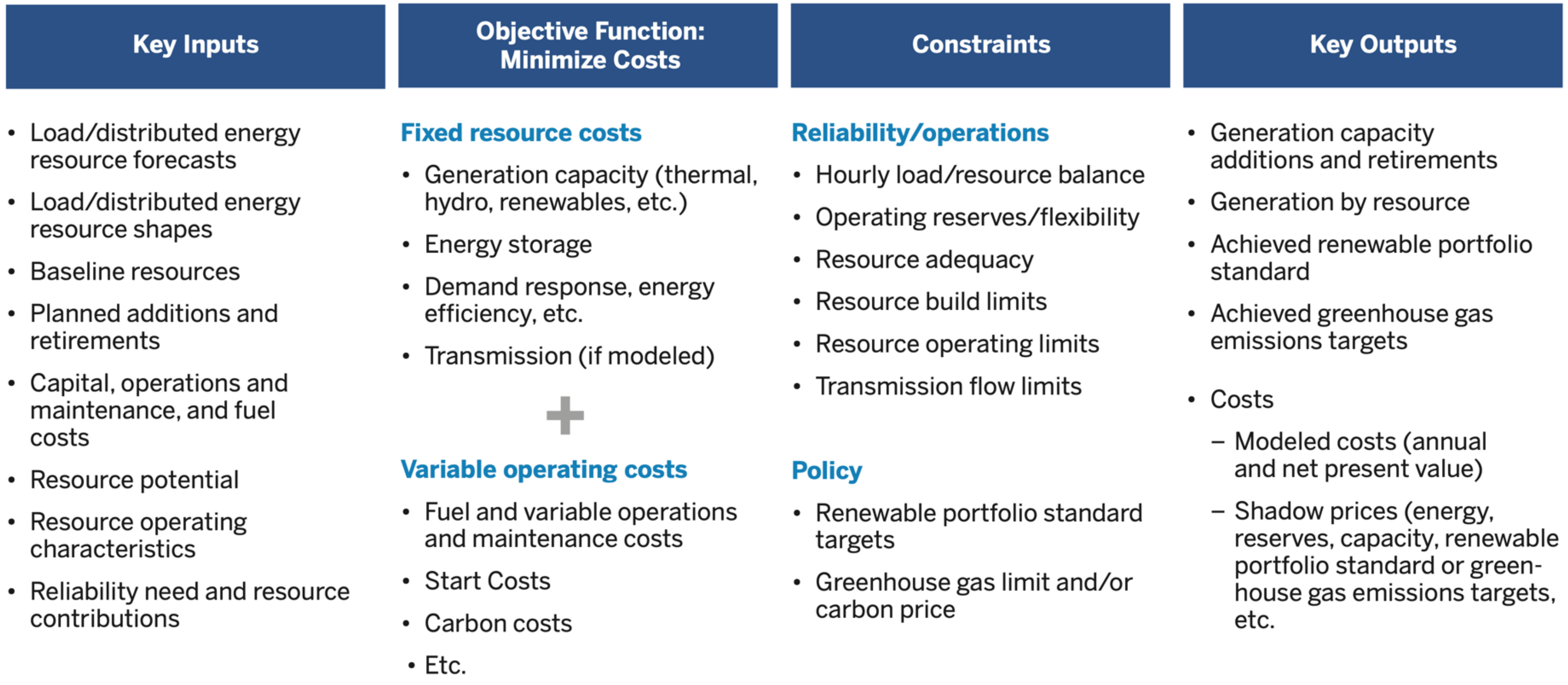
Optimization paper components

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 greenhouse gas emissions targets, etc.

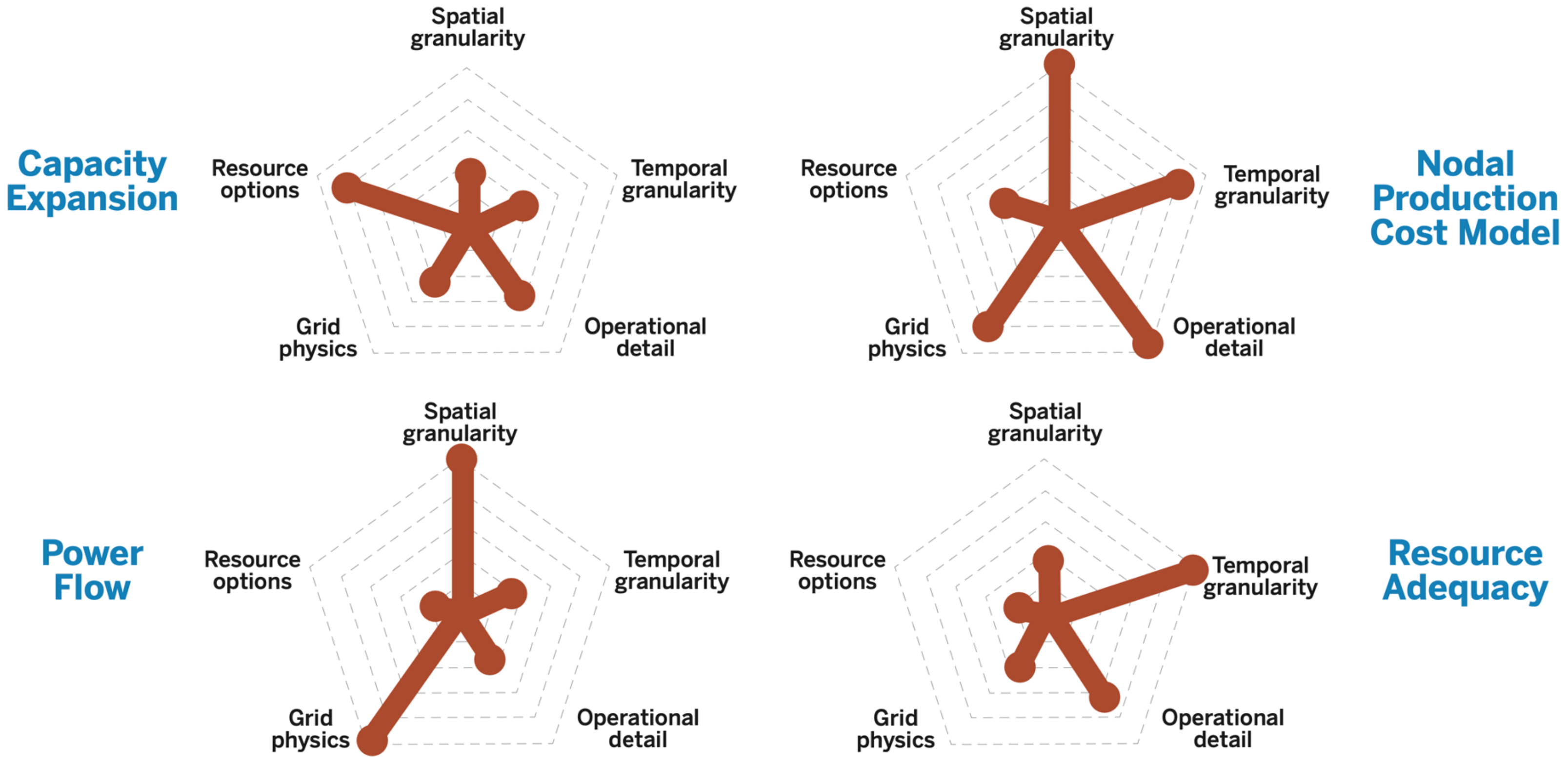
Source: Energy Systems Integration Group.

- 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

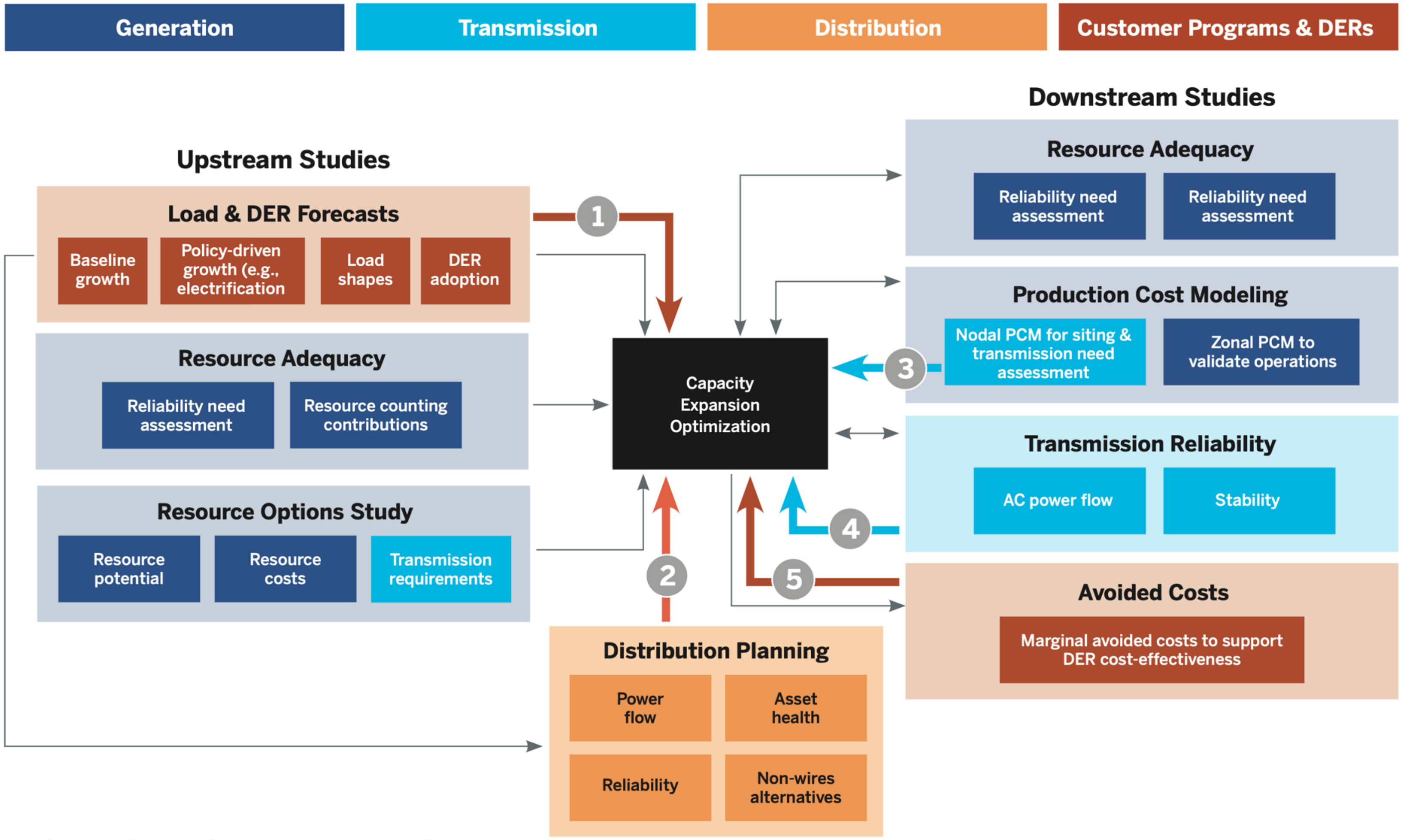


Source: Energy Systems Integration Group.

☐ *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



Generation **Transmission** **Distribution** **Customer Programs & DERs**

Upstream Studies

Load & DER Forecasts
Baseline growth
Policy-driven growth (e.g., electrification)
Load shapes
DER adoption

Resource Adequacy
Reliability need assessment
Resource counting contributions

Resource Options Study
Resource potential
Resource costs
Transmission requirements

Capacity Expansion Optimization

Distribution Planning
Power flow
Asset health
Reliability
Non-wires alternatives

Downstream Studies

Resource Adequacy
Reliability need assessment
Reliability need assessment

Production Cost Modeling
Nodal PCM for siting & transmission need assessment
Zonal PCM to validate operations

Transmission Reliability
AC power flow
Stability

Avoided Costs
Marginal avoided costs to support DER cost-effectiveness

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”

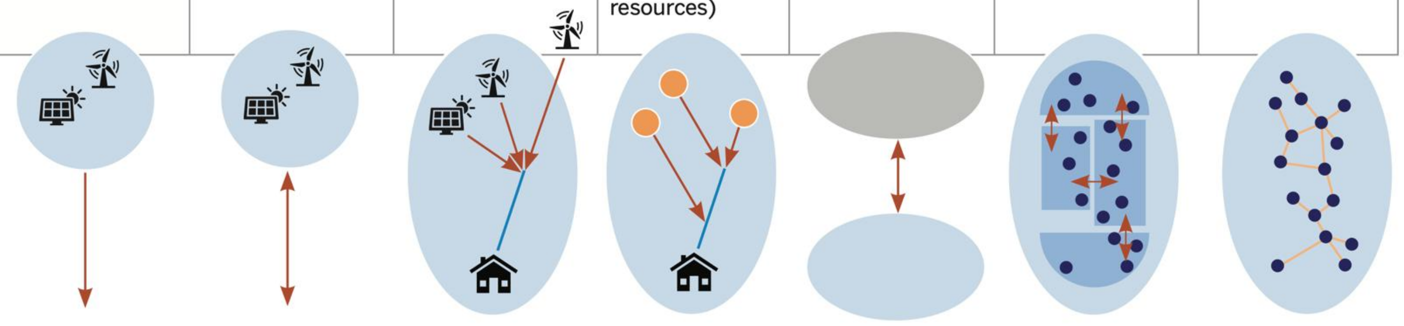
Process challenges

- 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

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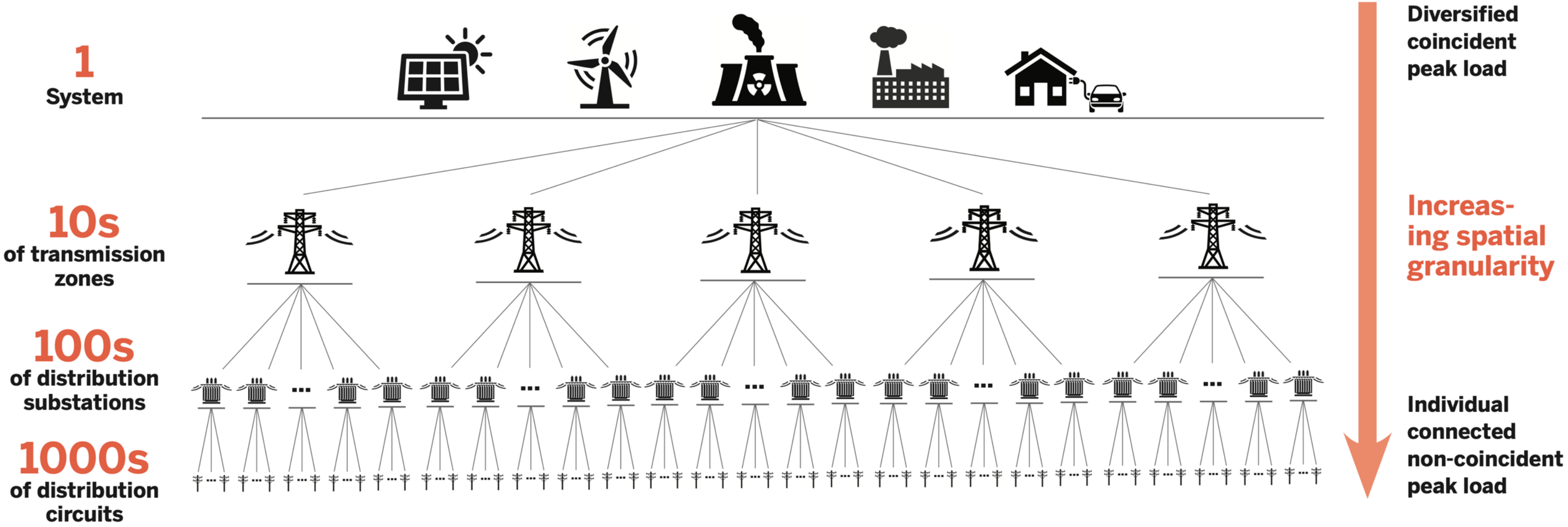
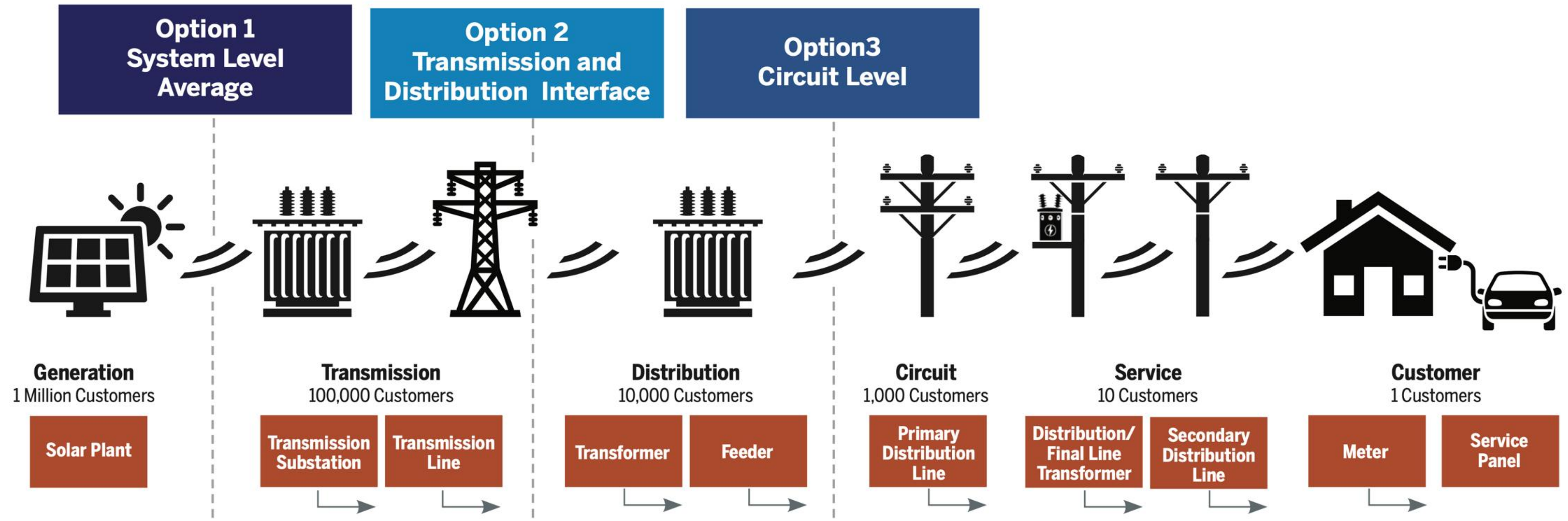
An Example of Relative Scales of a System-Wide Zonal Expansion Problem Versus a Granular Distribution-Level Expansion Problem



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



Option 1
System Level Average

Option 2
Transmission and Distribution Interface

Option3
Circuit Level

Generation
1 Million Customers
Solar Plant

Transmission
100,000 Customers
Transmission Substation
Transmission Line

Distribution
10,000 Customers
Transformer
Feeder

Circuit
1,000 Customers
Primary Distribution Line

Service
10 Customers
Distribution/ Final Line Transformer
Secondary Distribution Line

Customer
1 Customers
Meter
Service Panel

- **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**

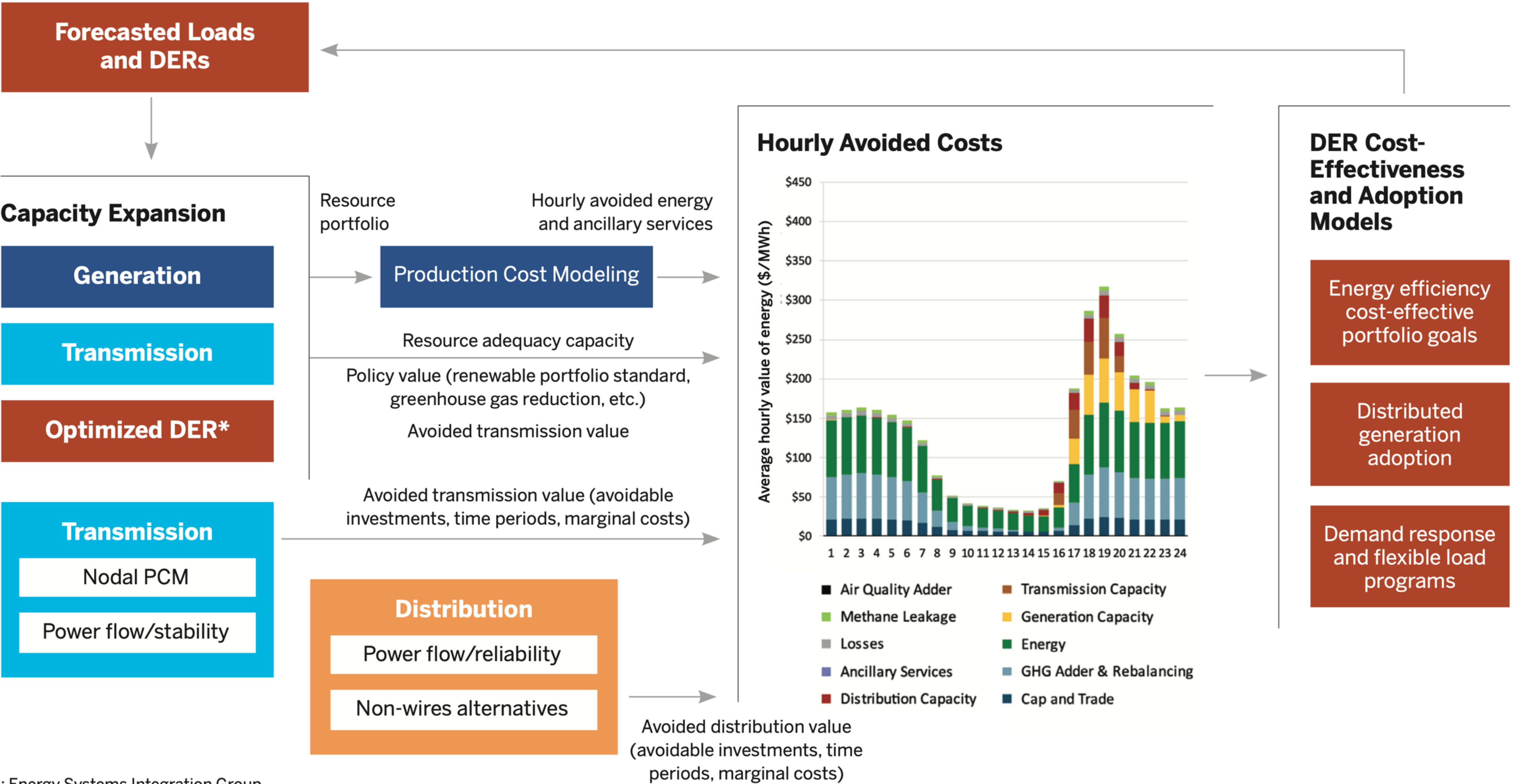
e.g., circuit level L/R dispatch of parameterized locational supply curve

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



Forecasted Loads and DERs

Capacity Expansion

Generation

Transmission

Optimized DER*

Resource portfolio

Hourly avoided energy and ancillary services

Production Cost Modeling

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

Initial bulk-grid resource plan

Capacity Expansion

Generation

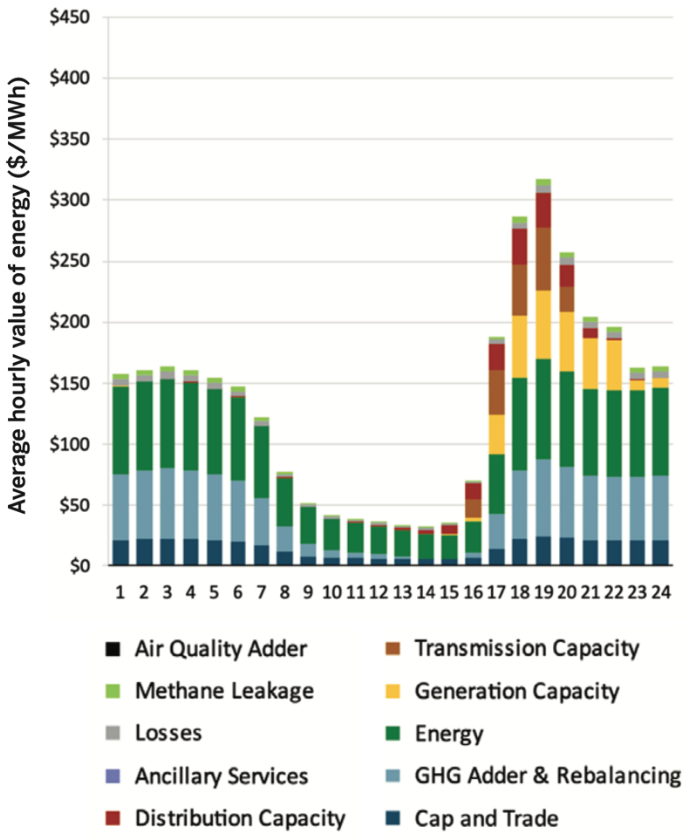
Transmission

Forecasted and/or Optimized DER

→

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

Hourly Avoided Costs



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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

→

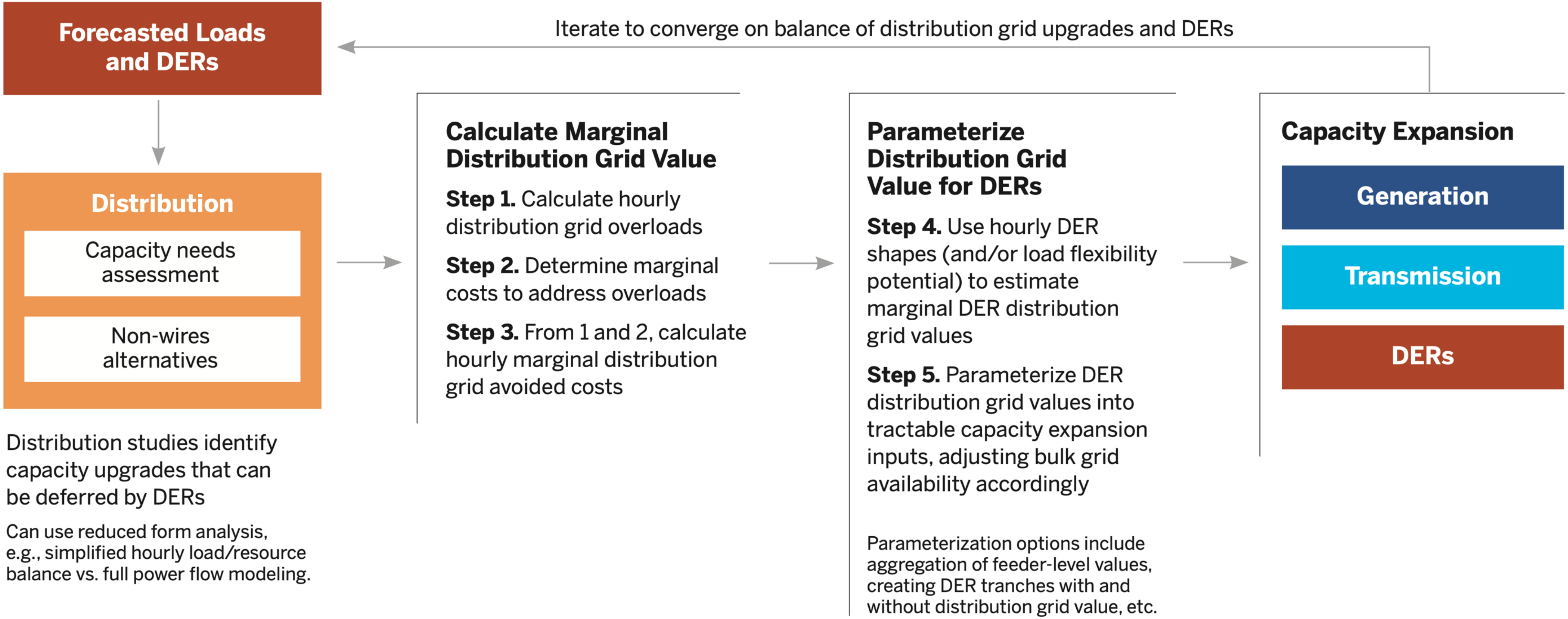
Final bulk-grid resource plan

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