The **GridPath** Electricity Modeling Platform

Advanced Software for Power-System Planning

Ana Mileva

Blue Marble Analytics

Ranjit Deshmukh

University of California,
Santa Barbara

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Blue Marble Team

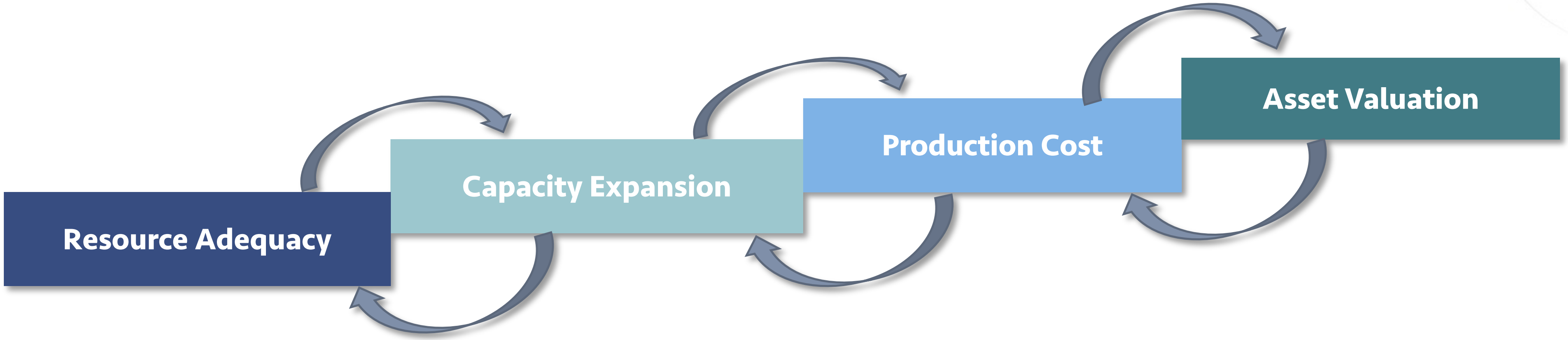
Dr. Ana Mileva is the founder of Blue Marble Analytics and the primary architect of the GridPath platform. Previously a consultant at E3, Ana was the lead developer of the RESOLVE model, now used widely for resource planning. She has wide-ranging experience consulting for utilities, government agencies, NGOs, and developers.

Dr. Ranjit Deshmukh is an Assistant Professor in the Environmental Studies department at UCSB and a faculty scientist at LBNL. Ranjit's research interests lie at the intersection of energy, environment, and economics, specifically in low-carbon energy systems, electricity markets, and clean energy access.

Gerrit De Moor is an expert in integrated resource planning, renewable integration, and system reliability modeling. In his previous role at (E3), he was one of the main contributors to the development of E3's production simulation, capacity expansion planning, and resource adequacy tools.

GridPath in Detail

GridPath is an open-source modeling ecosystem that enables faster and more technically sophisticated planning for the clean energy transition.


Resource Adequacy

Capacity Expansion

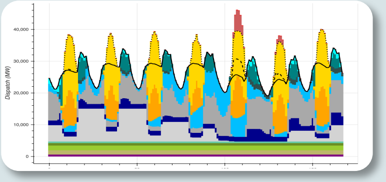
Production Cost

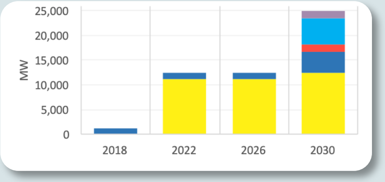
Asset Valuation

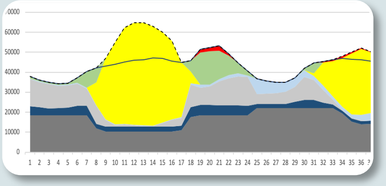
GridPath’s modular architecture enables:

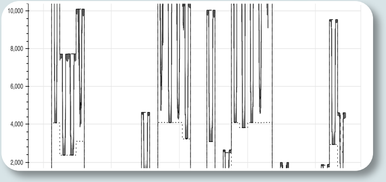
A seamless interface between different modeling approaches	**Varying levels of complexity**	**Extensibility and adaptability**
Reduces the labor-intensive data-translation requirements across applications	User has flexibility to include or exclude features easily User-defined granularity levels for modeling	Novel functionality can be added quickly and seamlessly to tackle new questions about an evolving, decarbonizing grid

GridPath Functionality









Production Cost

Detailed operations of a specified power system over a short period

Multi-stage unit commitment and dispatch at subhourly temporal resolution

High-fidelity operations (e.g. heat-rate curves, minimum up and down times, startup trajectories for generators; DC power flow for transmission)

Capacity Expansion

Investment in new infrastructure over a long period

Simplified modeling of system operations

Lower temporal resolution

Simplified and/or aggregated representation of generation and transmission

Resource Adequacy

Loss of load probability and capacity needs

Monte Carlo simulation of low-resolution system dispatch over many conditions

Simplified and/or aggregated representation of generation and transmission

Asset Valuation

Market performance of set of assets

Detailed operations of an asset or a set of assets

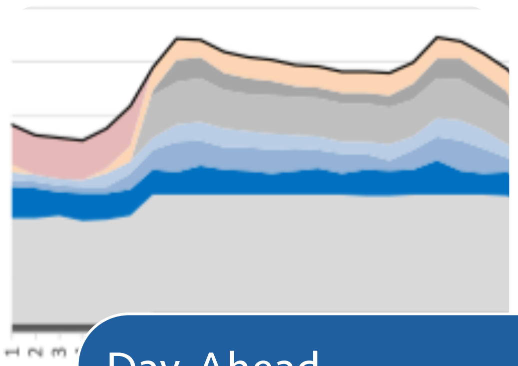
Price-taker with exogenous energy and/or A/S price streams

Production-Cost Simulation with GridPath

Multi-Stage Unit-Commitment and Dispatch

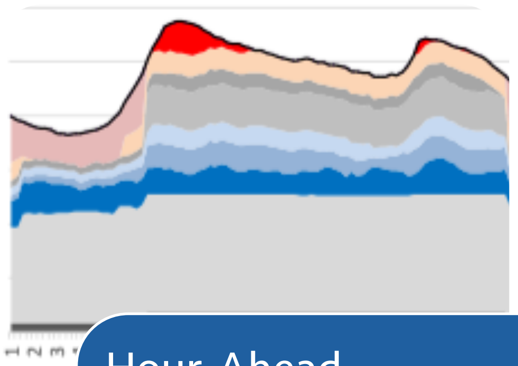
Multi-stage unit-commitment and dispatch with flexible temporal span and resolution

✓ Can understand system operations and impact of fixed commitment decisions and forecast error



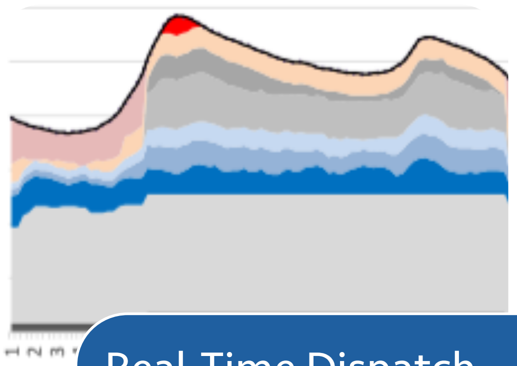
Day-Ahead Commitment

- Generator commitment schedules based on day-ahead load and renewable forecasts (e.g. hourly)
- Contingency, load-following, and regulation reserves



Hour-Ahead Commitment

- Residual generator commitment schedules based on hour-ahead load and renewable forecasts (e.g. 15-minute)
- Contingency, load-following, and regulation reserves



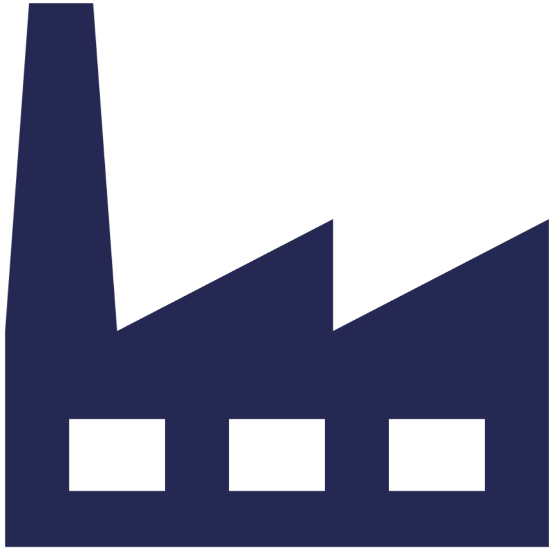
Real-Time Dispatch

- Actual load and renewable output (e.g. 5-minute)
- Contingency and regulation reserves
- Load-following reserves allowed to dispatch to compensate for net load forecast error

Generator Representation

Generators modeled with a high level of operational fidelity

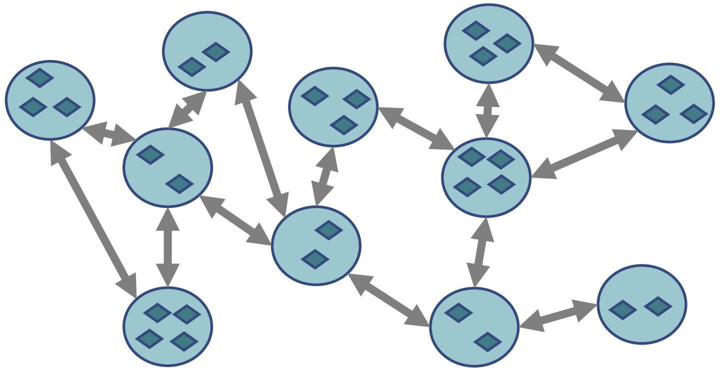
- Heat rate curves
- Minimum up and down times
- Ramp rates
- Start costs by cooling state
- Startup and shutdown trajectories

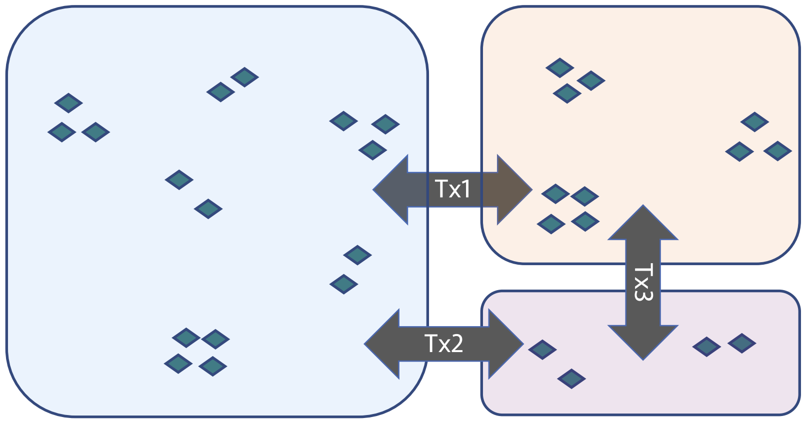


Simplified formulations also possible

Transmission Representation

Zonal or nodal topographies possible

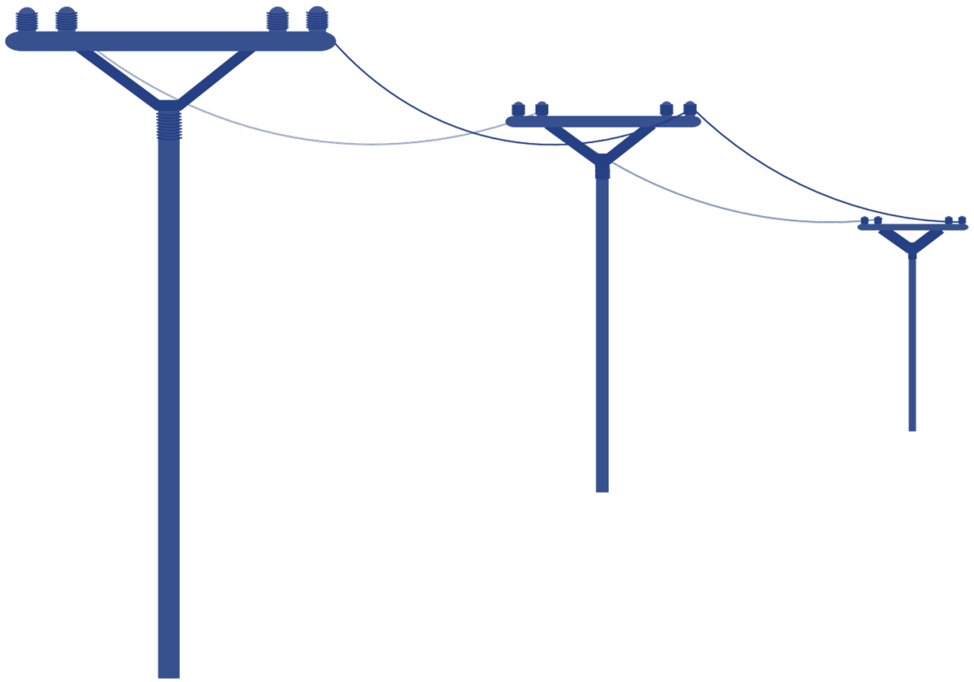




Transmission lines can be represented via

Transport model

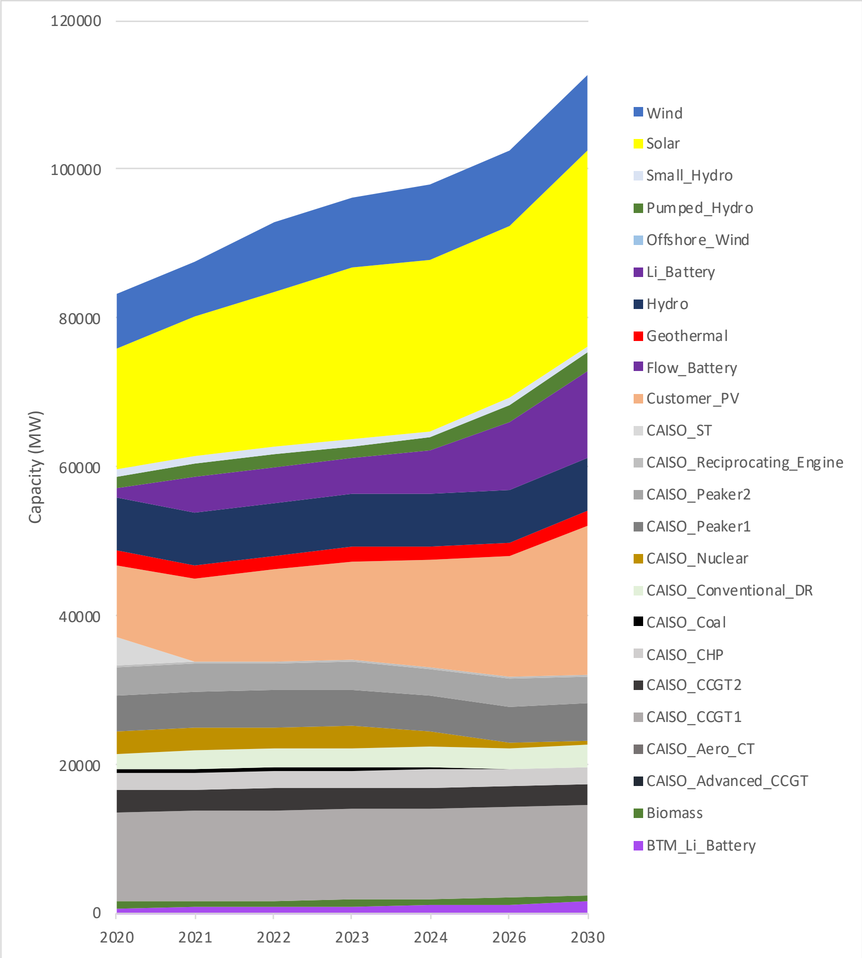
DC power flow



Capacity-Expansion with GridPath

Examine how the grid should evolve over the long term

Decide whether to **build or retire generation, storage, and transmission**



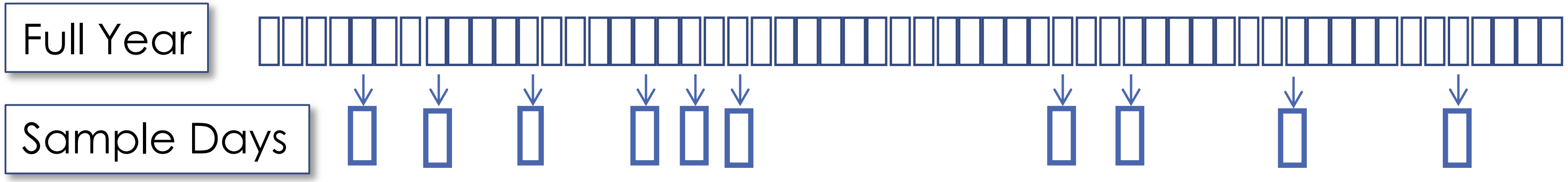
Consider the impact of:

- ✓ Load growth and load profile changes
- ✓ Power system policies
  - ✓ Renewables Portfolio Standard (RPS)
  - ✓ Carbon cap
- ✓ Reliability requirements

Temporal Resolution

Computational feasibility generally requires that aspects of the system be modeled in a simplified manner

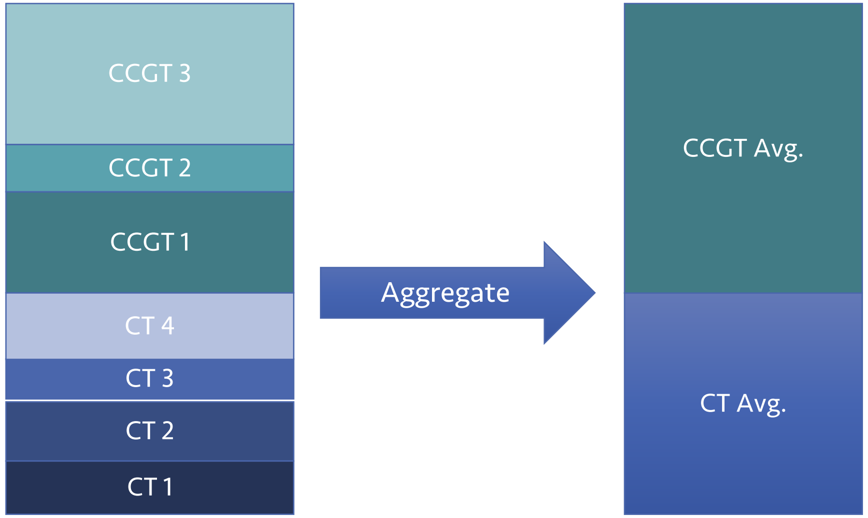
✓ Sample days instead full year of dispatch



Generator Representation

Computational feasibility generally requires that aspects of the system be modeled in a simplified manner

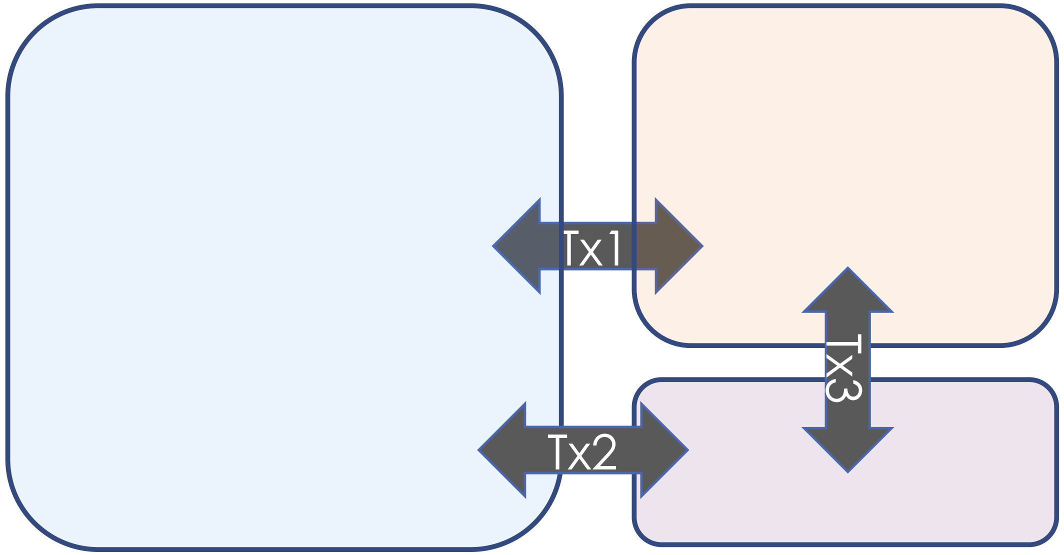
✓ Aggregation of plants



Transmission Representation

Computational feasibility generally requires that aspects of the system be modeled in a simplified manner

✓ Zonal topography and simplified transmission representation



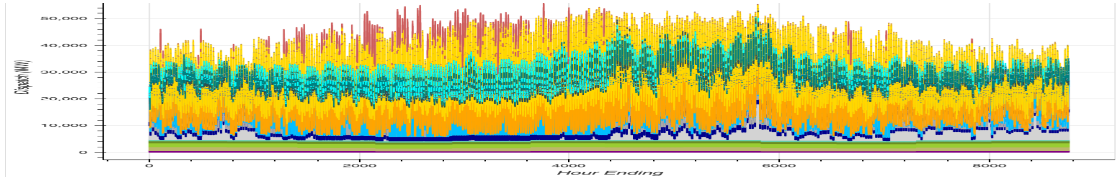
Problem formulation is flexible

Computational feasibility generally requires that aspects of the system be modeled in a simplified manner BUT

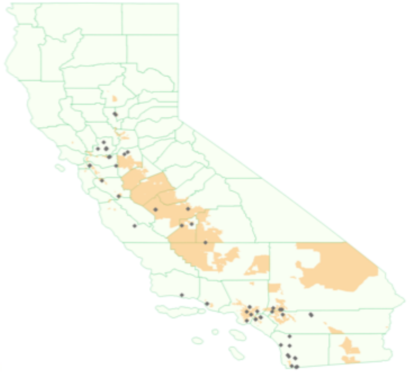
Unlike other capacity-expansion models, GridPath does not decide what to simplify ahead of time

User can add detail usually reserved for production cost simulation in a capacity-expansion model (while potentially removing detail elsewhere to keep problem tractable)

✓ 8760 dispatch



✓ Plant-level detail



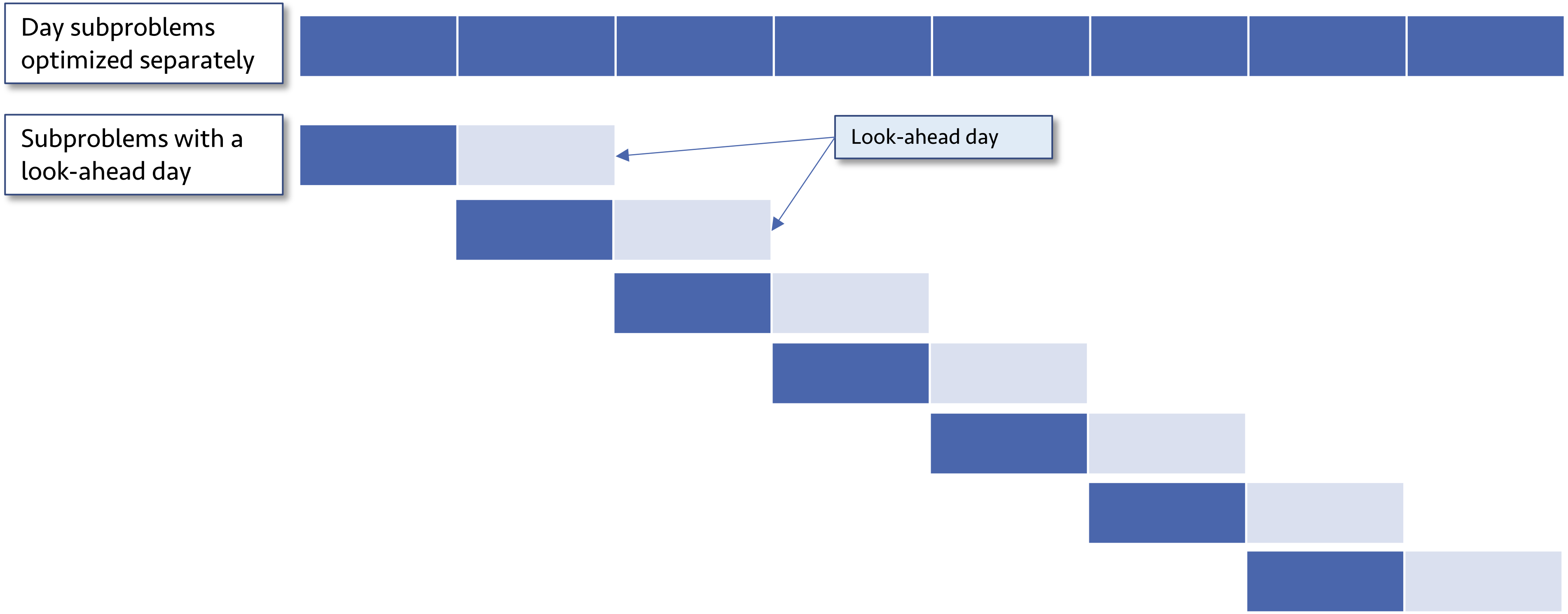
Temporal Setup

GridPath Subproblems


Day subproblems optimized separately

- A GridPath scenario can consist of one or multiple runs called “subproblems”
- For example, a typical production-cost scenario might solve for unit commitment and dispatch for the full year, but one day at a time
    - The scenario consists of 365 different “subproblems” – each day is solved separately
- Capacity-expansion scenarios are generally a single subproblem, i.e. all investment and dispatch decisions are optimized simultaneously

Spinup and lookahead functionality

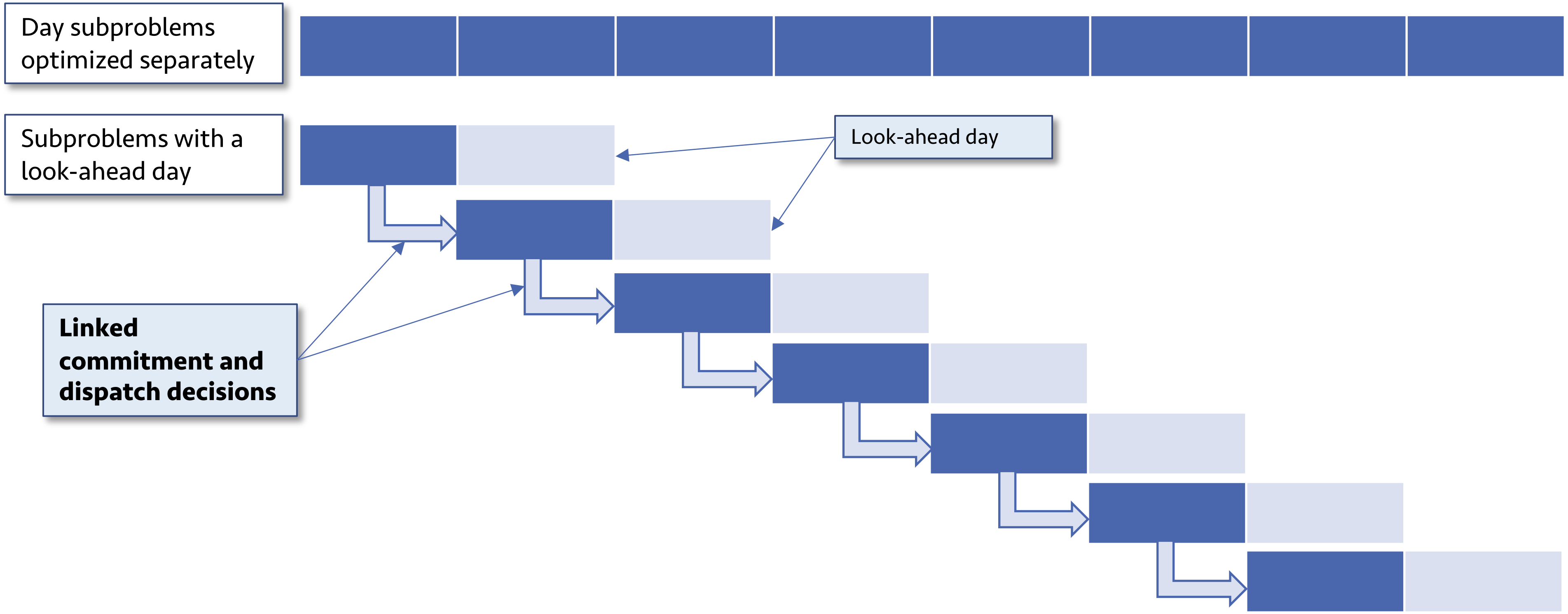

Day subproblems optimized separately

Subproblems with a look-ahead day

Look-ahead day

- Reduce seams between subproblems by considering past or future conditions

Decisions can carry over



Day subproblems optimized separately

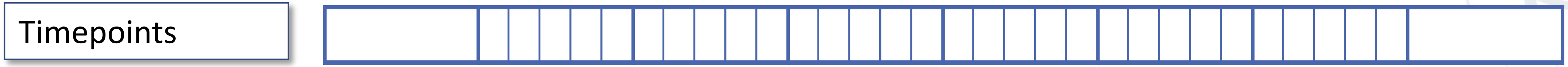
Subproblems with a look-ahead day

Look-ahead day

Linked commitment and dispatch decisions

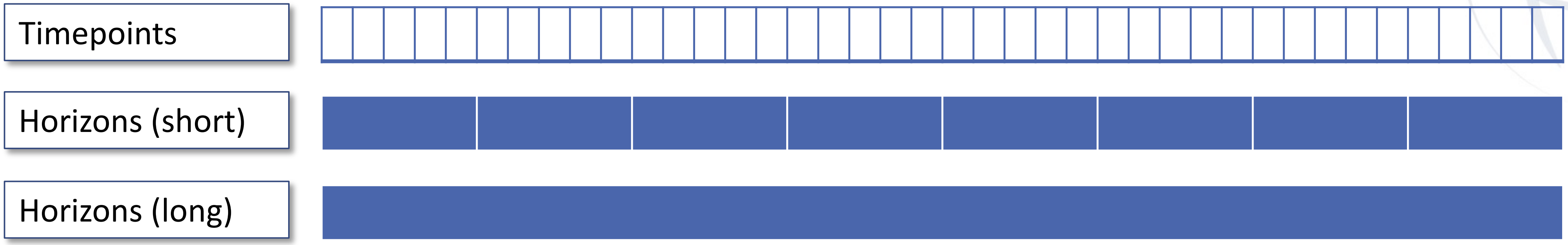
- Reduce seams between subproblems by considering past or future conditions

GridPath Timepoints



- Operational decisions (commitment, power produced, charge/discharge, etc.) are made in each **timepoint** of a subproblem
- Timepoint duration is flexible (e.g. 1-hour, 5-minute, 15-minute, 4-hour, etc.)
- Timepoint duration can be different for different timepoints
  - Timepoint resolution can be coarser when detail isn't needed (e.g. when load is steady and low, fo the spinup and lookahead days, etc.)
- Timepoints can be assigned weights to represent times not explicitly modeled

GridPath Horizons



Timepoints

Horizons (short)

Horizons (long)

- **Horizons** are foresight windows within a subproblem
- Horizon duration is flexible and multiple horizons with different durations can be modeled in the same optimization
  - Each timepoint belongs to one or more horizons (e.g. timepoint 1 may belong to day 1, week 1, month 1, and year 1)
- Horizons are independent from each other and some constraints, such as storage energy balance and hydro energy budgets, are enforced across a horizon
- Different resources can have different horizons (e.g. battery could a daily energy balance constraint while pumped storage could be balanced weekly)

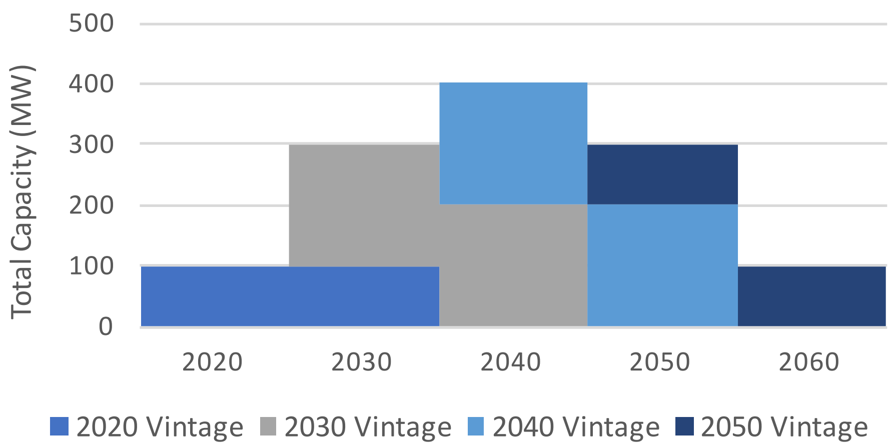
GridPath Periods


Timepoints

Horizons

Periods

- In a capacity-expansion setting, a **period** is when decisions to build or retire infrastructure are made
- Can model multiple investment periods
- Periods can represent more than one year to limit problem size
- Once new infrastructure is built, it is available in subsequent periods for a pre-specified lifetime


Example: Generation with 20-year Lifetime

GridPath Projects

GridPath "Types"

- Generation, storage, and load-side resources in GridPath are called "projects"
- For each project we want to include, we must specify, at a minimum, its load zone, its capacity type, availability type, and its operational type

project	load_zone	capacity_type	availability_type	operational_type
Generator1	LZ1	gen_spec	endogenous_bin	gen_always_on
Generator2	LZ1	gen_spec	exogenous	gen_commit_bin
Generator3	LZ1	gen_new_bin	exogenous	gen_always_on
Hydro	LZ1	gen_spec	exogenous	gen_hydro
PumpedHydro	LZ2	stor_spec	exogenous	stor
Wind	LZ2	gen_new_lin	exogenous	variable

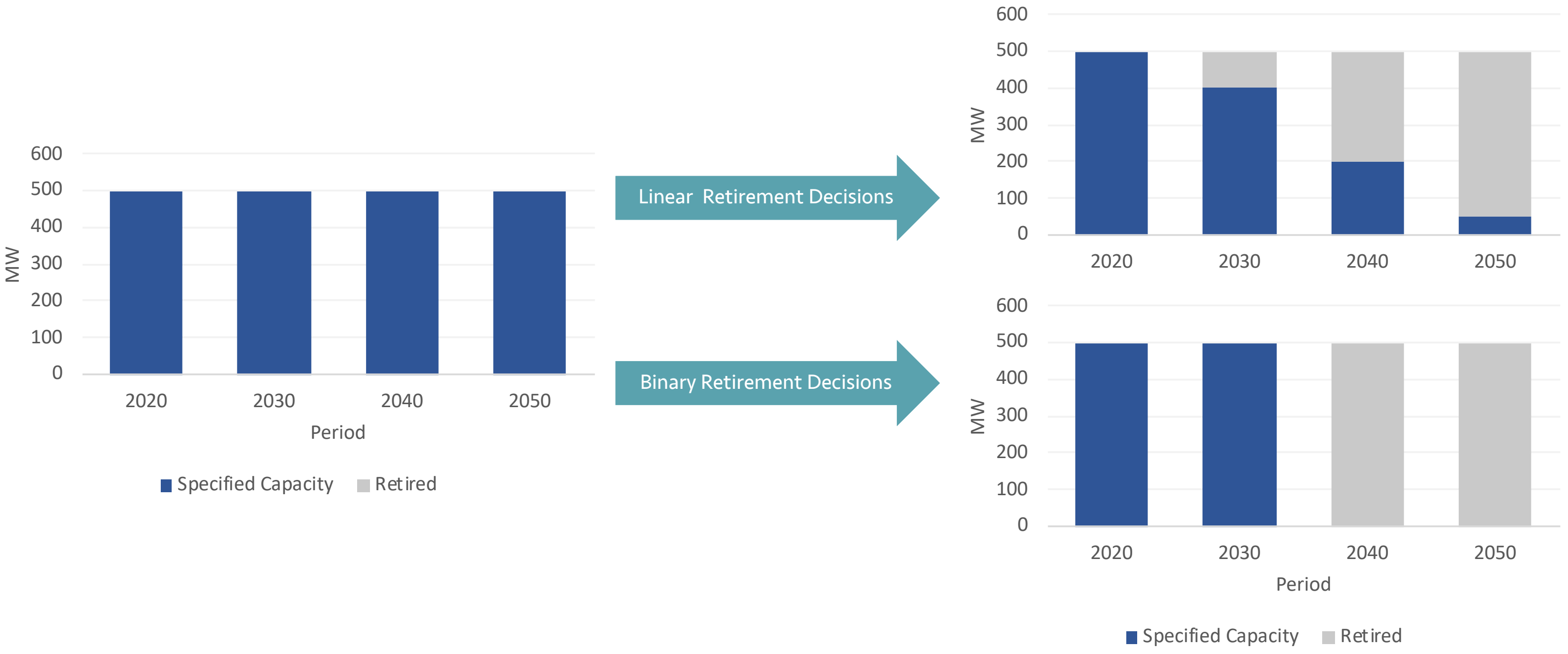
GridPath ”Capacity Types”

Capacity Type	Explanation
Specified Generation (*gen_spec*)	User-specified capacity in each investment period
Specified Storage (*stor_spec*)	User-specified storage capacity (power and energy) in each investment period
Specified Generation Linear Retirement (*gen_ret_lin*)	Specified generation whose fixed O&M can be (partly) avoided by retiring (part) of the project
Specified Generation Binary Retirement (*gen_ret_bin*)	Specified generation whose fixed O&M can be avoided by retiring the whole project (binary decision)
New Generation Linear Build (*gen_new_lin*)	New generation/transmission that can be built at a specified fixed cost with optional capacity limits
New Generation Binary Build (*gen_new_bin*)	New generation/transmission that can be built at a specified build size and cost
New Storage Linear Build (*stor_new_lin*)	New storage that can be built at a specified cost with optional capacity limits; power and energy are decided independently (duration is endogenous)
New Storage Binary Build (*stor_new_bin*)	New storage that can be built at a specified build size (power and energy) and cost

GridPath ”Capacity Types”

Capacity Type	**Explanation**
Specified Generation Linear Retirement (*gen_ret_lin*)	Specified generation whose fixed O&M can be (partly) avoided by retiring (part) of the project
Specified Generation Binary Retirement (*gen_ret_bin*)	Specified generation whose fixed O&M can be avoided by retiring the whole project (binary decision)

- Generators whose fixed O&M cost can be avoided by retiring them
- Once retired, the capacity cannot be available again

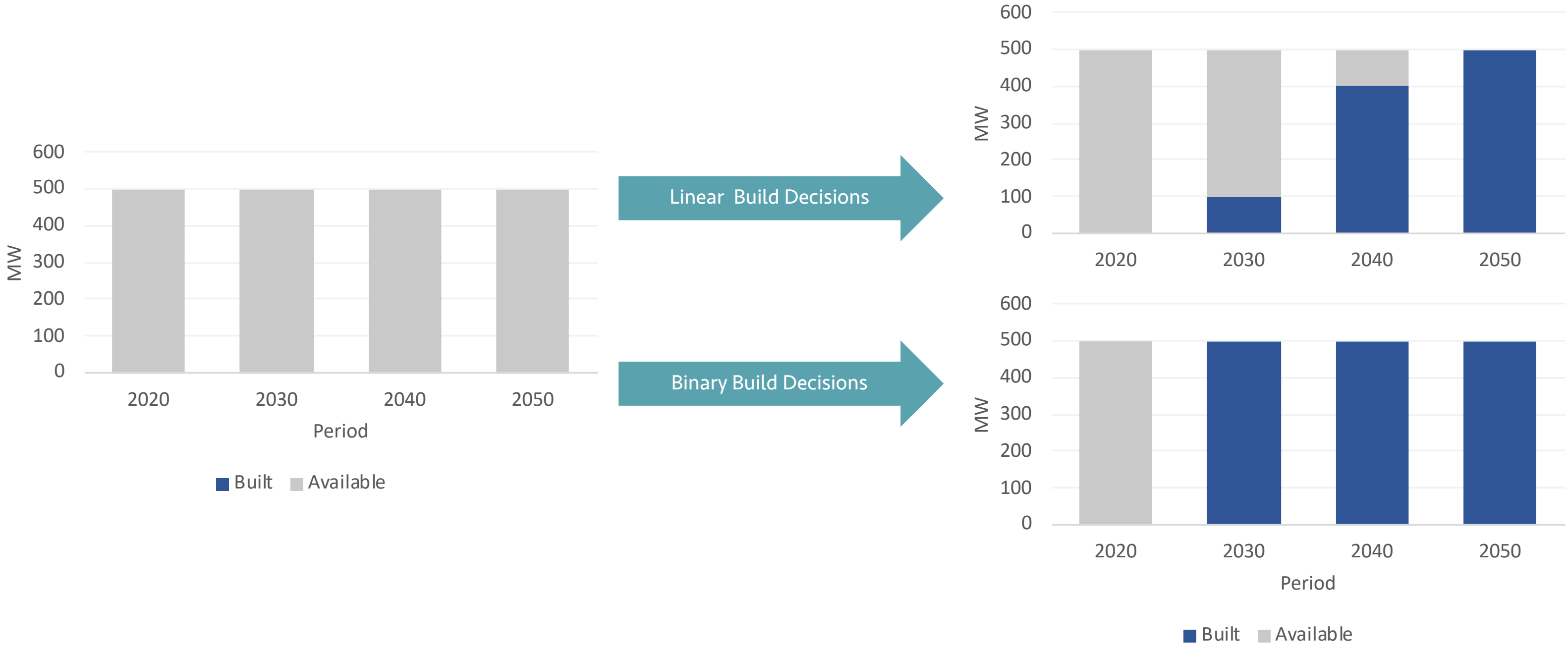

Linear Retirement Decisions

Binary Retirement Decisions

GridPath ”Capacity Types”

Capacity Type	Explanation
New Generation Linear Build (*gen_new_lin*)	New generation that can be built at a specified fixed cost with optional capacity limits
New Generation Binary Build (*gen_new_bin*)	New generation that can be built at a specified build size and cost

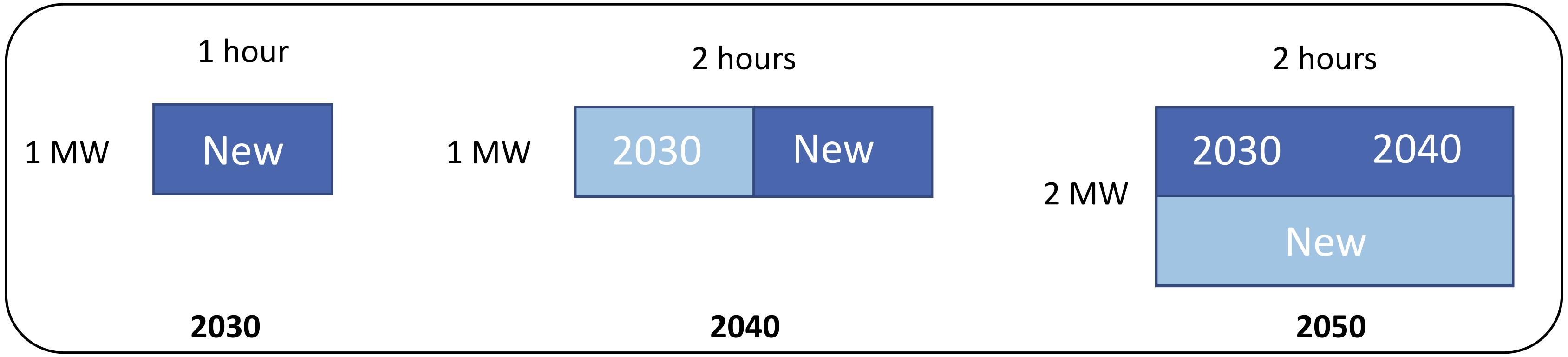
- New generation capacity the optimization may build
- Once built, the capacity remains available for the duration of its lifetime
- Annualized investment and O&M costs are incurred in each period the project is available
- Optional minimum and maximum capacity constraints



GridPath ”Capacity Types”

Capacity Type	Explanation
New Storage Linear Build (*stor_new_lin*)	New storage that can be built at a specified cost with optional capacity limits; power and energy are decided independently (duration is endogenous)
New Storage Binary Build (*stor_new_bin*)	New storage that can be built at a specified build size (power and energy) and cost

- Modeling “new” storage requires two variables: the power capacity and the energy capacity
- Investment costs are specified separately for power and energy capacity
- Storage sizing is endogenous, i.e. determined by the model
- Minimum and maximum power capacity and duration constraints can be optionally implemented



Capacity-Expansion Implementation

- There is no capacity-expansion “toggle”
- Implementation uses GridPath’s modular approach: “capacity type” designates whether generator/storage/transmission capacity is *specified* or a *model decision*
- If *specified*, requires capacity inputs by period; if *model decision*, requires investment cost inputs
- Production-cost model can become a capacity-expansion problem by simply changing the capacity type of a generator

GridPath ”Availability Types”

Operational Type	Explanation
Exogenous	Projects with a specified (un)availability schedule
Endogenous Binary	Endogenously determined (un)availability schedule, e.g. for planned maintenance, based on binary decisions variables
Endogenous Linear	Same as the endogenous binary type but the binary variables are relaxed

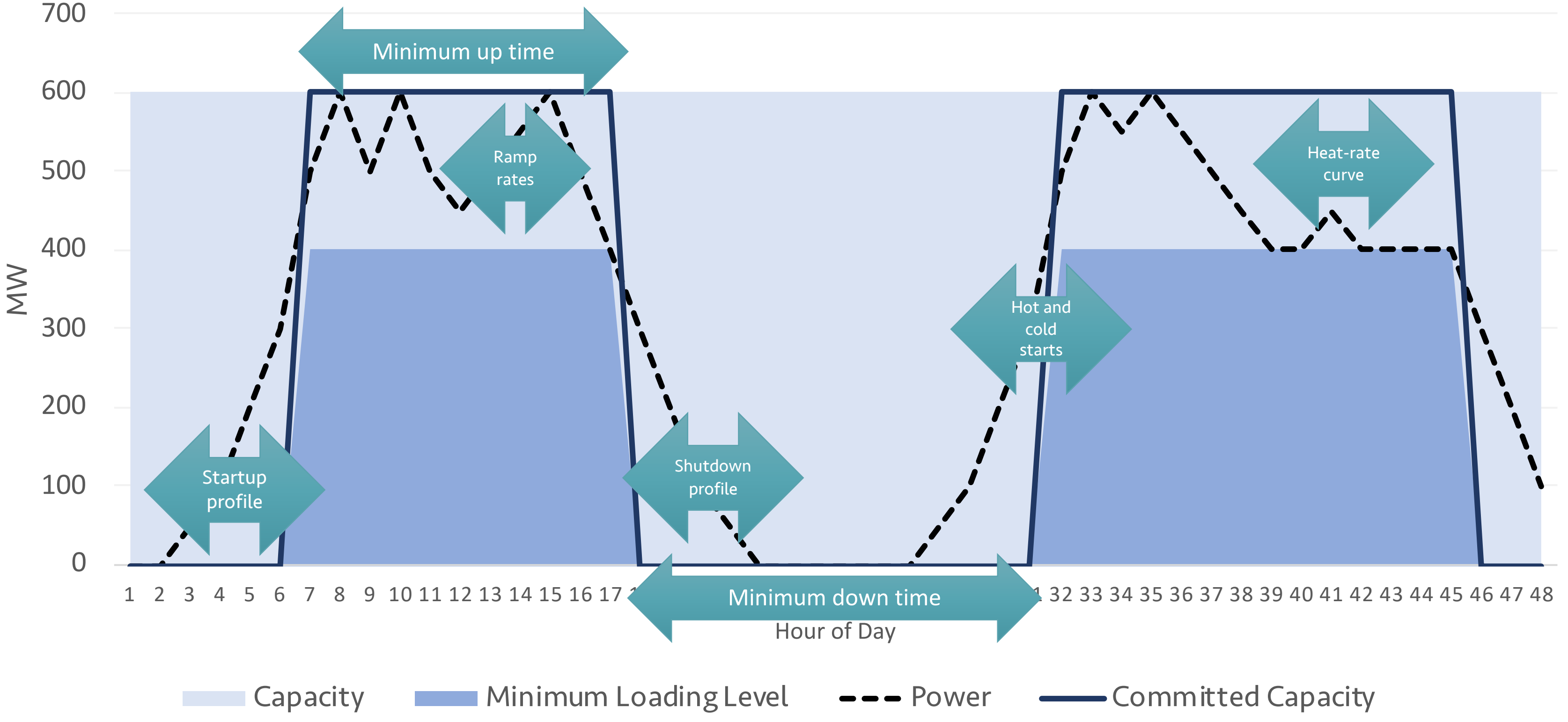
- The availability type that determines how much of a project’s capacity is available to operate in each timepoint
- Can be exogenously specified by the user or determined by GridPath based on constraints on the number of hours of unavailability per period, the event duration, and the duration between events

GridPath "Operational Types"

Operational Type	Explanation
Binary Commit (*gen_commit_bin*)	Detailed generator operations including heat rate curves, ramp rates, minimum up and down time, startup costs and trajectories, etc.
Linear Commit (*gen_commit_lin*)	Same as binary commit but with relaxed commitment decisions
Capacity ("Fleet") Commit (*gen_commit_cap*)	Linearized commitment of fleet with optional experimental ramp rate and minimum up/down features
Must-Run (*gen_must_run*)	Generators that produce constant power equal to their capacity in all timepoints
Always On (*gen_always_on*)	Must produce power in all timepoints but can vary output between a pre-specified minimum stable level and their available capacity
Hydro (*gen_hydro* or *gen_hydro_must_take)*	Can vary power output between a minimum and maximum level and must produce a pre-specified amount of energy on each horizon
Variable (*gen_var or gen_var_must_take*)	Power output is equal to a pre-specified fraction of their available capacity (a capacity factor parameter) in every timepoint
Storage (*stor*)	Described by its charging level, discharging level, and the energy available in storage in each timepoint

Binary Commit: Detailed Generator Representation

Operational Type	Explanation
Binary Commit	Detailed generator operations including heat rate curves, ramp rates, minimum up and down time, startup costs and trajectories, etc.
Linear Commit	Same as binary commit but with relaxed commitment decisions

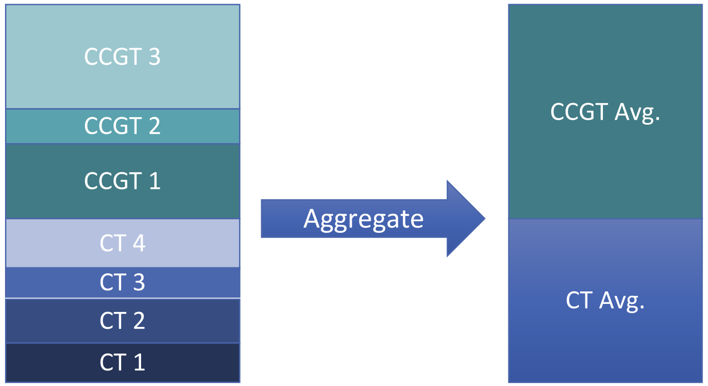


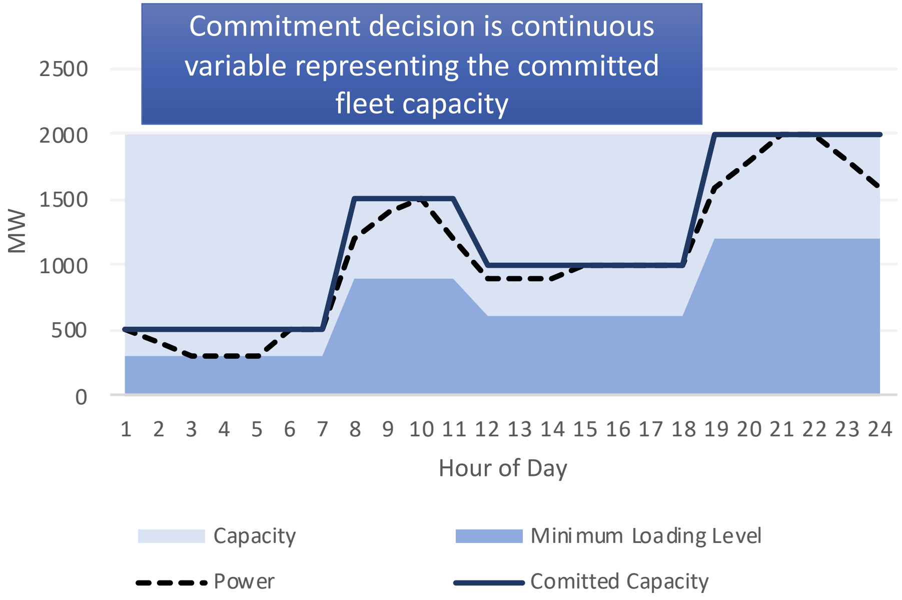
- Generator operations can be modeled with a high degree of operational fidelity, but constraints can also be easily excluded

Capacity Commit: Fleet Aggregation

Operational Type	Explanation
Capacity (“Fleet”) Commit	Linearized commitment of fleet with optional experimental ramp rate and minimum up/down features

- Rather than modeling individual generators’ unit commitment, aggregate similar generators into fleets
  - Calculate weighted average operational characteristics (heat rates, loading levels, ramp rates, up/down times)
- “Capacity commit” operational type allows for linearized commitment of fleet with optional experimental ramp rate and minimum up/down features

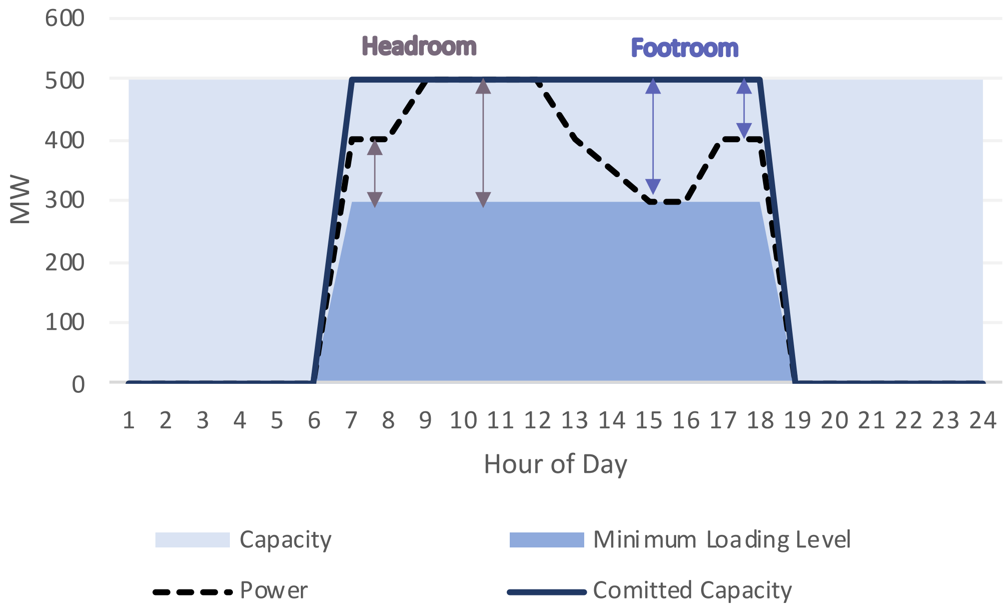



Commitment decision is continuous variable representing the committed fleet capacity

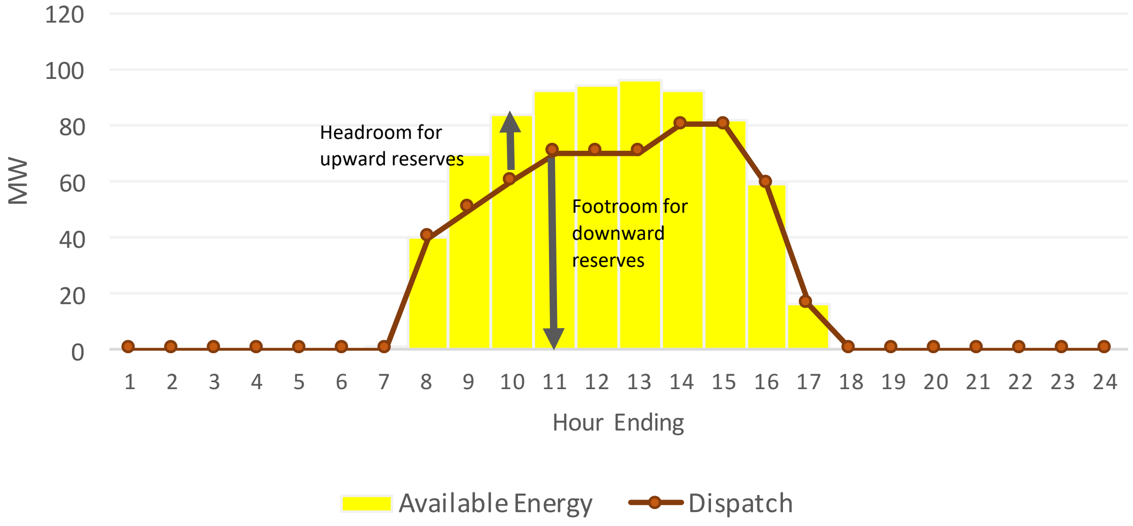
Provision of Operating Reserves

- All operational types except must-run can be optionally allowed to provide operating reserves, limited by their available headroom/footroom and ramp rates

Thermal Generator



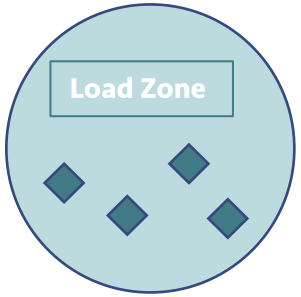
Variable Generator



Transmission

Flexible Spatial Resolution

- GridPath can model a single load zone (copper plate) or multiple load zones depending on required resolution



Flexible Spatial Resolution

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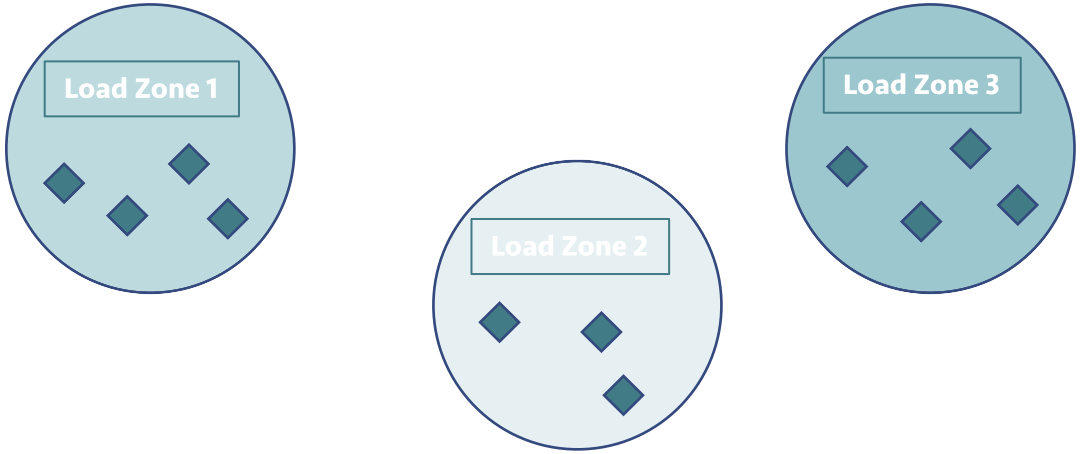
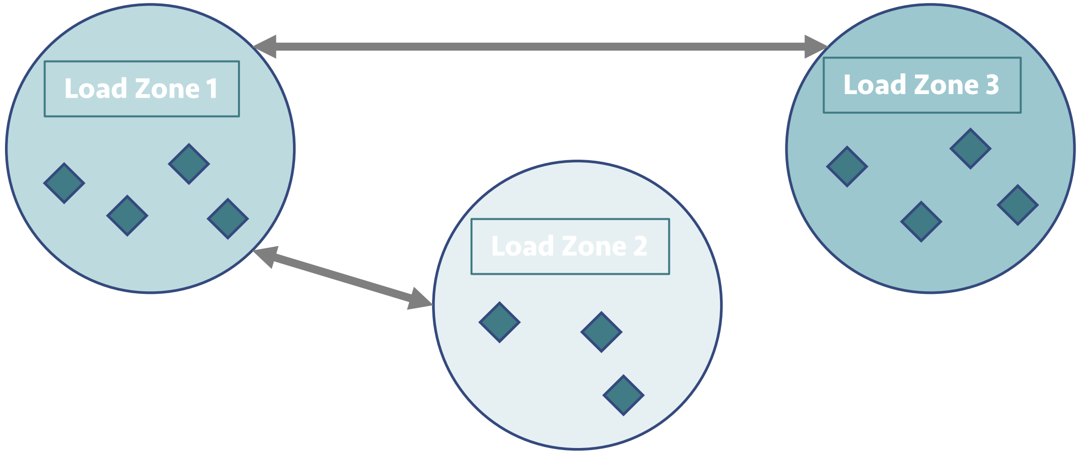


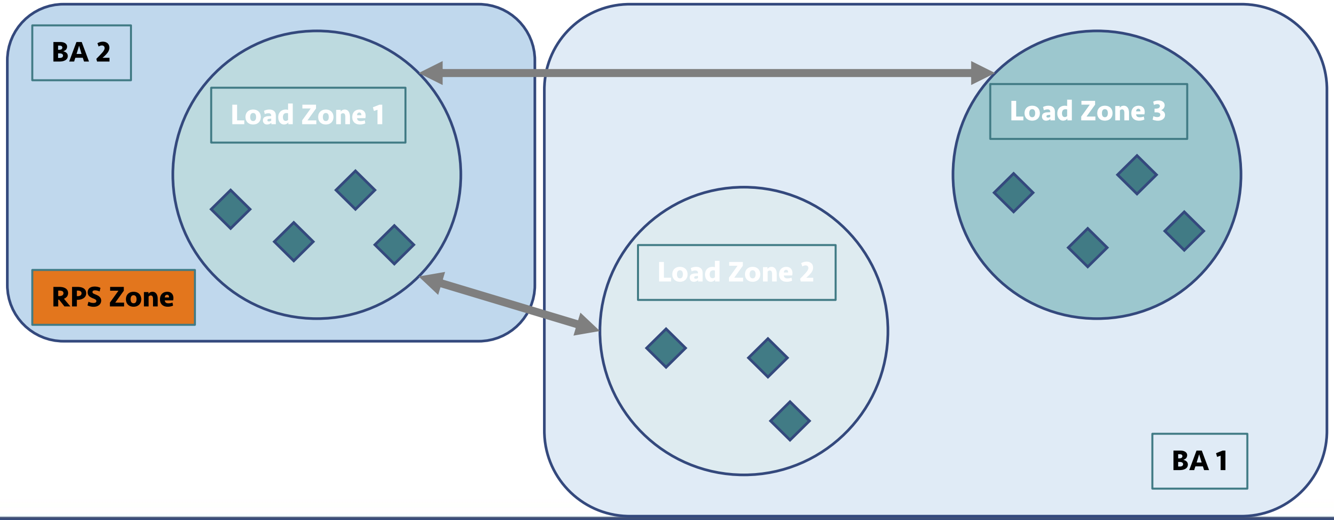
Flexible Spatial Resolution

- GridPath can model a single load zone (copper plate) or multiple load zones depending on required resolution
- Load zones can be connected with transmission or not in any configuration
  - Flow constraints defined independently in each direction



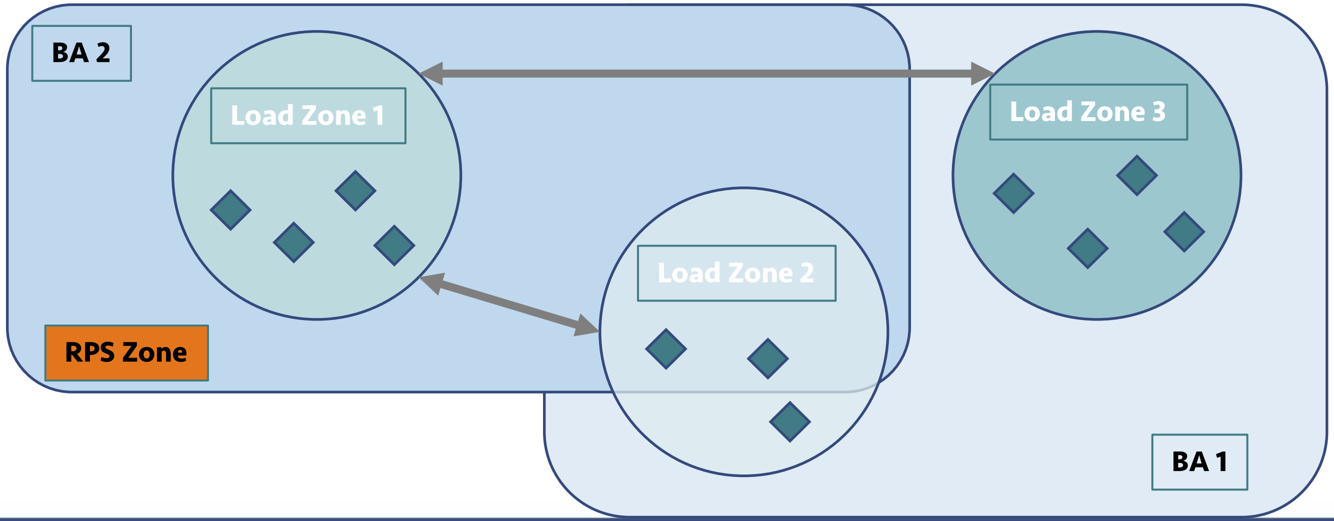
Flexible Spatial Resolution

- Transmission lines do not affect the definition of reserve balancing areas or policy zones (e.g. RPS, carbon cap). These other “zones” are defined independently from load zones for each generator



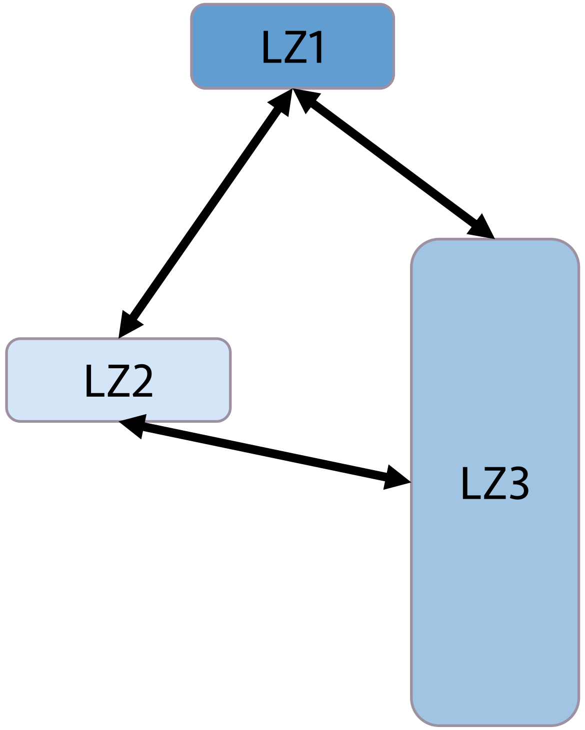
Flexible Spatial Resolution

- Transmission lines do not affect the definition of reserve balancing areas or policy zones (e.g. RPS, carbon cap). These other “zones” are defined independently from load zones for each generator
    - A generator can contribute to a different balancing area from other generators in its load zone
    - Can better capture contractual complexities



Transmission Operational Types

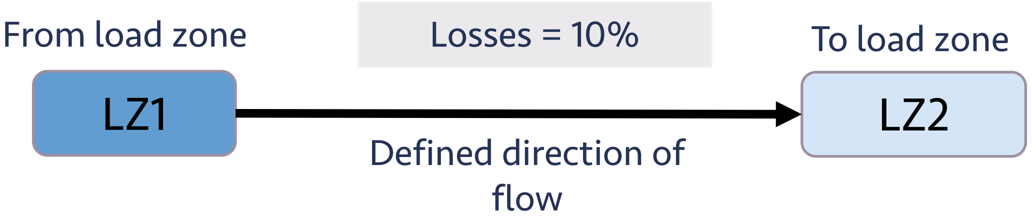
- Transmission lines also have an “operational type”
    - *tx_simple:* Transmission flows are simulated using a linear transport model
    - tx_dcopf: Transmission flows are simulated using DC optimal power flow



Note: Although operational types can be mixed, it is not recommended because tx lines with the operational type ”simple” will not be included in estimating network constraints for DC OPF, leading to inaccurate network flows.

Transmission Losses – simple operational type

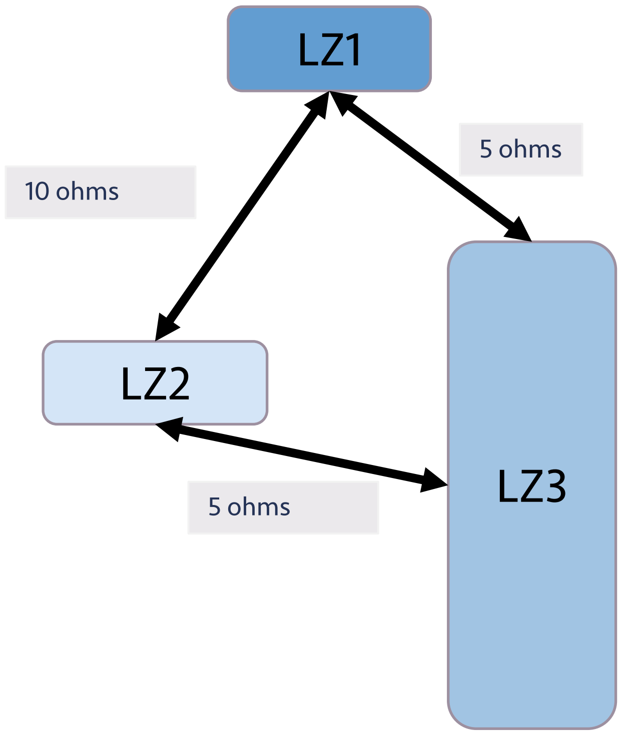
- Transmission losses are defined as a fraction of the line flow
  - Transmission loss factor can only be applied to the *tx_simple* operational type
  - User needs to predetermine the losses based on transmission line or corridor specifications, distance, and historical flows.



	From load zone	To load zone
EXAMPLE A	100 MW	90 MW
EXAMPLE B	-90 MW	-100 MW

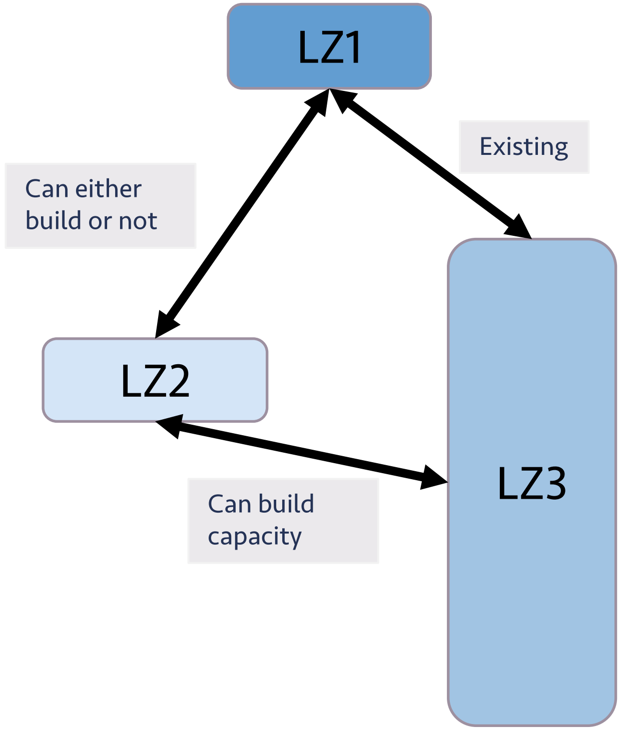
Transmission Operational Types – DC optimal power flow

- AC OPF is a nonlinear noncovex optimization problem; difficult to solve
- DC OPF is a linearized approximation of AC OPF [it does not model “direct current”]
  - Line resistances are small compared to line reactances; reactive flows are ignored
  - Voltage magnitudes are fixed and voltage angles are close to zero
- Transmission reactance for each line is defined in ohms
- Present formulation (Kirchoff approach from Horsch et al.) does not include losses



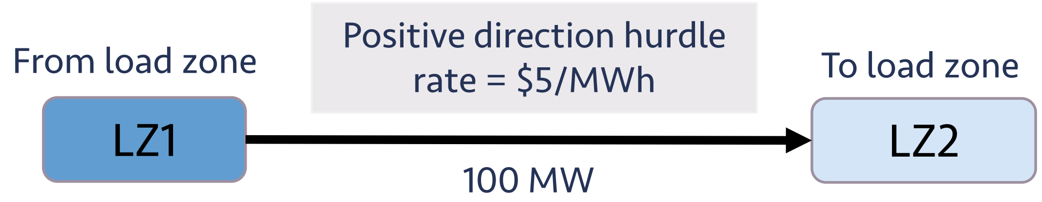
Transmission Capacity Types

- Like projects, transmission lines have “capacity types” that determines the available transmission capacity
  - Specified transmission
  - Linear new-build transmission
  - Binary new-build transmission

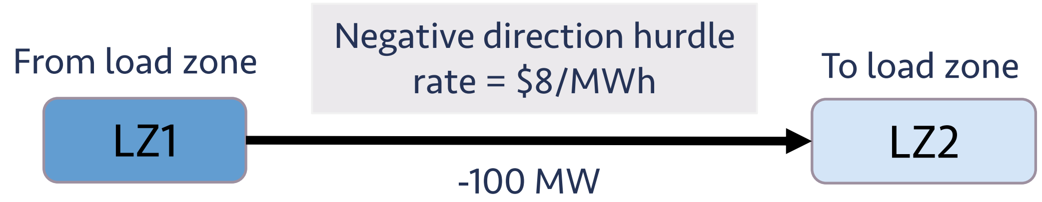


Transmission Hurdle Rates

- Hurdle rates are applied to represent additional costs due to transactional barriers; these costs are not included in final system costs.
- They are applied to power sent across a transmission line
- They can be applied separately for each direction of the power flow



100 MW * $5/MWh = $500 added to objective function costs

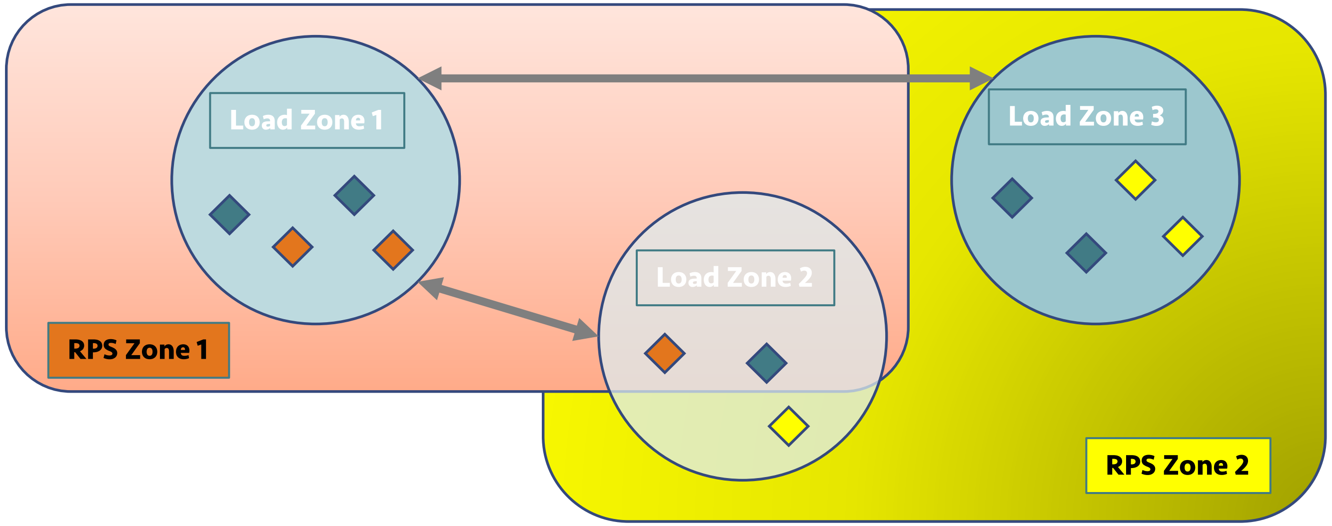


100 MW * $8/MWh = $800 added to objective function costs

Policy

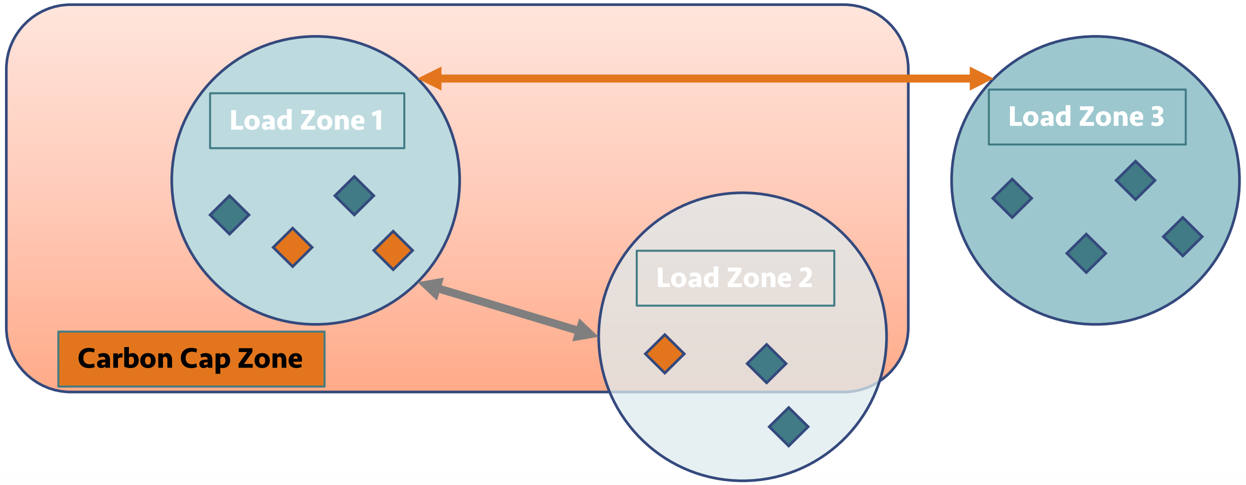
Policy: Renewables Portfolio Standard/ Obligation

- GridPath can optionally impose renewables portfolio standard (RPS) requirements
- The user must define RPS zones with their associated period-level requirement and assign a zone to each RPS-eligible project
  - Requirement can be annual energy quota or fraction of load
- The project’s ’operational type’ determines how much energy it contributes to the RPS requirement



Policy: Carbon Cap

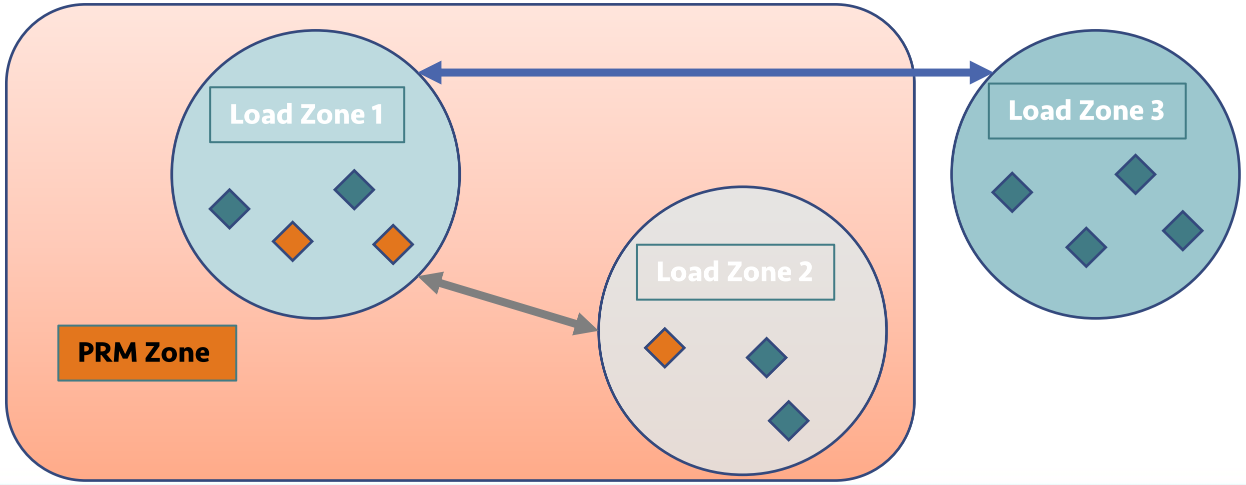
- GridPath can optionally impose a carbon cap constraint
- The user must define the “carbon cap zones” with their associated period-level emissions limit and assign a zone to each carbonaceous project
- The project’s ’operational type’ determines how much fuel it burns, i.e. how much emissions it contributes to the carbon cap
- An emissions intensity can also be applied to transmission flows into the carbon cap zone



Reliability

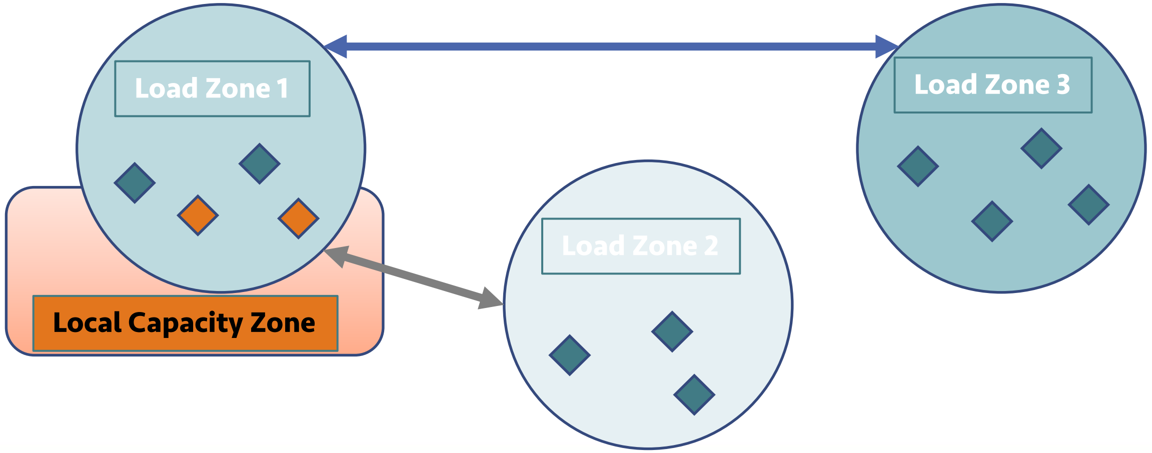
Reliability: Planning Reserve Margin

- GridPath can optionally impose a PRM target constraint
- The user must define the "PRM zones" with their associated period-level PRM target and assign a zone to each PRM project
    - Target is generally a certain percentage above median peak load
- The project's contribution to the PRM target is usually a user specified value ("simple PRM")
    - Users can optionally parameterize a project's ELCCs as a function of penetration ("ELCC surface")
    - Users can change the "PRM type" to account for transmission deliverability (i.e. project can only contribute capacity if an additional cost is incurred for transmission upgrades)



Policy: Local Capacity

- GridPath can optionally impose a local capacity requirement
- The user must define the "local capacity zones" with their associated period-level local capacity requirement and assign a zone to each local capacity project, as well its local capacity contribution
- Local capacity allows for a more granular level of reliability requirements within constrained load pockets



Thank You

Contact

ana@bluemarble.run

rdeshmukh@ucsb.edu