Adequacy and Capacity Expansion with a Changing Resource Mix: ENELYTIX

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UVIG

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TCR / ENELYTIX CHALLENGE

- Sections 83D and 83C of Chapter 169 of the Acts of 2008, as amended by chapter 188 of the Acts of 2016, *An Act to Promote Energy Diversity*
  - OBJECTIVE: to accelerate the reduction in Carbon BY MA CONSUMERS
  - To be implemented by the distribution utilities of the Commonwealth
    - Eversource >50%
    - National Grid < 50%
    - Unitil <2%
  - 83D sought to acquire 9.45 terawatt-hours of clean energy generation for the Commonwealth [Energy could come from any source in NE or NY but "bookkept" to MA consumers only]
  - 83C seeks to provide contracts to acquire the energy from 1600 MW of offshore wind in 4 x 400 MW tranches located roughly 17 miles southwest of Martha's Vineyard with first installation in 2023 and final in 2029
- 83D received more than 50 bids and combinations ranging in size from 20MW to 1100MW and from Solar and Wind to major Hydro Connections from Hydro Quebec. Of those 46 passed the screening to be evaluated via ENELYTIX
  - Award in in dispute but will be for a Hydro Connection from Quebec
- 83C has received 14 bids from 3 bidders with lease sites off of MA. These are now being evaluated.

TCR / ENELYTIX Responsibility: Development

- Develop the Quantitative Analytic Engine
  - Develop, test and validate the data structure for New England and New York
    - Noda (LMP)l for every generator, load bus and PPA point of delivery
    - Full Transmission Topology
    - All constraints that could bind and impact LMPs
    - Replicating all ISO NE Market Rules and Demand Curves
  - Develop a "but for" Base Case that included capacity expansion requirements out 30 years
  - Develop the analytic structure to evaluate projects hourly for 22 years including capacity expansion for each individual proposed project case
  - Develop the quantitative metrics to arrive at the levelized NPV of energy and environment RECs to be single quantitative score for ranking
  - Develop the EXCEL based results analysis templates and workbooks

TCR / ENELYTIX Responsibility: Implementation

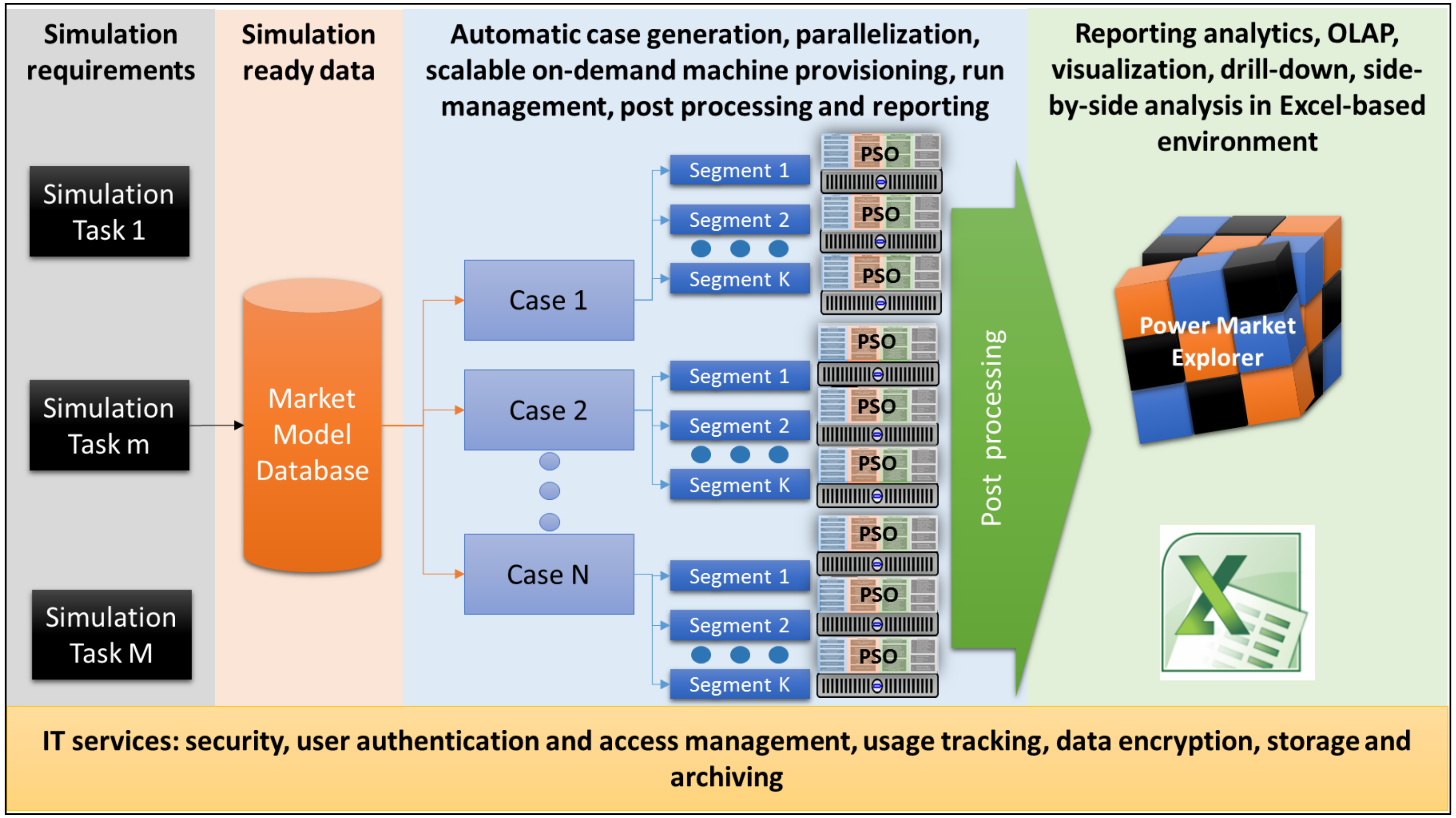
In conjunction with the Electric Distribution Companies (EDCs), implement the developed Quantitative Analytic Engine

- Run ENELYTIX Software on the Cloud
- Complete Data analysis and aggregation on the Cloud
- EXCEL accessed data in the CUBE on the cloud
- Implement Metrics Workbook evaluation of individual project
- Create portfolios of proposals to reach mandated 9.45 terawatt-hour objectives
- Evaluate portfolios through ENELYTIX and Metrics Workbooks

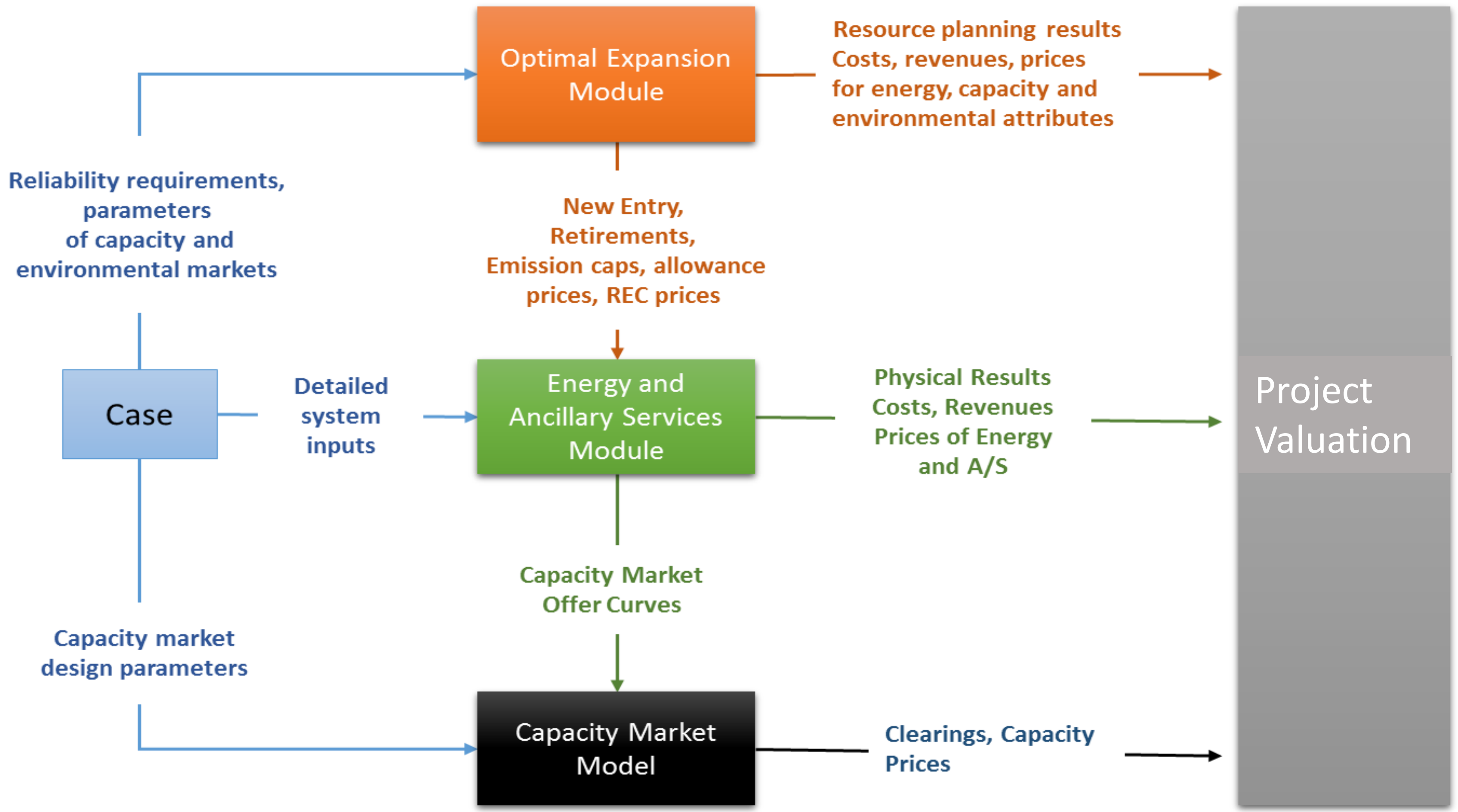
TCR / ENELYTIX 83D Accomplishments

- TCR evaluated over 50 projects and portfolios against an unreasonably tight schedule
- Each project evaluation ran through three steps
  - System expansion (30 year-optimization)
  - Energy and Ancillary Services modeling (22 years hourly chronological SCUC and SCED modeling + 3 month extreme gas prices scenario)
  - Capacity Market modeling (22 annual period FCA replication)
- Each evaluation used:
  - 600+ virtual machines on the cloud
  - Taking under 3 hours of clock time
  - Often running 2 evaluations in parallel utilizing over 1200 virtual machines
- Each evaluated project produced over 250 GB of data.
  - Automatic post processing and generation of all metrics and visuals was critical
- The need for expert review of results (QC) was the most constraining factor in the schedule, not computing resources

The ENELYTIX Modeling Framework



ENELYTIX Case Evaluation with Capacity Expansion



- Inputs generated for all three modules out of the same database

The Model Solution Sequence

1. Capacity Expansion module determines the optimal capacity expansion plan over the study period and resulting changes to the capacity and generation mix over that period.
   - Its objective function is to minimize the net present value of the total cost, i.e., capital, fuel and operating, of the generation fleet serving the forecast load in the wholesale market within the ISO-NE electrical footprint.
   - It minimizes these costs subject to the resource adequacy, RPS, GWSA, transmission and operational constraints.
   - While processing these requirements, the model evaluates economic trade-offs between the capital and operating costs of existing and new resources vis-à-vis their ability to meet these requirements and standard operating constraints. The model will identify the optimal resource mix, locational and technology specific new build decisions and retirement decisions.
   - outputs include unit retirements, generic new capacity additions, shadow prices of CO_2 emissions and Class 1 REC prices.

The Model Solution Sequence (Continued)

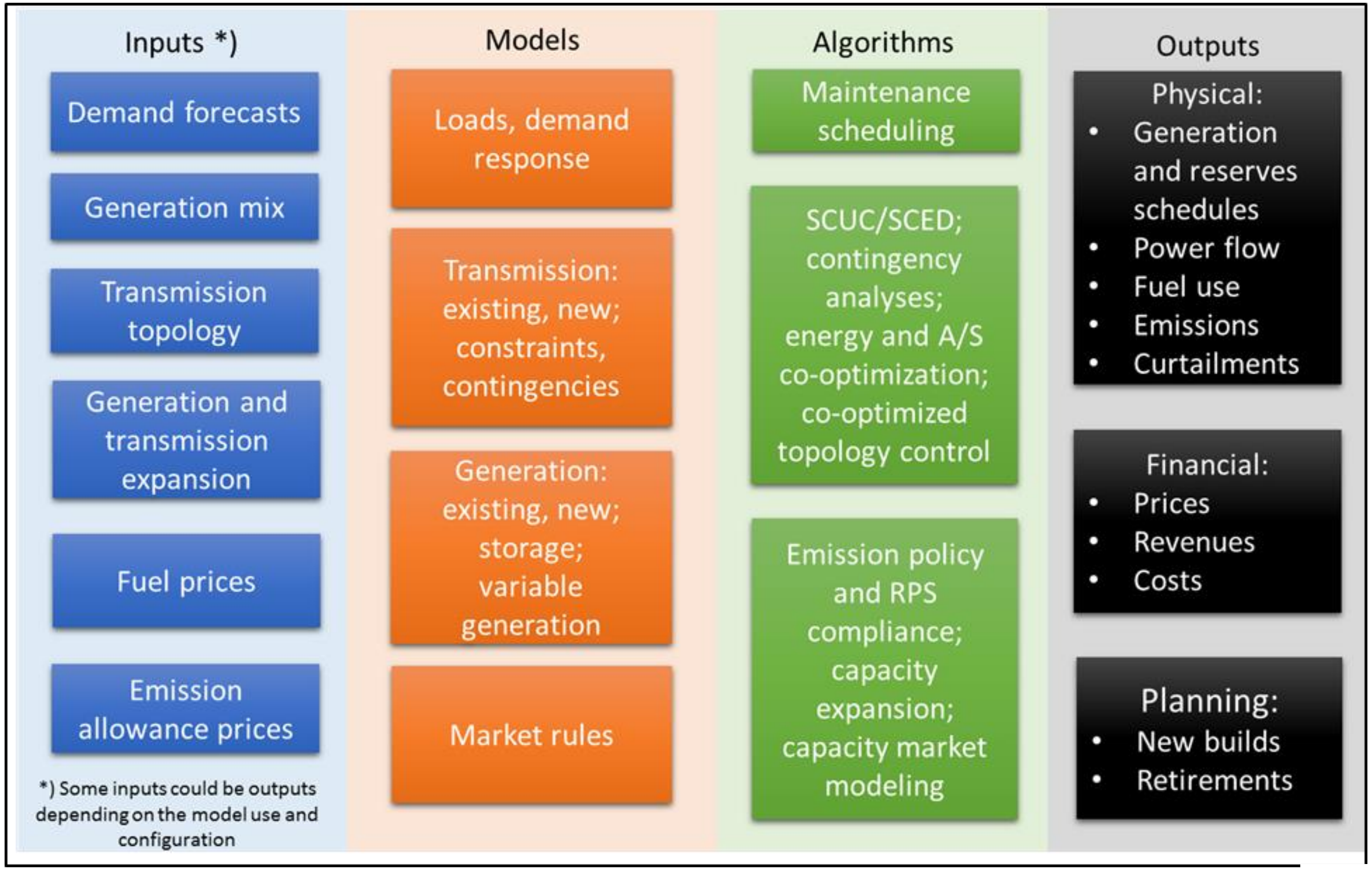
2. Energy and Ancillary Services (E&AS) module uses outputs from Capacity Expansion module.
   - E&AS module models security constrained unit commitment and economic dispatch for ISO-NE and NYISO markets with distinct but coordinated commitment and dispatch processes
   - SCUC and SCED enforce over 1000 contingency constraints in New England especially focusing on projects interconnection and delivery locations
   - It calculates nodal locational marginal prices (LMP) for load and generators, net revenues that each generating unit would receive from the Energy and A/S markets, and carbon emissions among other outputs.
   - For each unit it compares the annual net energy revenues to the fixed cost requirement to calculate the "missing money" each unit will seek to recover in the capacity market.
   - TCR then develops each unit's "FCM offer curve" for each power year.

The Model Solution Sequence (Continued)

3. The Forward Capacity Market (FCM) module uses the FCM offer curves from the E&AS module to compute capacity market prices. .

- FCM module replicated the current design of the New England capacity market:
  - Enforces system-wide installed capacity requirements
  - Local souring requirements and limitations for export and import constrained zones
  - Computed capacity prices using the FERC approved structure of demand curves based on Marginal Reliability Index for the system and for constrained zones
- Special provisions on capacity market clearing and effect on capacity prices were made to account for projects under PPA

Analytic Structure of PSO: The ENELYTIX Engine



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Capacity Expansion (summary)

The Capacity Expansion Problem

- Objective is to minimize the net present value of total cost (capital, fuel and operating costs) of the generation fleet
  - Subject to resource adequacy, operational, transmission and environmental constraints.
- By respecting these constraints, the optimization algorithm explicitly evaluates the needs for:
  - energy delivered to each load zone
  - resource adequacy
  - Curbing emissions to comply with regulatory policies
  - renewable resources to comply with state-specific RPS requirements

ENELYTIX Capacity Expansion: Key Features

- Stochastic, MIP-based optimization
- Nodal capacity expansion
- Rolling Horizon modeling
- Multi-Cycle modeling
  - Two cycles were used to construct a “but for” case. The first expansion was solved as if the 83D rules were not in place. In the second, the buildout was valued as if 83D rules were in place.
- Locational resource adequacy, operational, build/retire, regional and state-specific emission, RPS and CES constraints were enforced
- Resource adequacy constraints consistent with the design of ISO-NE capacity markets
- Transmission constraints modeled using linearized DC model
- Capacity expansion and production cost input generation from a single source
- Automated conversion of capacity expansion outputs to production cost inputs

Nodal Modeling & Rolling Horizon Applications

Nodal Analysis

- Evaluate build retirement decisions at specific locations with respect to major transmission constraints or other operational requirements
- Location specific RPS requirements by class subject to banking and borrowing provisions
  - Exceptions/carve-outs and resource eligibility

Rolling Horizon

- Traditionally, all capacity expansion decisions for the entire horizon are made concurrently.
  - Decisions in the future can be heavily discounted and may adversely impact decisions vis-à-vis MIP gap
- PSO's rolling horizon approach allows decisions to be re-visited and finalized closer to "real-time", better reflecting the discount rate or other information at the time of the decision

Emission and RPS Constraints

- Represent both emission limits and allowance prices.
  - Emission limits can be set in absolute terms or in the form of the emission rates, and can be subject to banking and borrowing provisions.
  - Multiple constraints for the same emission type as well as the simultaneous use of emission limits and emission allowance prices.
  - Price caps and floors can be imposed both on emission and RPS constraints to reflect state-specific and regional rules.
- Energy Pool construct supports energy constraints over time and scenarios
  - Model REC banking and borrowing and alternative compliance payment (ACP) prices that change over time
  - Ability to impose max banking and borrowing rules per year

Transmission Topology

- ISO New England footprint. Model of Energy &Ancillary services (E&AS) also incorporates detailed representation of NYISO transmission system.
- locations of all network resources organized per substation and node mapping.
- transmission topology and bus, branch characteristics, connectivity information and power flow system state data and electric characteristics of transmission facilities modeled per 2020 SUMMER Peak power flow case from ISO-NE.
- TCR uses internal New England interface definitions and operating limits per ISO-NE. It applies seasonal limits on interfaces not scheduled to be upgraded by year 2020 where sufficient statistical data exist to support those limits.

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Interface Assumptions

- TCR models the following interchanges with New England:
  - NYISO interchanges, hourly economic dispatch
    - Cross Sound Cable HVDC interconnection with NYSIO
    - Roseton AC interface with NYSIO
  - Quebec interchanges, hourly schedules from 2012
    - Phases I and II Interface with Hydro Quebec via HVDC
    - Highgate interface with Hydro Quebec via HVDC
  - New Brunswick interface at Keswig external node, hourly schedule from 2016
- TCR calendar shifts interchange flow data for each forecast year and therefore remains synchronized with the load pattern in ISO New England.

ENELYTIX is Built Using Best in Class Components

Newton Energy Group

SaaS integrator & provider

- Simulator: Power Systems Optimizer (PSO)
- AIMMS — Modeling Language
- IBM — MIP Solver CPLEX
- amazon web services — Cloud: Amazon Web Services
- Microsoft — Business Analytics Services

TCR

Solution Overview: PSO, ENELYTIX Simulation Engine

Inputs

- Demand forecasts
- Generation mix
- Transmission topology
- Generation and transmission expansion
- Fuel prices
- Emission allowance prices

Models

- Loads, demand response
- Transmission: existing, new; constraints, contingencies
- Generation: existing, new; storage; variable generation
- Market rules

Algorithms

- Maintenance scheduling
- SCUC/SCED; contingency analyses; energy and A/S co-optimization; co-optimized topology control
- Emission policy and CPP compliance

Outputs

Physical:

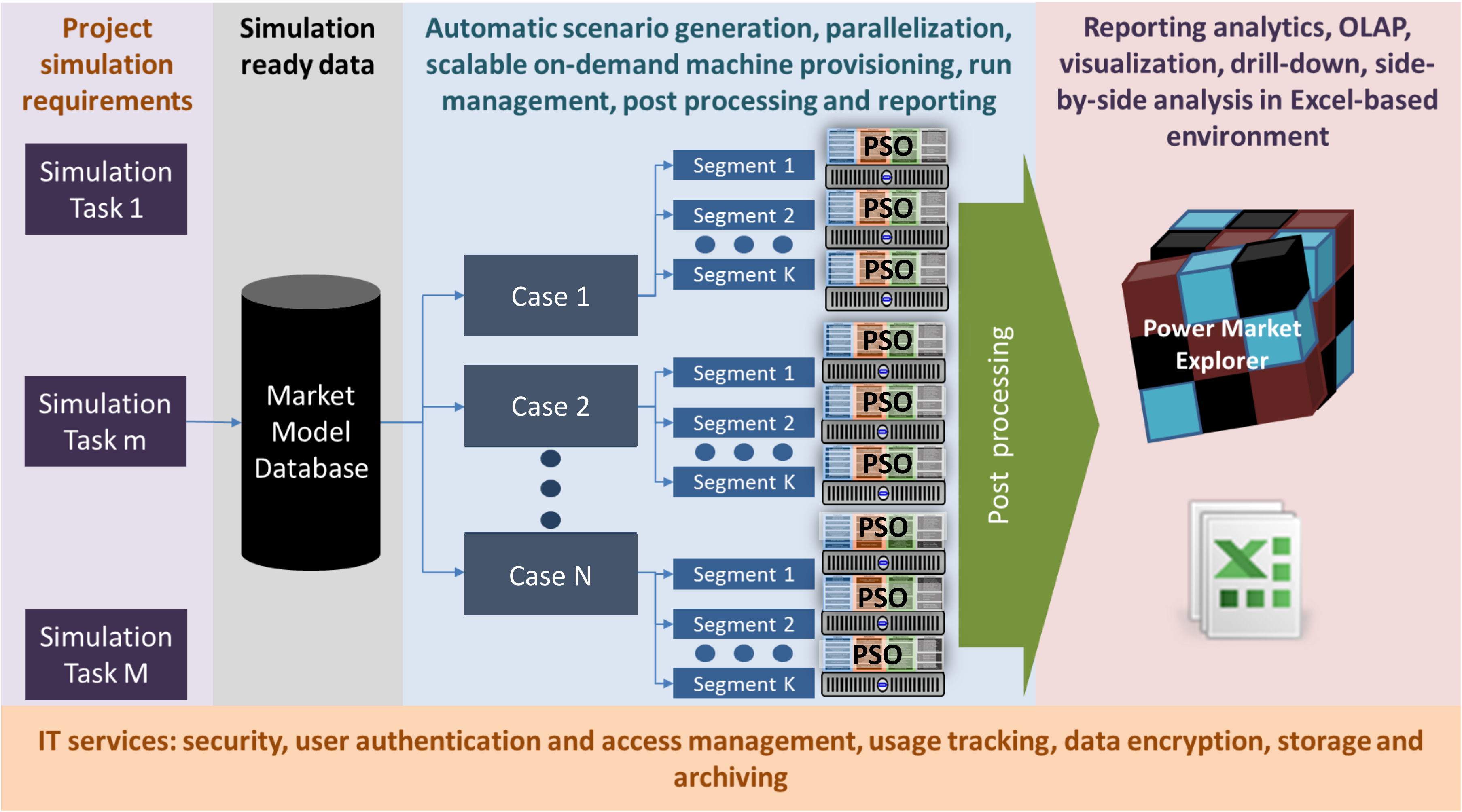
- Generation and reserves schedules
- Power flow
- Fuel use
- Emissions
- Curtailments

Financial:

- Prices
- Revenues
- Costs

Solution Overview: Workflow and Key Components

ENELYTIX is a comprehensive turn-key solution providing users access to all resources required for planning studies



Rolling Horizon Modeling in ENELYTIX

Decision periods | Look-ahead periods

Horizon 1 minimizes costs for decision periods

“**non-recourse**” decisions = **final**
“**recourse**” decisions = **provisional**

Decision periods | Look-ahead periods

Horizon 2 minimizes costs for decision periods

Decision periods | Look-ahead periods

Horizon 3 minimizes costs for decision periods

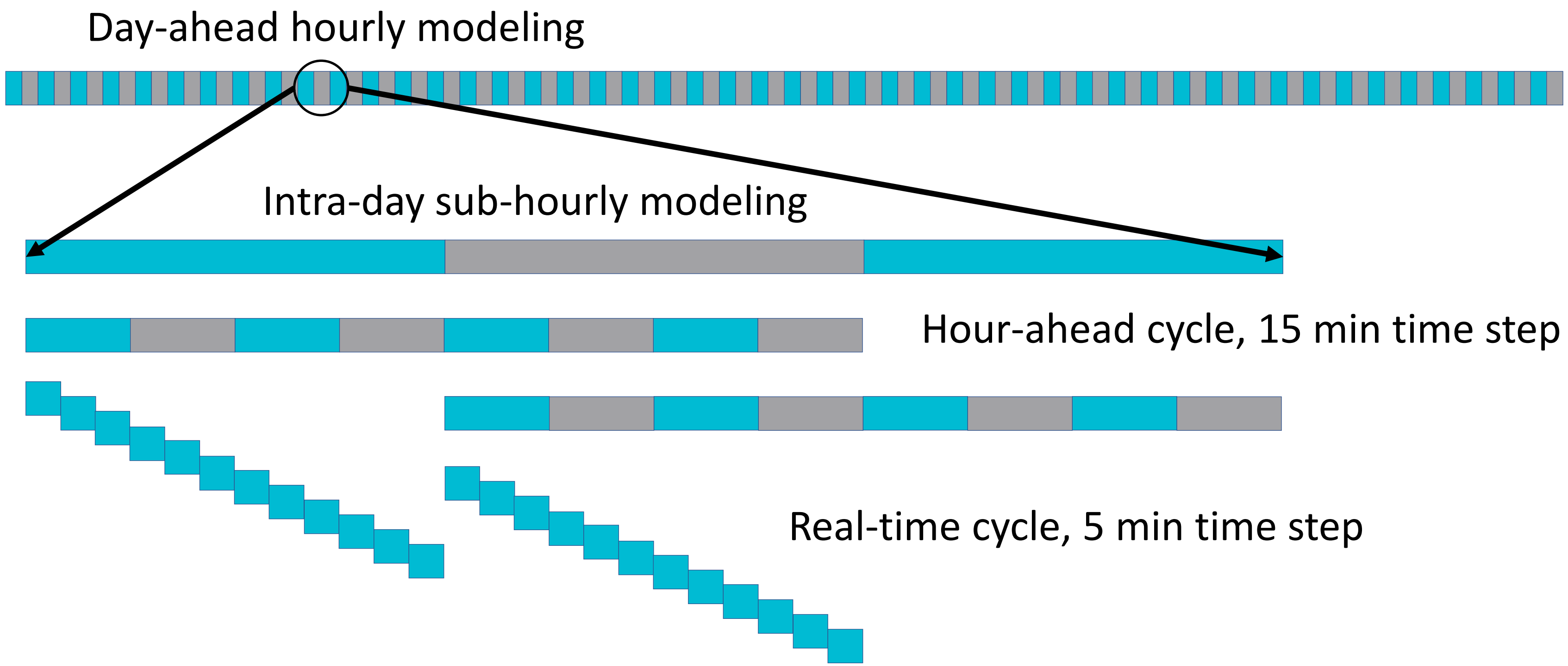
Applicable to intra-day operations, day-ahead unit commitment or multi-year capacity expansion

Decision periods | Look-ahead periods

Horizon 4 minimizes costs for decision periods

Decision cycles and sub-hourly simulations

Use of decision cycles is essential for proper modeling of variable generation, storage and distributed energy resources



Flexible set-up, easy to add or remove cycles
Flexible designation of decision variables as “final” vs. “provisional” between cycles
Rich data structures to model how information changes from cycle to cycle

ENELYTIX Structural Advantages

- Bridges the gap between planning and operations
  - multiple decision cycles with rolling horizon (RT, intraday, DA, …)
  - uncertainty (outages, forecasts)
  - intra-hour impacts of renewables, cascading hydro, storage, combined cycle, …
- Chronological model using MIP
  - replicates operational market engines
  - avoids heuristics
- Advanced models
  - solves prices for multiple simultaneous ancillary-service and emission constraints
  - optimized transmission switching
- Parallel processing on private cloud
  - Seamless reintegration of results (years, decades)