Expanding the scope of electric power infrastructure planning

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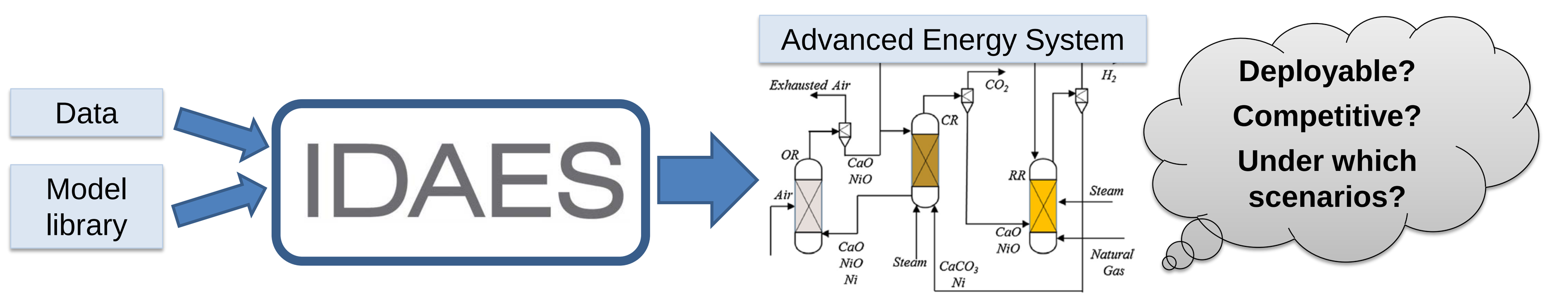
Motivation



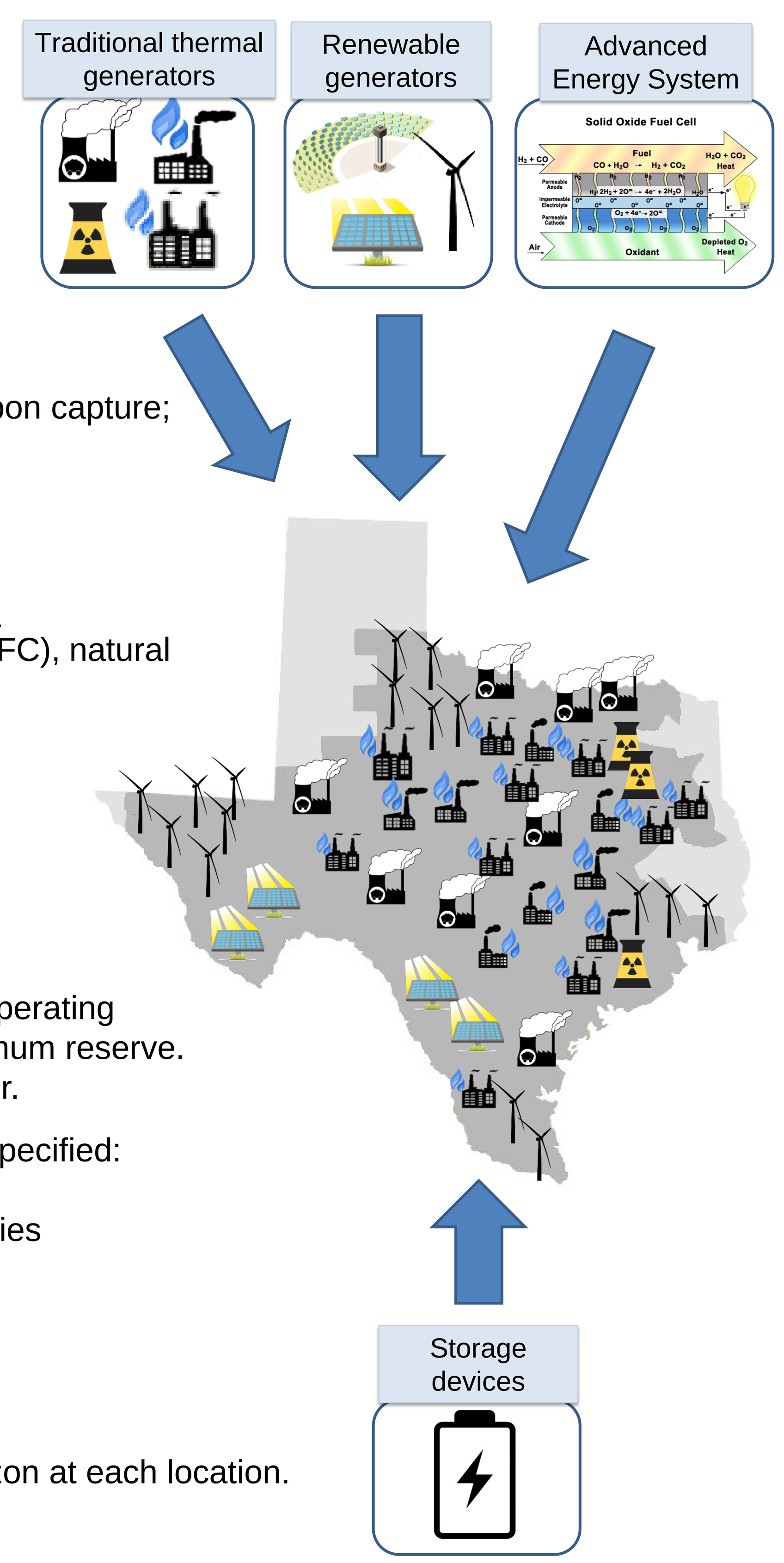
The major **goal** of this project is to help understanding the characteristics needed to develop **new advanced energy generation technologies** that can be **competitive** in the anticipated future market considering all sources of competition.

Problem statement

Given:

A set of **existing** and **potential generators** with the respective:

- generation technology
  - nuclear: steam turbine;
  - coal: steam turbine, IGCC w/ or w/o carbon capture;
  - natural gas: steam turbine, gas-fired combustion turbine, and combined cycle w/ or w/o carbon capture;
  - solar: photo-voltaic, concentrated solar panel;
  - wind turbines
  - advanced fossil fuel energy systems: integrated gasification fuel cell (IGFC), natural gas fuel cell (NGFC).
- location,
- nameplate capacity,
- age and expected lifetime,
- CO_2 emission,
- operating costs,
- investment cost (if applicable),
- operating data:
  - thermal generators: ramping rates, operating limits, spinning and quick-start maximum reserve.
  - renewable generators: capacity factor.



A set of **potential storage devices**, with specified:

- technology:
  - lithium-ion, lead-acid, and flow batteries
- investment cost,
- power rating,
- rated energy capacity,
- charge and discharge efficiency,
- storage lifetime.

Projected load demand over the time-horizon at each location.

Distance between locations.

Transmission loss per mile.

Find:

- The location, year, type, and number of generators and storage devices to **install;**
- When to **retire** the generators;
- Whether or not to **extend their lifetime;**
- Approximate power flow between locations;
- Approximate **operating schedule;**

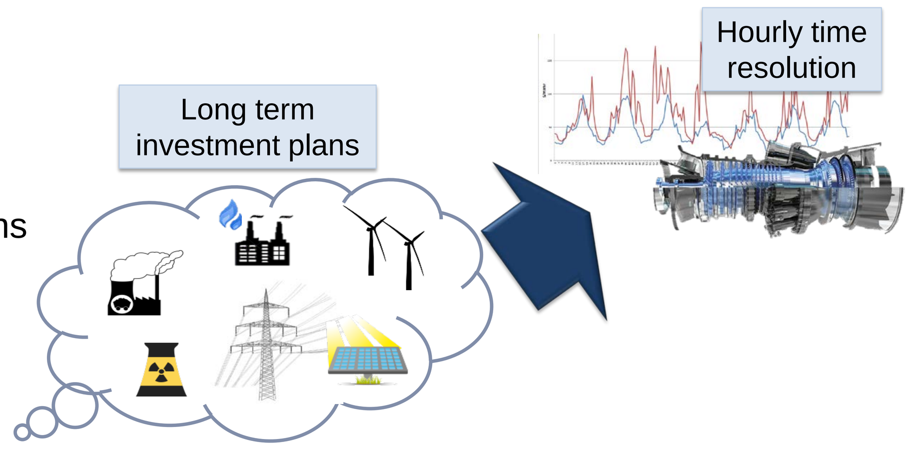
in order to **minimize** the overall **operating, investment,** and **environmental costs.**

Modeling strategies

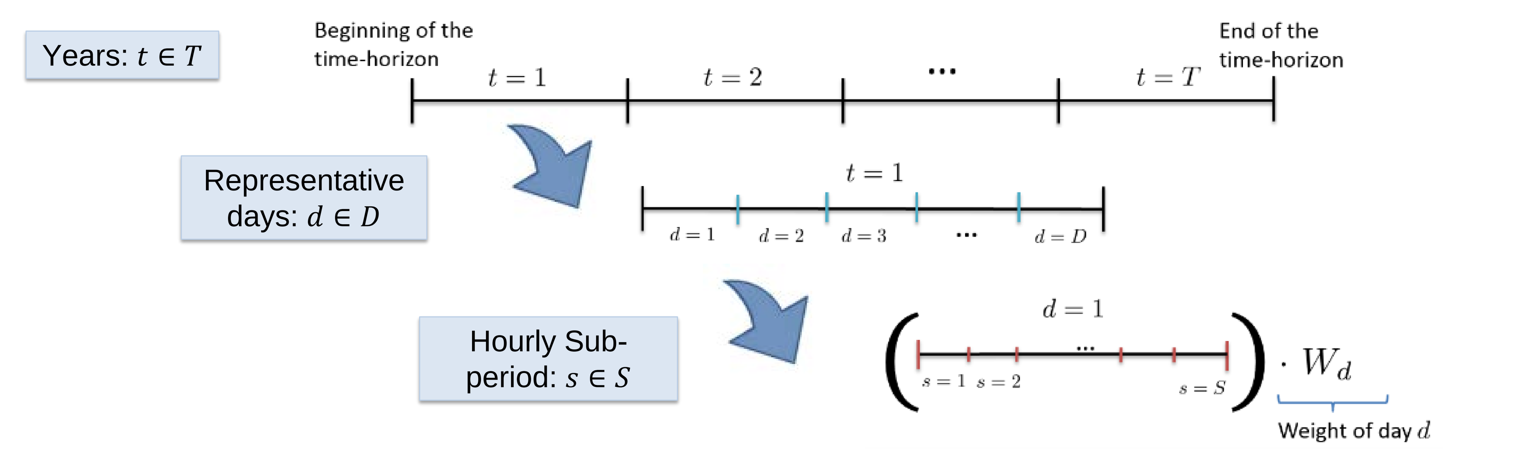
Modeling Challenges

Multiscale problem

- **Temporal:** Investment decisions are made **yearly**, while operation decisions are made **hourly.**
- **Spatial:** Large number of potential locations and generators

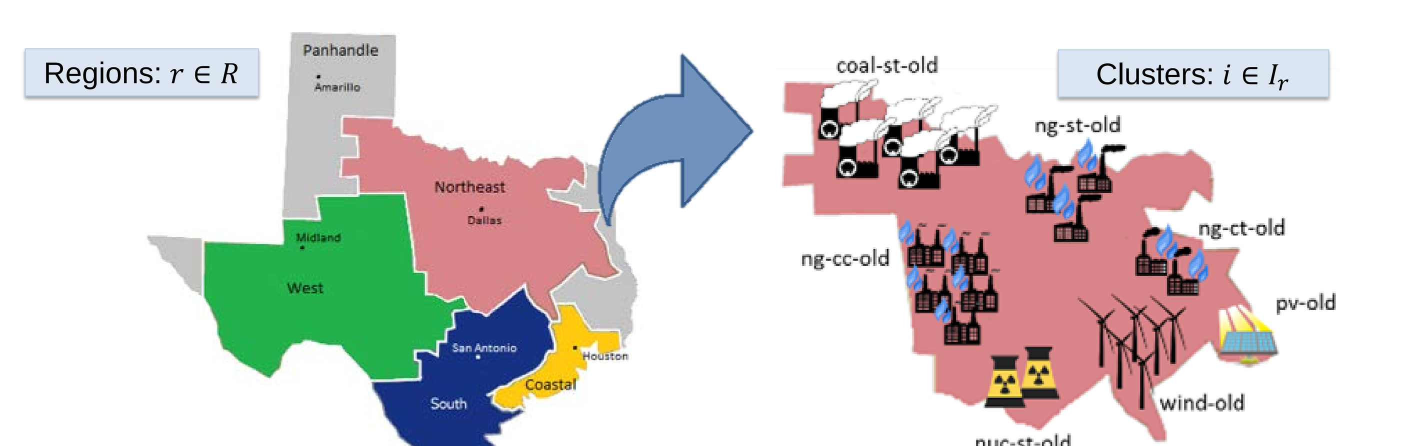


Time-scale Approach



d representative days per year with **hourly level** information (account for unit commitment).

Region and Cluster Representation

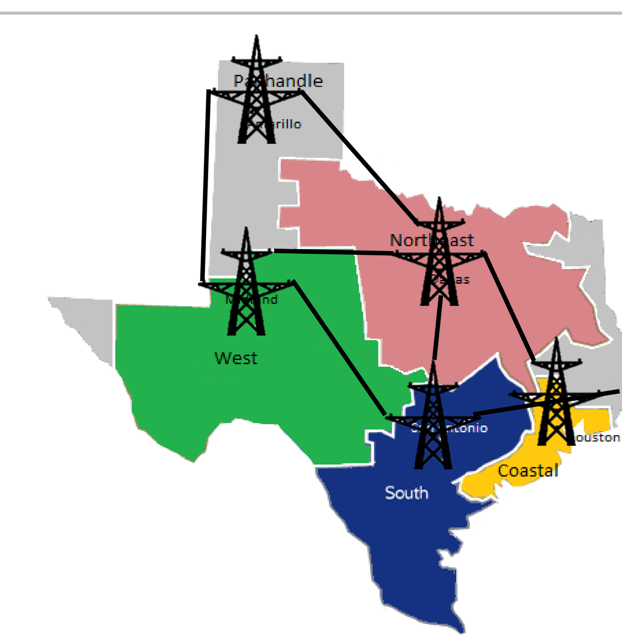


- Area divided into regions *r*.
- Potential locations for generators are the midpoint of each region *r*.
- Clustering* of generators and storage devices in each region *r*.
- Decision regarding generators and storage devices (e.g., install/retire, start-up/shut-down) are modeled as **integer variables.**

*Palmintier, B., & Webster, M. (2014). *Heterogeneous unit clustering for efficient operational flexibility modeling*

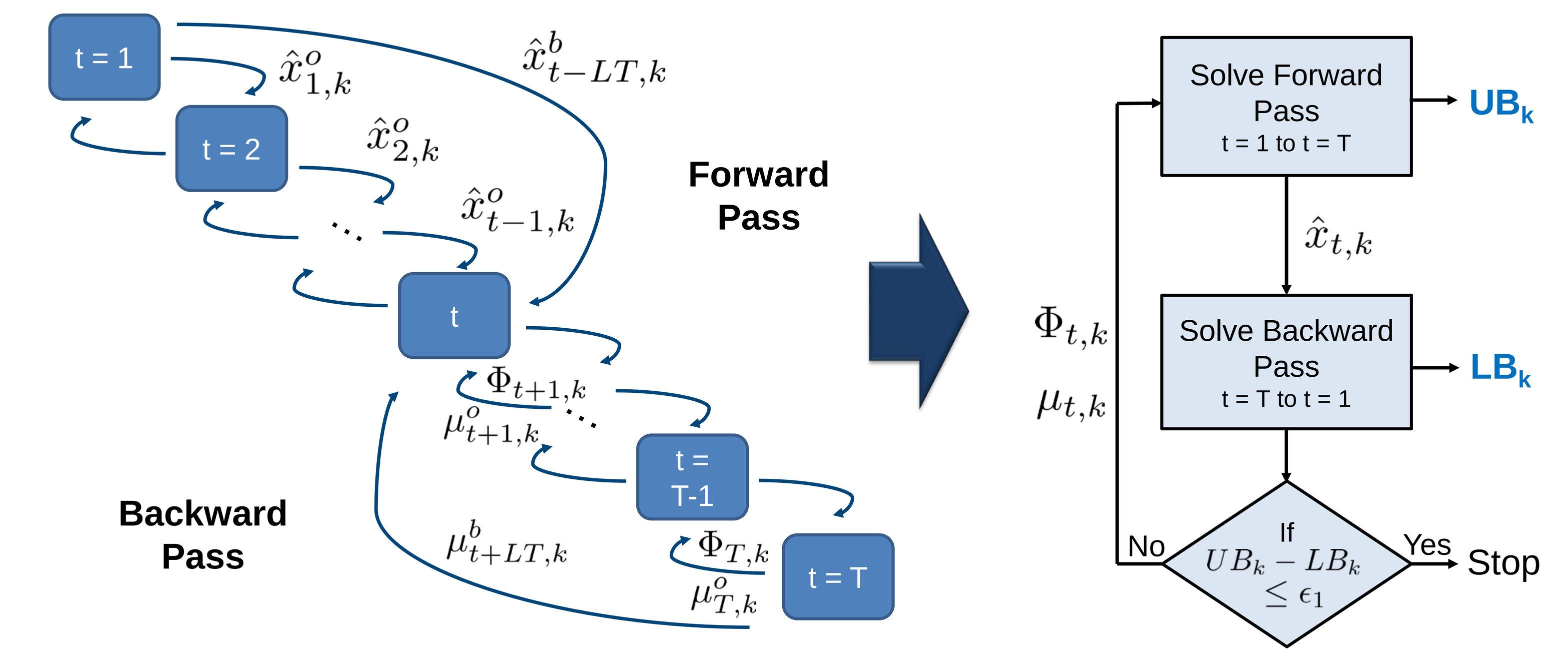
Transmission Representation

- Flow in each line is determined by the **energy balance** between each region *r*.
- This approximation ignores *Kirchhoff's Circuit Law*, which dictates that the power will flow along the path of least impedance.
- Assumed maximum transmission line capacity, but no transmission expansion allowed.



Nested Decomposition for MILP problems

- The algorithm decomposes the problem by **time period *t*** (year)
- Consists of **Forward** and **Backward Passes.**
- The **Forward Pass** solves the problem in myopic fashion (1 year time horizon).
- The **Backward Pass** projects the problem onto the subspace of the linking variables by adding Benders-like cuts.



Zou, Ahmed & Sun (2016). *Nested Decomposition of Multistage Stochastic Integer Programs with Binary Variables*

Case Study: ERCOT (Texas)

- 30 year time horizon (1st year is 2015)
- Data from ERCOT database
- Cost information from NREL (Annual Technology Baseline Spreadsheet 2016)
- Advanced fossil fuel data from Iyengar et al. (2014), and Newby and Keairns (2013).
- Storage device data from Schmidt et al. (2017), and Luo et al. (2015).
- Fuel price data from EIA Annual Energy Outlook 2015 - Reference case

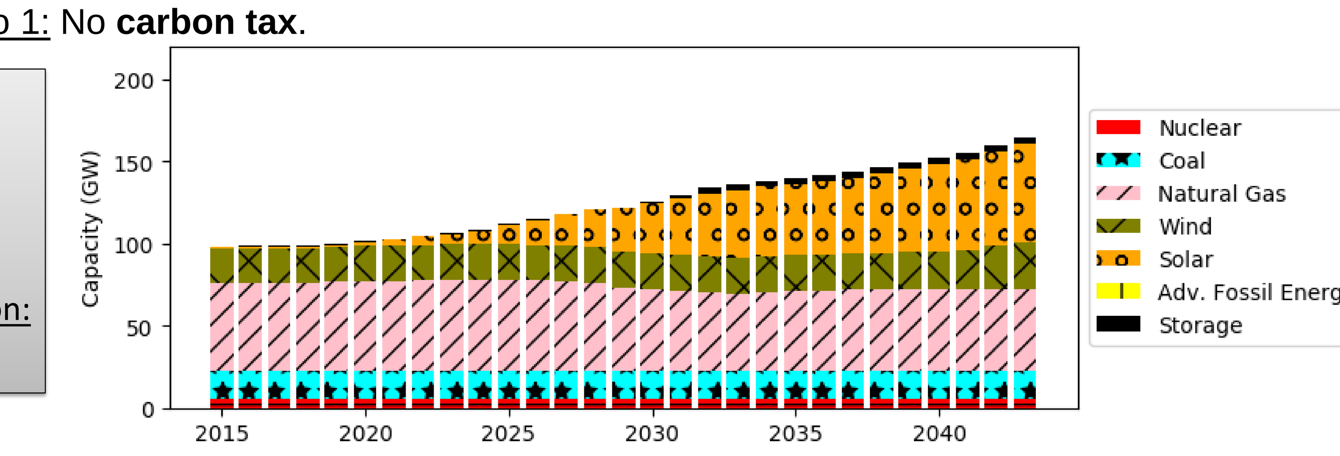
4 representative days per year

Discrete variables: **500,500**	Equations: **1,730,491**
Continuous variables: **810,181**	Solver: Gurobi

PYOMO

- Scenario 1: No **carbon tax**.

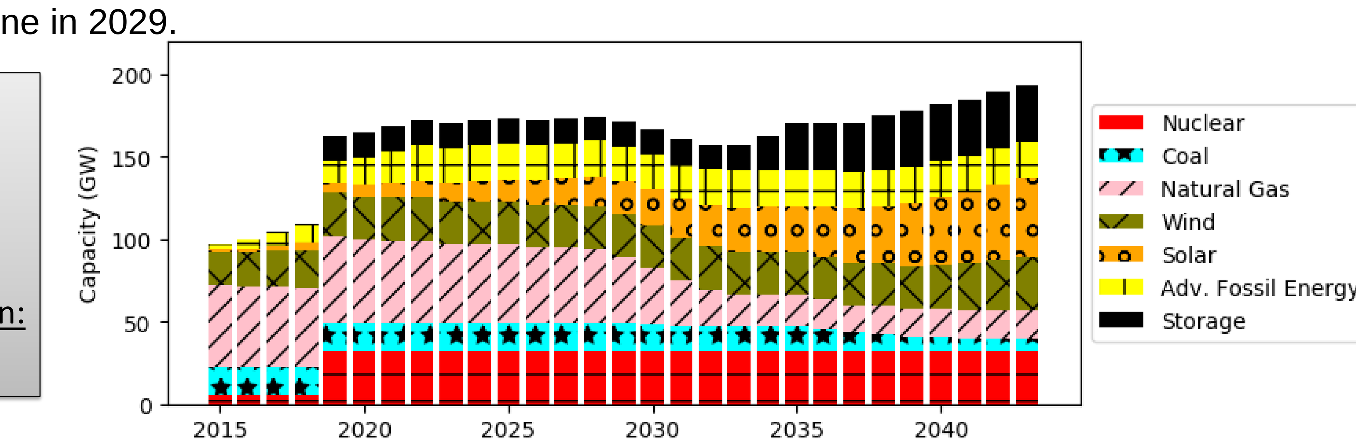
Solution time
Full-space: 10.1 hours
Nested Decomposition: 5.2 hours



Natural gas favored to handle renewable generation and load demand

- Scenario 2: **Carbon tax** starting at \$10/tonne in year 2020, and increasing linearly to \$100/tonne in 2029.

Solution time
Full-space: 4.0 hours
Nested Decomposition: 2.8 hours



Advanced fossil fuels, nuclear and storage favored instead of natural gas