MULTIPERIOD/MULTISCALE MILP MODEL FOR OPTIMAL PLANNING OF ELECTRIC POWER INFRASTRUCTURES

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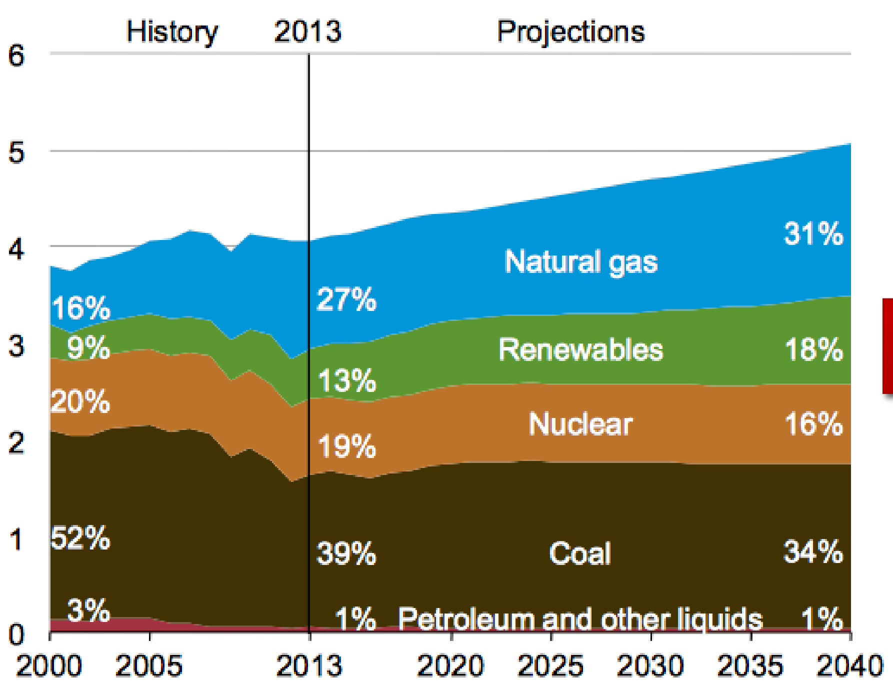
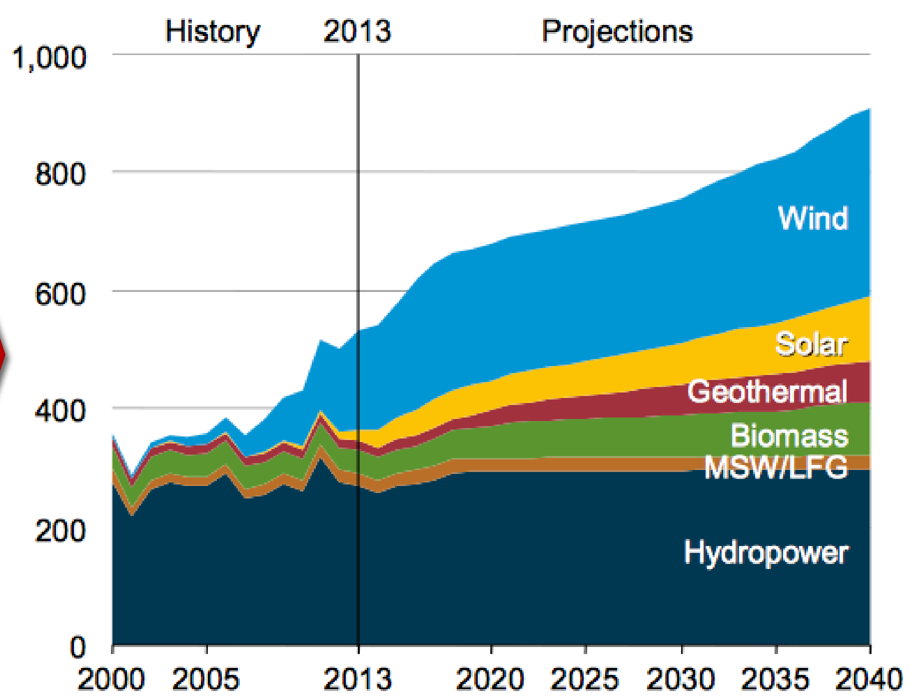
Electricity mix gradually shifts to lower-carbon options

Electricity generation by fuel type (trillion kWh)



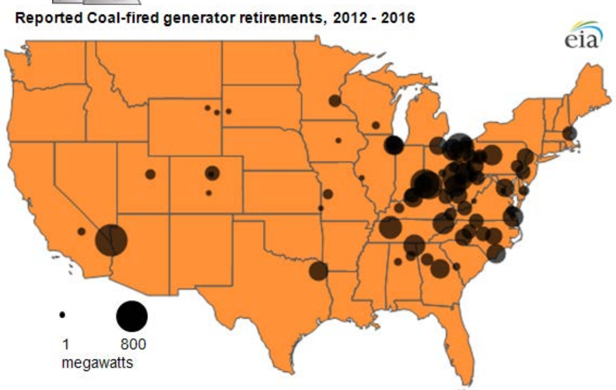
Renewable electricity generation by fuel type (trillion kWh)

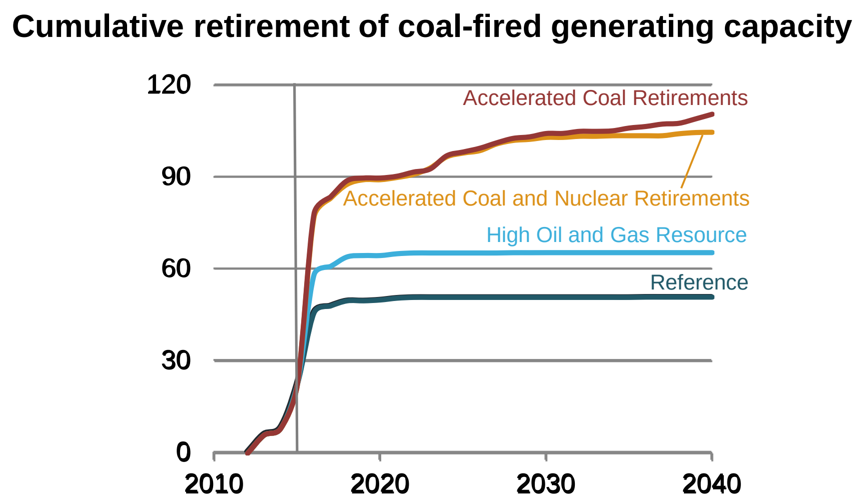


Source: EIA, Annual Energy Outlook 2015 Reference case

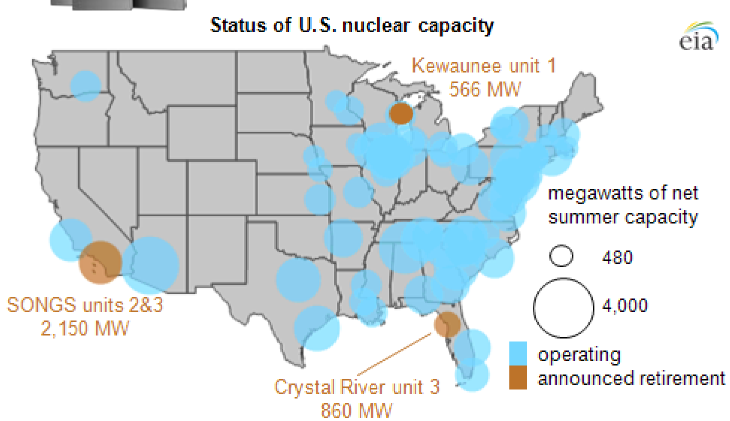
Potential accelerated retirements

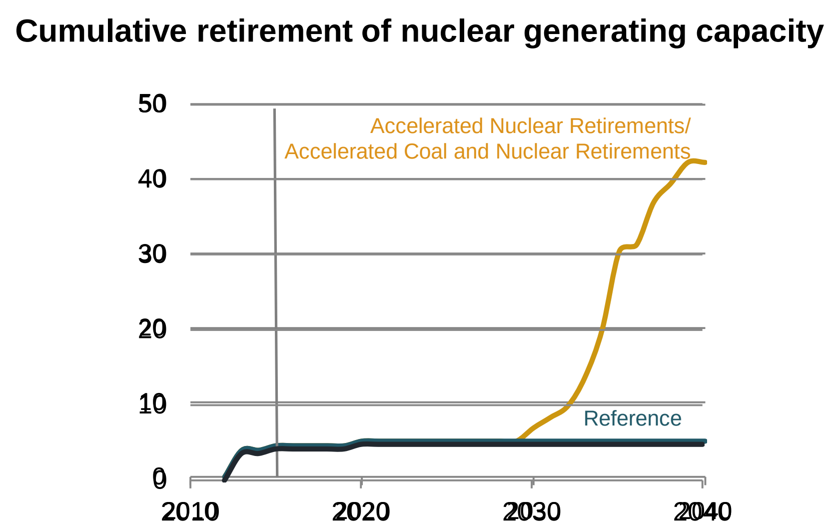
Coal-fired





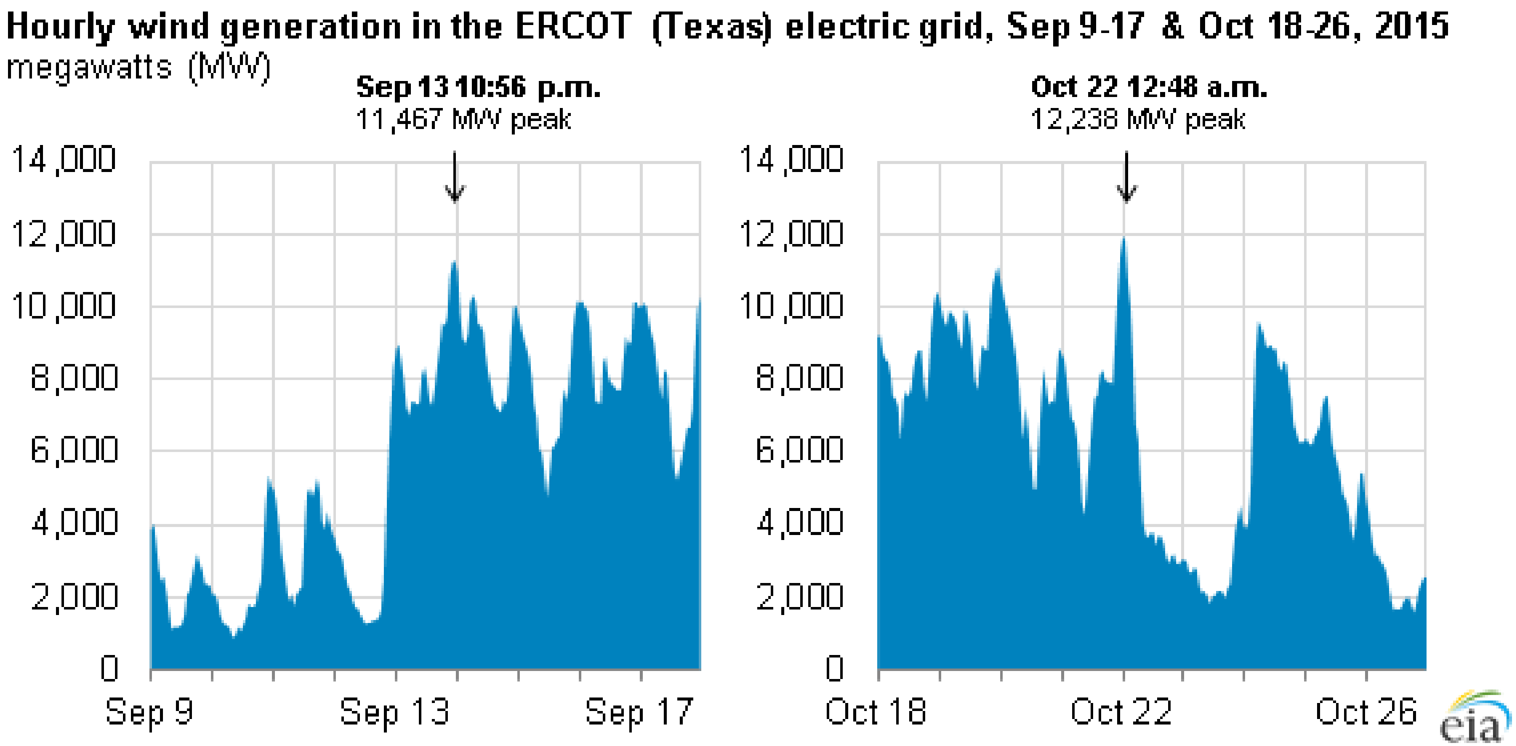
Nuclear





Source: EIA, Annual Energy Outlook 2014

High variability on the renewables capacity factor



- Increasing contribution of renewable power generation in the grid make it crucial to include **operation details in the hourly level** in long term planning models to capture their variability

Source: U.S. Energy Information Administration, based on the Electric Reliability Council of Texas (ERCOT)

Problem statement

By taking the viewpoint of a **central planning**, identify

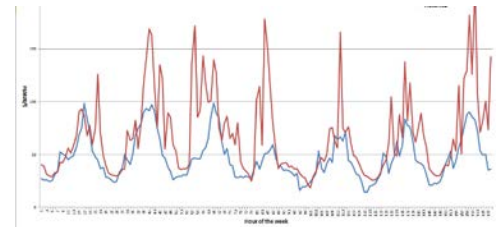
- type
- source
- capacity

of future **power generation** infrastructure that can meet the projected electricity demand while minimizing:

- capital investment of all new generating units
- the operating and maintenance costs of both new and existing units
- environmental costs

Problem statement

Hourly time resolution



In order to be able to capture the variability of generation by renewable source units, and assure that the **load demand is met at anytime**, **operational** decisions are also taken

- ramping limits
- unit commitment status

Long term investment plans

MILP Model

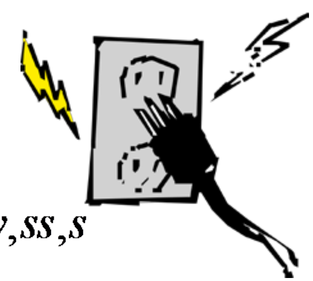
<u>Objective function</u>: Minimization of the discounted total cost over the planning horizon comprising

- Variable operating cost
- Startup cost
- Fixed operating cost
- Cost of investments in new capacities
- Penalty for not meeting the minimum renewable annual energy production requirement

subject to

- <u>Energy balance</u>: ensures that the sum of instantaneous power equal load at all times plus a slack for potential excess generation by the renewable source generators (wind and solar)

$$\sum_{i} P_{i,y,ss,s} = L_{y,ss,s} + c_{y,ss,s}$$



MILP Model

Objective function: Minimization of the discounted total cost over the planning horizon comprising

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subject to

- Unit minimum and maximum power output for **thermal generators**

Minimum % of the capacity nameplate

Capacity nameplate

$$P_i^{\min} \cdot Q_i^{np} \leq P_{i,y,ss,s} \leq Q_i^{np}$$

MILP Model

<u>Objective function</u>: Minimization of the discounted total cost over the planning horizon comprising

- Variable operating cost
- Startup cost
- Fixed operating cost
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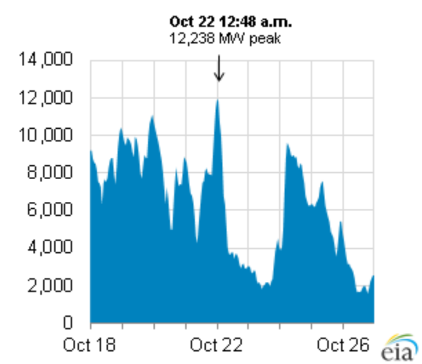
- Penalty for not meeting the minimum renewable annual energy production requirement

subject to

- <u>Capacity factor</u> for **renewable source generators**

$$P_{i,y,ss,s} = Q_i^{np} \cdot c^f_{i,y,ss,s}$$



MILP Model

Objective function: Minimization of the discounted total cost over the planning horizon comprising

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- Penalty for not meeting the minimum renewable annual energy production requirement

subject to

- Minimum reserve margin requirement: ensures that the generation capacity is greater than the peak load by a predefined margin

- Minimum annual Renewable Energy Source (RES) contribution requirement: establish that if the RES quota target (imposed by environmental treaties) is not satisfied, there will be a penalty applied to the deficit in RES production

MILP Model

Objective function: Minimization of the discounted total cost over the planning horizon comprising

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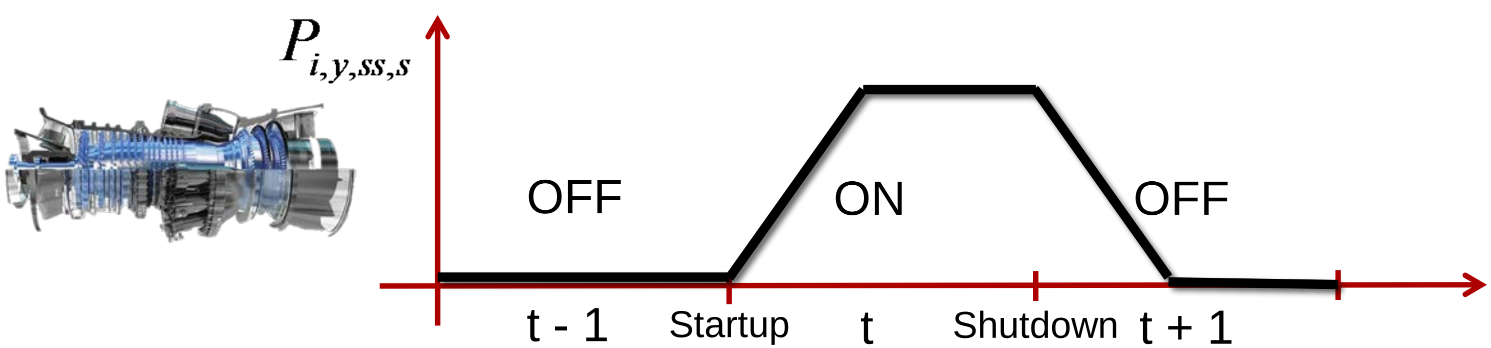
- Fixed operating cost
- Cost of investments in new capacities
- Penalty for not meeting the minimum renewable annual energy production requirement

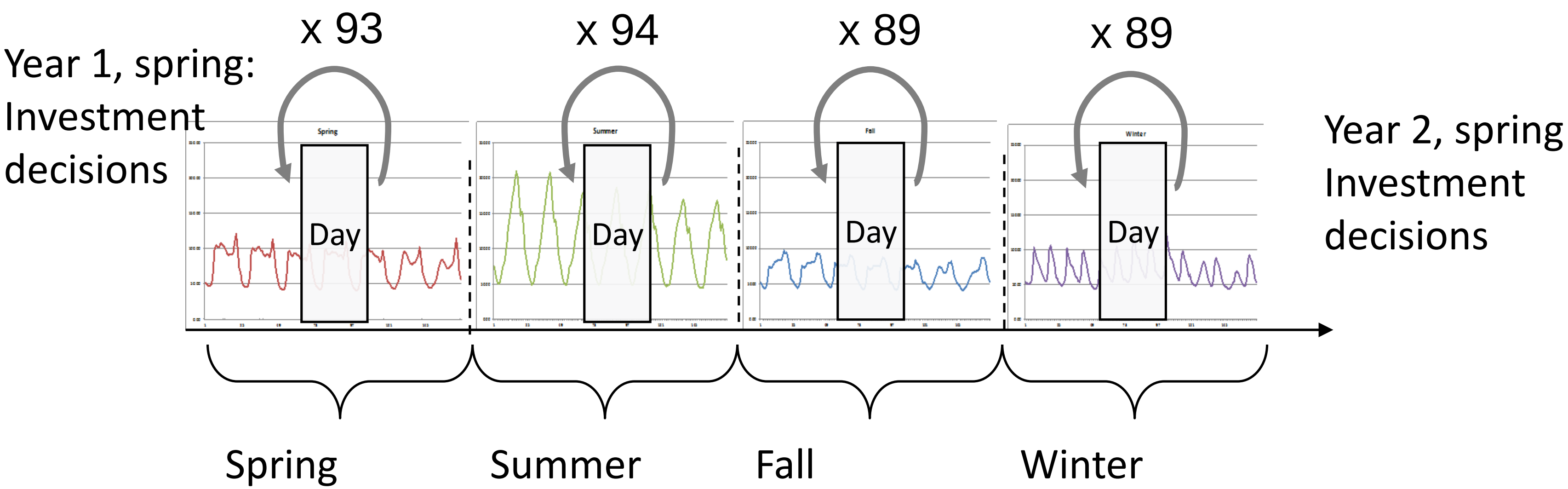
subject to

- Unit commitment status and ramping limits for the **thermal generators**



Modeling strategies for MULTISCALE

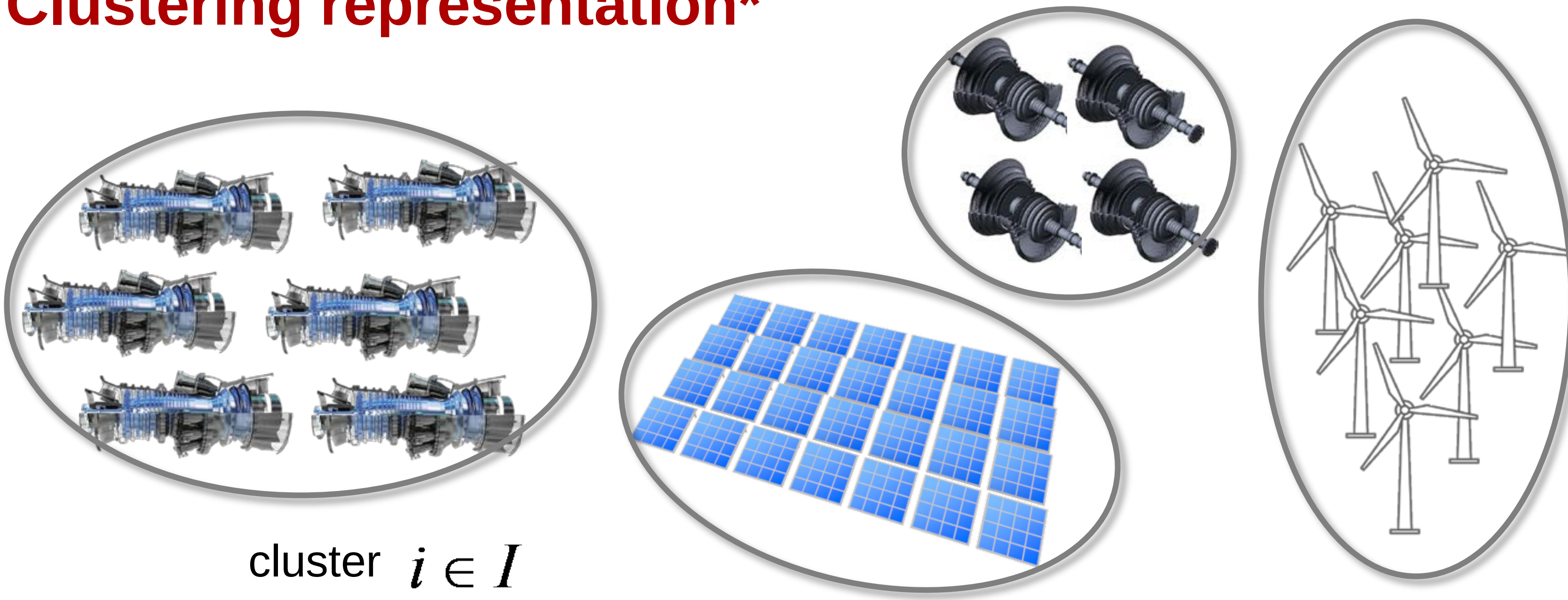
Time scale approach



- Horizon: **30 years**, each year has **4 periods** (spring, summer, fall, winter)
- Each period is represented by **one representative day on an hourly basis**
  Varying inputs: **load demand data, capacity factor of renewable source generators**
- Each representative week is repeated in a **cyclic** manner (~3 months reduced to **1 day**)
- Connection between periods: only through investment decisions

Modeling strategies for MULTISCALE

Clustering representation*



- Instead of representing each generator separately, aggregate same type of generators in **clusters**
- Decision of building/retiring and starting up/shutting down a generator switched from binary to **integer variables**

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

Case study: ERCOT region

30 year time horizon

Data from **ERCOT database**

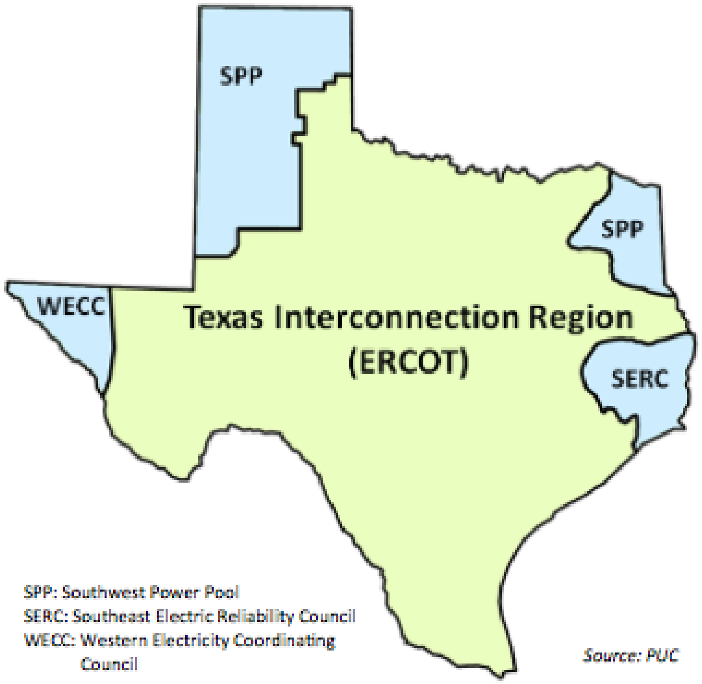
All costs in **2012 U$**

Clusters considered:

- coal-st-old1
- coal-st-old2
- ng-ct-old
- ng-cc-old
- ng-st-old
- nuc-st-old
- pv-old
- wind-old
- coal-igcc-new
- coal-igcc-ccs-new
- ng-cc-new
- ng-cc-ccs-new
- ng-ct-new
- nuc-st-new
- pv-new
- wind-new
- csp-new

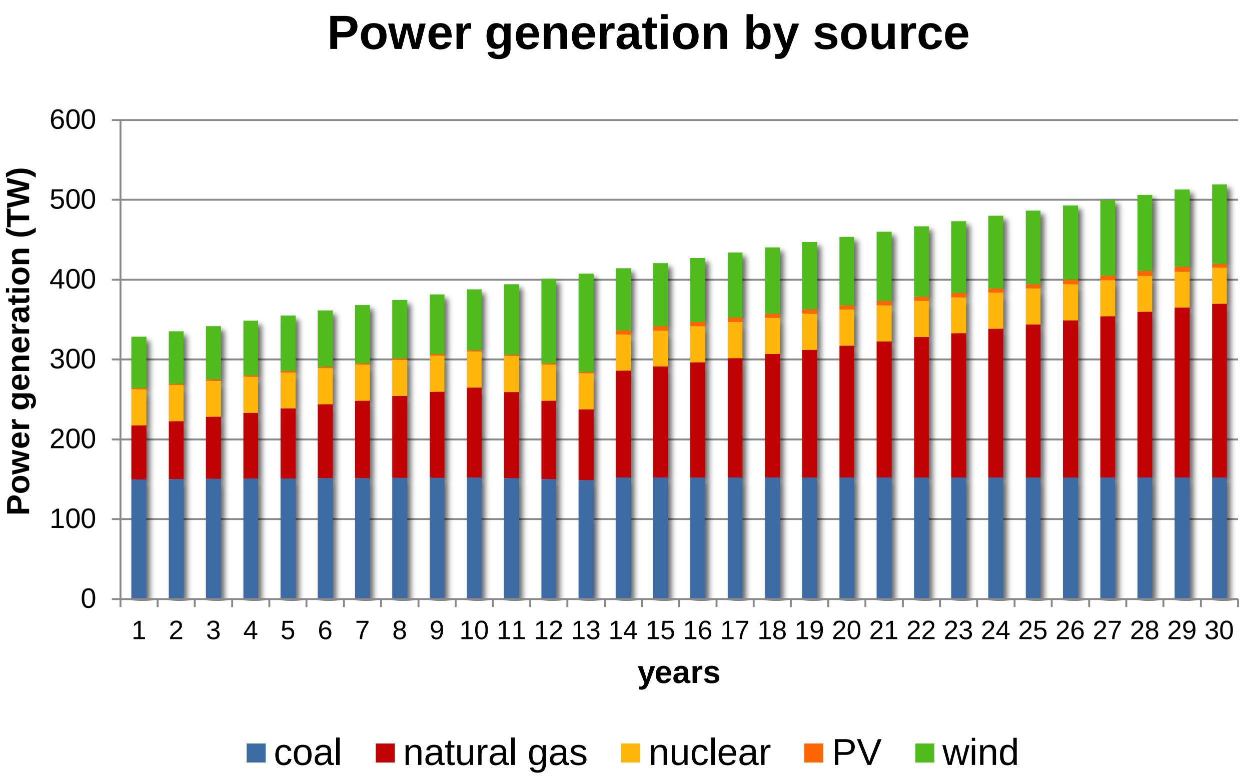
Considers reference* case scenario

Discrete variables: 103,050
Continuous variables: 101,071
Equations: 278,183
CPLEX
optcr = 0.05%

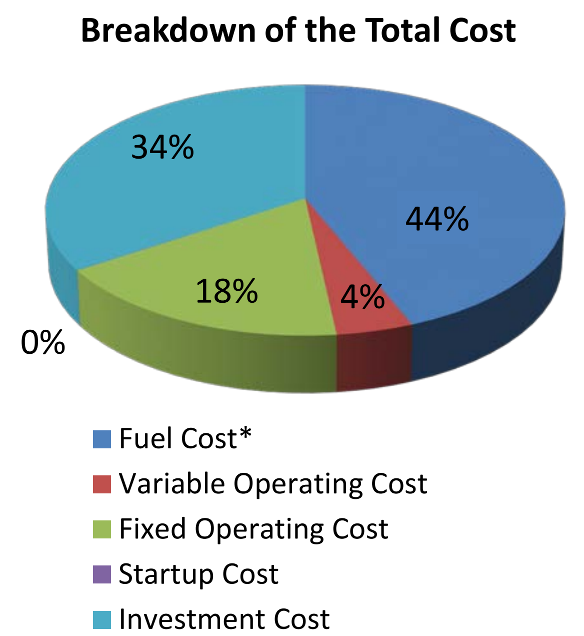


*Based on EIA Annual Energy Outlook 2015 fuel price data

Case study: ERCOT region



Minimum cost: **$ 304.9 billions**
Optimality gap: 0.04%
CPU time: 637 s



Natural gas generation will grow from 21% to 42% of the total generation

Conclusions and Future Work

- Time scale and clustering approaches reduce considerably the size of the MILP, making it possible to solve large instances
- For ERCOT region, future investments will be focused on natural gas and wind generation
- Natural gas will be the major contributor for the overall generation by the end of the time horizon
- Future work:
  - Include transmission in the model (multiple generation nodes)
  - Apply decomposition techniques to speed up the solution
  - Address the uncertainty by extending MILP model to multi-stage MILP stochastic programming model

Acknowledgments

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Thank you!