ReEDS Performance Improvement

Merve Turan[1]

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Collaborators: Atharv Bhosekar,[2] Maxwell Brown,[3] Wesley Cole,[1] and Adam Christensen[2]

[1] National Renewable Energy Laboratory (NREL)

[2] GAMS Development Corp.

[3] Division of Economics and Business, Colorado School of Mines

Contents

The Regional Energy Deployment System (ReEDS)

ReEDS is an open-source, spatially explicit, long-term capacity expansion model for the bulk electric power system. It finds the least-cost evolution of utility-scale generation, storage, and transmission assets from present day to midcentury.

Inputs

- **Existing and planned** capacity
- **Variable renewable energy** temporal (hourly) and spatial availability
- State and federal **policies**, including Inflation Reduction Act
- **Hourly load** projections for 134 zones across contiguous United States
- Capital, operations and maintenance, and fuel **cost** projections
- **Technology** availability and performance projections

ReEDS

Outputs

- Generation and storage **capacity** additions and retirements in each solve year, typically through 2050
- **Transmission** capacity additions
- **Operations**: electricity generation, firm capacity, and operating reserves by technology
- CO_2, NOx, SO_2, CH_4 **emissions**
- System **cost** ($billion), electricity **price** ($/megawatt-hour), retail **rates** (¢/kilowatt-hour)

https://www.nrel.gov/analysis/reeds/

https://github.com/NREL/ReEDS-2.0

Motivation

- More complexity = longer runtime

- ReEDS solve times have increased from ~4–6 hours in 2018 to 18–48+ hours in 2023.
- Solve time increases have primarily come from increased model complexity (more variables and constraints).
- Some hard-to-solve cases cannot be solved without tuning solver settings.
- New technologies and research questions continue to add pressure to capture more complexity within the model.

Methods

- Aspects that contribute to runtime

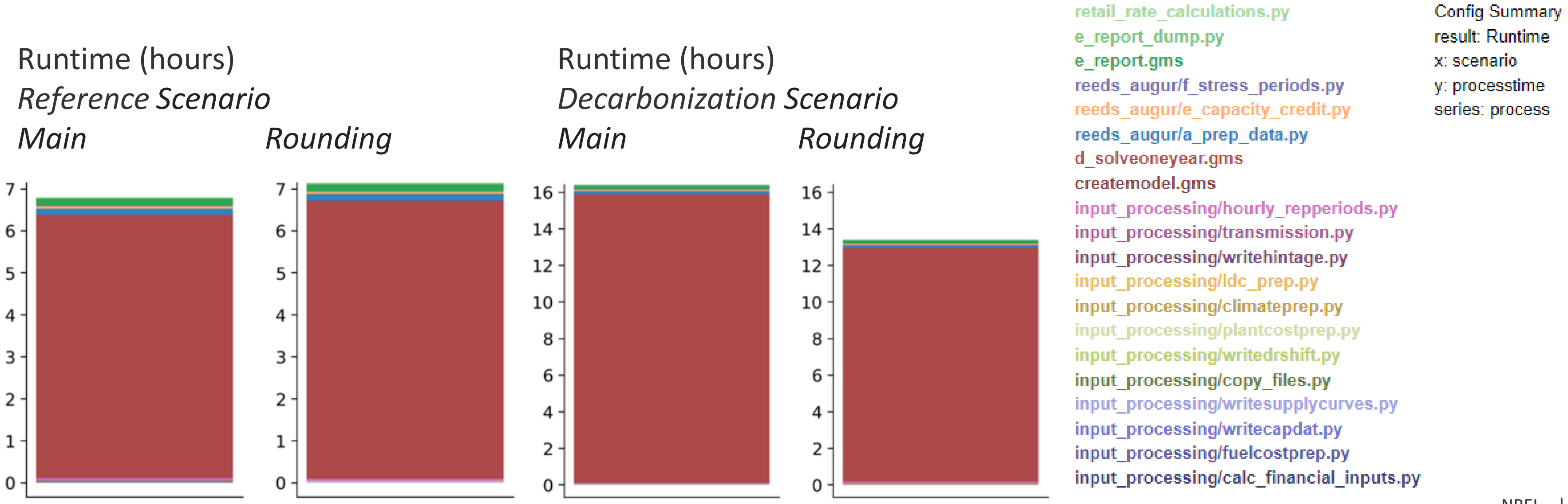
- Data preparation
  - Rounding and eliminating small numbers
  - Reciprocal tests
- Model
  - Shrinking valid capacity set (i.e., trimming variables and constraints)
  - Reducing storage vintages
  - Removing small penalty in the objective function
- Solver tuning
  - Threads test
  - Optimality tolerance.

Methods

- ReEDS was tested using default settings (reference) and a decarbonization scenario (100% decarbonization by 2035)
  - The decarbonization scenario allows for endogenous hydrogen, which is not allowed in the reference scenario
  - The reference and decarbonization scenarios had 2.1 and 2.6 million equations, respectively, in 2023.
- The ReEDS model version used in these tests most closely aligns with 2024.0.0 (https://github.com/NREL/ReEDS-2.0/releases/tag/v2024.0.0)
- Scenarios were run on the NREL high-performance computer (Kestrel)
  - Dual-socket Intel Xeon Sapphire Rapids 52-core processors (104 cores total)
  - 256 GB DDR5 RAM.

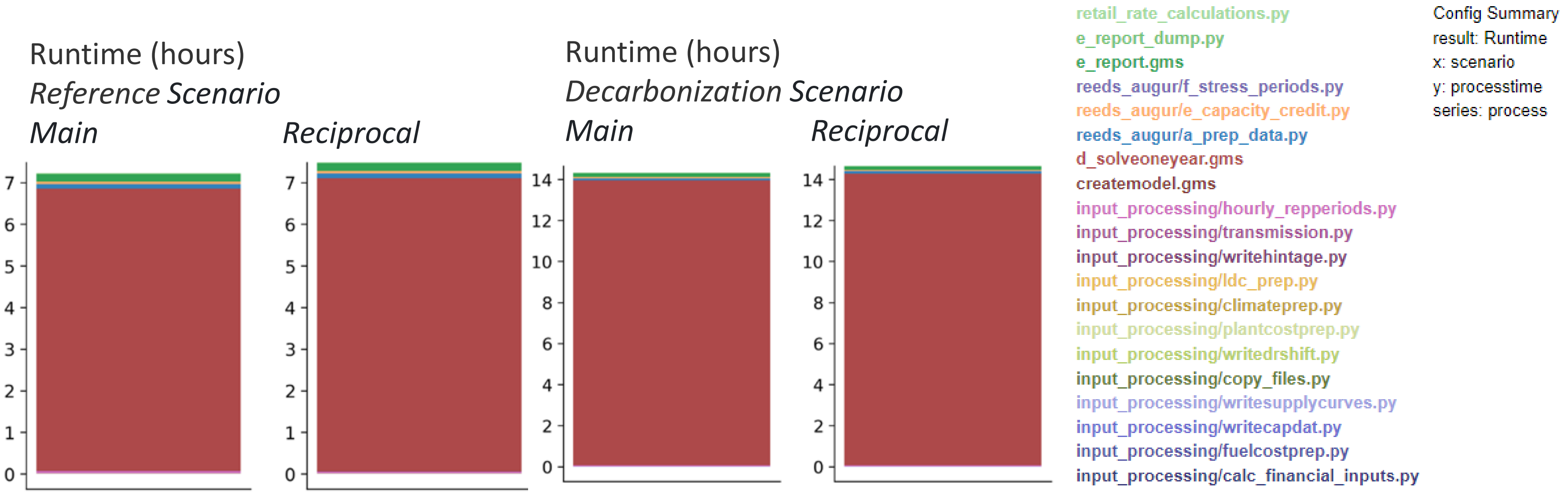
Data Preparation: Rounding and Eliminating Small Numbers

- **Challenge:** ReEDS's parameters vary from 1e-10 to 1e10. However, parameter values that are very close in the model can increase runtime. We tested runtimes with rounding and reorganizing parameter preparation under reference and decarbonization scenarios.
- **Results:** Rounding and reorganizing reduce runtime by **12.5%** under the **decarbonization** scenario, but they do not have a significant effect under the reference scenario. Moreover, comparison of the model size before and after pre-solve shows rounding improves pre-solve performance under the decarbonization scenario.



Data Preparation: Reciprocal Test

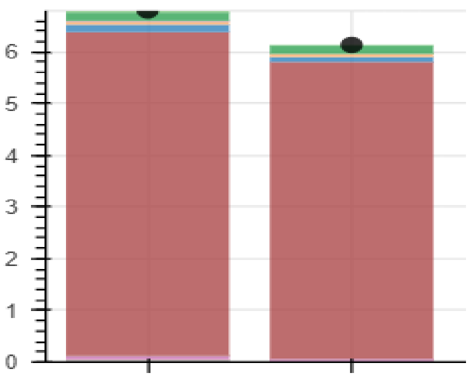
- **Challenge:** In the ReEDS objective function and constraints, some coefficients of variables are defined by multiplying multiple parameters or the reciprocal of a parameter. This can lead to an increased number of digits in the computed parameter. We defined a single parameter with multiplication of corresponding parameters and rounded it to reduce the number of digits. We then tested this methodology under reference and decarbonization scenarios.
- **Results:** This method **does not have a significant effect** on runtime under both scenarios.



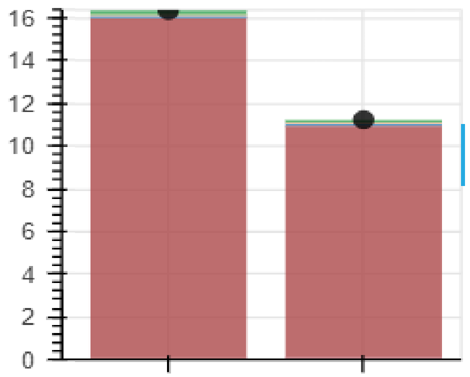
Model: Shrinking Valid Capacity

- **Challenge:** ReEDS defines a set valid capacity (valcap) for the allowable capacity combinations within the model. Because ReEDS tracks vintages of technologies, when one is not invested in, it will no longer be an option in future years. Because nearly all equations in the model are conditioned by valcap, these unused elements increase the model size as it progresses through time. We tested a shrinking method to eliminate unused sets of the current year in next year's valcap if no investments in that technology occurred in a given region.
- **Results:** Runtime reduced by **10%** and **25%** in reference and decarbonization scenarios, respectively.

Runtime (hours)
Reference Scenario
Main *Shrinking Valcap*



Runtime (hours)
Decarbonization Scenario
Main *Shrinking Valcap*



retail_rate_calculations.py
e_report_dump.py
e_report.gms
reeds_augur/f_stress_periods.py
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reeds_augur/a_prep_data.py
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createmodel.gms
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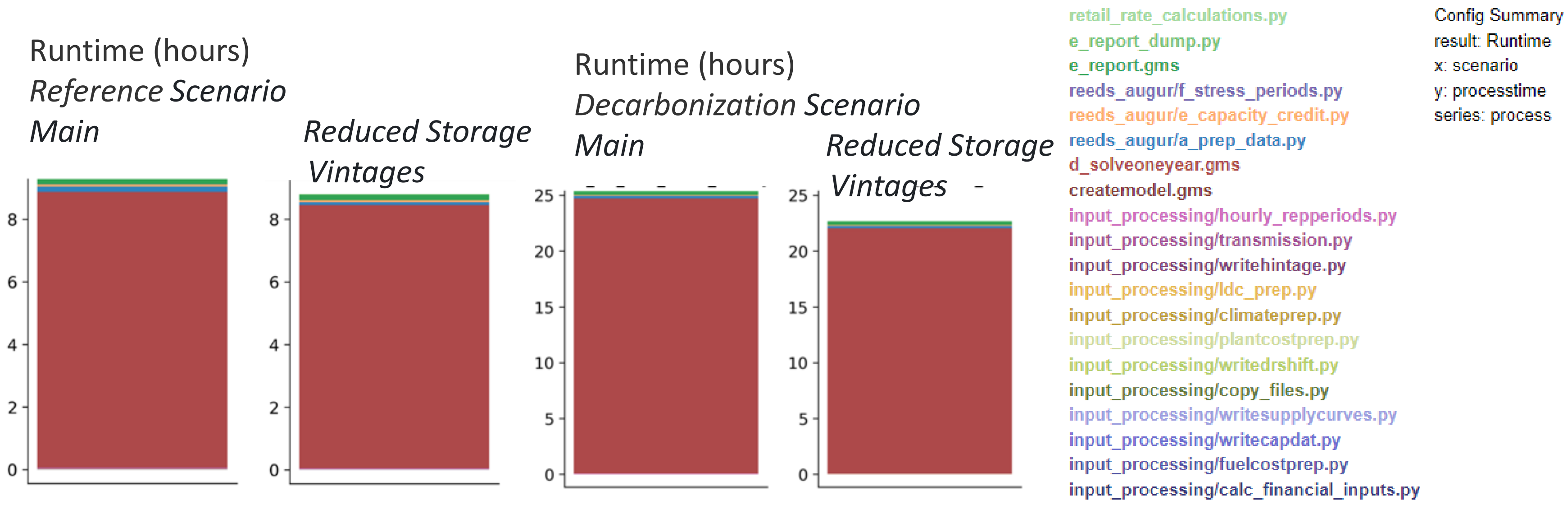
input_processing/transmission.py
input_processing/writehintage.py
input_processing/ldc_prep.py
input_processing/climateprep.py
input_processing/plantcostprep.py
input_processing/writedrshift.py
input_processing/copy_files.py
input_processing/writesupplycurves.py
input_processing/writecapdat.py
input_processing/fuelcostprep.py
input_processing/calc_financial_inputs.py

Config Summary
result: Runtime
x: scenario
y: processtime
series: process

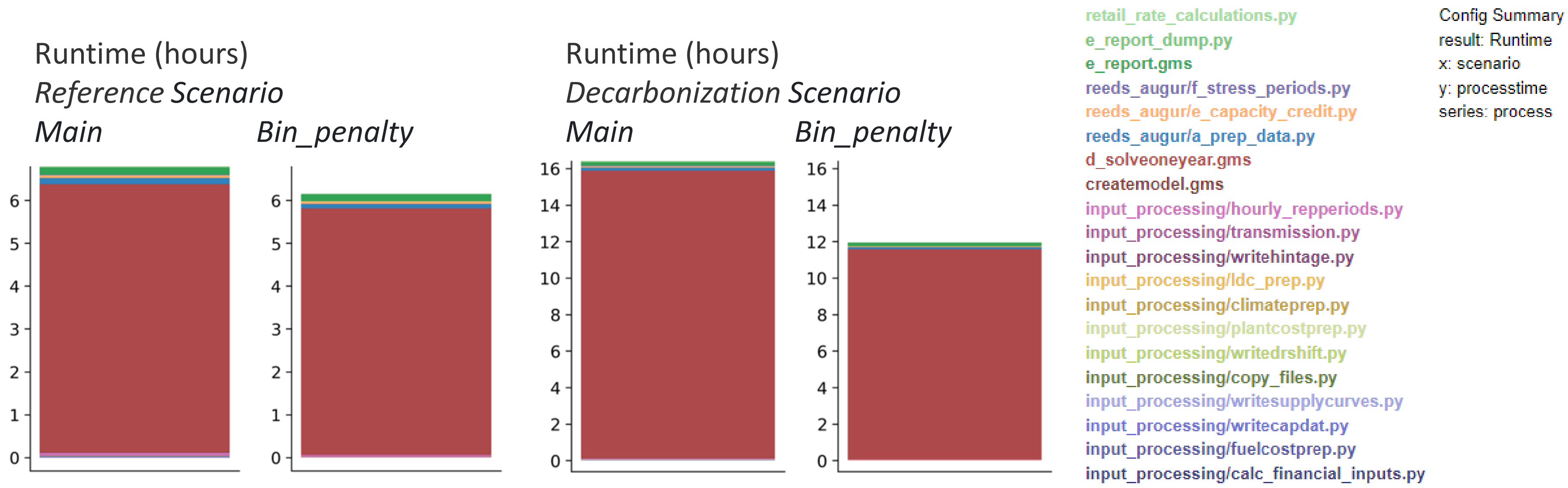
Model: Reduced Storage Vintages

- **Challenge:** Storage equations and variables are one of the high-density equations in the model. To reduce the number of these dense equations, only one storage vintage is allowed for each storage technology. We tested this vintage reduction on solve time under both reference and decarbonization scenarios.
- **Results:** There is **no meaningful runtime impact** in the reference scenario, but we saw a **10% reduction** in runtime in the decarbonization scenario.



Model: Removing Small Objective Function Penalty

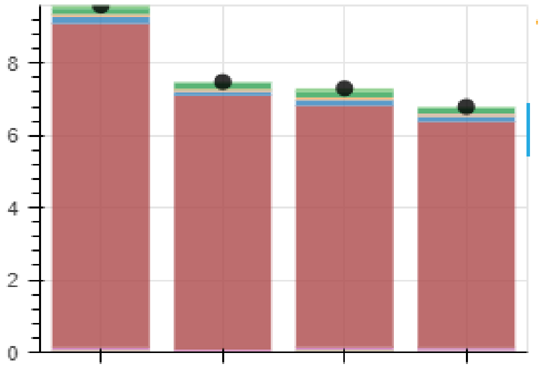
- **Challenge:** The ReEDS objective function includes a small penalty (1e-5) on one of the variables to create cleaner outputs. However, this penalty is very close to the optimality tolerance, and because the objective function value is by far the smallest, it leads to very large ratios between the smallest and largest coefficients (~1e12).
- **Results:** Eliminating these penalties from the objective function reduced runtime by **7%** and **25%** in the reference and decarbonization scenarios, respectively.



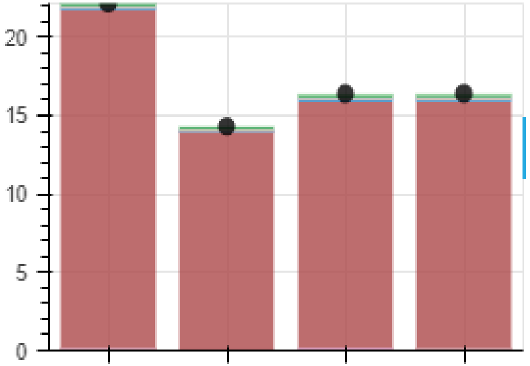
Solver Tuning: Thread Number

- **Challenge:** The thread number defines the number of cores CPLEX uses during a parallel optimization. Because using a higher thread count can increase the complexity of parallel solving, we tested solve time with 4 (prior default), 8, 16, and 32 threads under both reference and decarbonization scenarios.
- **Results:** Setting thread number to **8** reduced runtime nearly **22%** and **35%** under reference and decarbonization scenarios, respectively.

Runtime (hours)
Reference Scenario
Thr 4 - Thr 8 - Thr 16 - Thr 32



Runtime (hours)
Decarbonization Scenario
Thr 4 - Thr 8 - Thr 16 - Thr 32



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Config Summary
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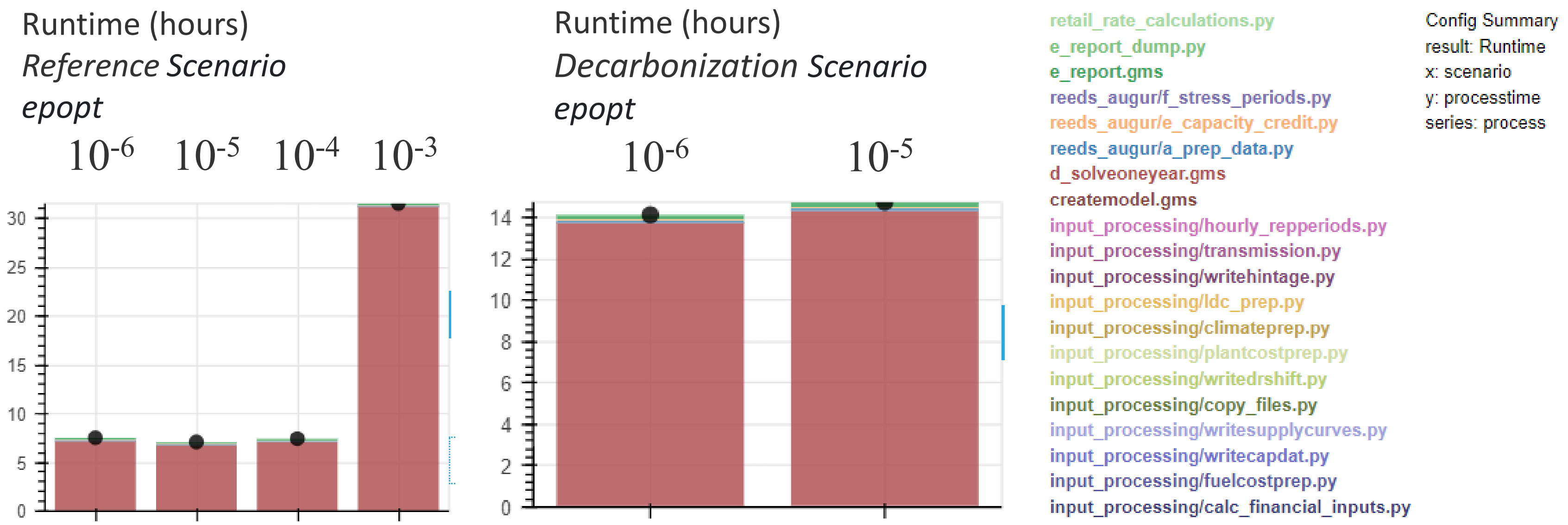
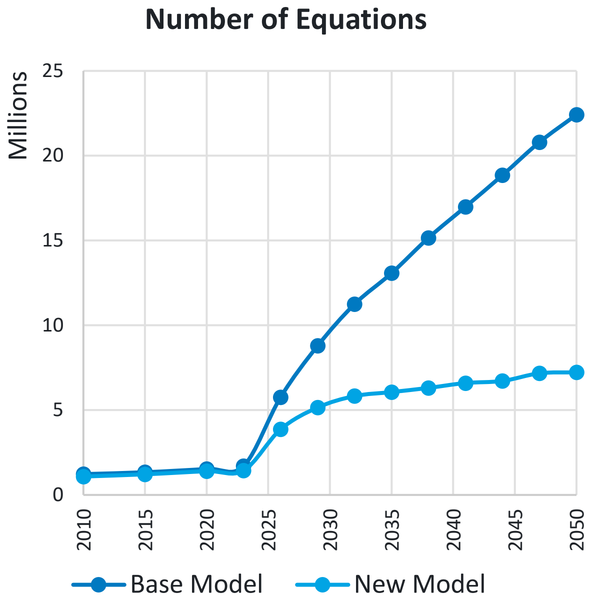
Solver Tuning: Optimality Tolerance (epopt)

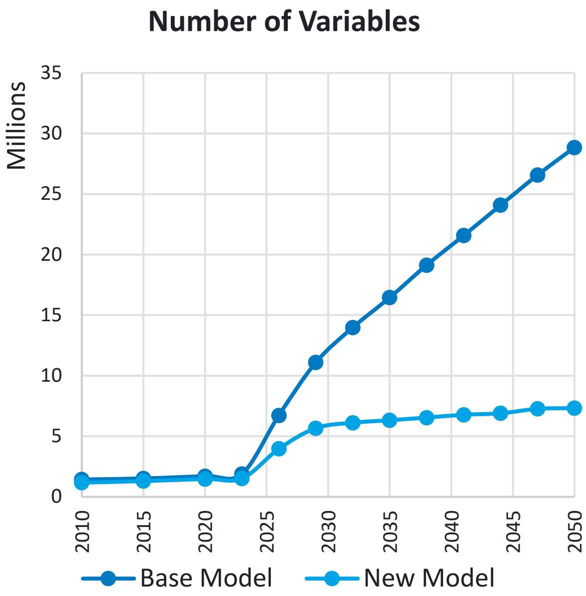
- **Challenge:** The optimality tolerance influences the reduced-cost tolerance for optimality. Reducing the optimality tolerance decreases the difference between the model optimal solution and the precise optimal solution and can influence runtimes. We tested solve times with epopt numbers 1e-6, 1e-5, 1e-4, and 1e-3. The model does not complete with epopt 1e-4 and 1e-3 under decarbonization scenarios.
- **Results:** Increasing epopt **does not** reduce runtime under both scenarios.

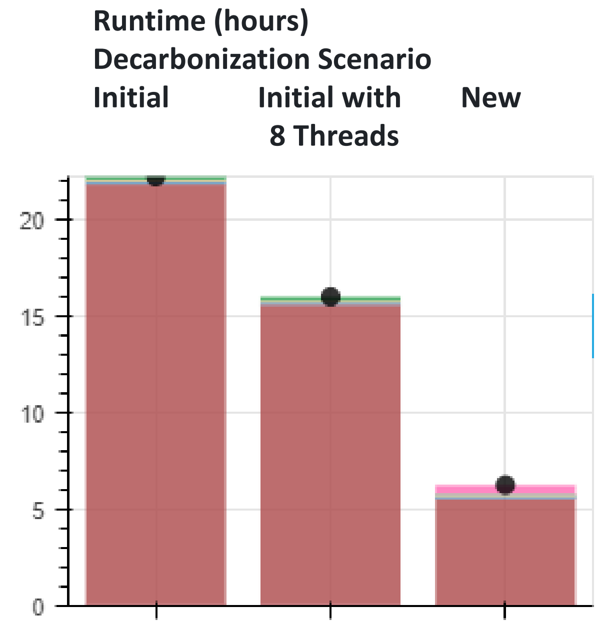


Conclusions

Method	Reference Runtime	Decarbonization Runtime
Data Preparation		
Rounding and eliminating small numbers	No effect	13% reduction
Reciprocal tests	No effect	No effect
Model		
Shrinking valcap	10% reduction	31% reduction
Reducing storage vintages	No effect	10% reduction
Removing small penalty in objective function	7% reduction	25% reduction
Solver Tuning		
Threads test	22% reduction	35% reduction
Optimality tolerance	No effect	No effect







Conclusions

- All the studied methodologies have significant impact:
  - 75% reduction in the number of equations and variables
  - 77% reduction in runtime
  - 66% in runtime when both models have the same number of threads.

Thank you

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NREL/PR-6A40-91641

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