TulipaEnergy

Faster Solving and Higher Detailed Large-Scale Energy System Models

Diego Tejada | JuMP dev 2024

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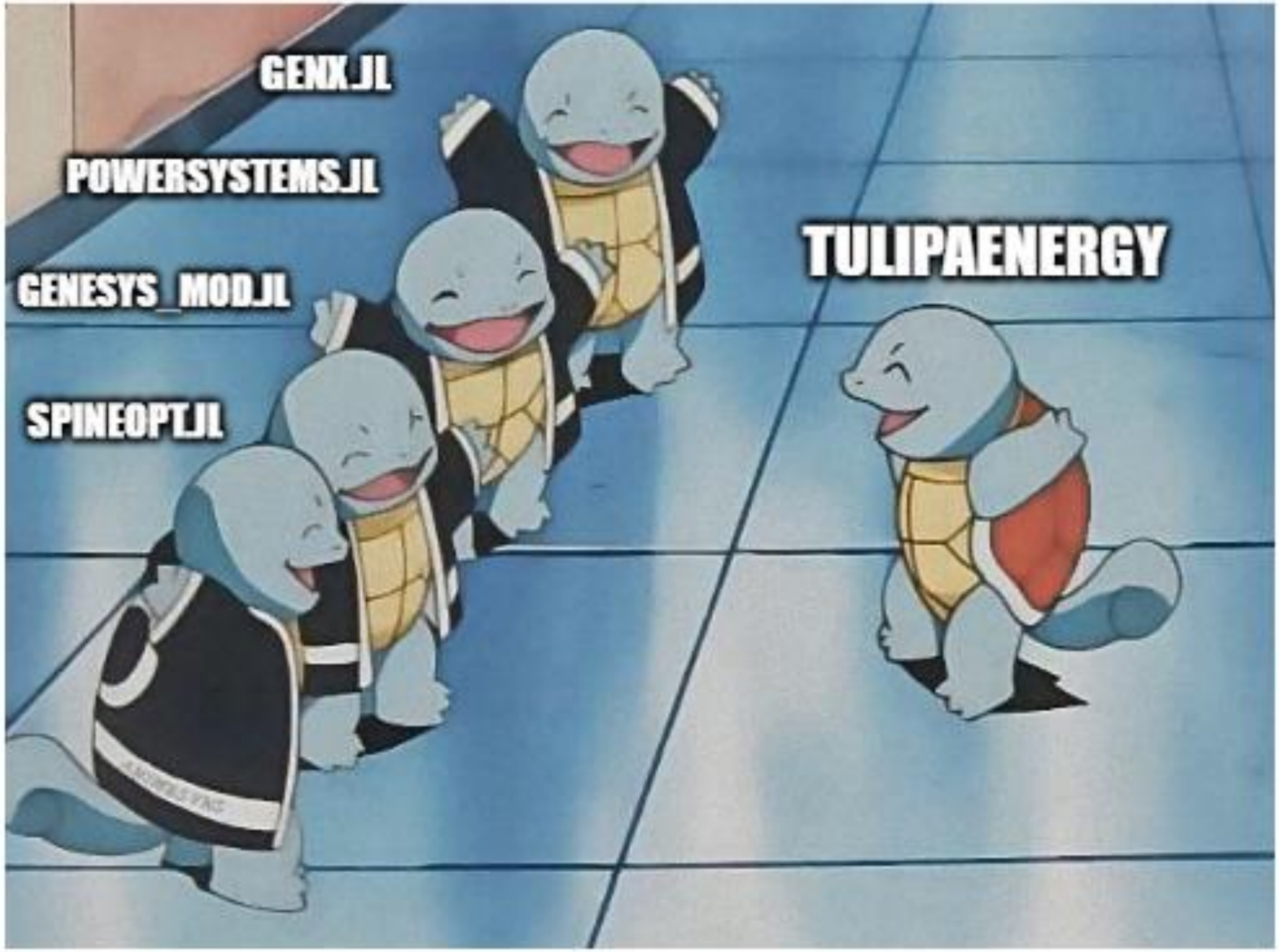
Netherlands Organisation for Applied Scientific Research

Creating impactful innovations for the sustainable wellbeing and prosperity of society.

MOBILITY & BUILT ENVIRON...	DEFENCE, SAFETY & SECU...	ENERGY & MATERIALS TRA...
HEALTHY LIVING & WORK	HIGH TECH INDUSTRY	ICT, STRATEGY & POLICY

Yet Another Energy System Model in Julia...



The Challenge

- Models aid in integrating renewable energy and coupling energy carriers.
- Optimizing investments helps stakeholders understand system dynamics for energy transition.
- Existing models excel in either technological, operational, or spatial-temporal detail, but never all three simultaneously.
- Key challenge: including enough details while remaining computationally tractable.

Project Description

- New energy model from scratch (model design and coding)
- Sector coupling: e.g., electricity, H2 and heat
- The main objective is to determine the optimal investment and operation decisions
- Representation of different types of energy assets (e.g., producers, consumers, conversions, storages, and transports)

⭐ Focus on compact and efficient formulations and implementations suitable for expert energy system researchers

The TulipaEnergy Team

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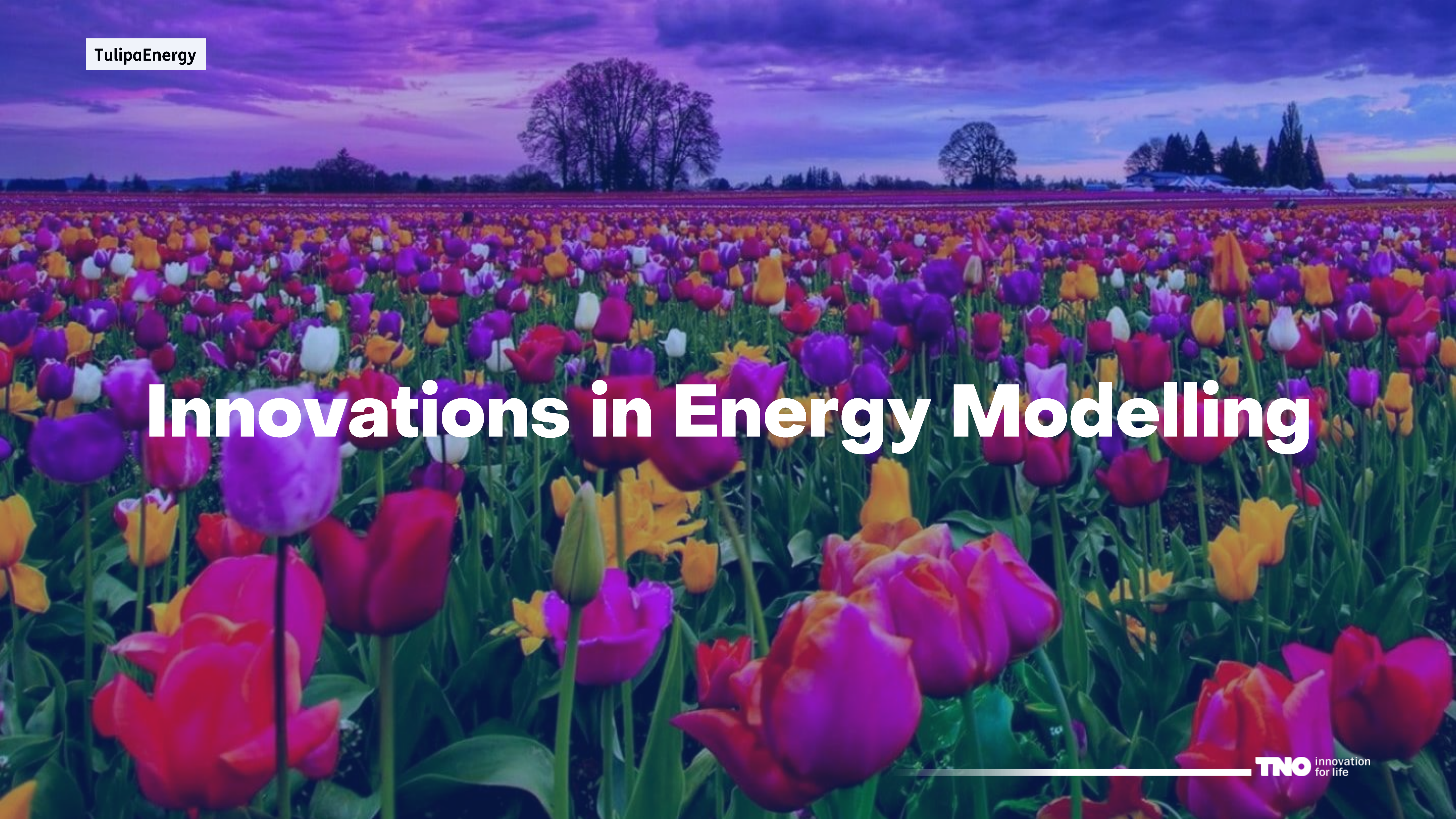
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Innovations in Energy Modelling
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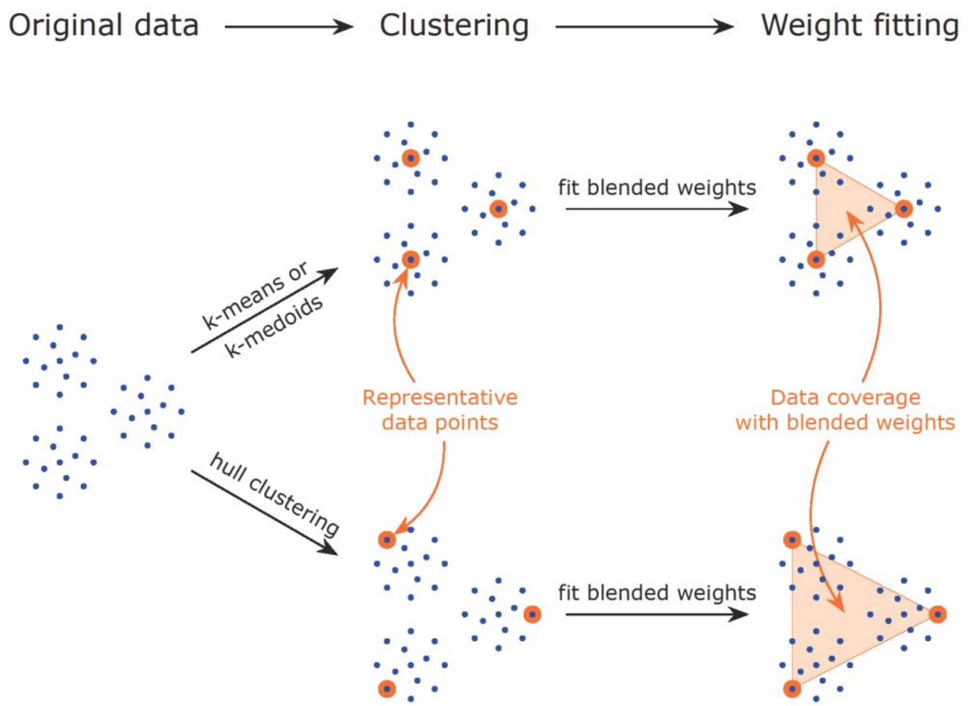
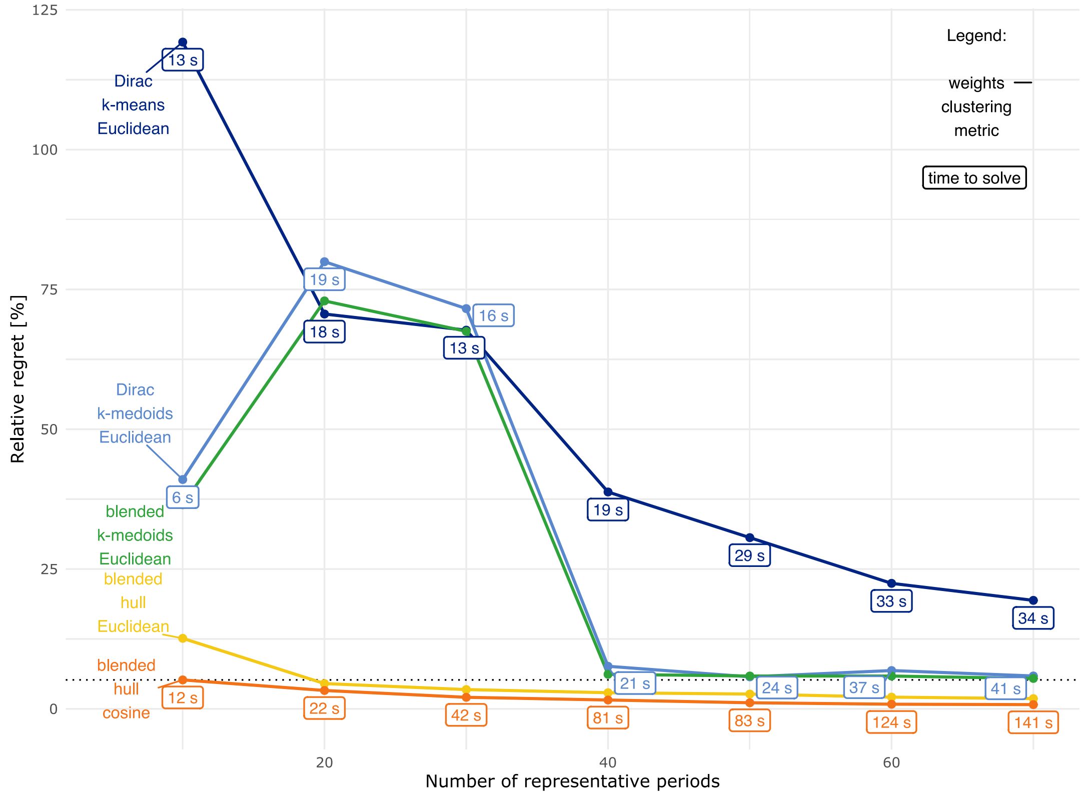
Hull Clustering with Blended Representative Periods

- Method of hull clustering with blended representative periods (RPs)
- Advantages over k-means/medoids in data representation
- Faster performance with lower relative regret using fewer RPs

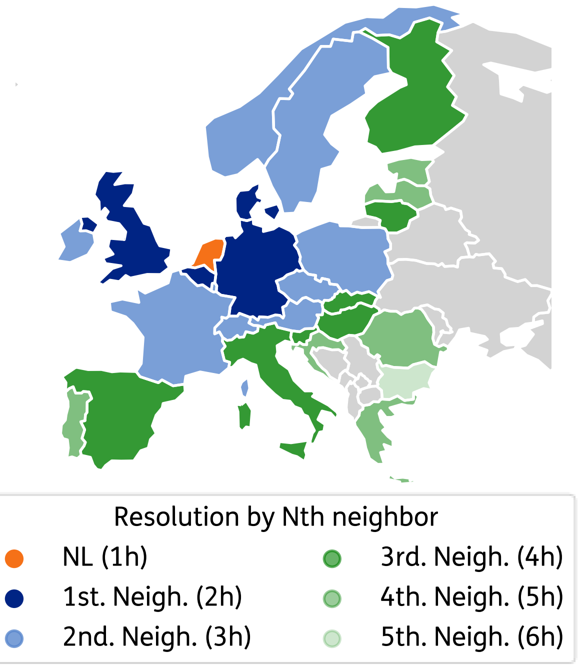




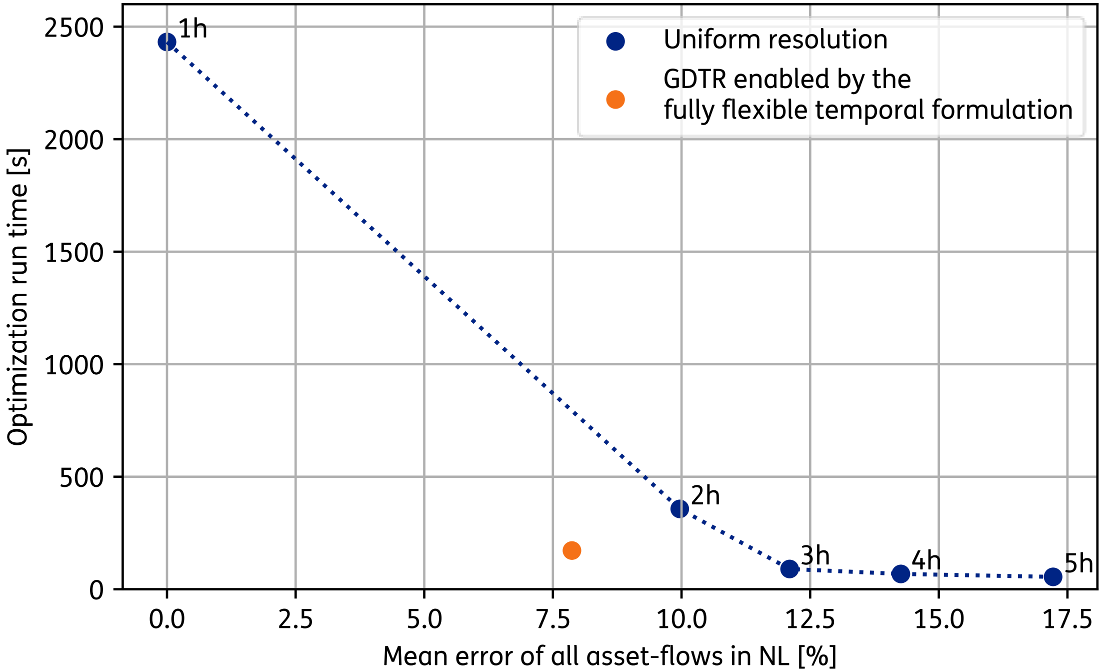
Fully Flexible Temporal Resolution

- Flexible formulation for temporal resolution
- Capability to mix independent resolutions across carriers, regions, and time horizons
- Example of geographical application in the Netherlands

Geographically Decreasing Temporal Resolution (GDTR)



Computational cost vs solution accuracy



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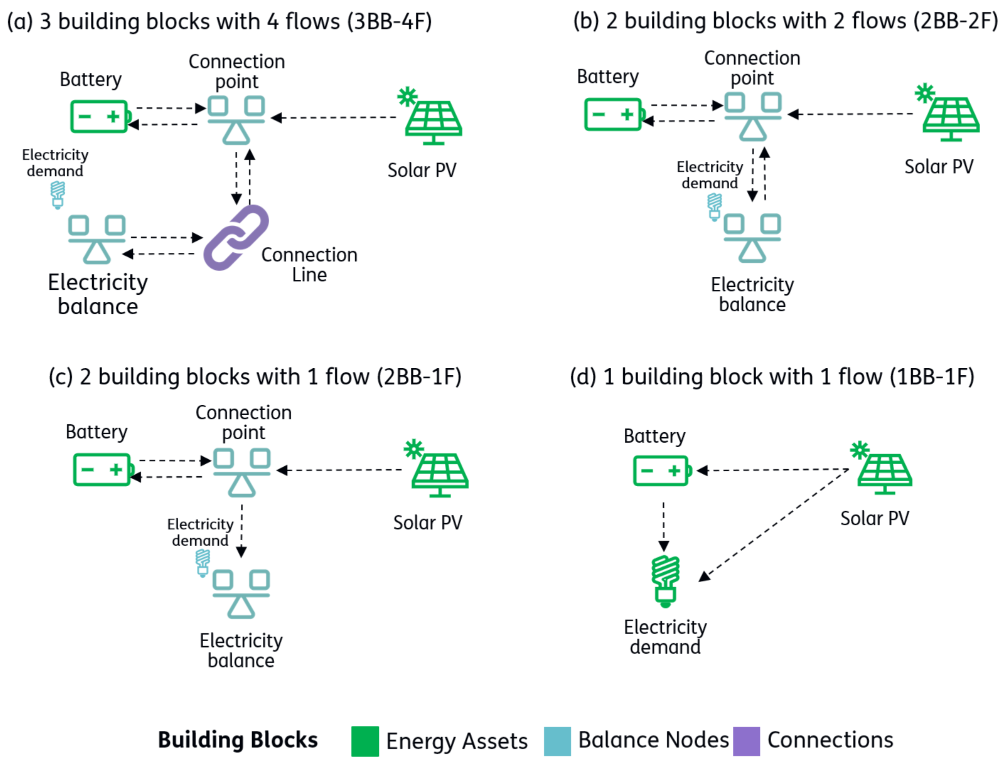
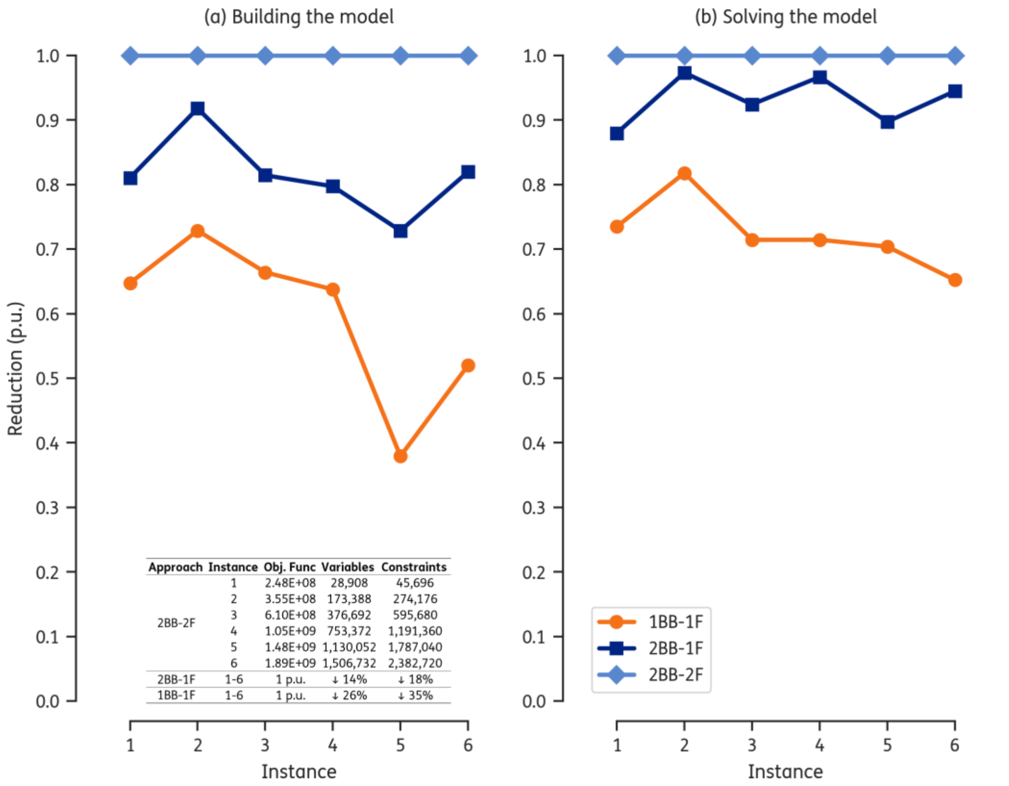
Graph-Based System Representation

- Breaking the misconception of LP as the simplest representation
- Graph theory approach reducing problem size without losing accuracy
- Faster model building and solving with increasing model size





Approach	Instance	Obj. Func	Variables	Constraints
2BB-2F	1	2.48E+08	28,908	45,696
	2	3.55E+08	173,388	274,176
	3	6.10E+08	376,692	595,680
	4	1.05E+09	753,372	1,191,360
	5	1.48E+09	1,130,052	1,787,040
	6	1.89E+09	1,506,732	2,382,720
2BB-1F	1-6	1 p.u.	↓ 14%	↓ 18%
1BB-1F	1-6	1 p.u.	↓ 26%	↓ 35%

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TulipaEnergy and Julia/JuMP

TulipaEnergy Packages

TulipaEnergyModel.jl

Builds and runs the optimisation model

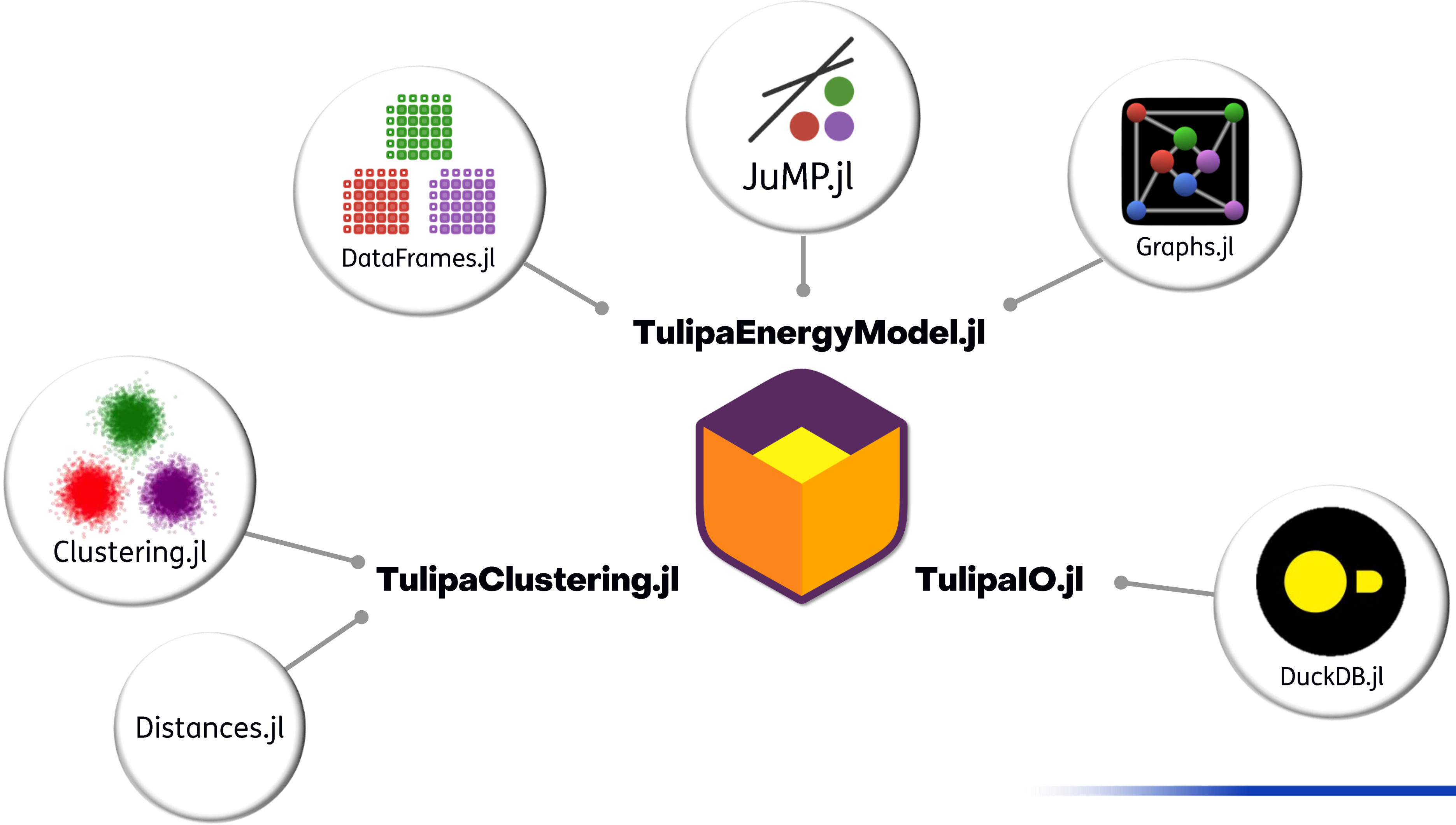
TulipaClustering.jl

Selects the Blended Representative Periods

TulipaIO.jl

Script-based IO for data manipulation

TulipaEnergy Main Dependencies



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TulipaEnergy and Useful Tool for Development

TulipaEnergyModel.jl

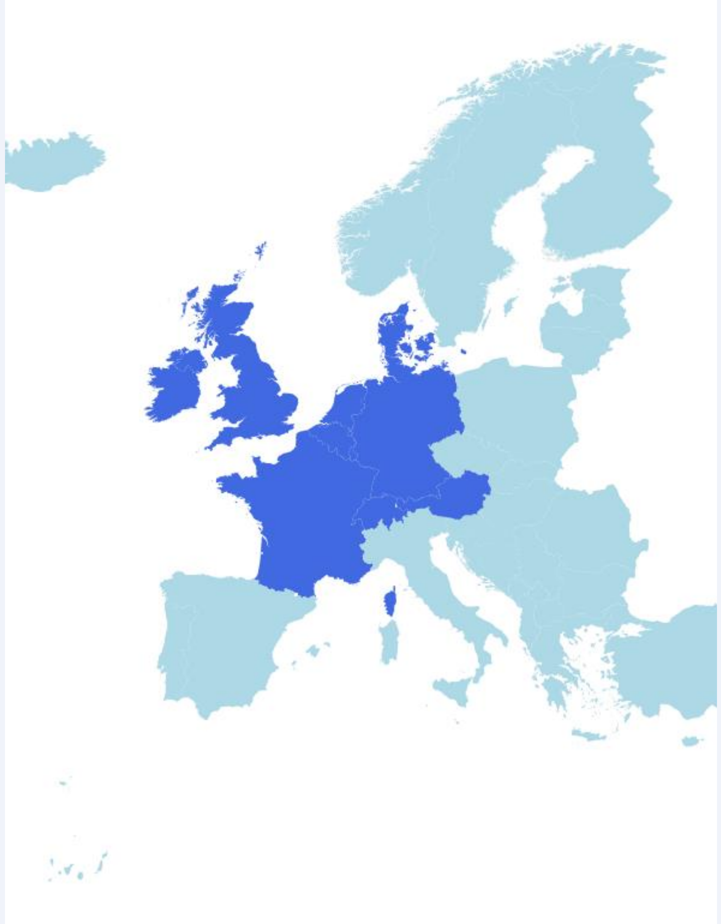
- Open-source Julia/JuMP package available on GitHub

- Timeline:
  - 2023 → Core features development and innovations
  - 2024 → Multi-year investment and power system operation constraints
  - 2025 → Operation constraints in other sectors (e.g., gas) and uncertainty

- Applying best practices for software development (e.g., atomic commits, semantic versioning, code review, tests, documentation)

Performance Results – Western European Countries

- 10 European Countries with an hourly resolution
- Minimize operating costs for one year
- Optimization problem size:
  - # variables: ≈ 1.2 million
  - # constraints: ≈ 2.5 million
- **TulipaEnergyModel.jl** building time† and memory usage:
  - Initial code: 314s and 32GB
  - Optimized code: 86s (**↓73%**) and 18GB (**↓44%**)



†First draft of the code: 8min for 2 EU countries

How did we achieve it?

Basic JuMP

```
@constraint(
    model,
    max_transport_flow_limit[f ∈ Ft, rp ∈ RP, B_flow ∈ graph[f...].partitions[rp]],
    duration(B_flow, rp) * flow[f, rp, B_flow] ≤ upper_bound_transport_flow[f, rp, B_flow]
)
```

Using DataFrames to linearise indices

```
df = filter(row -> (row.from, row.to) ∈ Ft, df_flows)
model[:max_transport_flow_limit] = [
    @constraint(
        model,
        duration(row.time_block, row.rp) * flow[row.index] ≤ upper_bound_transport_flow[row.index],
        base_name = "max_transport_flow_limit[($(row.from),$(row.to)),$(row.rp),$(row.time_block)]"
    ) for row in eachrow(df)
]
```

```
julia> energy_problem.dataframes[:flows]
648×9 DataFrame
 Row │ from    to      rep_period  timesteps_block  efficiency  index  flow
     │ Symbol  Symbol  Int64       UnitRange…       Float64     Int64  GenericV…
─────┼──────────────────────────────────────────────────────────────────────────────────
   1 │ ocgt    demand           1  1:1                     0.0      1  flow[(ocgt, demand), 1, 1:1]
   2 │ ocgt    demand           1  2:2                     0.0      2  flow[(ocgt, demand), 1, 2:2]
   3 │ ocgt    demand           1  3:3                     0.0      3  flow[(ocgt, demand), 1, 3:3]
```

https://discourse.julialang.org/t/help-improving-the-speed-of-a-dataframes-operation/107615

Some Final Thoughts

Good Things

- Speed & efficiency!
- Straight-forward syntax
- Great user community support!
- Others: DuckDB, Graphs, Clustering...
- Friendly to both
  researchers and software engineers

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Room for Improvement

- Skill required for best speed/memory
- Add more tips for speed/efficiency improvement
- New Extensions?
  - Gather Update Solve Scatter (GUSS)
  - NearOptimalAlternatives.jl* for modelling to generate alternatives – MGA

Check out our GitHub!

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