Which optimization "*flavor*" for sizing Microgrid energy systems?

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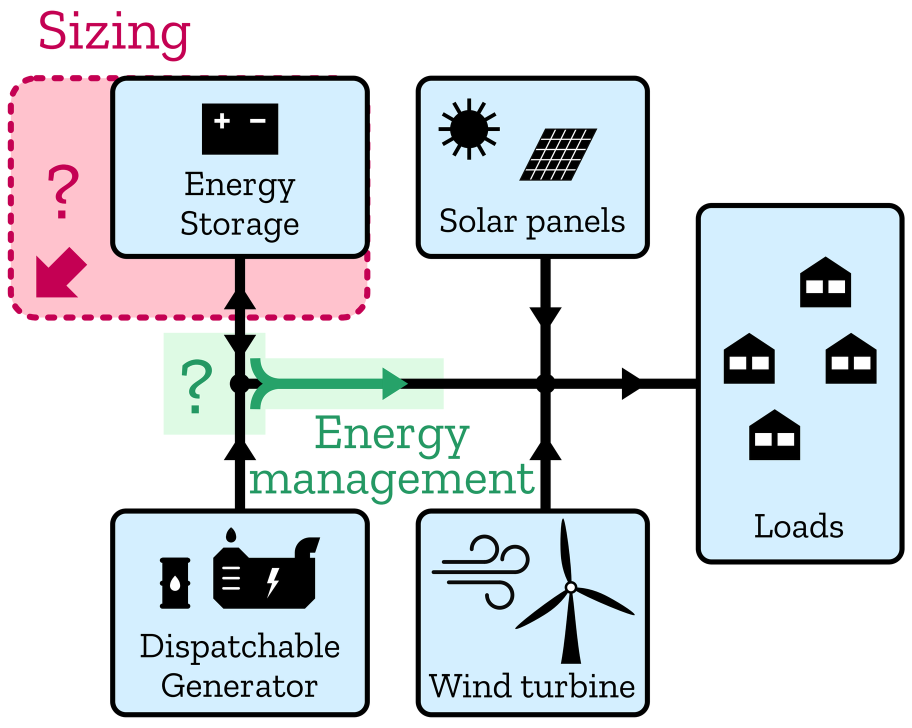
Microgrid optimal design: definition & challenges

Microgrids

Definition: **standalone energy systems**, e.g. needed for rural electrification



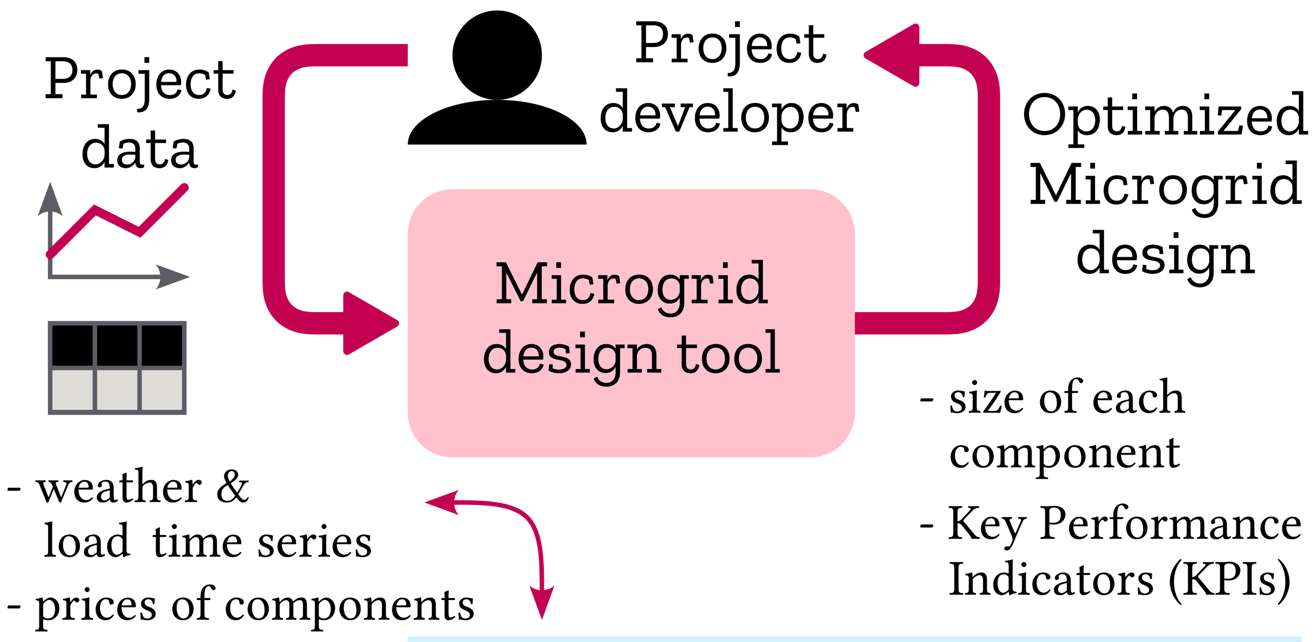
Microgrid **design objectives**:
(min) Lifecycle cost = Investment + Operation + Replace
(max) Quality of Service (→ min load shedding)
and also: environmental impact...

Two *intertwined* optimization problems
○ Microgrid **sizing**: find the optimal components' size
○ **Energy management (EM)**: choose, *at each instant*, the optimal power flows

Fact: model type **restricts** choice of optimization method
↓
Q: Which **microgrid model** & **optim methods** yield:
○ **fast** convergence? *(~ in seconds)*
○ **reliable** convergence? *(close to global optimum)*
○ robustness against data uncertainty?

Microgrid sizing tool

Since each project is a specific design
→ need for reliable microgrid sizing tool

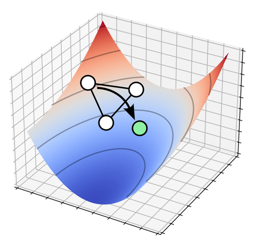


⚠ Uncertainty of project data: **anticipative** Energy Management may not be applicable on field (w/o forecast).

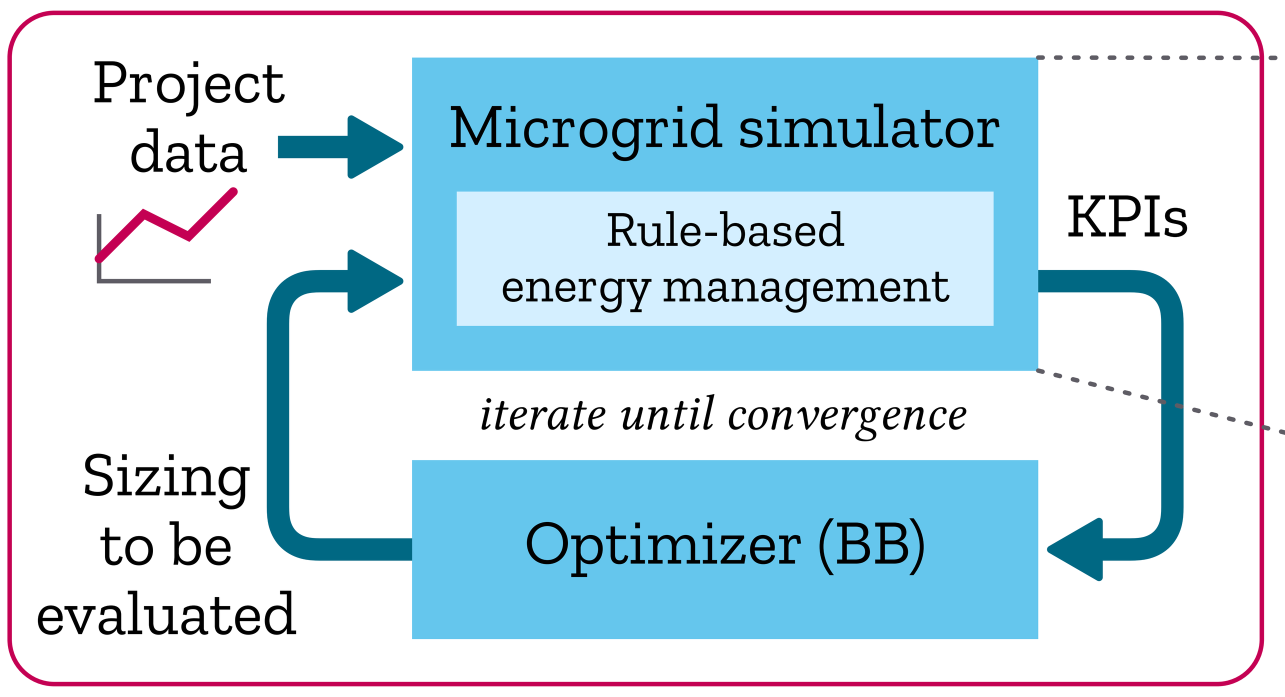
Two ½ flavors of optimization

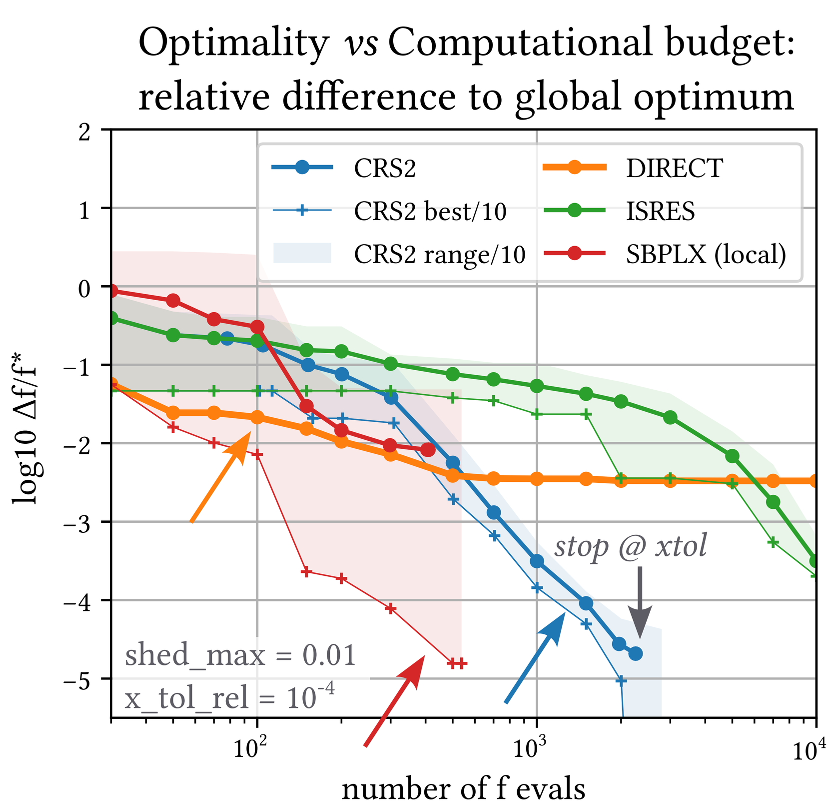
1. Blackbox (BB)

1a. Derivative-free



Microgrid model: **imperative** code ("simulator")
Simulator: sizing $x \mapsto$ KPIs(x)
Fact: Toptim. ≈ Tsim × neval → Needs:
○ **fast** simulation code: Tsim ↘ (i.e. Julia's JIT)
○ frugal optimizer: neval ↘ (but also reliable)

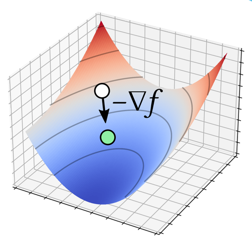




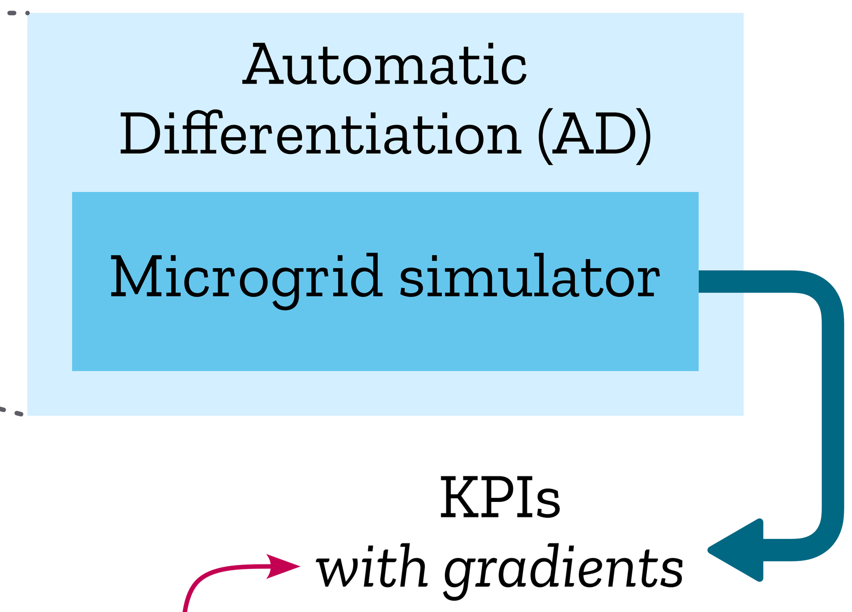
Q: **choice of optimizer**?
○ Tools: `NLopt.jl` library of optimization algorithms

Benchmark lessons:
1. if small budget (~100 iter): 🟠 DIRECT best & fully reliable
2. if medium budget (~1k iter): 🔵 CRS2 best & pretty reliable
3. if local method (SBPLX🔴): multistart is required

1b. Gradient-based

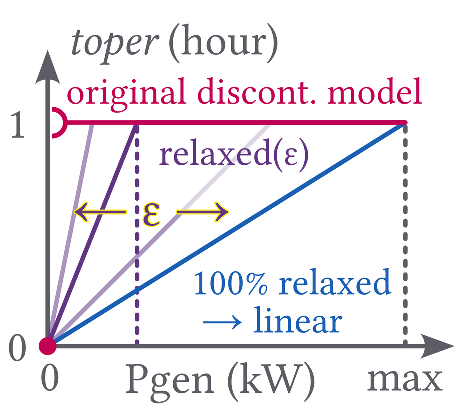


Idea: gradient-based optimization can **converge faster** (neval ↘):
○ Compute gradients of simulator with **Automatic Differentiation** (AD)
○ Tools: `ForwardDiff.jl`



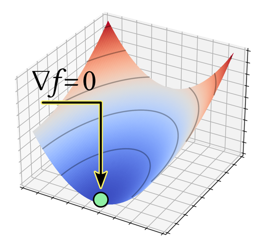
Issue: **discontiniuties** of some model expressions

Example: counting of the operation time of generator

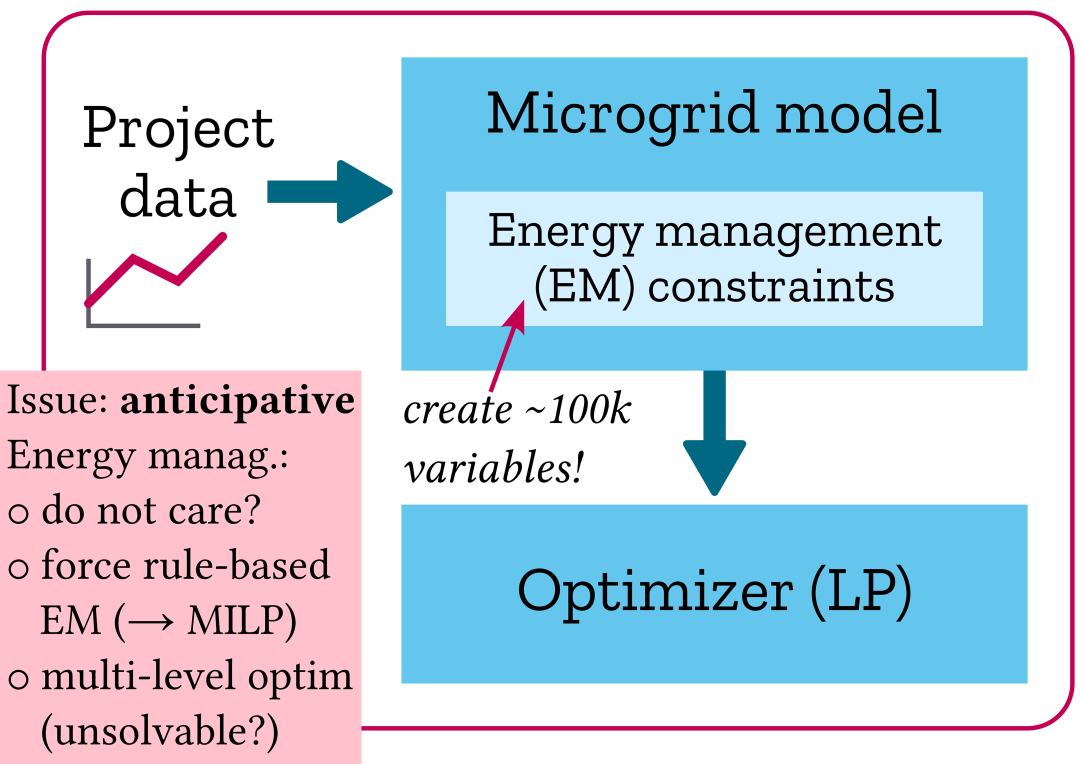


Influence:
toper
↓
replacements
↓
total cost

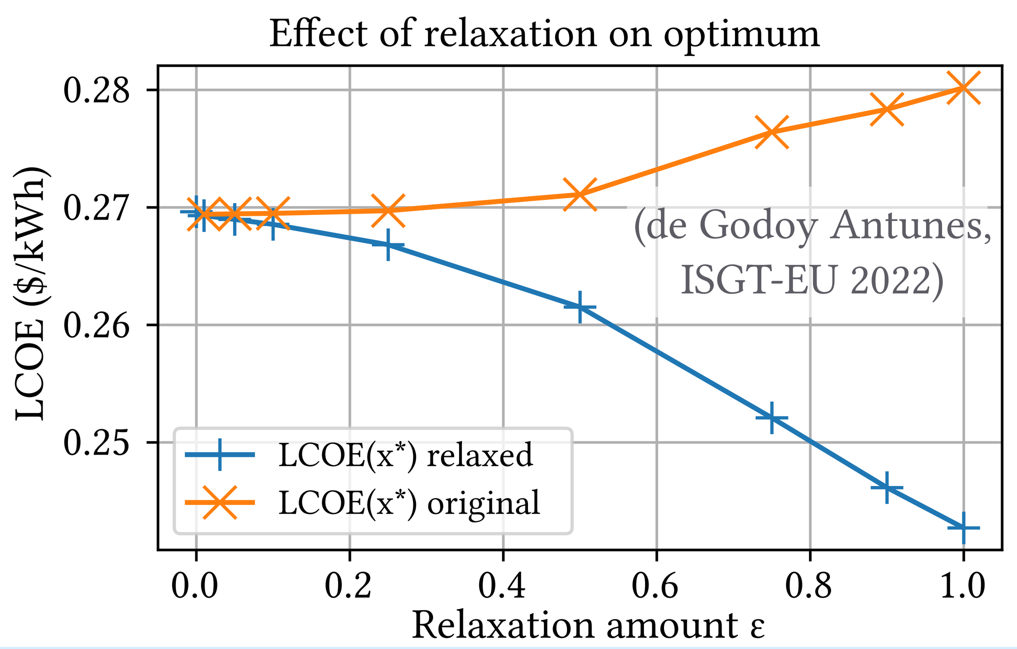
2. Algebraic



Microgrid model: **acausal** & algebraic
Simulator: sizing ↔ KPIs
Fact: convexity allows **reliable convergence**
○ Need to linearize models (for Linear Prog.)
○ Tools: `JuMP.jl` + LP solver (Clp...)



Issue: **anticipative** Energy manag.:
○ do not care?
○ force rule-based EM (→ MILP)
○ multi-level optim (unsolvable?)



Q: **Tuning** relaxation amount ε ? → **Compromise**: more *accurate* model ←|→ easier *convergence*

Tools

Microgrids.X

https://pierreh.eu/Microgrids-X/
Github: Microgrids-X/Microgrids.jl

Operational & economic simulation of Microgrids
- with simple rule-based energy management
- with sizing optimization example

Simulator performance in three languages:

Julia	Matlab	Python
0.15 ms	~0.5 ms *inside VM*	11 ms *no JIT compilation!*

Conclusions

Choice of optimization approach

○ **Derivative free BB**: more physical model ☺, non anticipative ☺ but simplistic ☹ Energy Management
○ **Gradient-based BB**: discontinuities require smoothing, faster convergence ☺, but multistart needed?
○ **Algebraic (Linear Prog)**: guaranted convergence ☺, but simplified physics ☹, not so fast with 100k variables and anticipative EM yields "overoptimistic" design ☹

→ *No clear winner, all are useful!*

Perspectives

For blackbox optimization:
- Study effect of **more optimization variables** for mid-project resizing (**recourse** against **uncertainty**: a few → dozens of variables): ranking of BB algorithms unchanged?
- Add more algorithms in benchmark (GAs, PSO... often used in literaturel)
- Test **multi-objective** optimization algorithms

For algebraic optim.: is there an efficient way to enforce **non anticipative** Energy Management?