A one-leader multi-follower approach to distribution network development planning
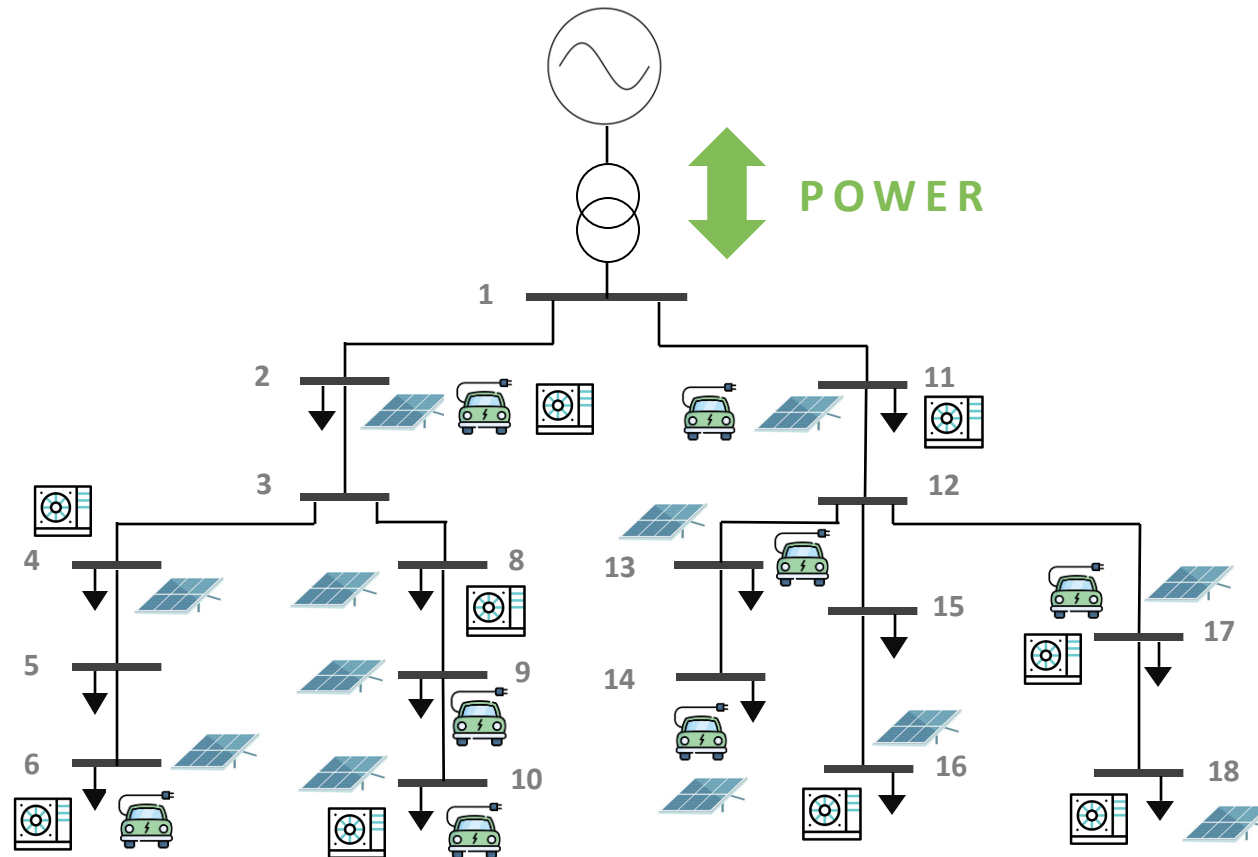
Geoffrey Bailly & Manon Cornet
Smart microgrids department
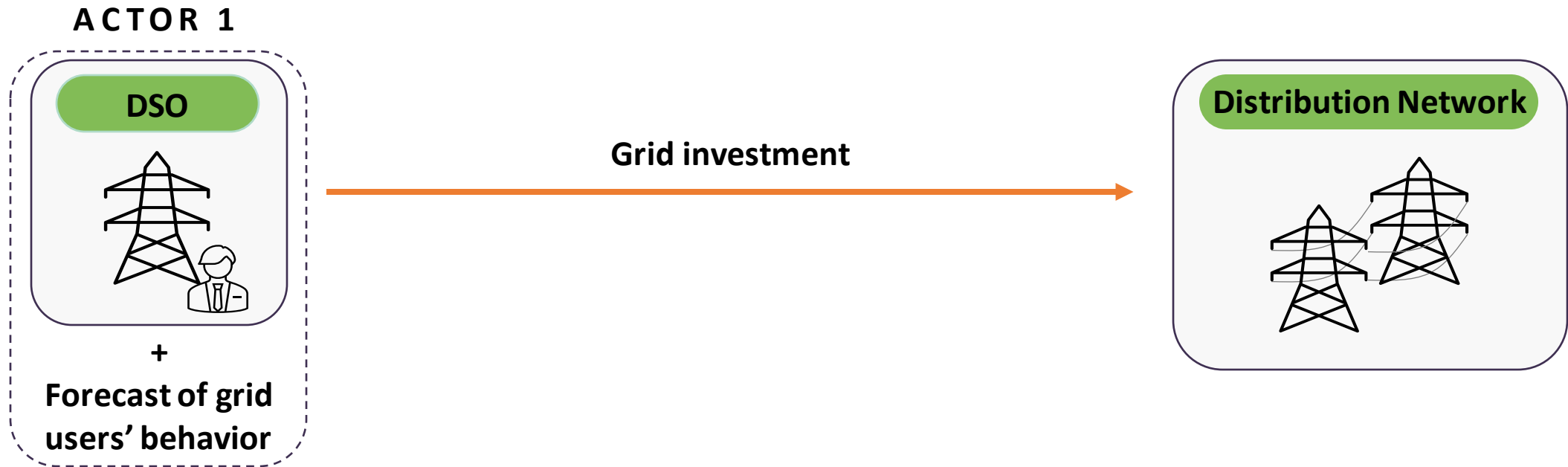University of Liège

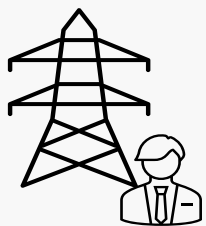# Distribution networks

Network planning

Traditional Approach

ACTOR 1

DSO

+

Forecast of grid users' behavior

Grid investment

Distribution Network

Network planning
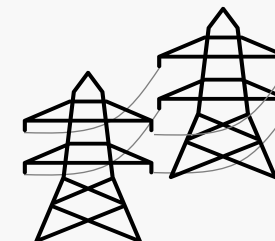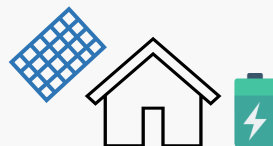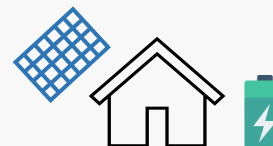
Research objective

Develop a **new framework** to devise

distribution network development plans ...

... considering the **DSO** and **grid users'** strategies ...

... that would allow to **evaluate** the **impact of external events.**

market decisions

technical solutions

technology prices

Problem statement
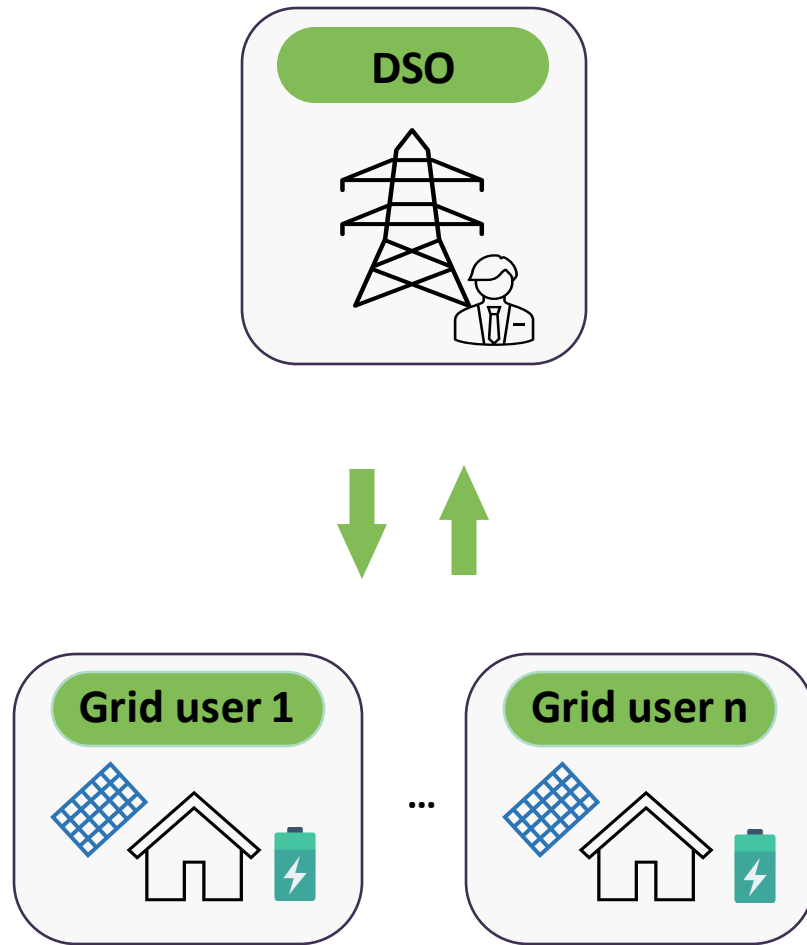
Goal : minimize investment & operational costs

Constraints :

- Budget balance

- Radial network

- Reliable network (voltage and current limits)

- Satisfied grid users' electricity demand

Goal : minimize investment & energy usage costs

Constraints :

- Grid connection capacity

- PV capacity

- Storage capacity

Distribution System Operator
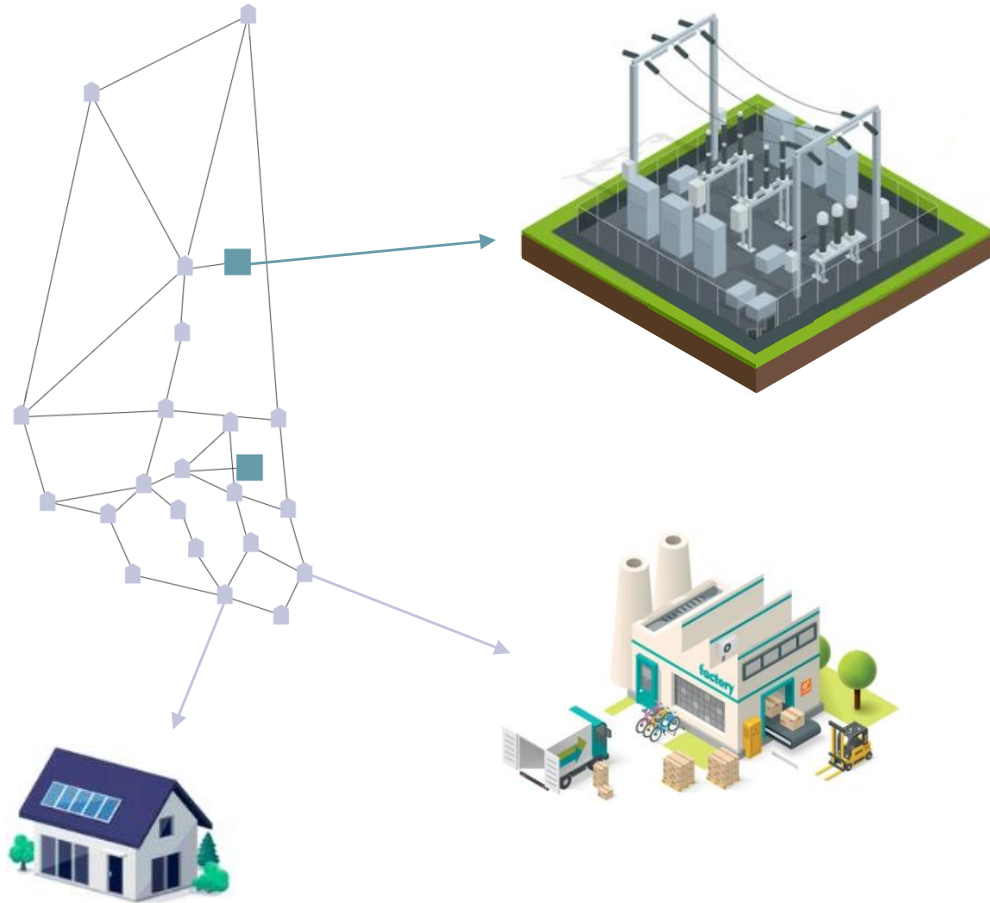
- Candidate substations & lines
  Topology from the DSO
  Existing or not

- Different types of conductors
  Section, impedance, cost

- Static solution
  Optimized at once, knowing the future
  Not multistage yet

- Great flexibility
  Medium ⇔ low voltage network

Grid users

- Load profiles
  Domestic load
  + electric vehicles & heat pumps

- PV profiles
  1 summer day & 1 winter day

- Sizing
  PV
  Grid connection
  Storage
  Converters

Co-optimization

Distribution System Operator   **Grid user**

Variables

lines to build or reinforce   PV installation

substations to build or reinforce   grid connection capacity

Constraints

power balance with losses   power balance
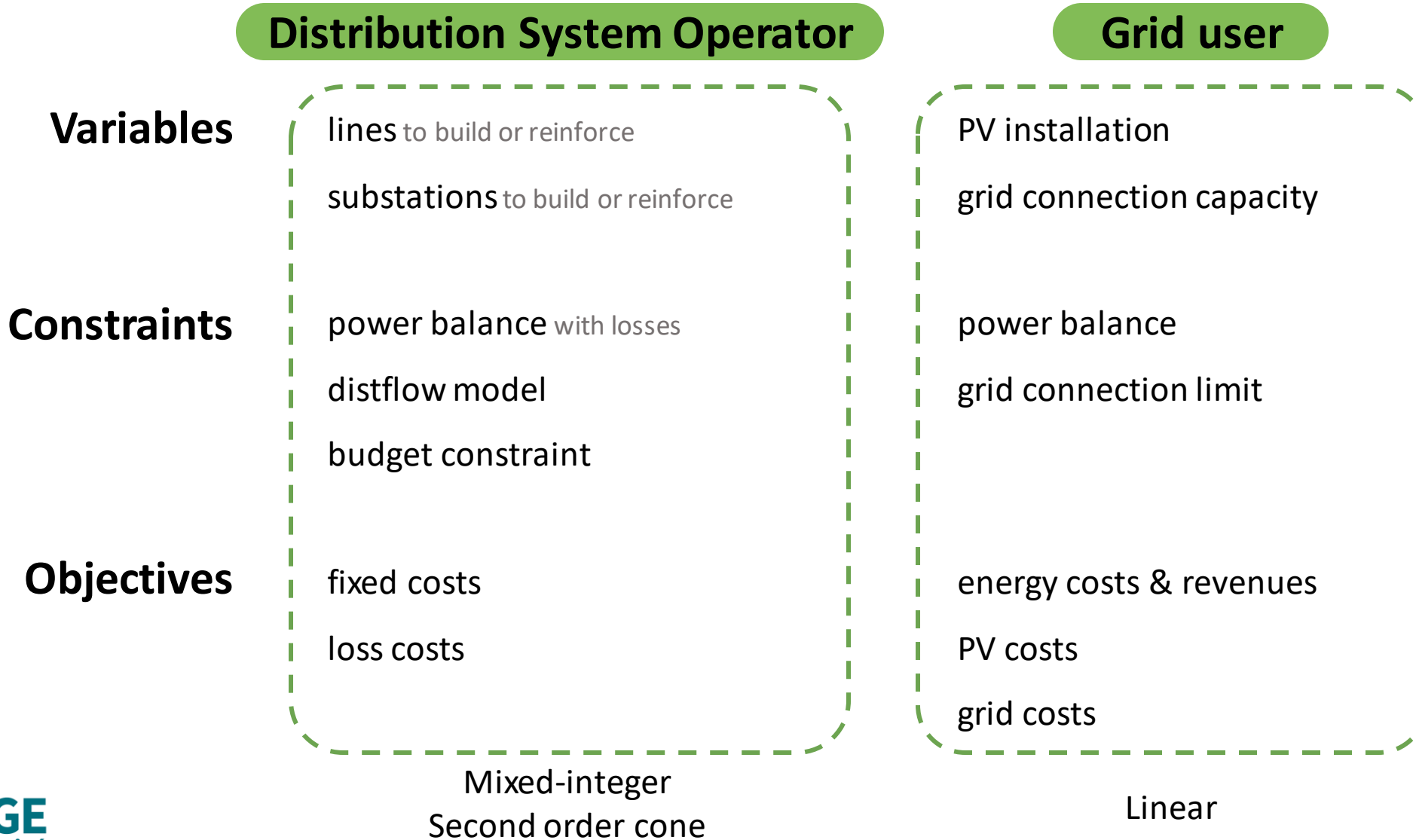
distflow model   grid connection limit

budget constraint

Objectives

fixed costs   energy costs & revenues

loss costs   PV costs

                                           grid costs

Mixed-integer
Second order cone   Linear

LIÈGE université

Bilevel formulation

Upper-Level (or Leader)

$$\min_{\boldsymbol{x} \in X} \quad F(\boldsymbol{x}, \boldsymbol{y})$$

$$\text{s.t.} \quad G_i(\boldsymbol{x}, \boldsymbol{y}) \leq 0, \quad i = 1, \dots, k$$

$\widetilde{\boldsymbol{y}}$
Subset of lower-level variables

$\widetilde{\boldsymbol{x}}$
Subset of upper-level variables

Lower-Level (or Follower)

$$\min_{\boldsymbol{y} \in Y} \quad f(\boldsymbol{x}, \boldsymbol{y})$$

$$\text{s.t.} \quad g_j(\boldsymbol{x}, \boldsymbol{y}) \leq 0, \; j = 1, \dots, m$$

Bilevel formulation

Power exchange

User grid connection capacity

Upper-Level (or Leader)

min DSO's objective

s.t. DSO's constraints

Lower-Level (or Follower)

min $\sum_i$ Grid user$_i$'s objective

s.t. Grid user's constraints

Results

time step 1

BASE CASE
No storage & Max PV capacity

Electric vehicles	Energy export price	Energy import price
None	0.1 k€/MWh	0.3 k€/MWh

with electric vehicles

x 2 energy export price

x 2 energy import price

DSO
x2 Investment costs
x10 Operational costs

DSO
= Investment costs
≈ Operational costs

DSO
= Investment costs
≈ Operational costs

Users
= PV costs
x2.5 electricity costs
x2 grid costs

Users
x1.3 PV costs*
x0.6 electricity costs
x2.5 grid costs

* PV converter

Users
= PV costs
x2 electricity costs
≈ grid costs

9

Next steps

✓ **Proof of concept**
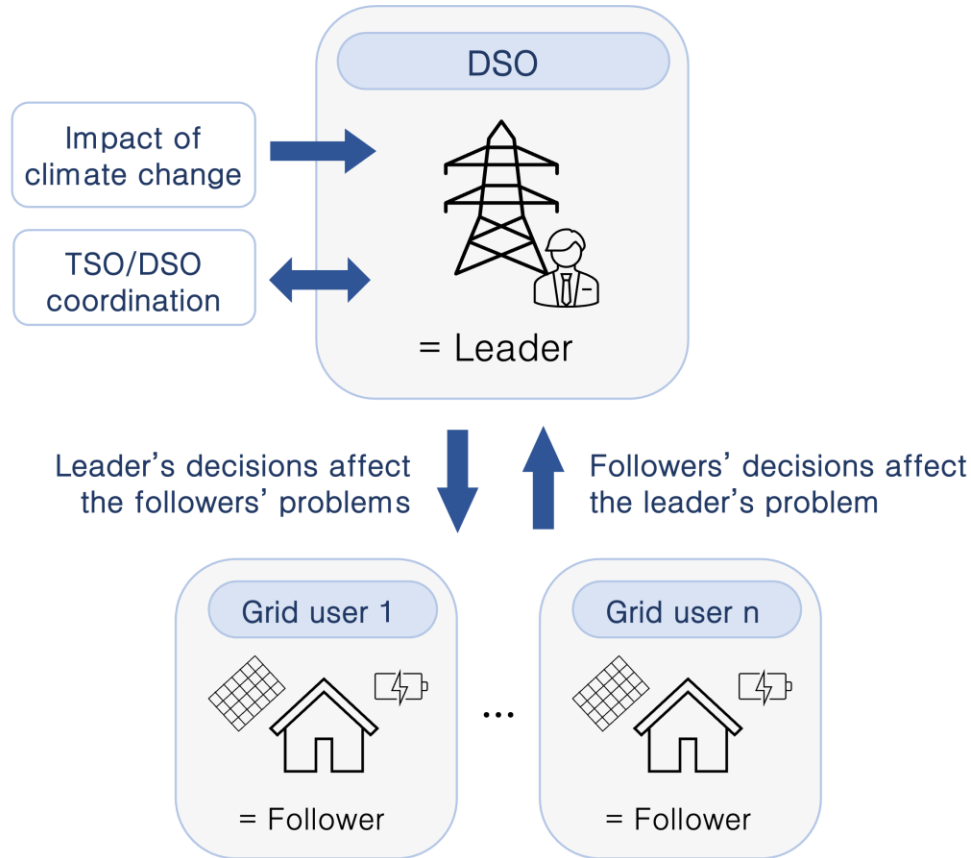
🕐 **Future work**

- Bilevel ➔ multi-objective

- Representative days

- Multistage

- …

Back-up slides

Implementation
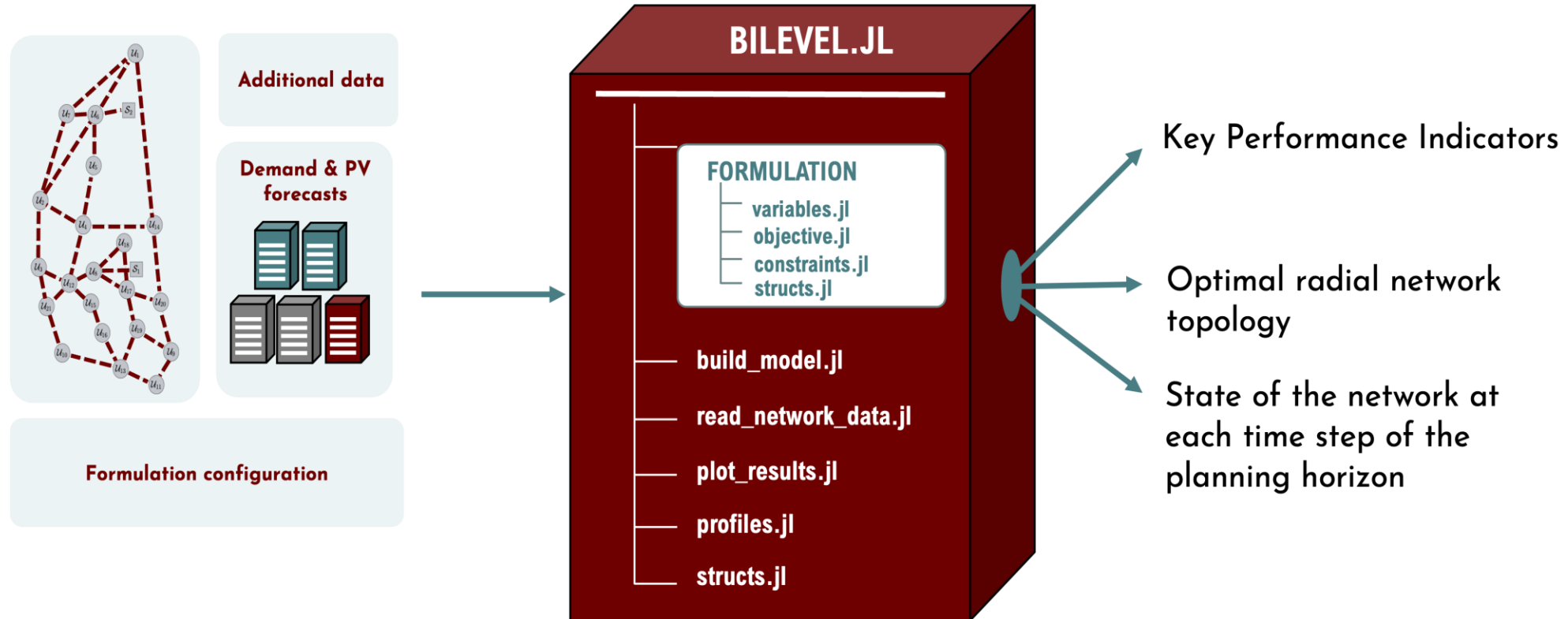
Solving bilevel formulation

?
Bilevel problem → one single problem

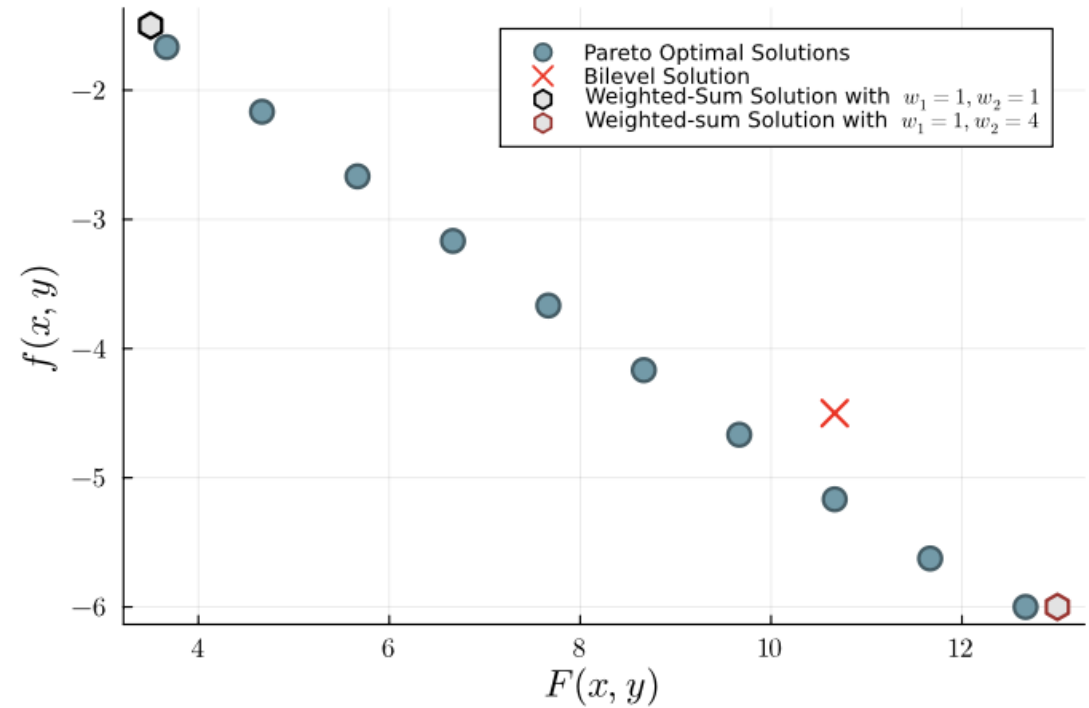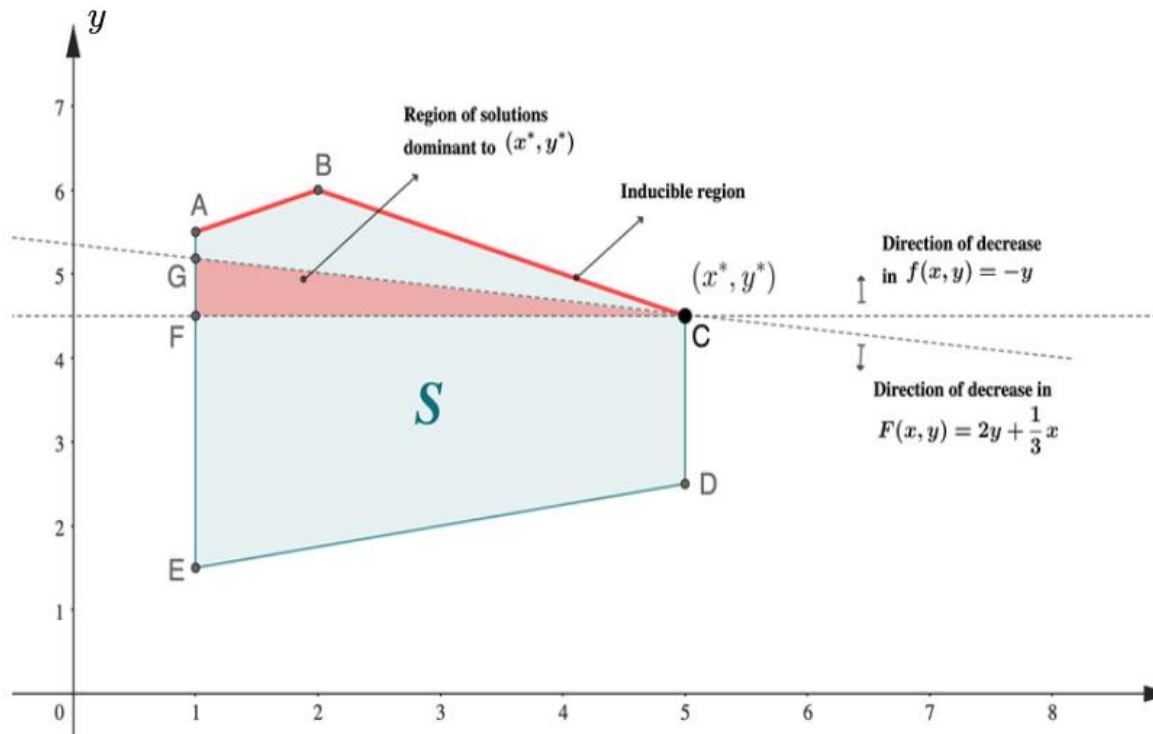Lower level → set of linear & non-linear constraints

using the KKT reformulation:
- primal feasibility
- dual feasibility   } convex
- stationarity
- complementary slackness → non convex

primal dual equality reformulation → non convex but easier to solve

Practical consequence

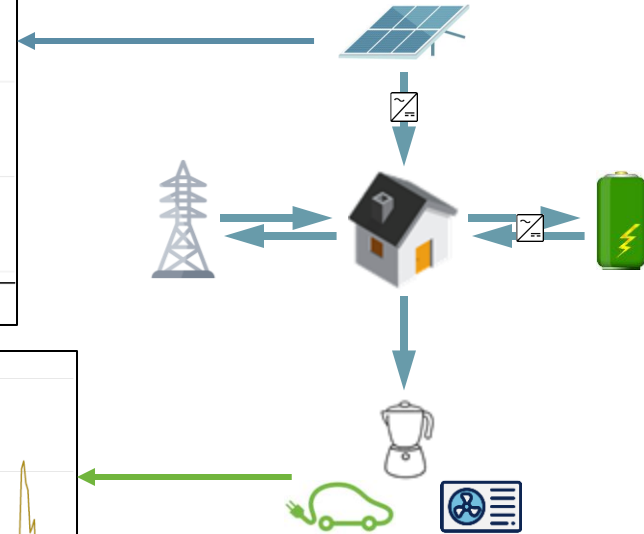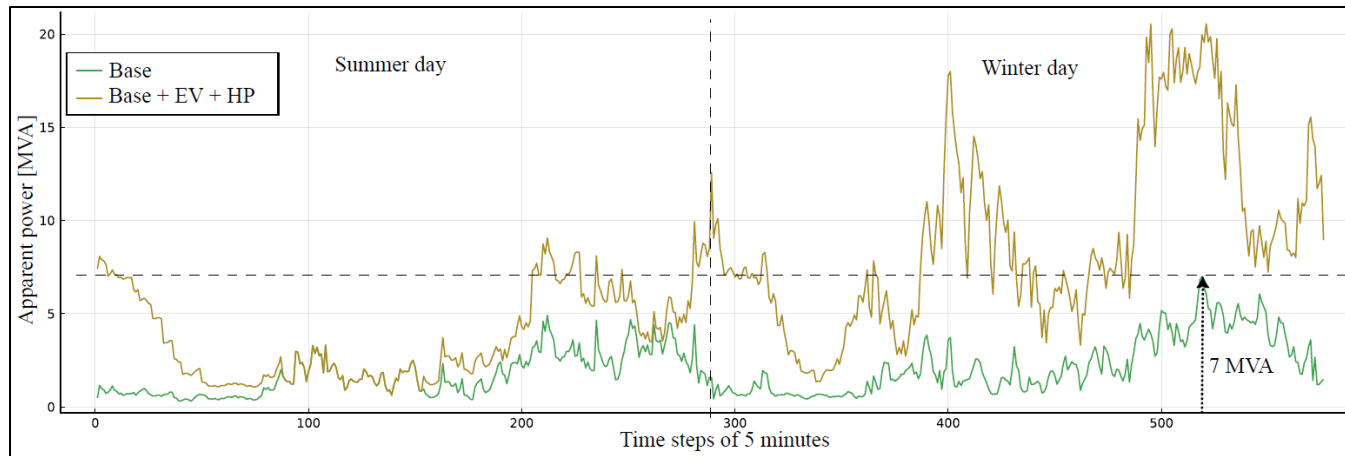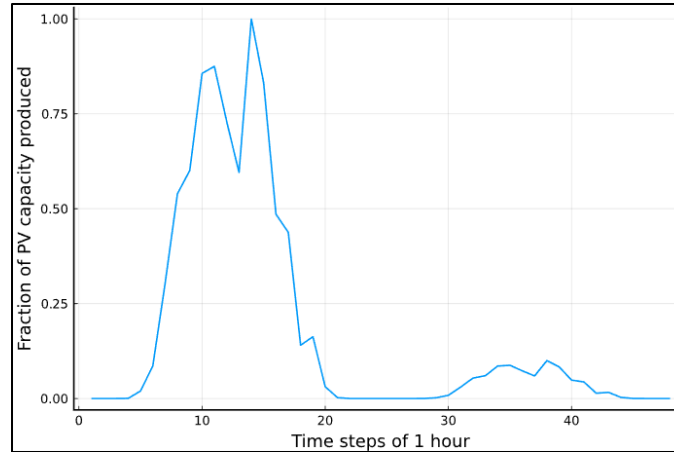The global solution optimizes the leader's objective.

Bilevel vs multi-objective

1

Users' load & PV profile

- 48 time steps of 1 hour

- Several load profiles

- 2 representative days

Back-up slides