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A one-leader multi-follower approach to distribution network development planning

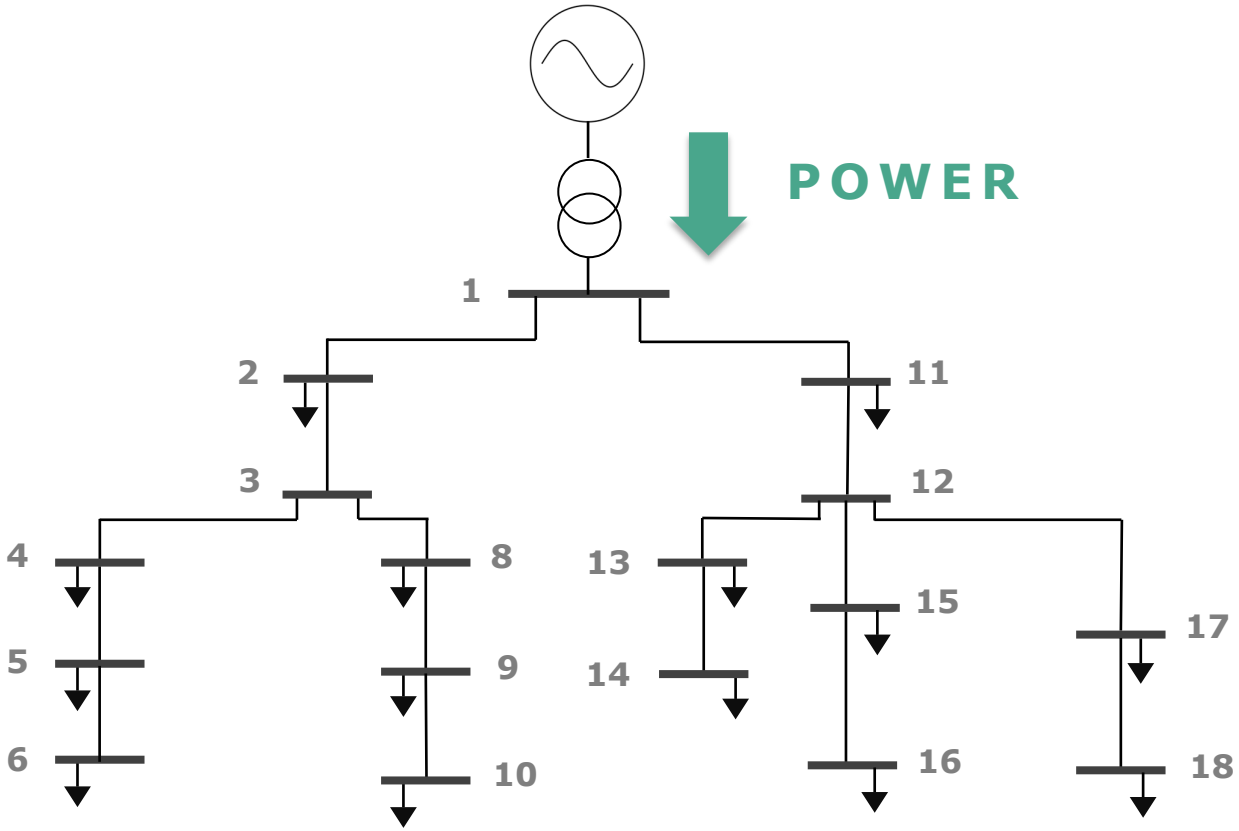
Geoffrey Bailly & Manon Cornet

From the Montefiore Institute of the University of Liège

Paper №: A9049GB

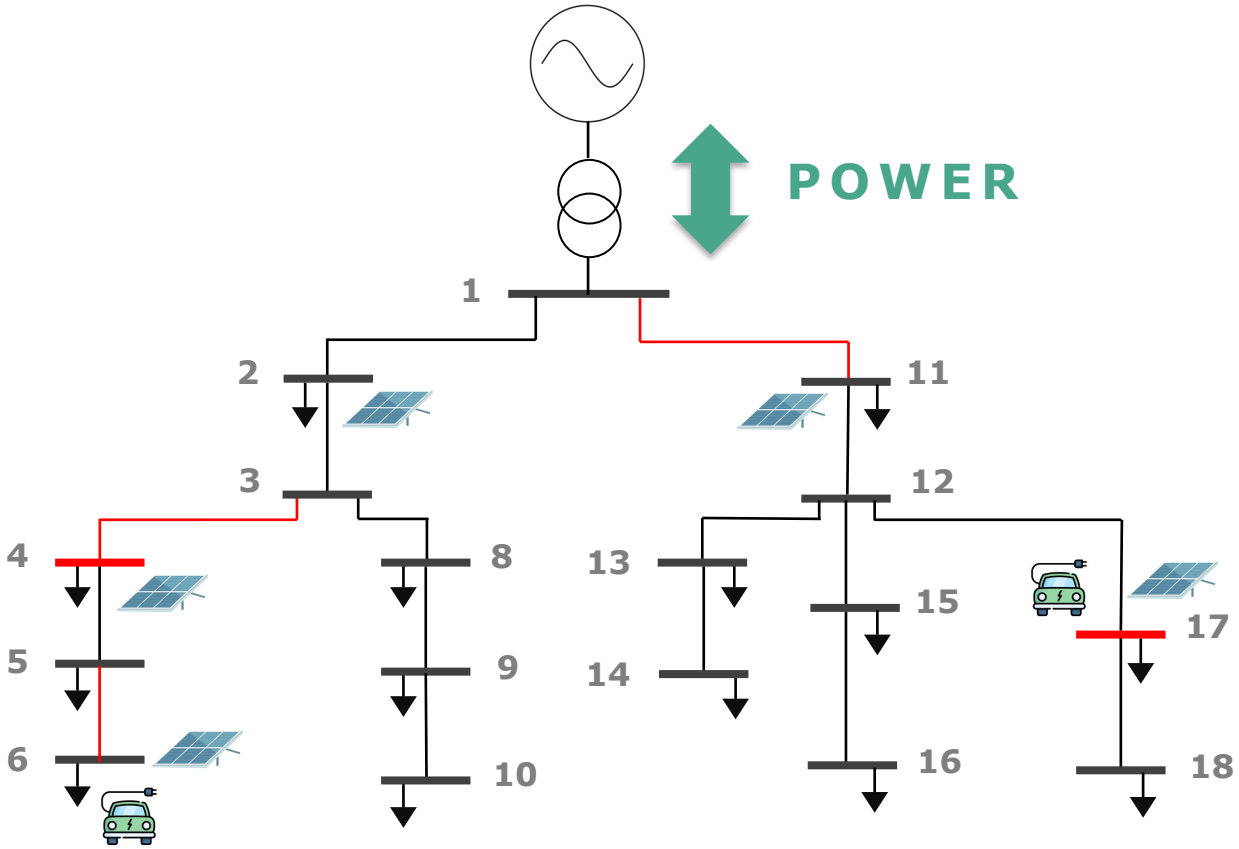
DISTRIBUTION NETWORKS

Yesterday



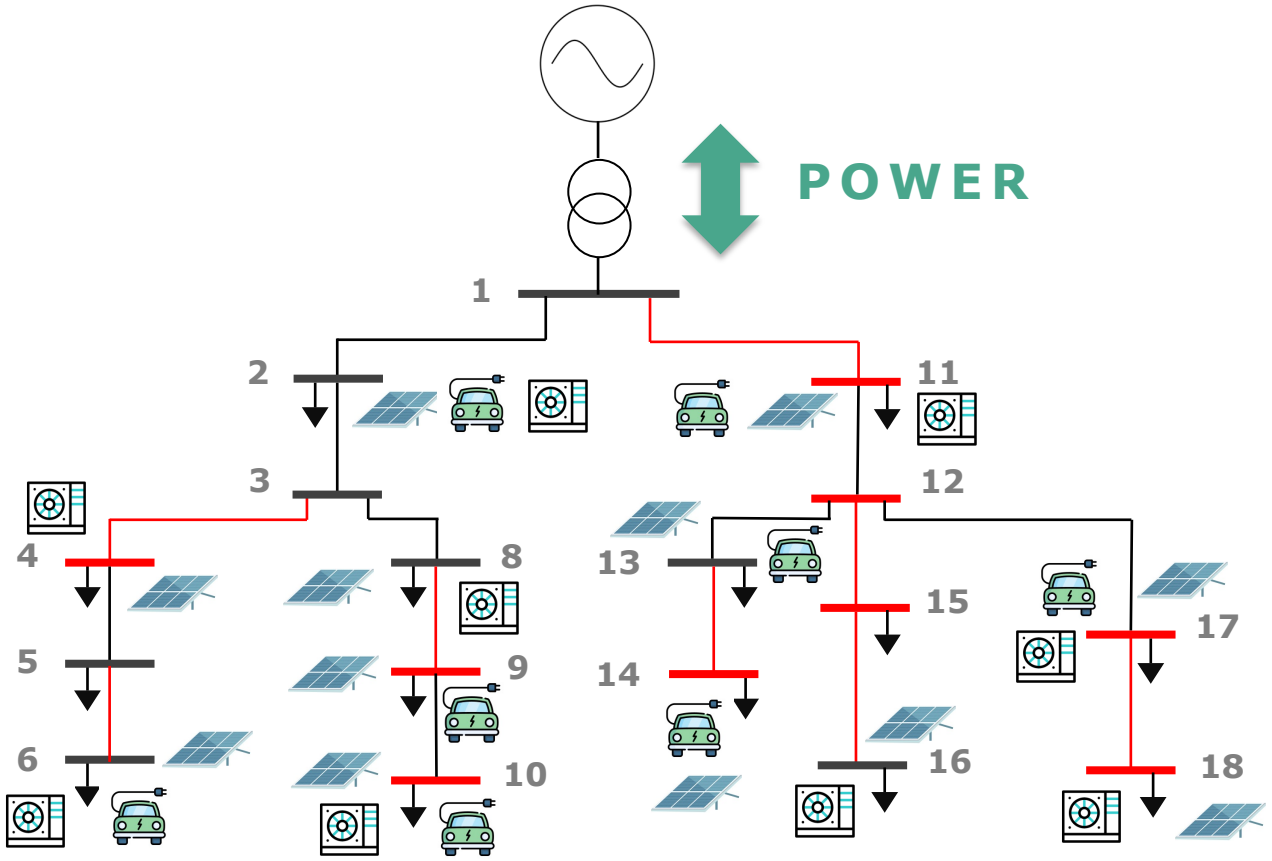
DISTRIBUTION NETWORKS

Yesterday | Today



DISTRIBUTION NETWORKS

Yesterday | Today | Tomorrow

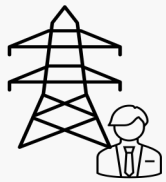


NETWORK PLANNING

Traditional Approach

ACTOR 1

DSO

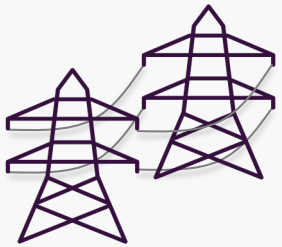


\+

Forecasts of grid users' behavior

Grid investment

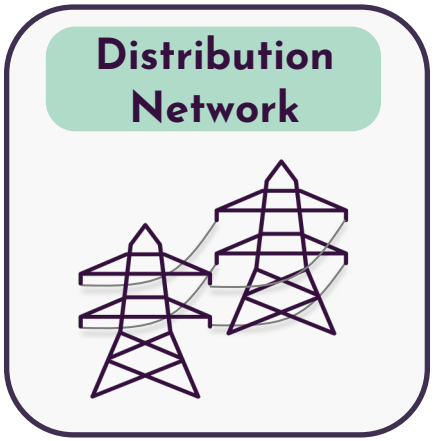
Distribution Network



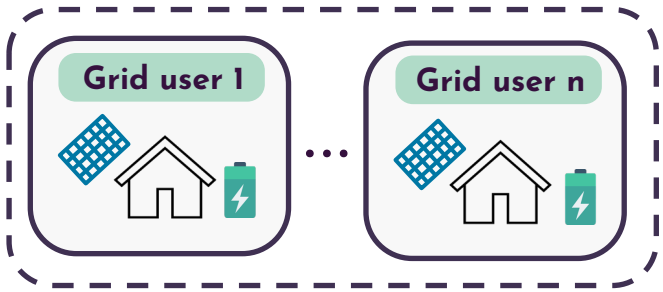
NETWORK PLANNING

Our Approach

ACTOR 1

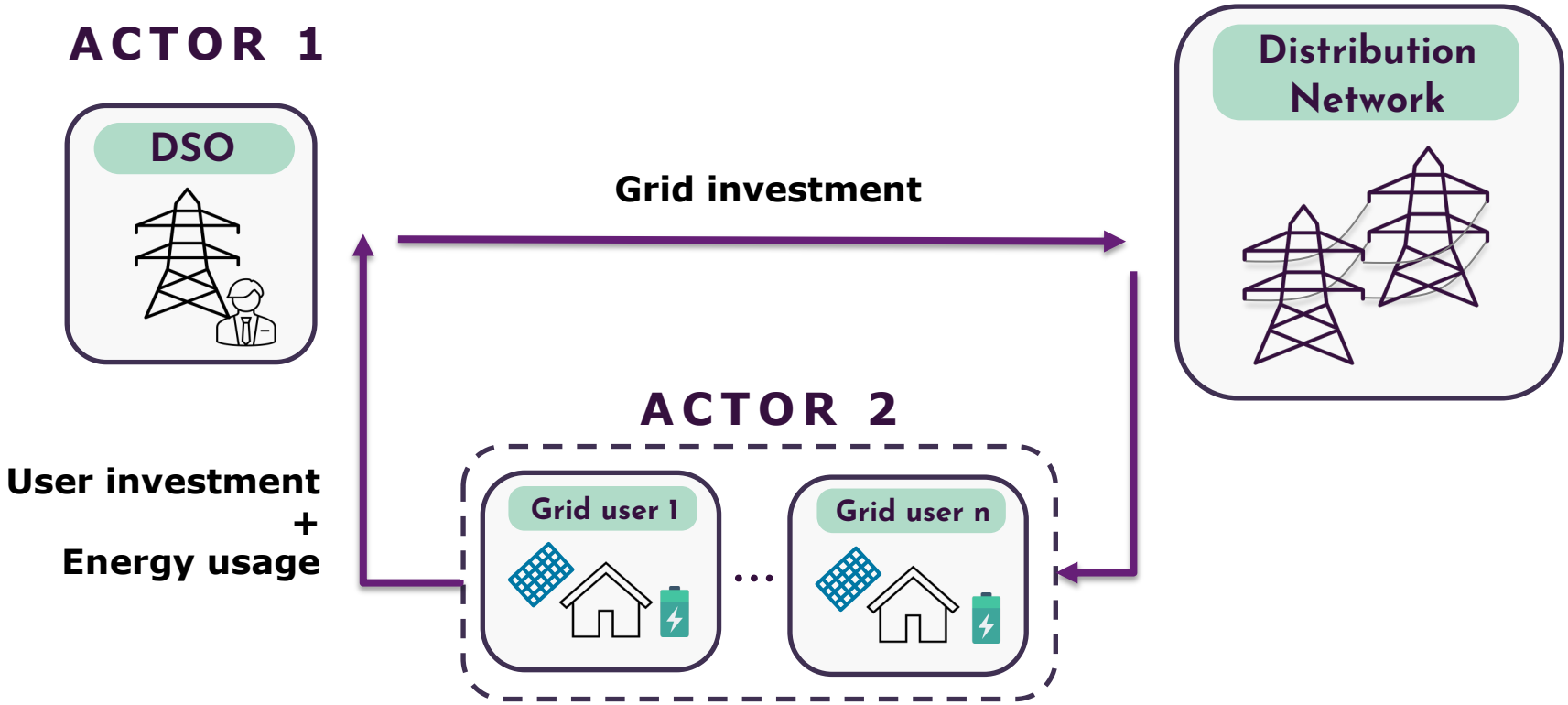


ACTOR 2



NETWORK PLANNING

Our Approach



RESEARCH OBJECTIVE

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Develop a **new framework** to devise

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

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Develop a **new framework** to devise

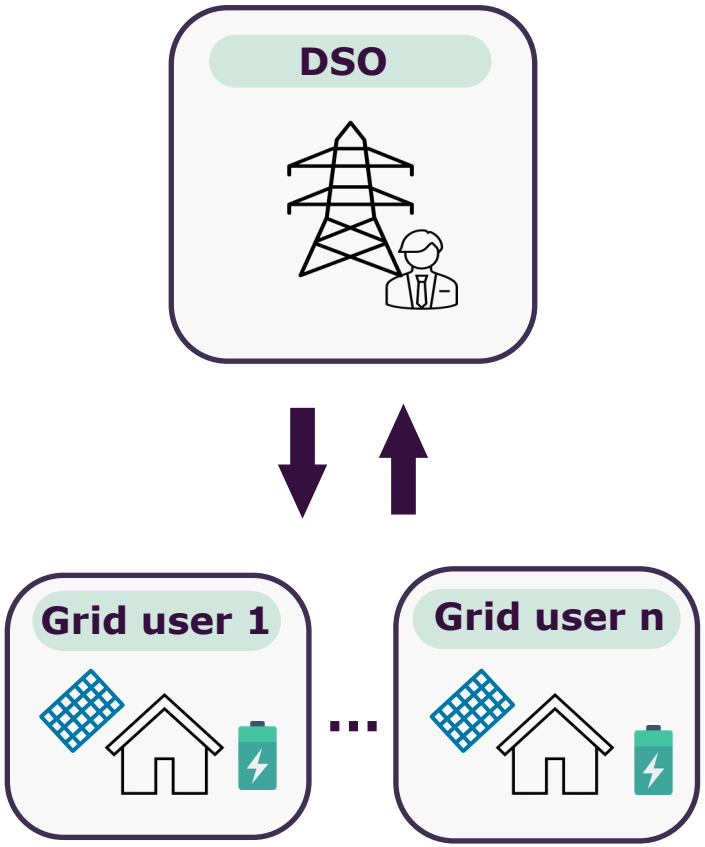
distribution network development plans …

… 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 :

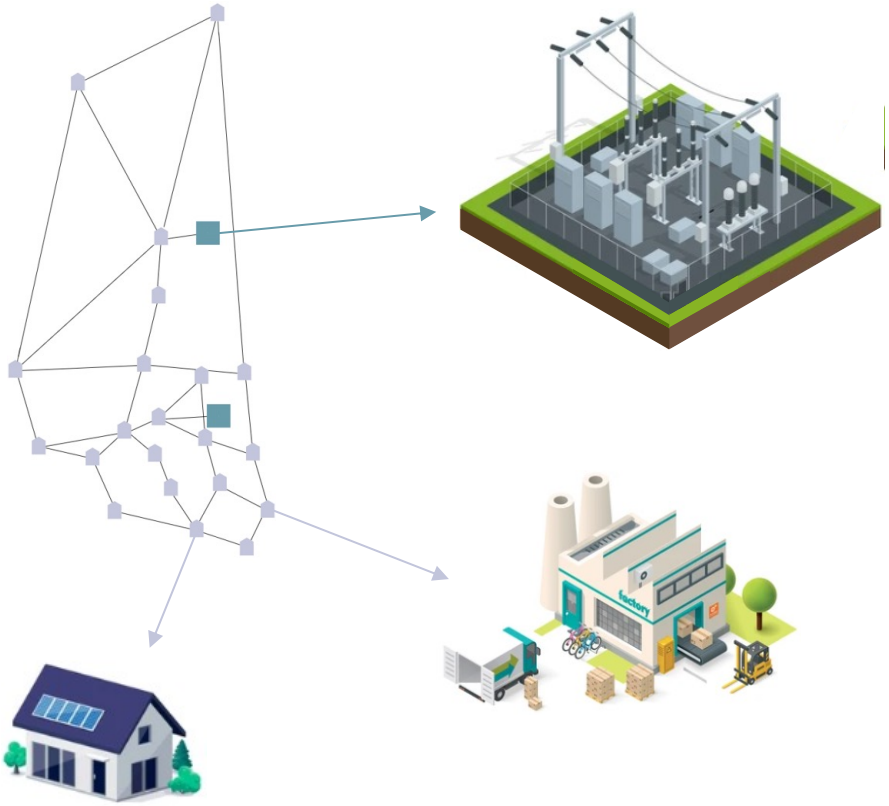
- Budget balance
- Radial network
- Reliable network (voltage and current limits)
- Satisfied grid users' electricity demand

Goal : minimize investment & energy usage costs

Constraints :

- Grid connection capacity
- PV capacity
- (Storage capacity)

DISTRIBUTION SYSTEM OPERATOR



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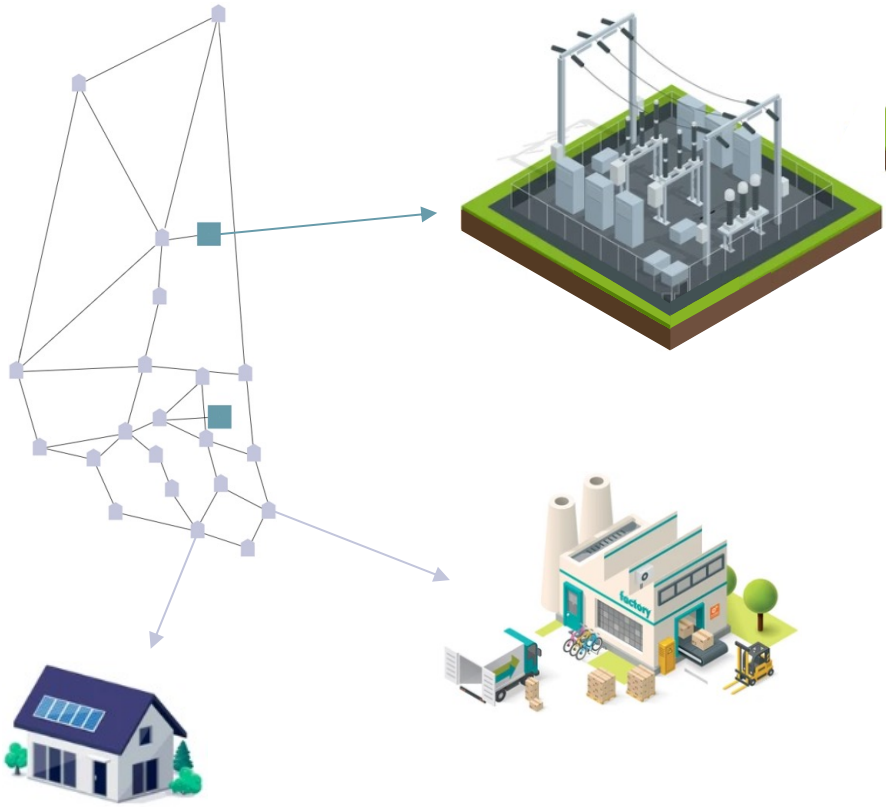

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  - Topology from the DSO
  - Existing or not

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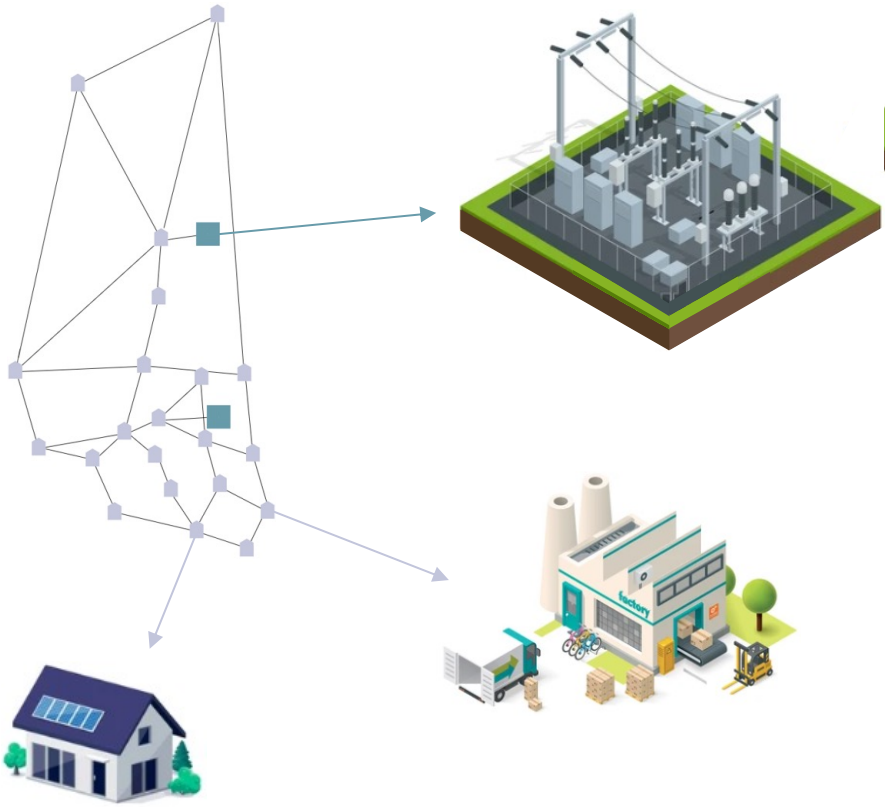

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- Different types of conductors
  - Section, impedance, cost

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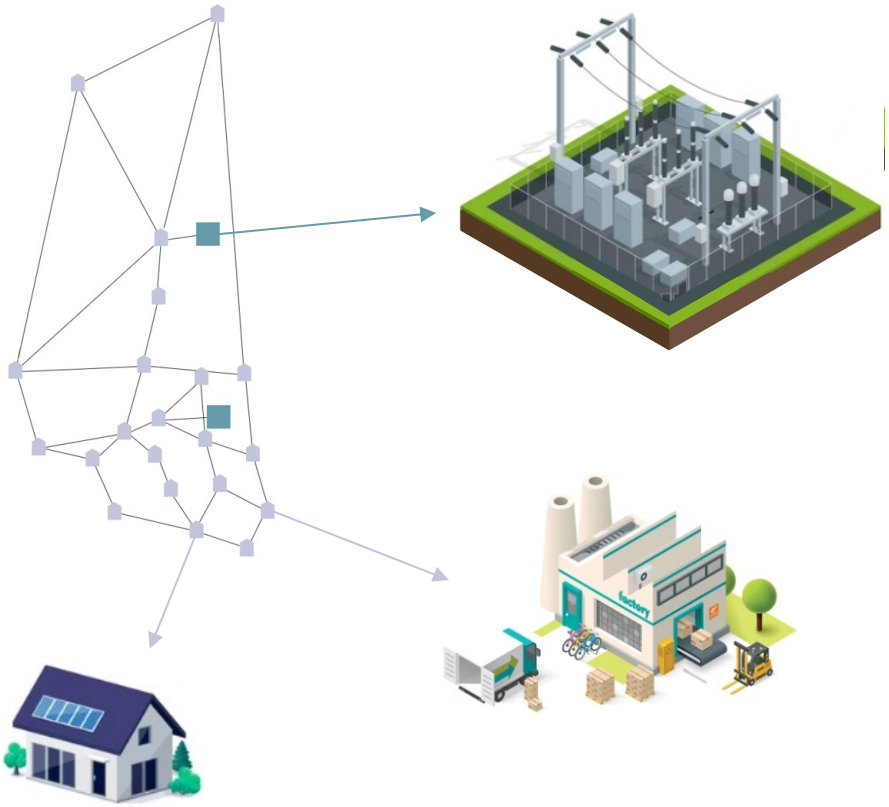

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  - connecting e.g.
    - TSO substations → industrial parks
    - medium voltage → residential estate

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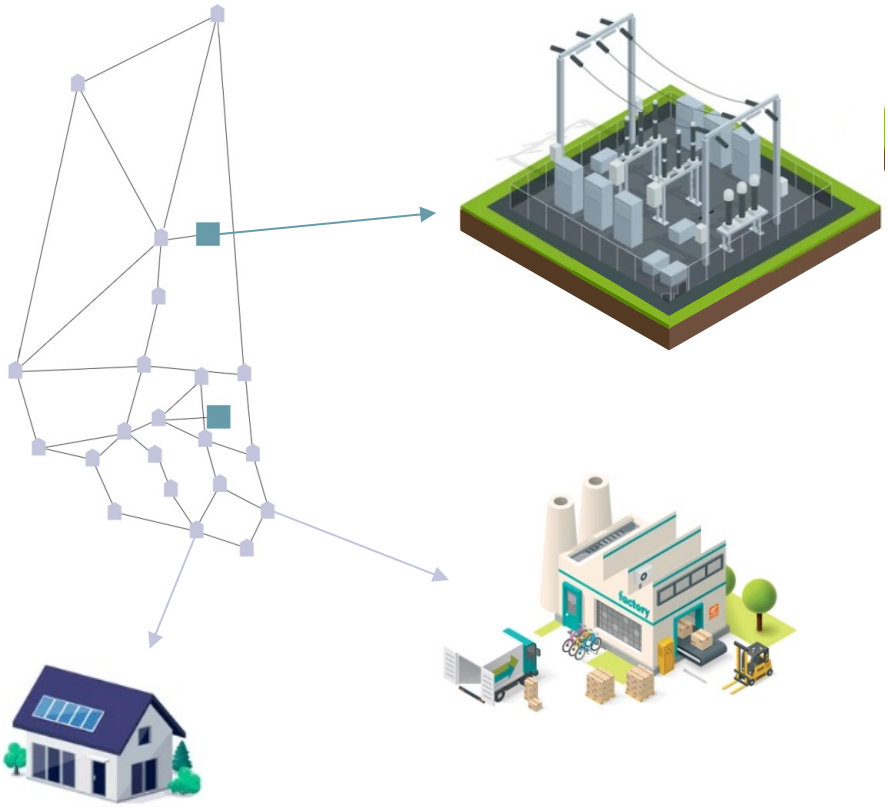

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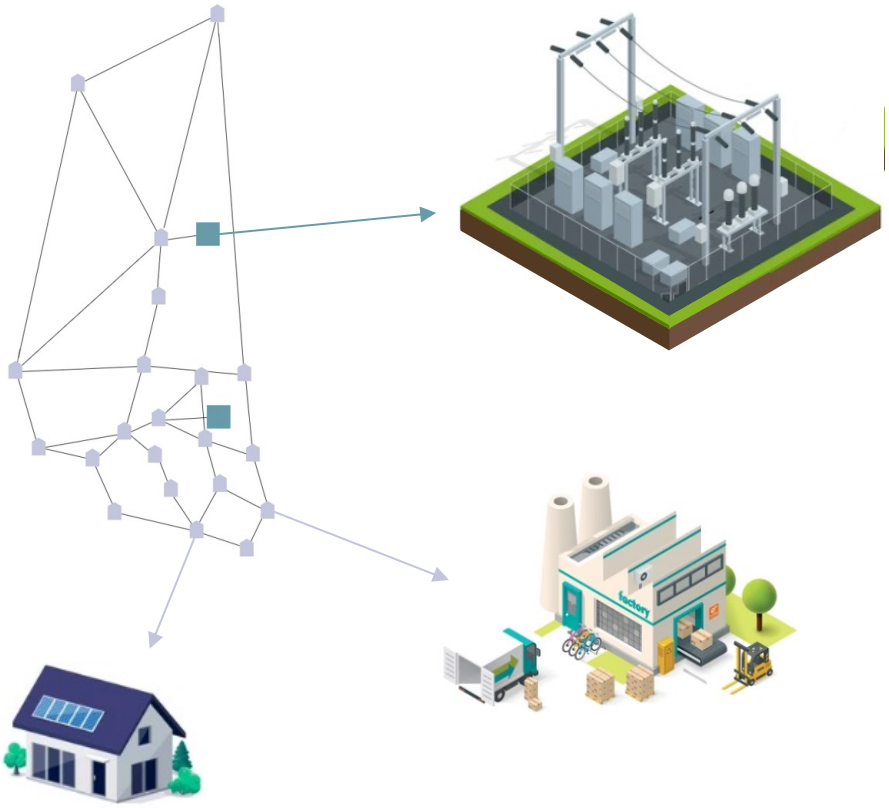

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  - Medium ⇔ low voltage network

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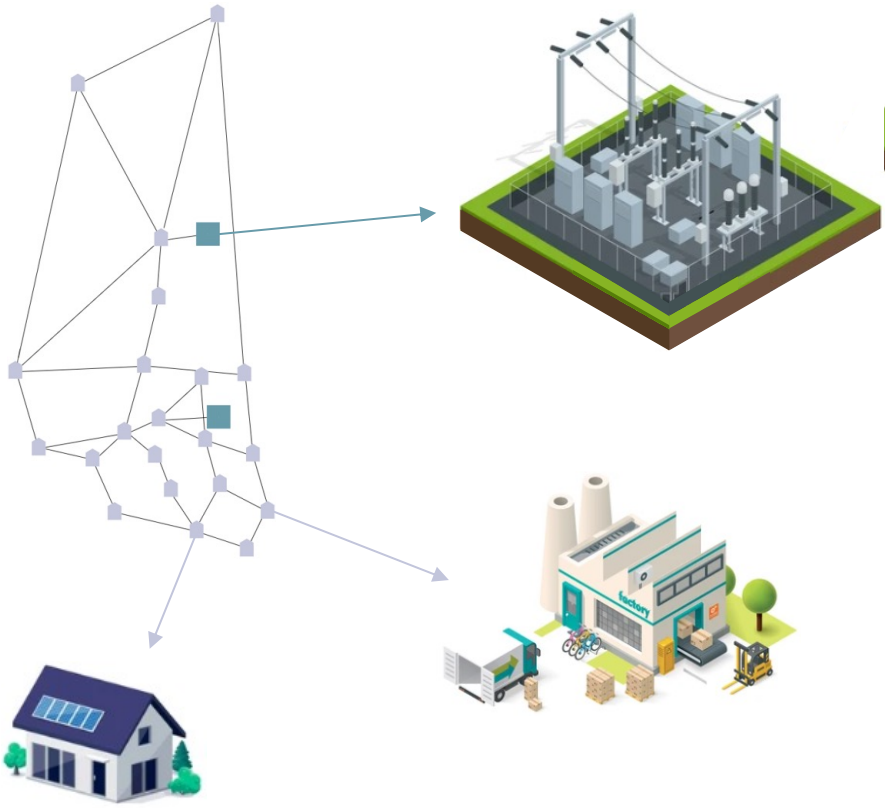

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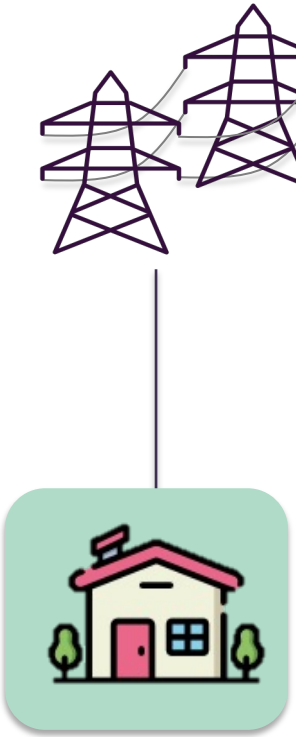
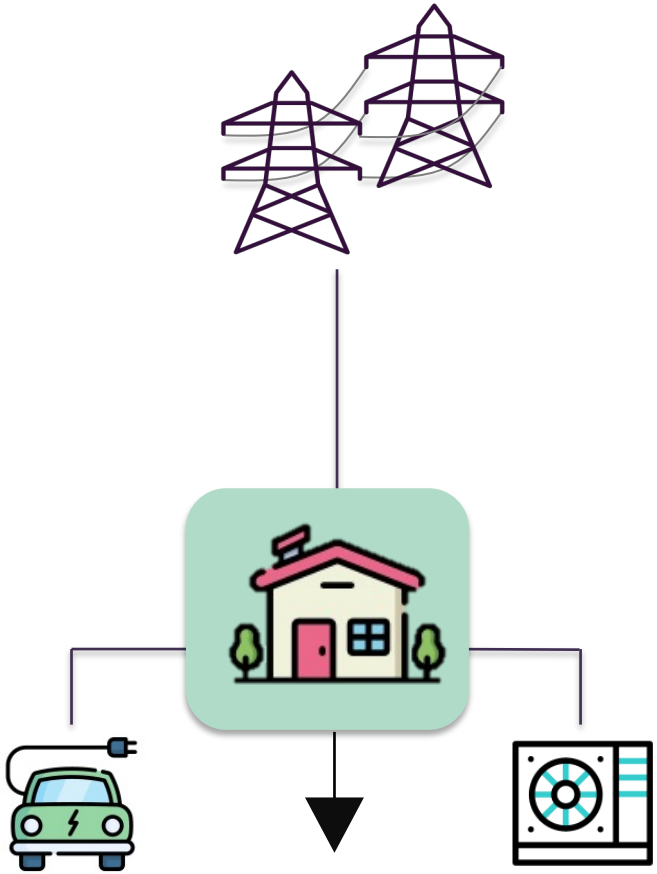
GRID USERS



GRID USERS

- Load profiles
  Domestic load
  + EV & HP



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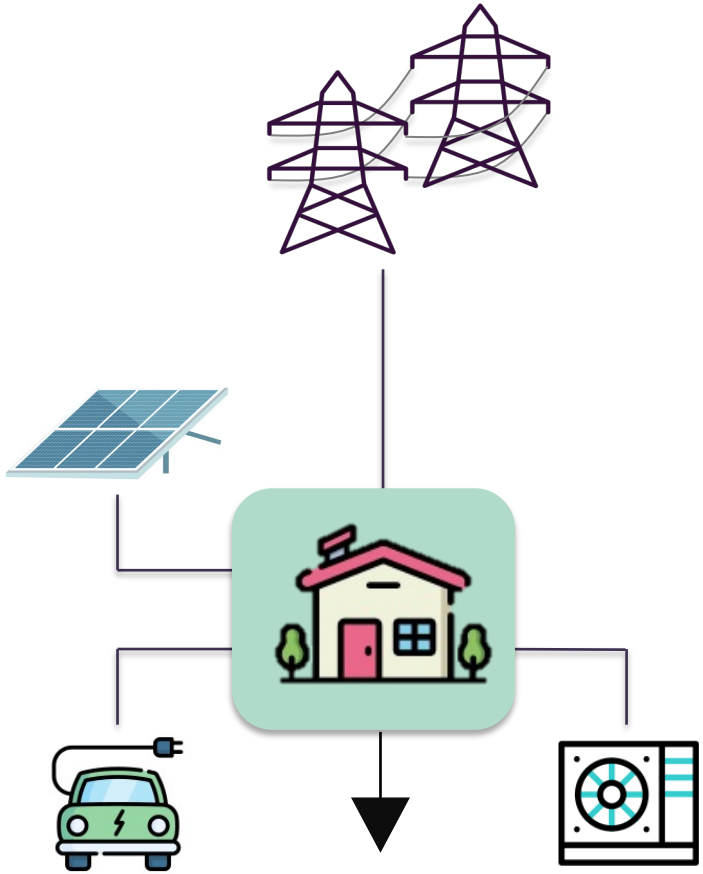
- PV profiles
  1 summer day & 1 winter day



GRID USERS

- Load profiles
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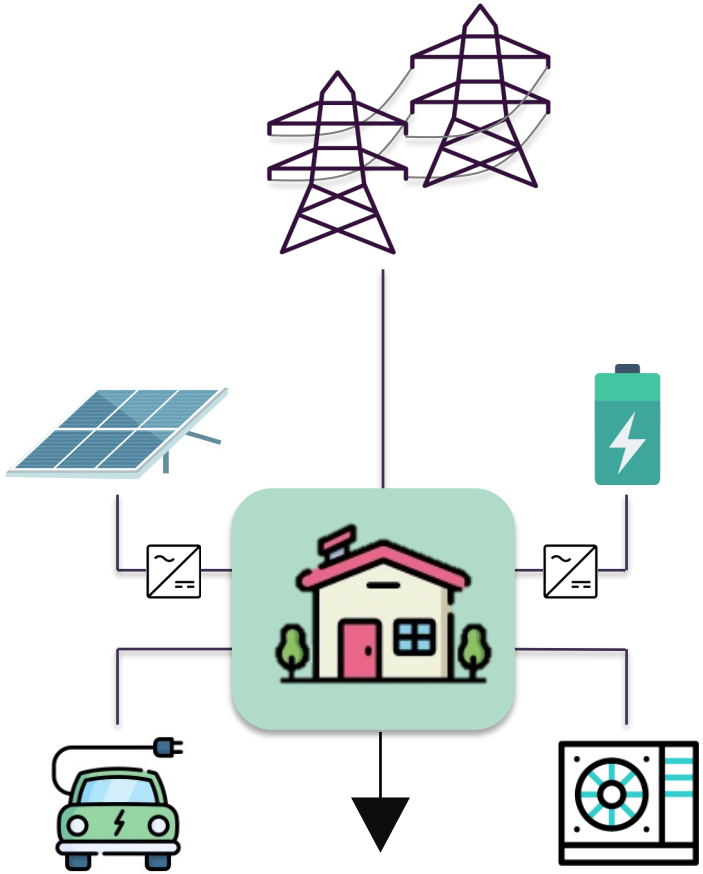
- PV profiles
  - 1 summer day & 1 winter day
- Sizing
  - PV
  - Grid connection
  - (Storage)
  - Converters



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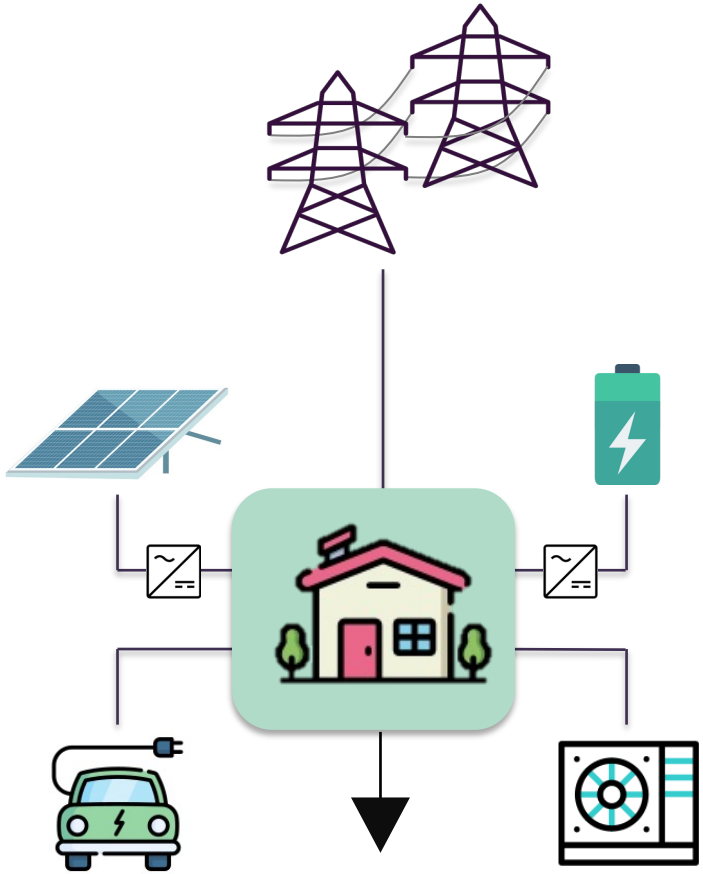

CO-OPTIMIZATION

Distribution System Operator

Grid user

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	Distribution System Operator	Grid user
Variables	lines to build or reinforce substations to build or reinforce	PV installation grid connection capacity

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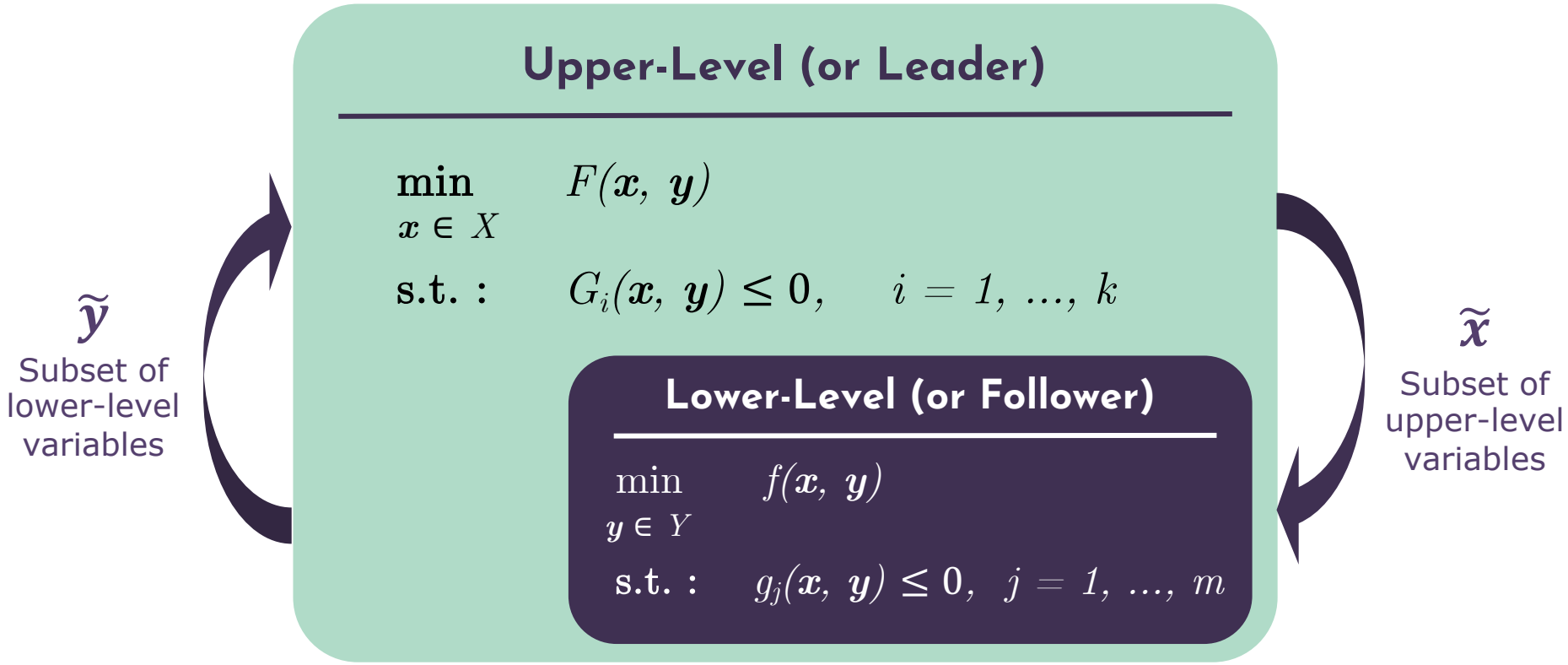
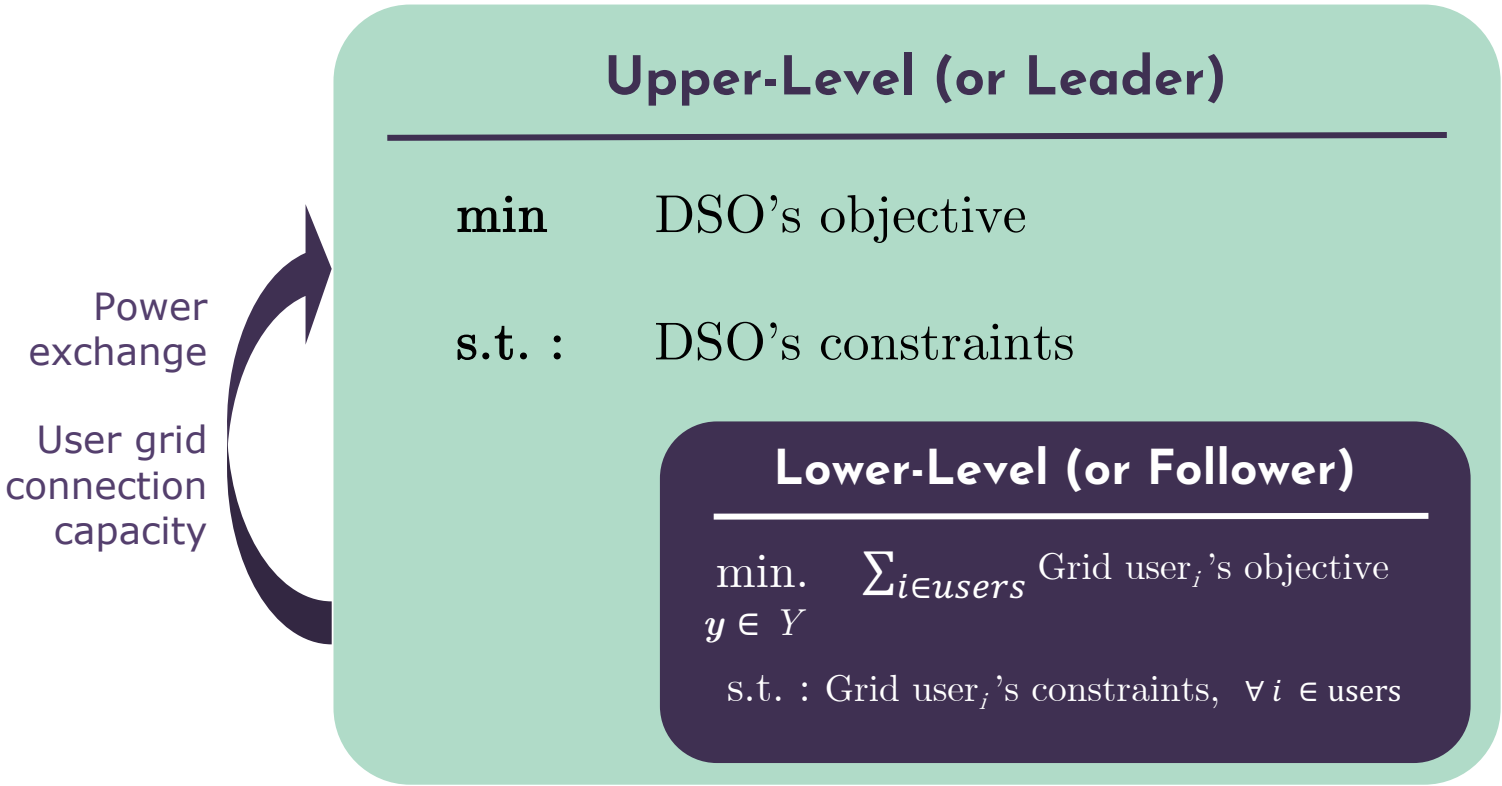
Objectives	fixed costs loss costs	energy costs & revenues PV costs grid costs
	Mixed-integer Second order cone	Linear

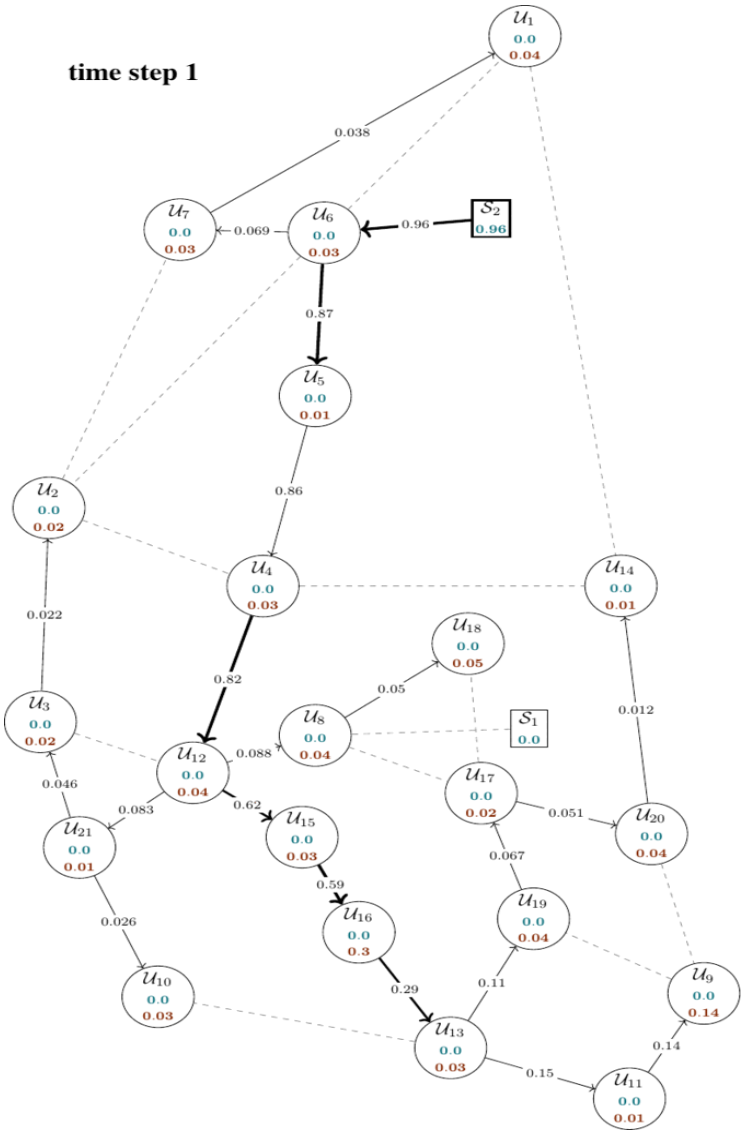
BILEVEL PROGRAMMING



BILEVEL FORMULATION



RESULTS


time step 1
$\mathcal{U}_1$ 0.0 0.04
$\mathcal{U}_2$ 0.0 0.02
$\mathcal{U}_3$ 0.0 0.02
$\mathcal{U}_4$ 0.0 0.03
$\mathcal{U}_5$ 0.0 0.01
$\mathcal{U}_6$ 0.0 0.03
$\mathcal{U}_7$ 0.0 0.03
$\mathcal{U}_8$ 0.0 0.04
$\mathcal{U}_9$ 0.0 0.14
$\mathcal{U}_{10}$ 0.0 0.03
$\mathcal{U}_{11}$ 0.0 0.01
$\mathcal{U}_{12}$ 0.0 0.04
$\mathcal{U}_{13}$ 0.0 0.03
$\mathcal{U}_{14}$ 0.0 0.01
$\mathcal{U}_{15}$ 0.0 0.03
$\mathcal{U}_{16}$ 0.0 0.3
$\mathcal{U}_{17}$ 0.0 0.02
$\mathcal{U}_{18}$ 0.0 0.05
$\mathcal{U}_{19}$ 0.0 0.04
$\mathcal{U}_{20}$ 0.0 0.04
$\mathcal{U}_{21}$ 0.0 0.01
$\mathcal{S}_1$ 0.0
$\mathcal{S}_2$ 0.96
0.038
0.069
0.96
0.87
0.86
0.022
0.82
0.05
0.088
0.012
0.046
0.083
0.62
0.051
0.067
0.59
0.026
0.29
0.11
0.14
0.15

RESULTS

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

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with Electric Vehicles

DSO

× 2 **Investment costs**
× 10 **Operational costs**

USERS

= **PV costs**
× 2.5 **electricity costs**
× 2 **grid costs**

RESULTS

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× 2 **Energy export price**

DSO
- = **Investment costs**
- ≈ **Operational costs**

USERS
- × 1.3 **PV costs**
- × 0.6 **electricity costs**
- × 1.25 **grid costs**

RESULTS

BASE CASE		
Electric vehicles	**Energy export price**	**Energy import price**
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with Electric Vehicles	× 2 Energy export price	× 2 Energy import price
DSO × 2 Investment costs × 10 Operational costs	**DSO** = Investment costs ≈ Operational costs	**DSO** = Investment costs ≈ Operational costs
USERS = PV costs × 2.5 electricity costs × 2 grid costs	**USERS** × 1.3 PV costs × 0.6 electricity costs × 1.25 grid costs	**USERS** = PV costs × 2 electricity costs ≈ grid costs

CONCLUSION

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Future work

- Storage
- GHG emissions
- Energy communities
- …

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Future work

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- GHG emissions
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- …

Proof of concept

- Bilevel program…
- for a one-leader multi-follower approach…
- to distribution network development planning…
- considering impacts from exogenous factors…
- showing expected results.