Doctoral thesis public defence

# Hosting capacity of low-voltage distribution networks

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LIÈGE université

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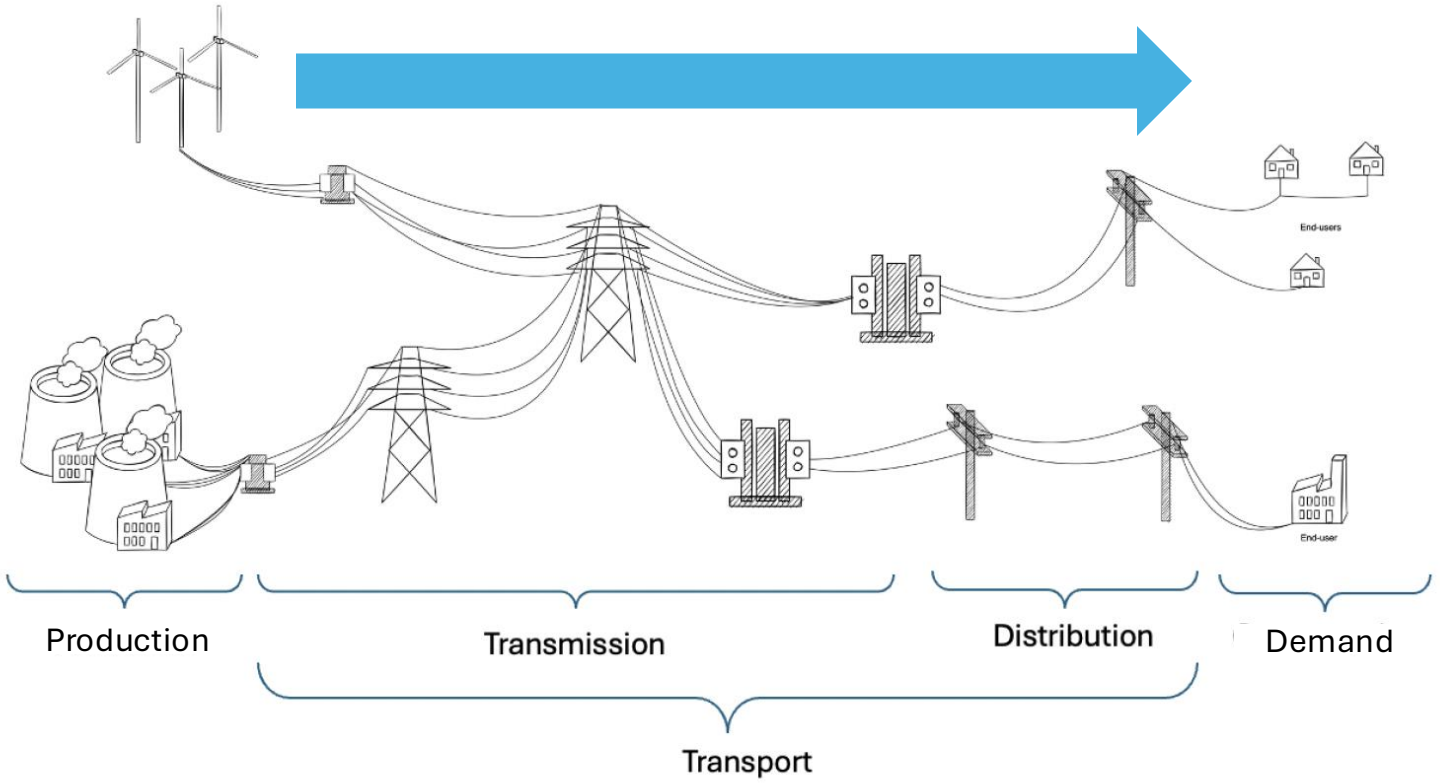
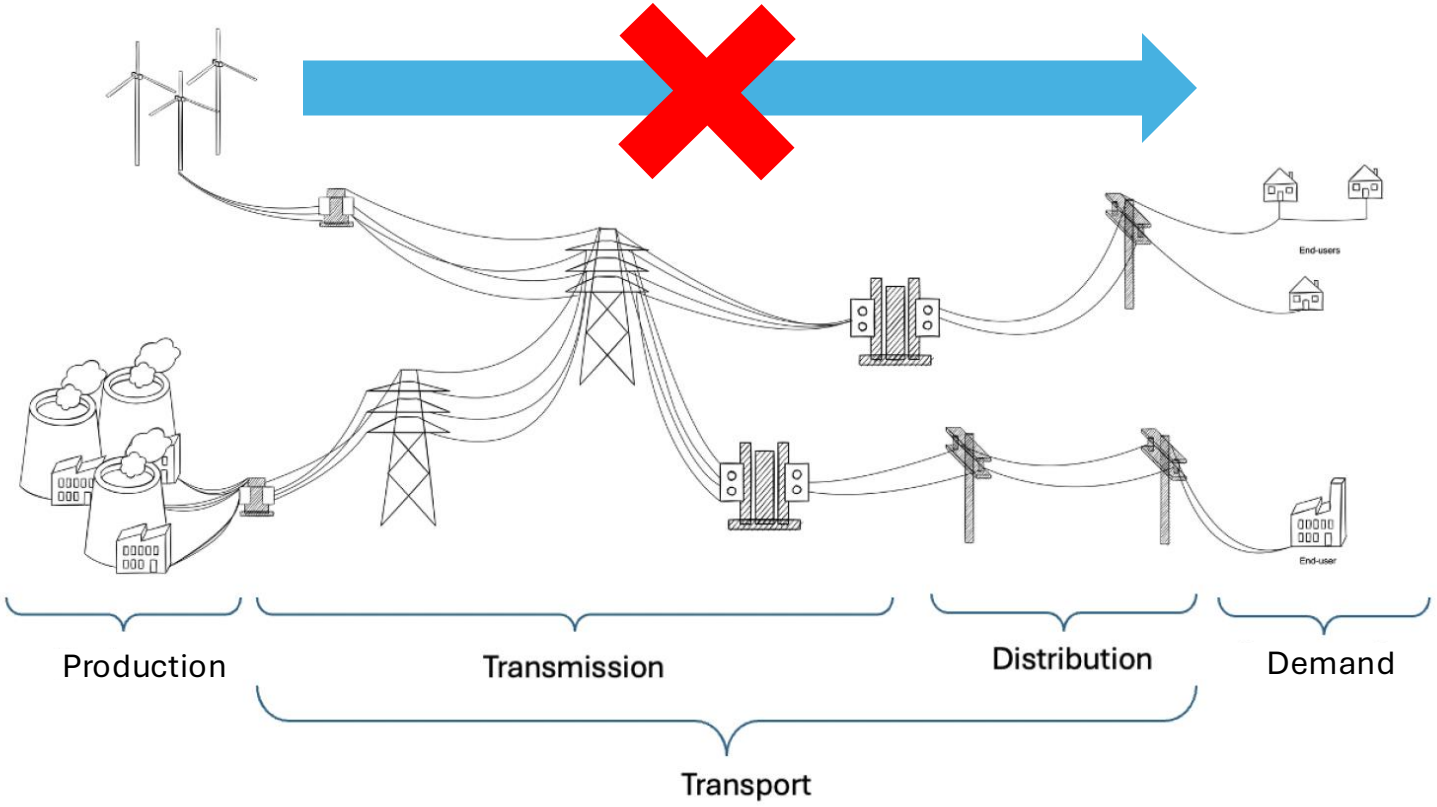
(Image from https://www.synox.io/cat-smart-energy/smart-grid-definition)

# Power System

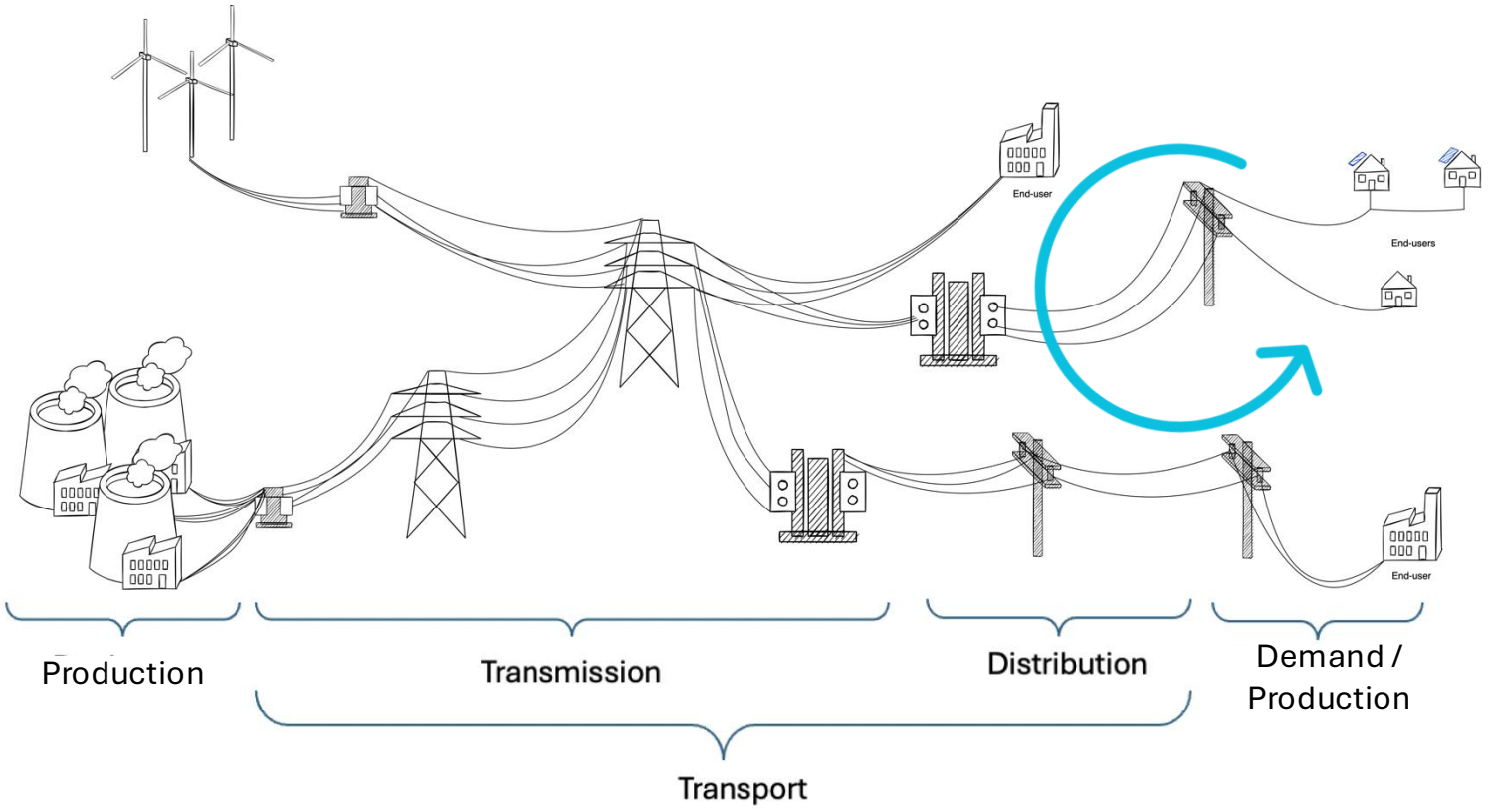
Traditional power system, one way power flow.



# Power System



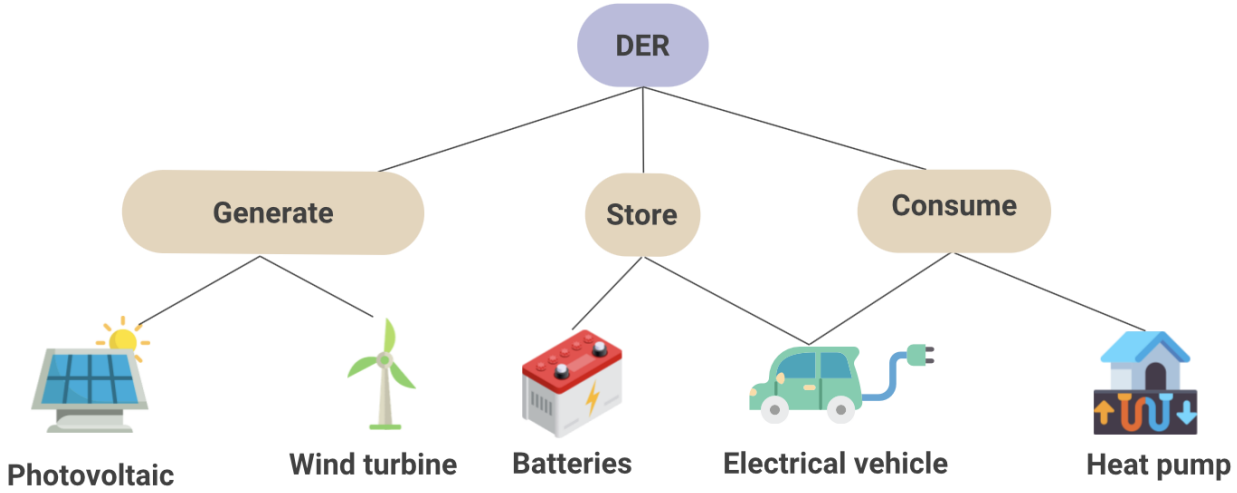
# Power System



# Distributed Energy Resources (DERs)

*Small-scale energy assets that generate, store or consume energy.*

e.g.:



# BREAKING NEWS

La Libre

L Detaches, network saturation, complaints from prosumers: photovoltaics under tension in Wallonia

rtbf actus

**Photovoltaic: with the overload on the network, the efficiency of the panels is often equal to zero**

rtbf actus

**New tile for photovoltaics: surges on the network paralyze some installations**

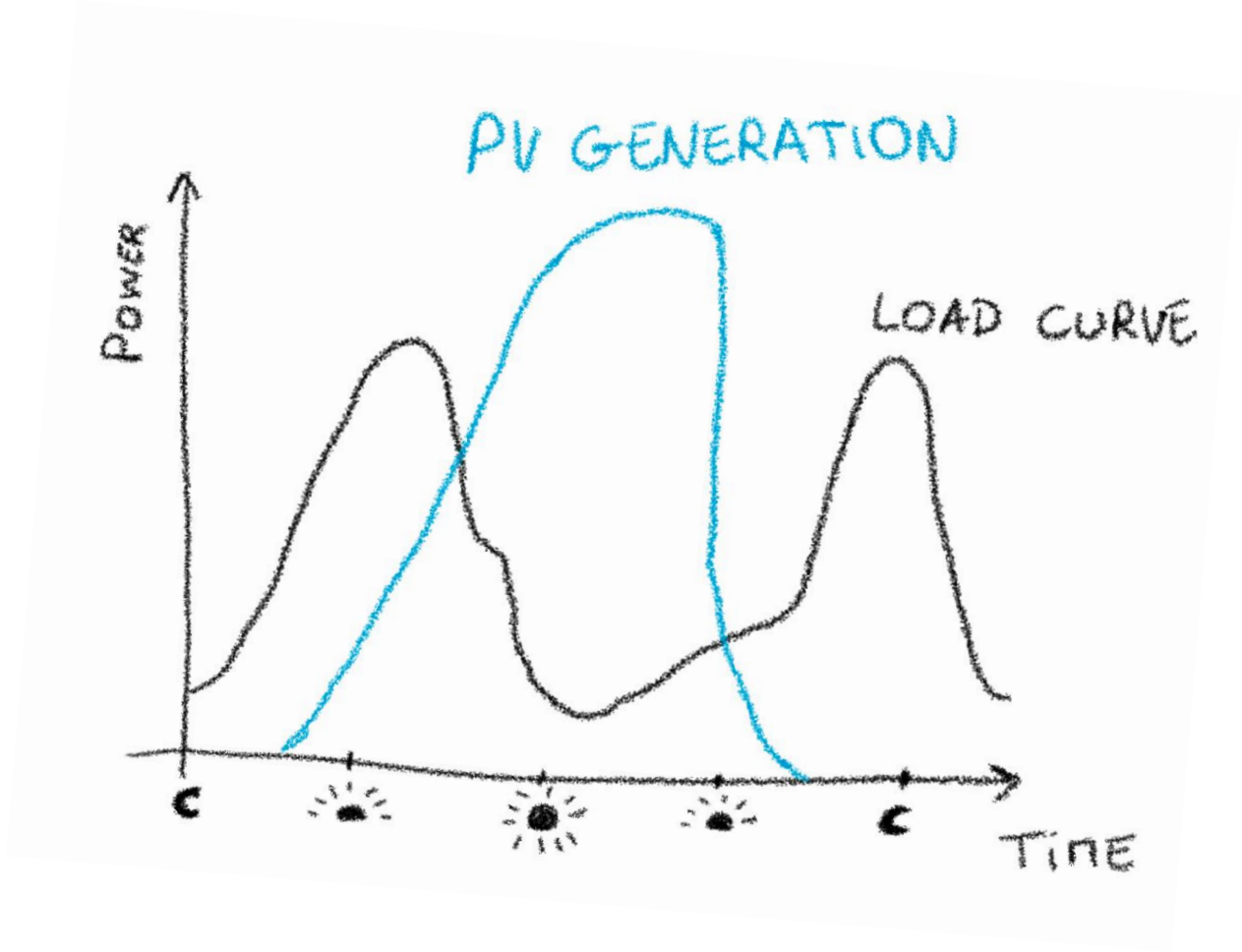
tendances Trends

**Charging electric cars, a challenge for the Belgian network?**

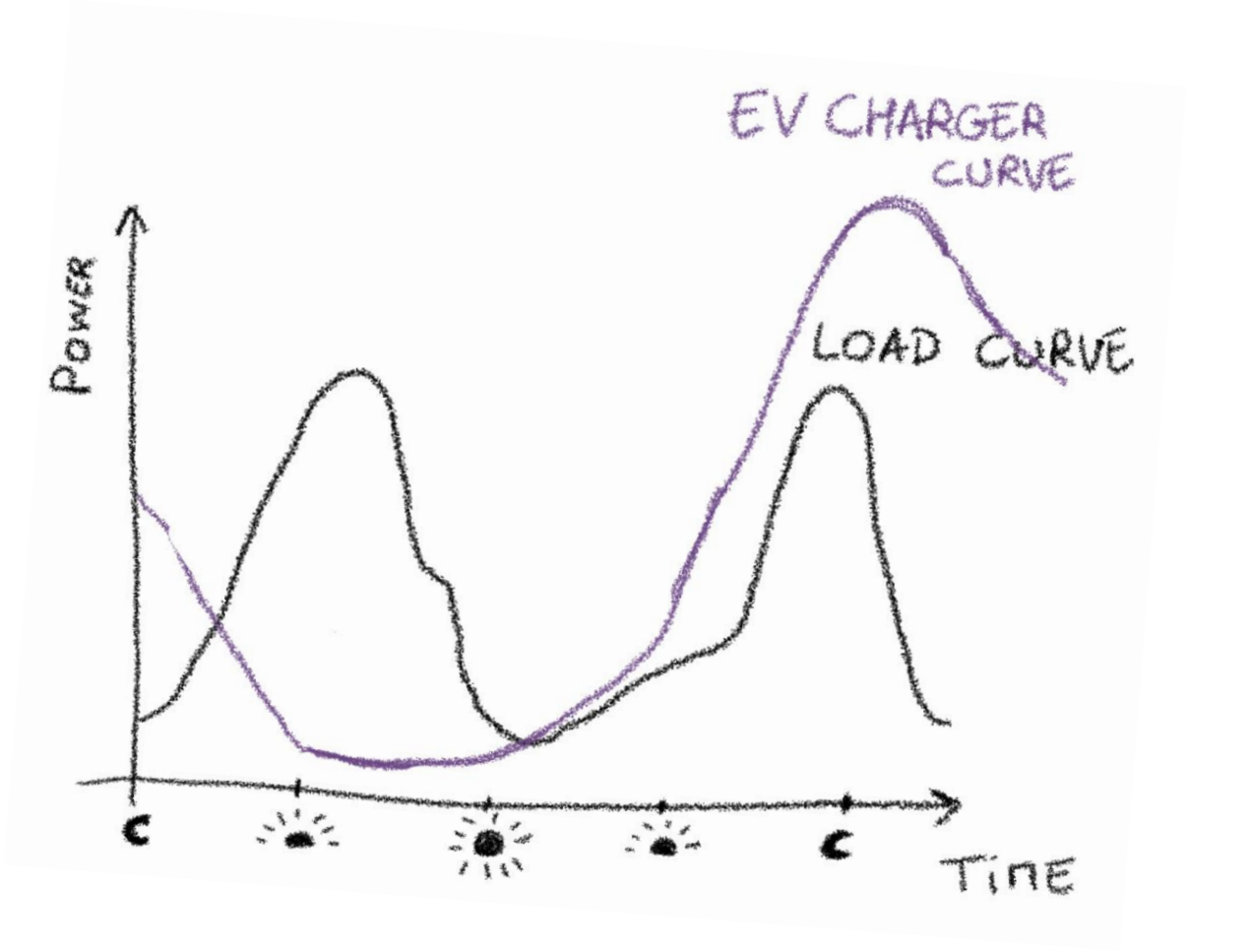
Auto Plus

**CAN ELECTRIC CARS OVERCHARGE THE POWER GRID?**

# DERs issues – Photovoltaic (PV) panels example



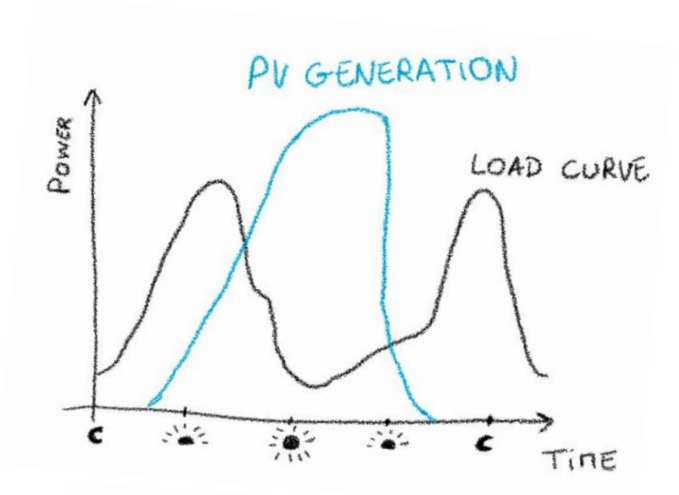
# DERs issues – Electrical Vehicle (EV) example

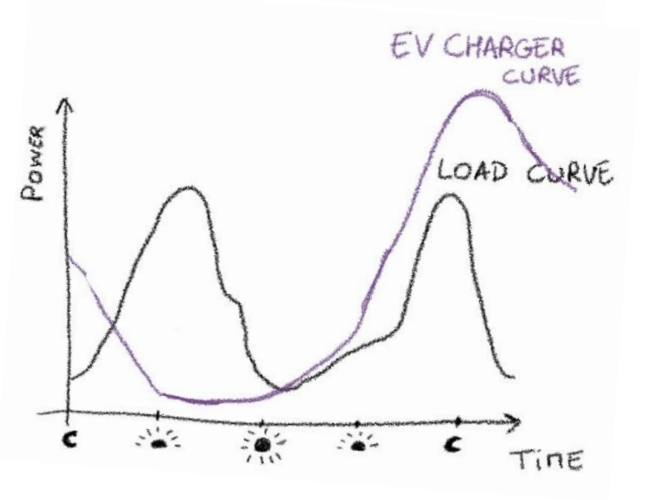


# DERs issues

Two examples of issues from the network point of view:

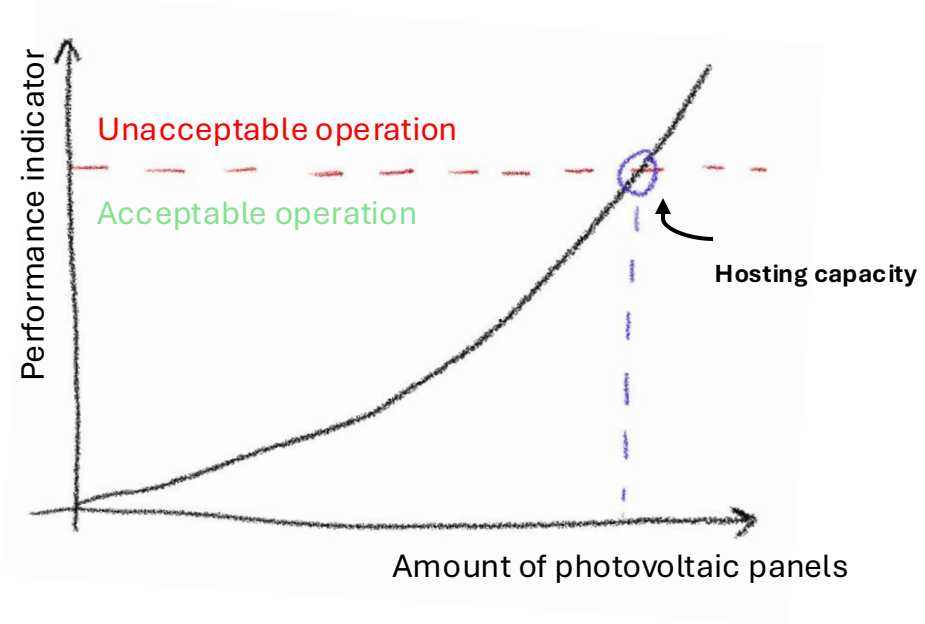
- Voltage rises or drops (produce or consume more than expected, beyond voltage limits)
- Congestion (due to high demand, network limits to deliver electricity are reached)

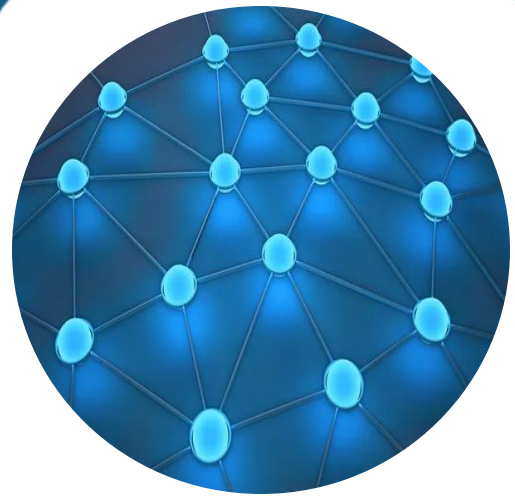


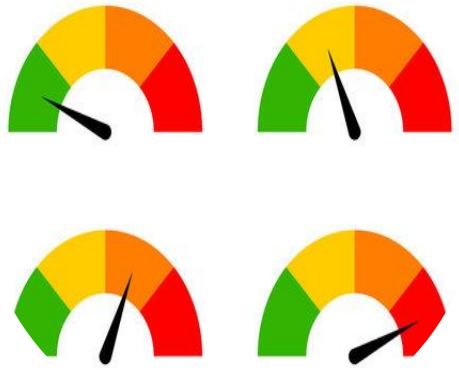
# The scope of this thesis

*The hosting capacity is the amount of new resources that can be hosted by a network before facing any issues, i.e., compromising its operational limits or violating safety constraints.*





Topology identification



Single technology HC




Unified HC definition

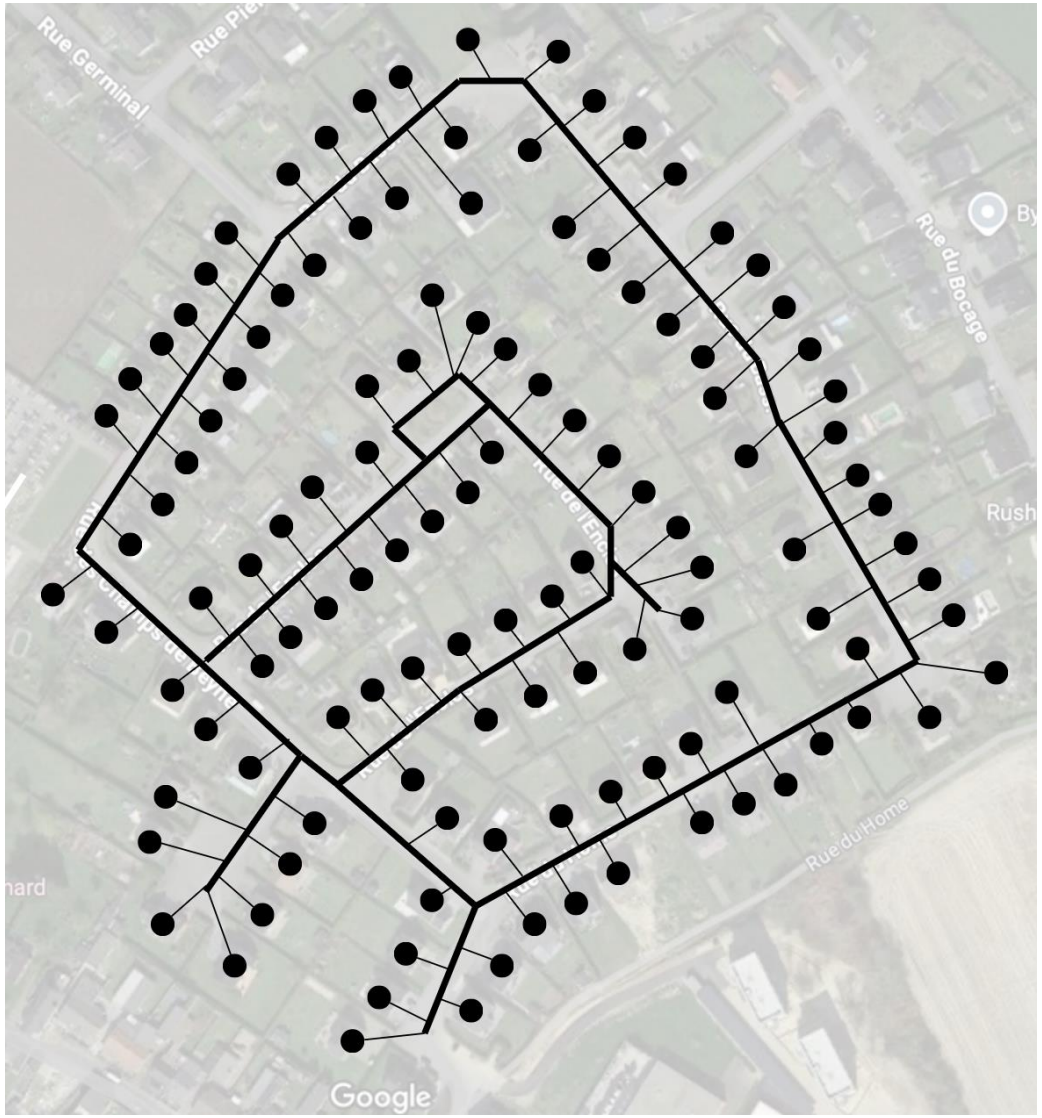


Combined HC

# Topology identification


Rue du Horne

# Street map



# Electrical network topology

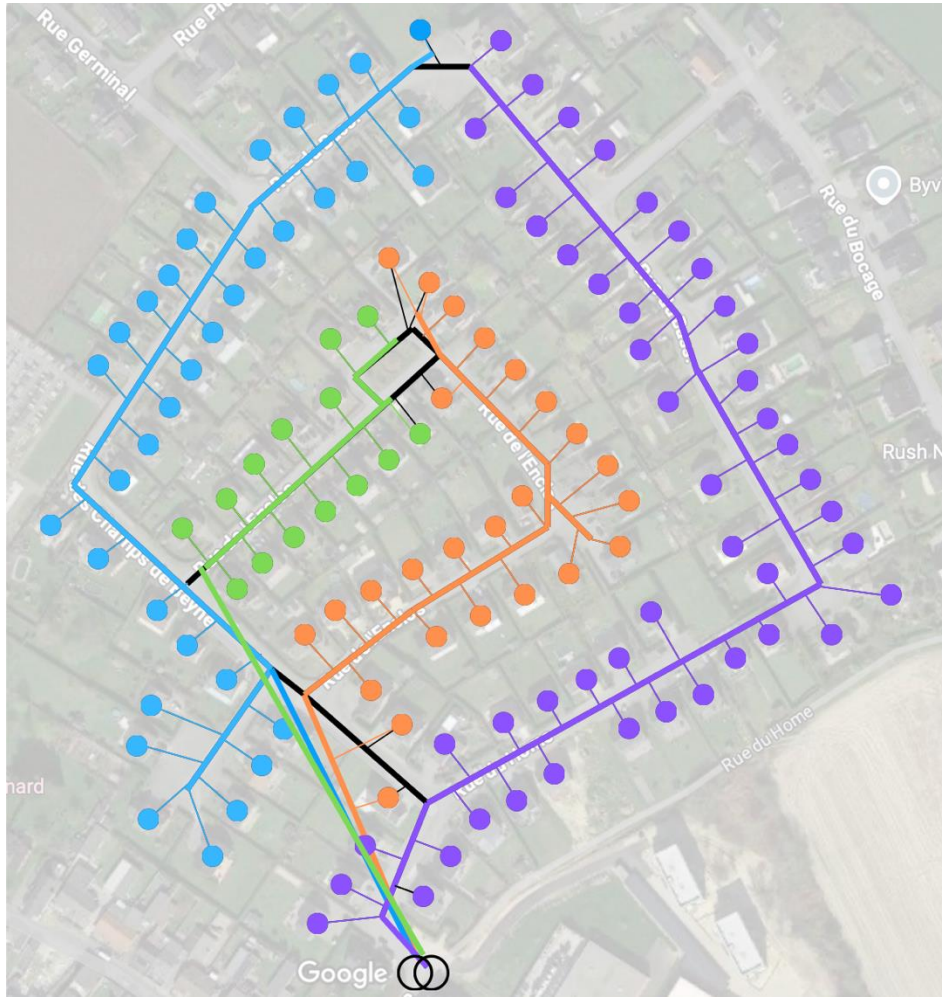
Substation

Feeder 1

Feeder 2

Feeder 3

Feeder 4



# Electrical network topology

Substation

Feeder 1

Feeder 2

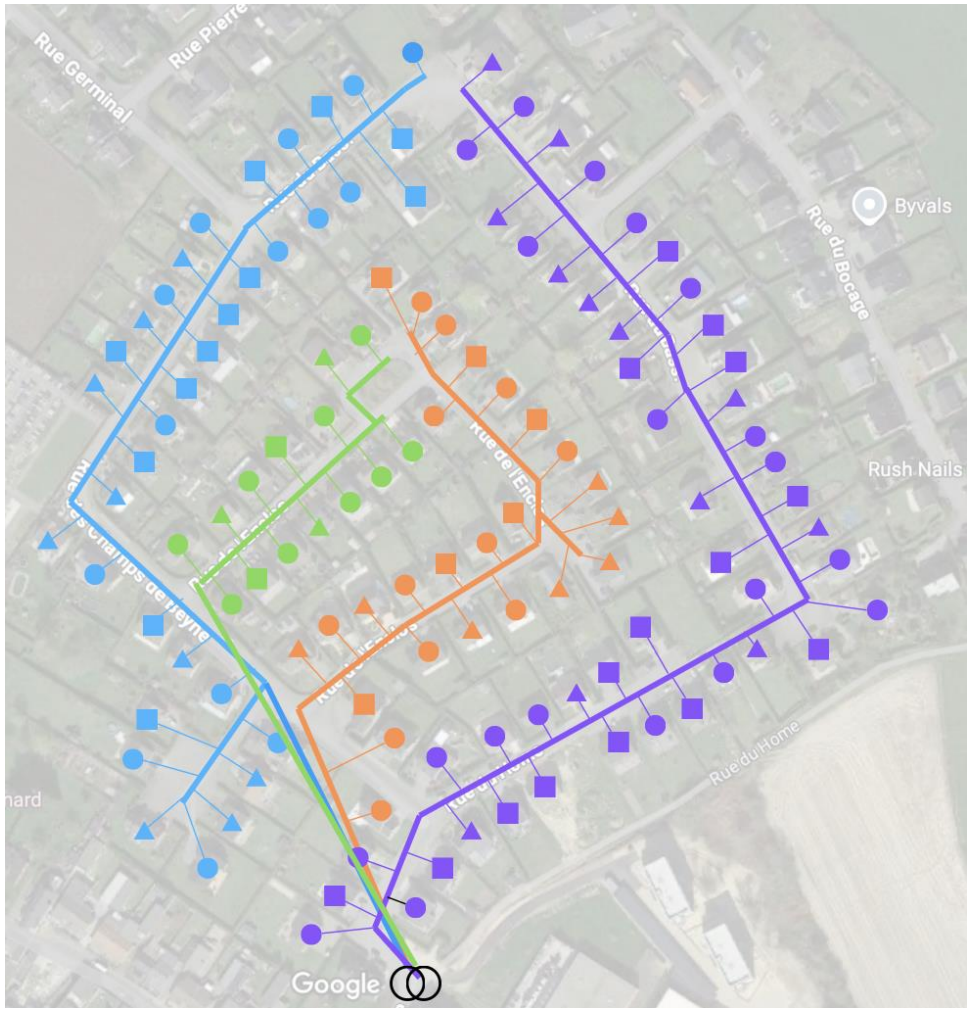
Feeder 3

Feeder 4

Phase 1

Phase 2

Phase 3



# Smart meters

Substation

Feeder 1

Feeder 2

Feeder 3

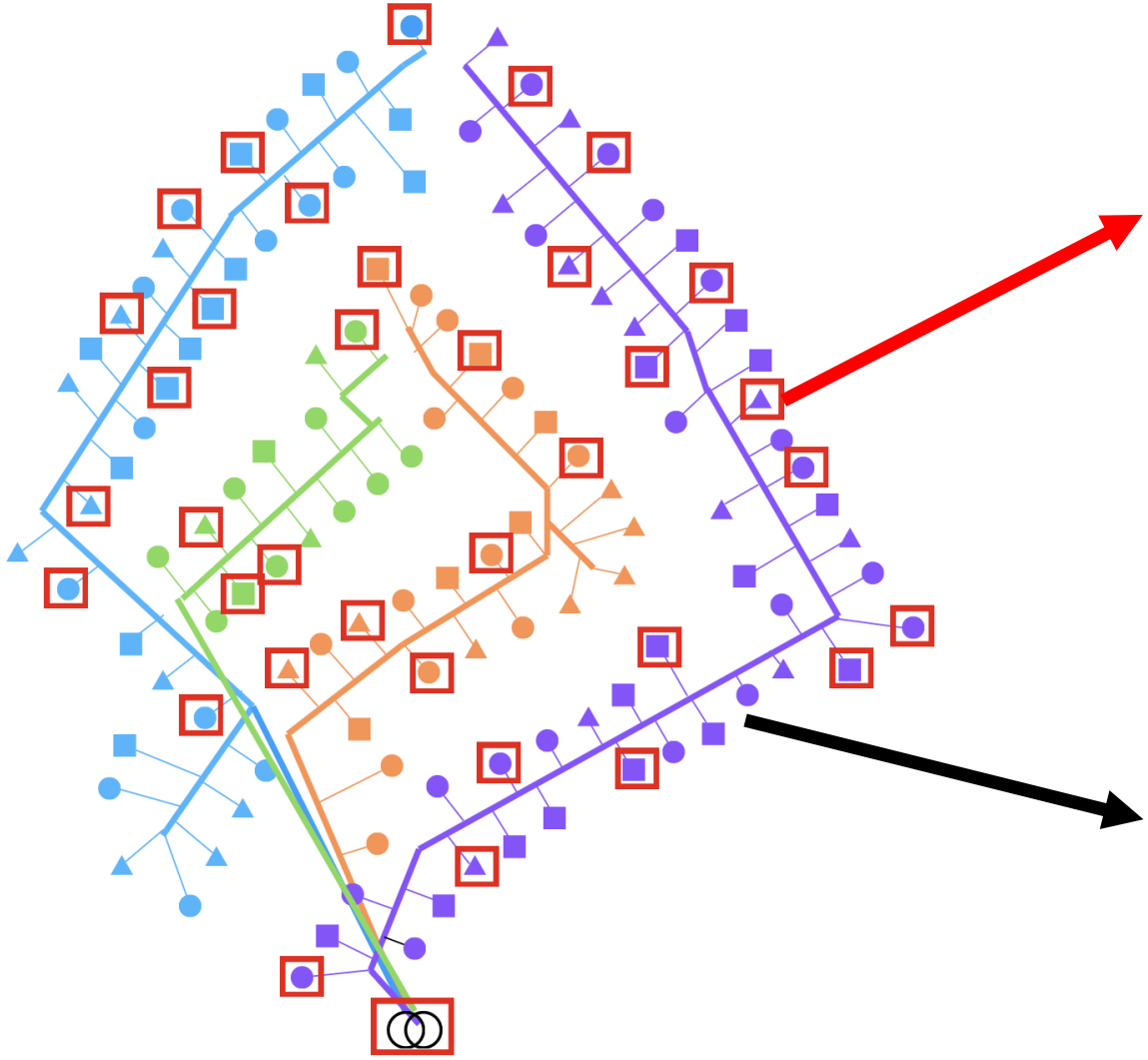
Feeder 4

Phase 1

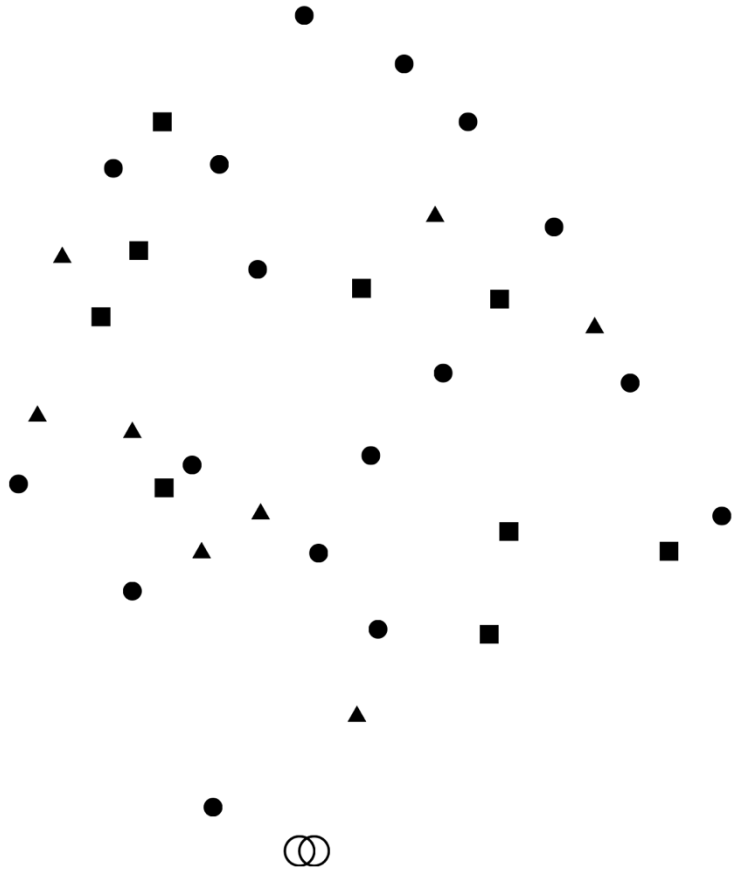
Phase 2

Phase 3

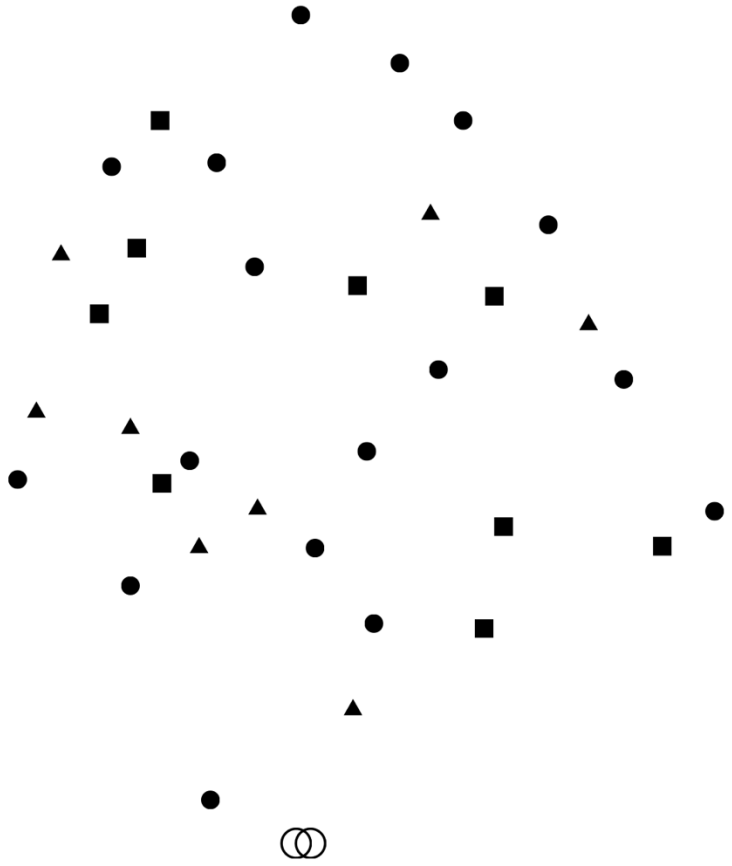
Smart-meters

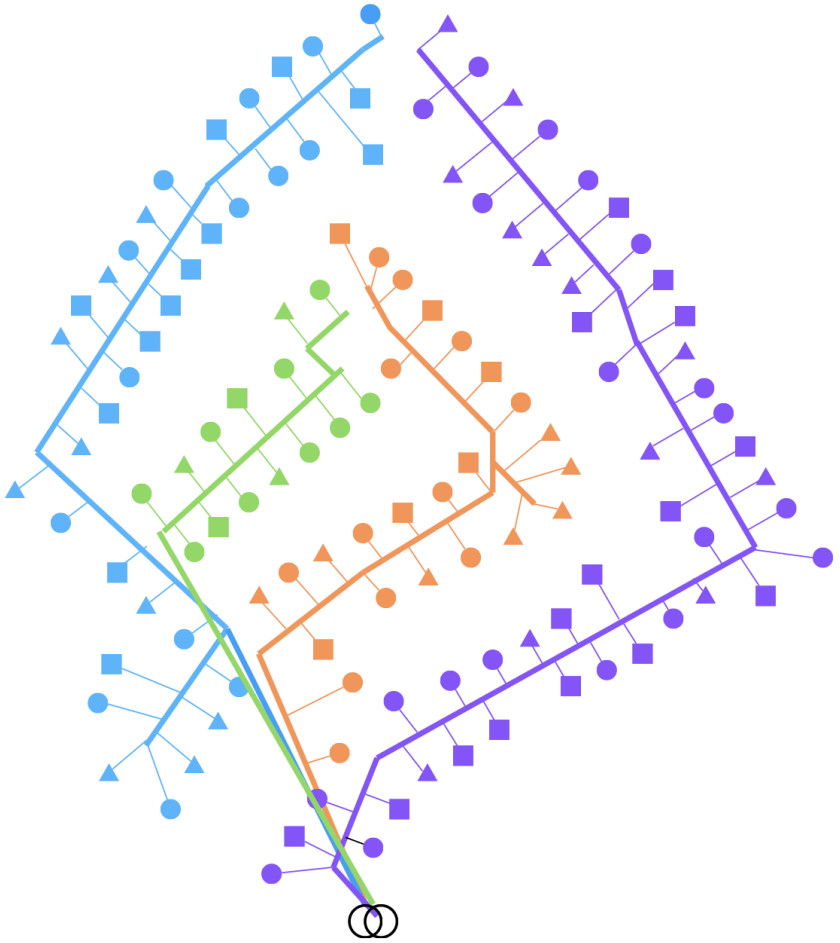


# Available data



# Topology reconstruction goal

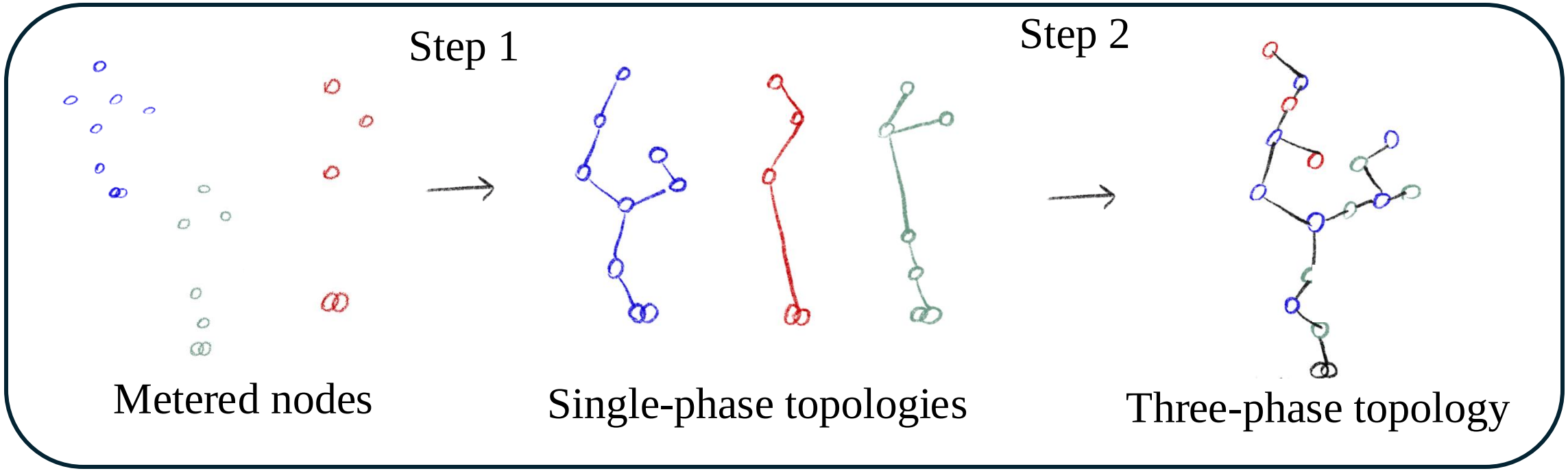




# Assumptions

- During the observation period, the **network topology does not change**
- Customer connections to the main feeder are **single-phase**
- Customers connection **phase is known**
- There is **at least one smart-meter** connected at **every phase** of **every feeder**
- Three-phase **measurements** of feeders at the **substation** are **available**

# Methodology

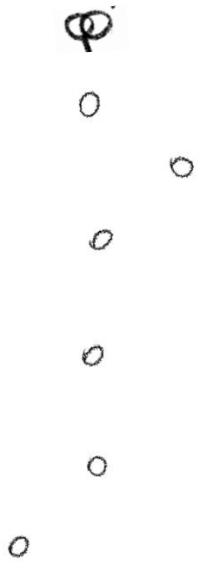



Two steps:

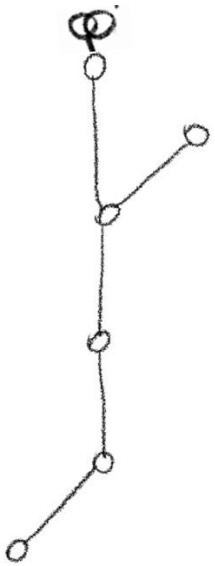
1. Construct single-phase estimates of the network topology for each.
2. Merge the three single-phase estimated typologies to form a three-phase feeder model

# Methodology – single phase reconstruction

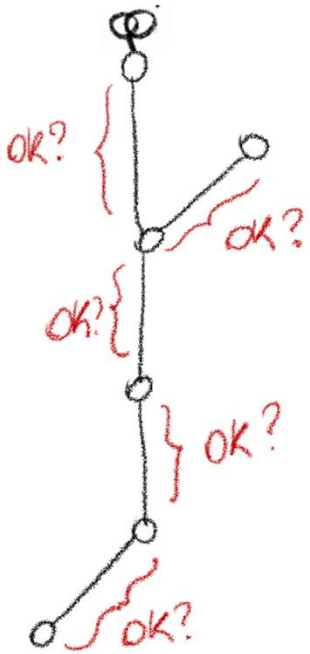
Available data

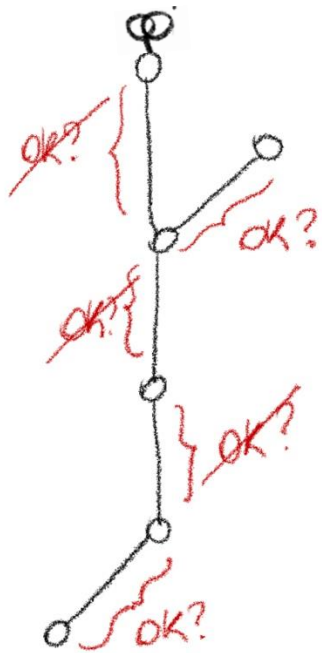


Topology estimation



Topology validation



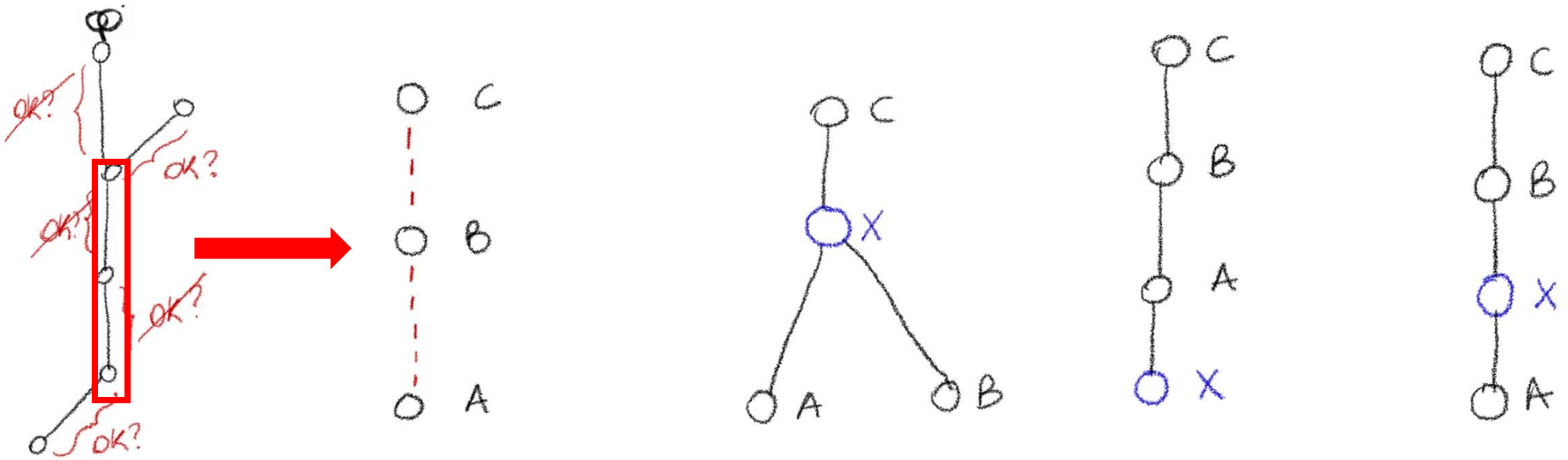




Real network

Unavailable

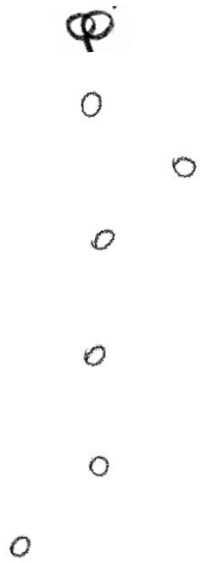
# Methodology – single phase reconstruction

Hidden nodes detection

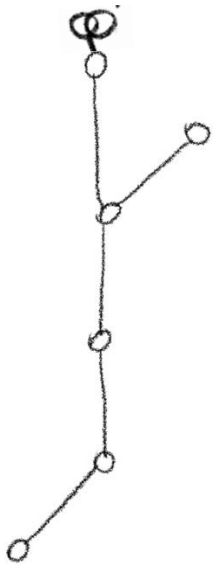


# Methodology – single phase reconstruction

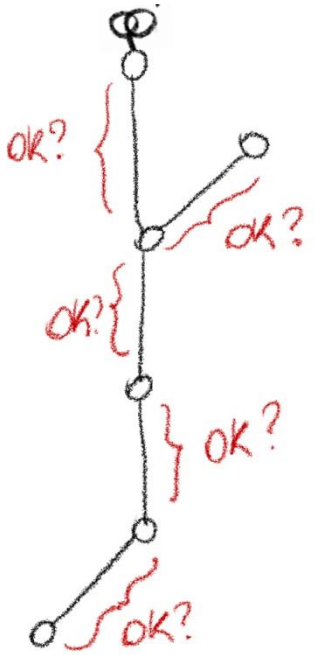
Available data



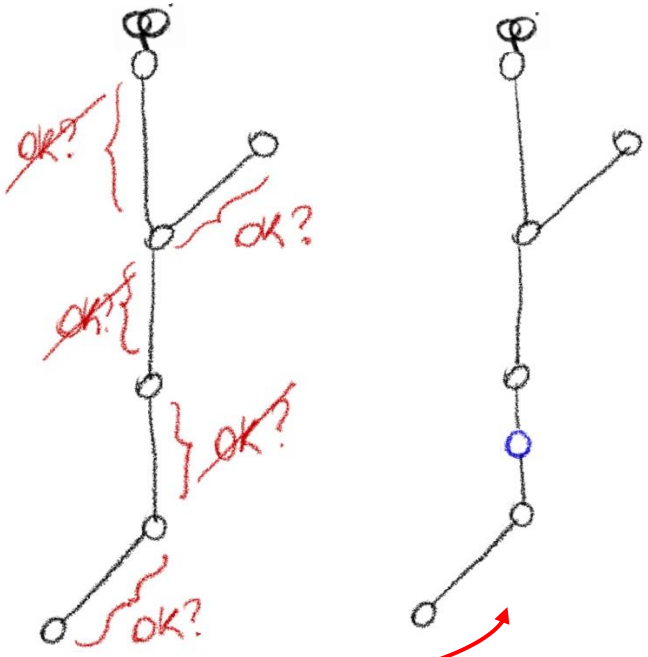
Topology estimation



Topology validation




Hidden node detection

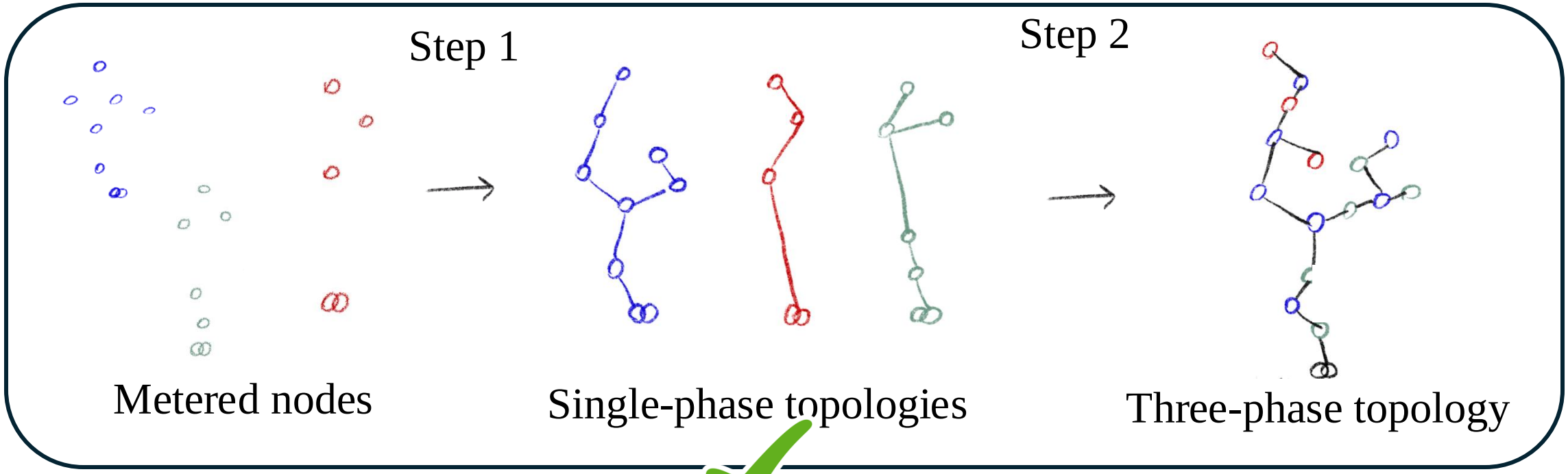



Real network

Unavailable

Single phase reconstruction

# Methodology




Two steps:

1. Construct single-phase estimates of the network topology for each.
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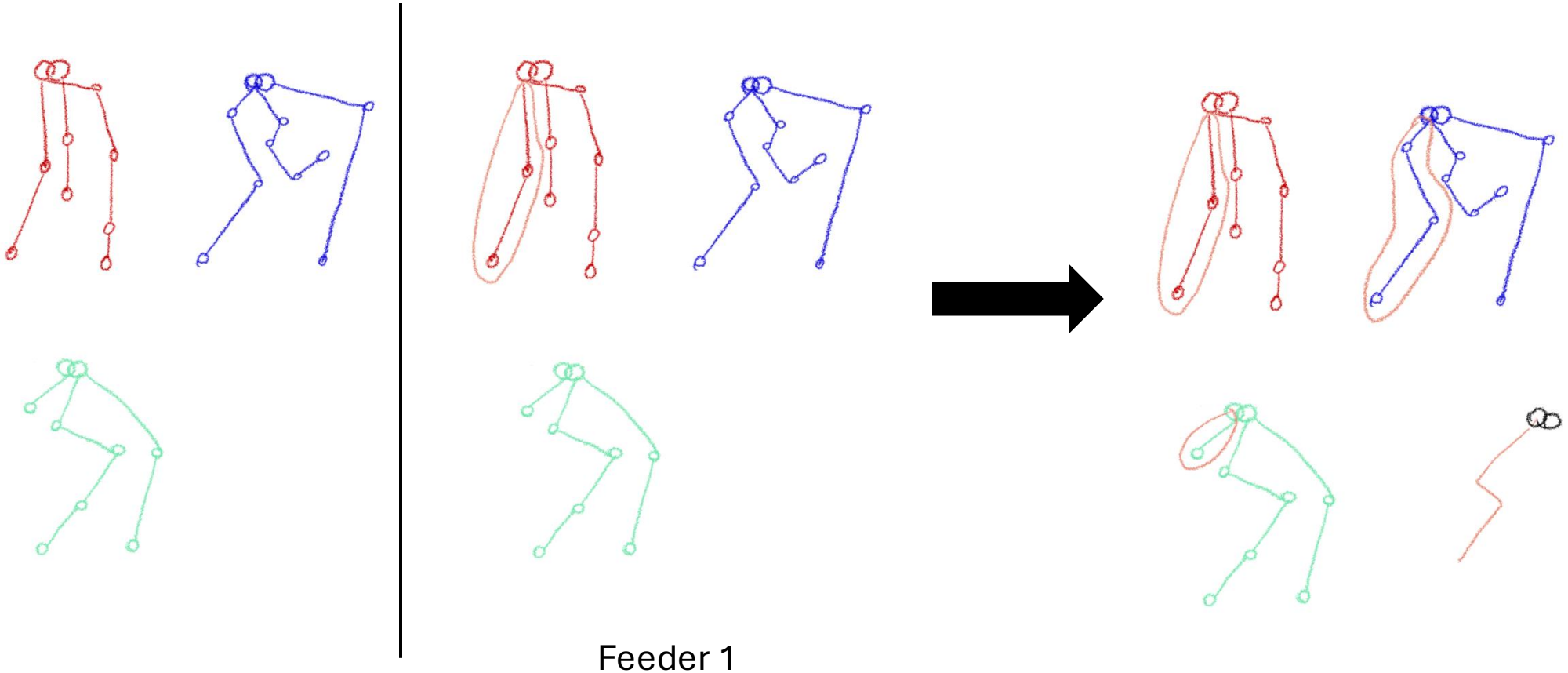
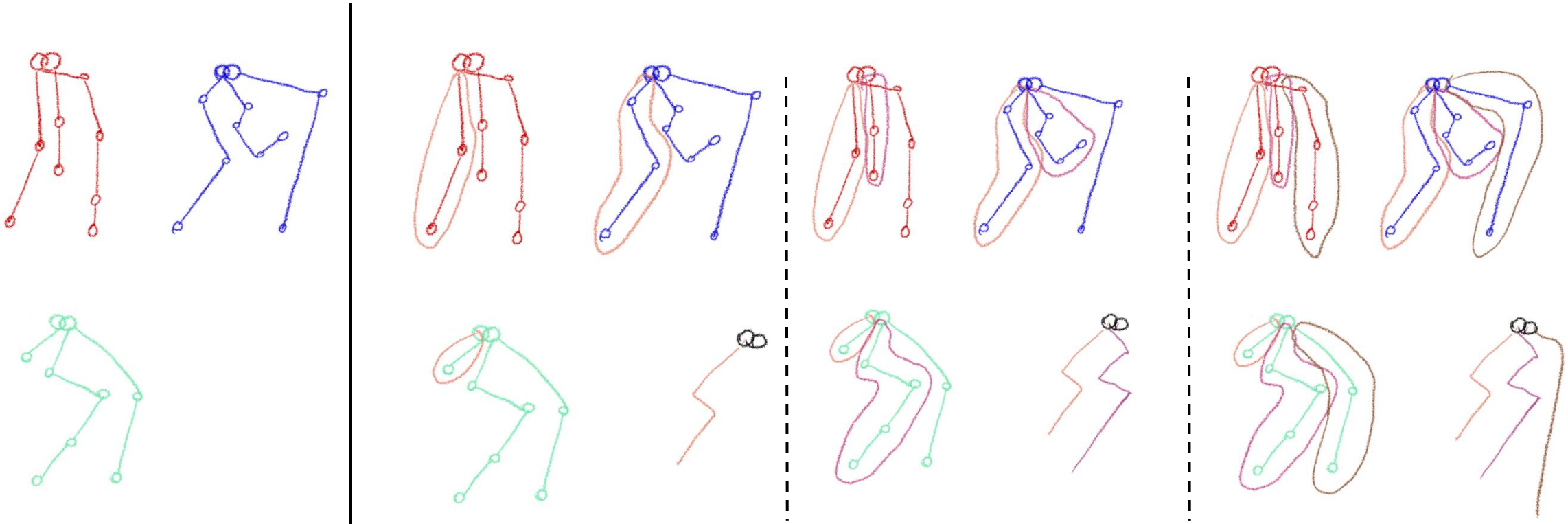
# Methodology – Three-phase topology formation

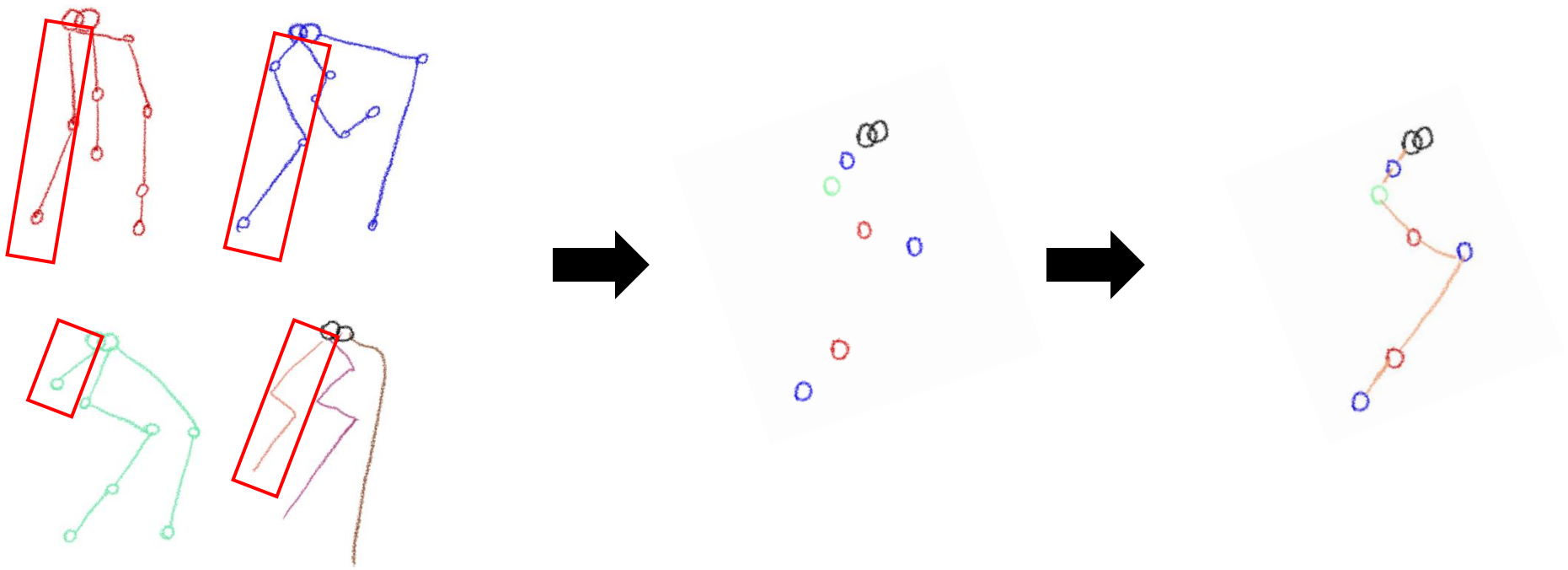


Feeder 1

# Methodology – three-phase topology formation

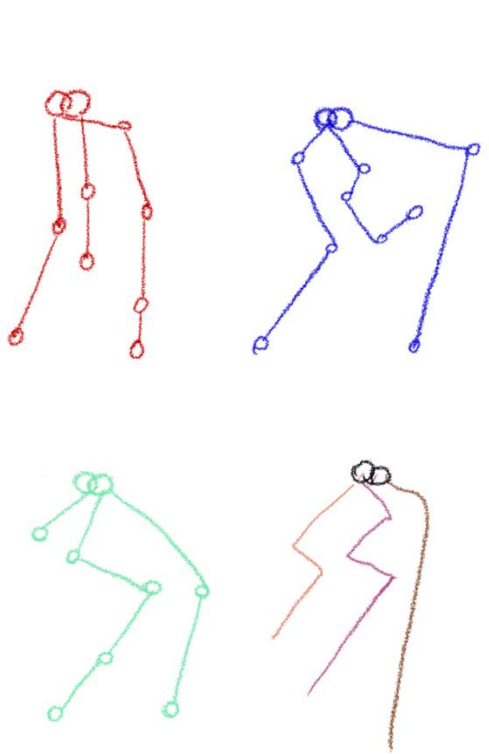


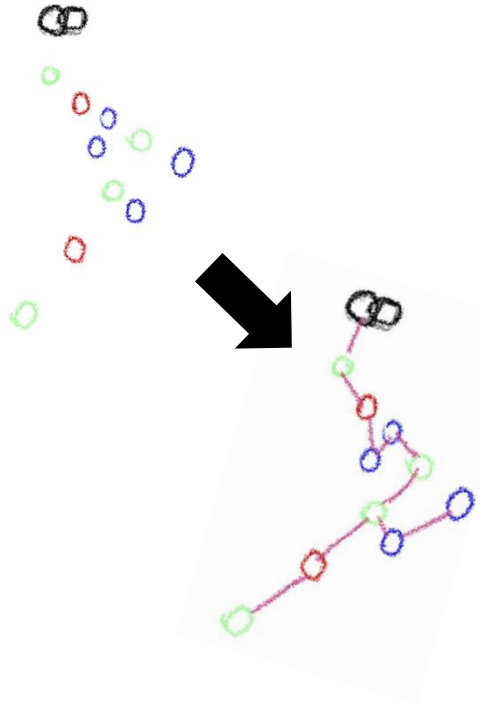
# Methodology – three-phase topology formation



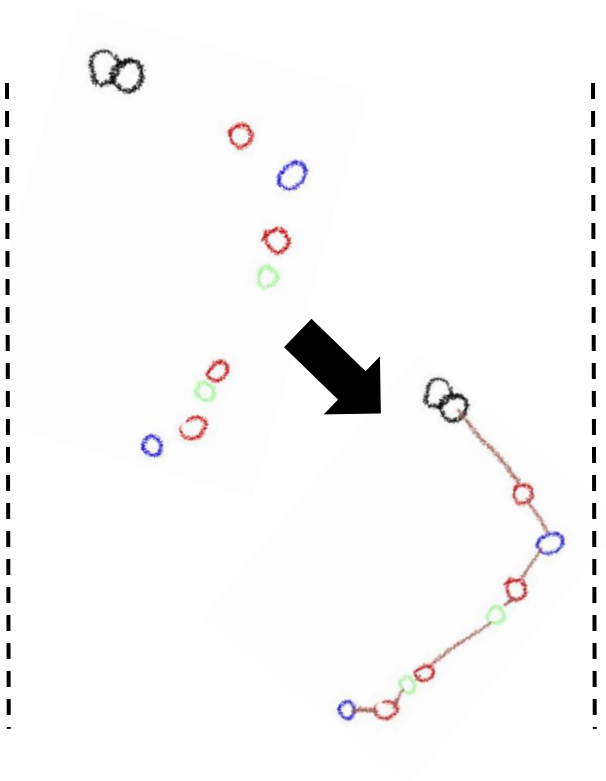
Feeder 1

# Methodology – three-phase topology formation

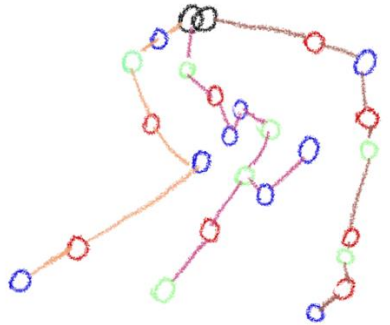




Feeder 2

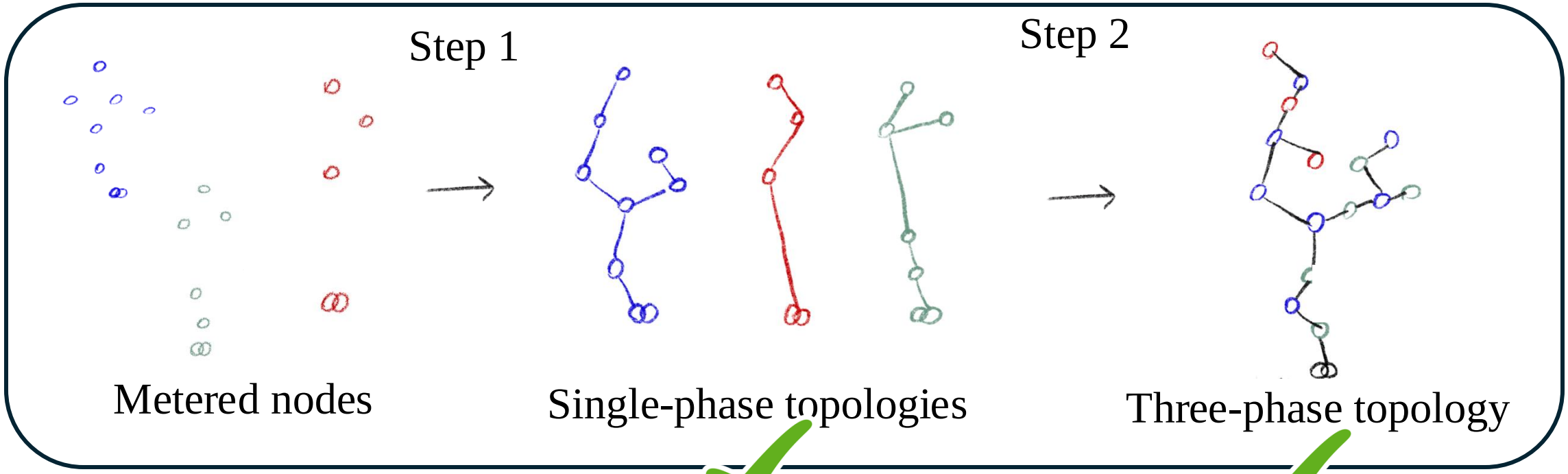


Feeder 3



Three-phase topology

# Methodology

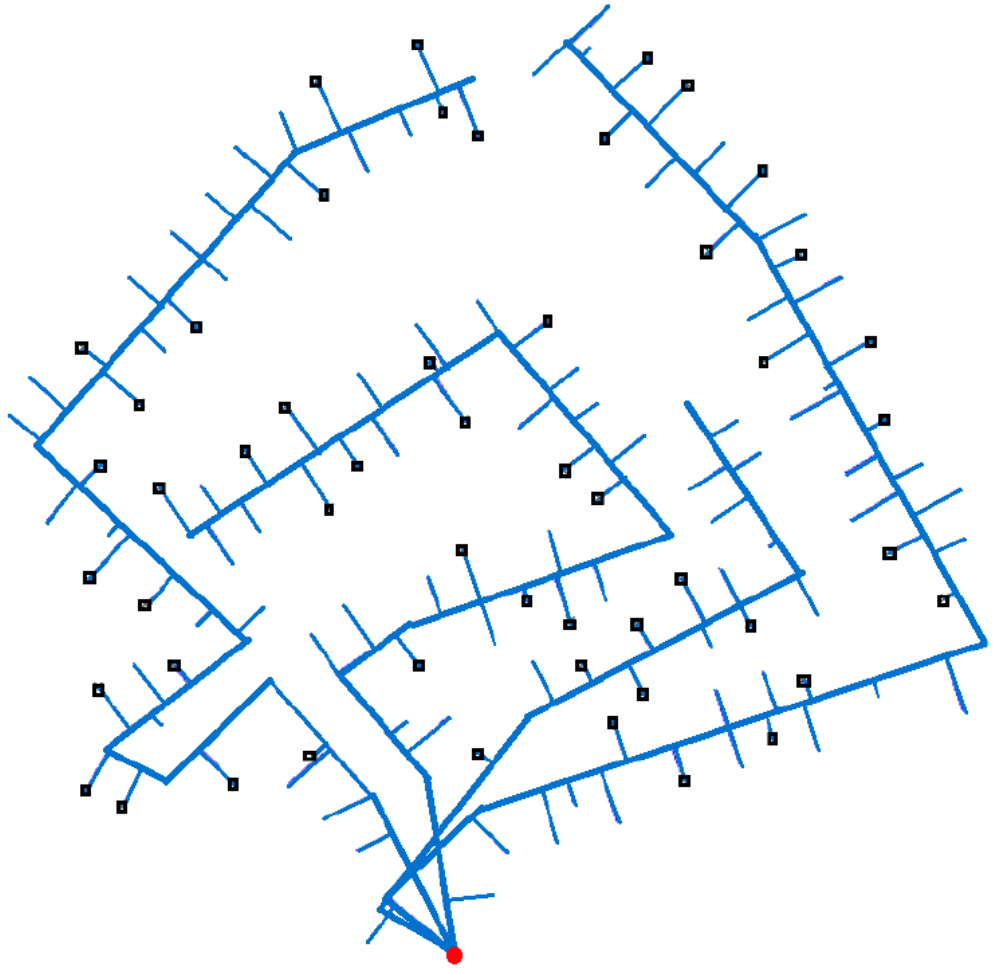



Two steps:

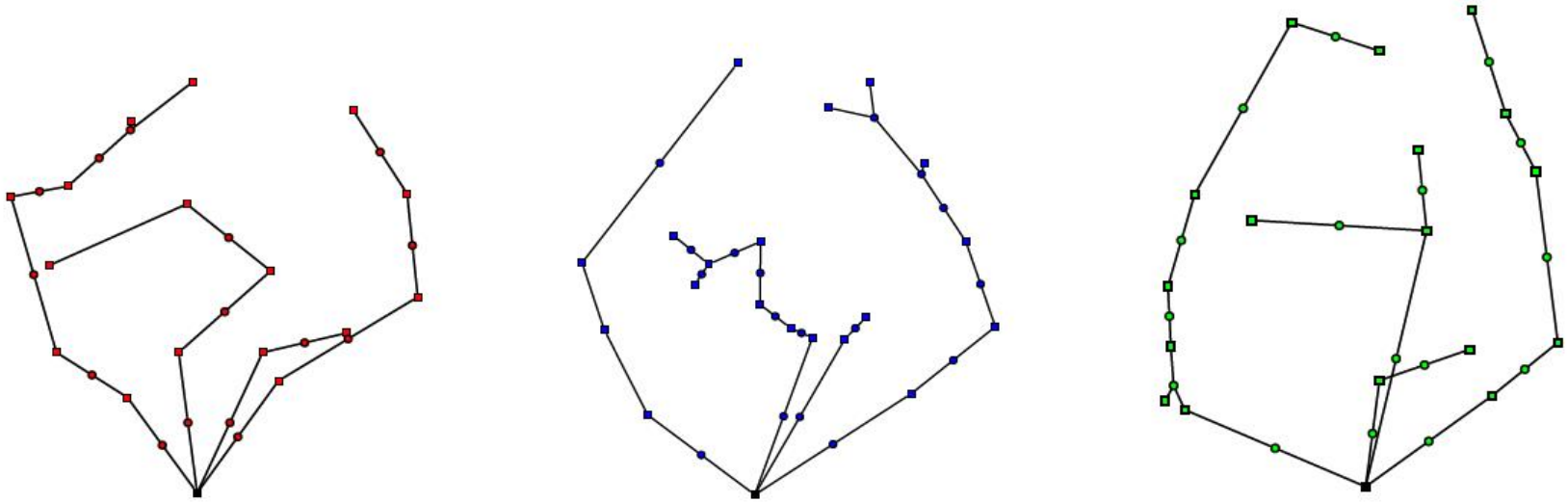
1. Construct single-phase estimates of the network topology for each.
2. Merge the three single-phase estimated typologies to form a three-phase feeder model

# Test case

- 1 substation (red dot)
- 4 feeders
- 216 nodes
- 128 customers
- 52 Smart meters (black rectangles)

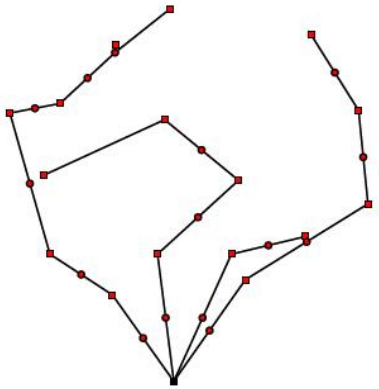


# Results

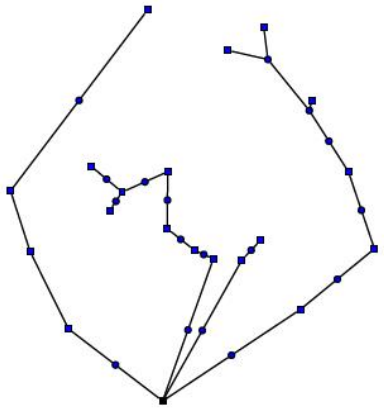


Phase A Phase B Phase C

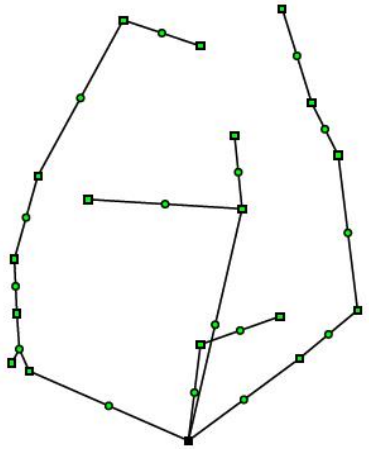
# Results



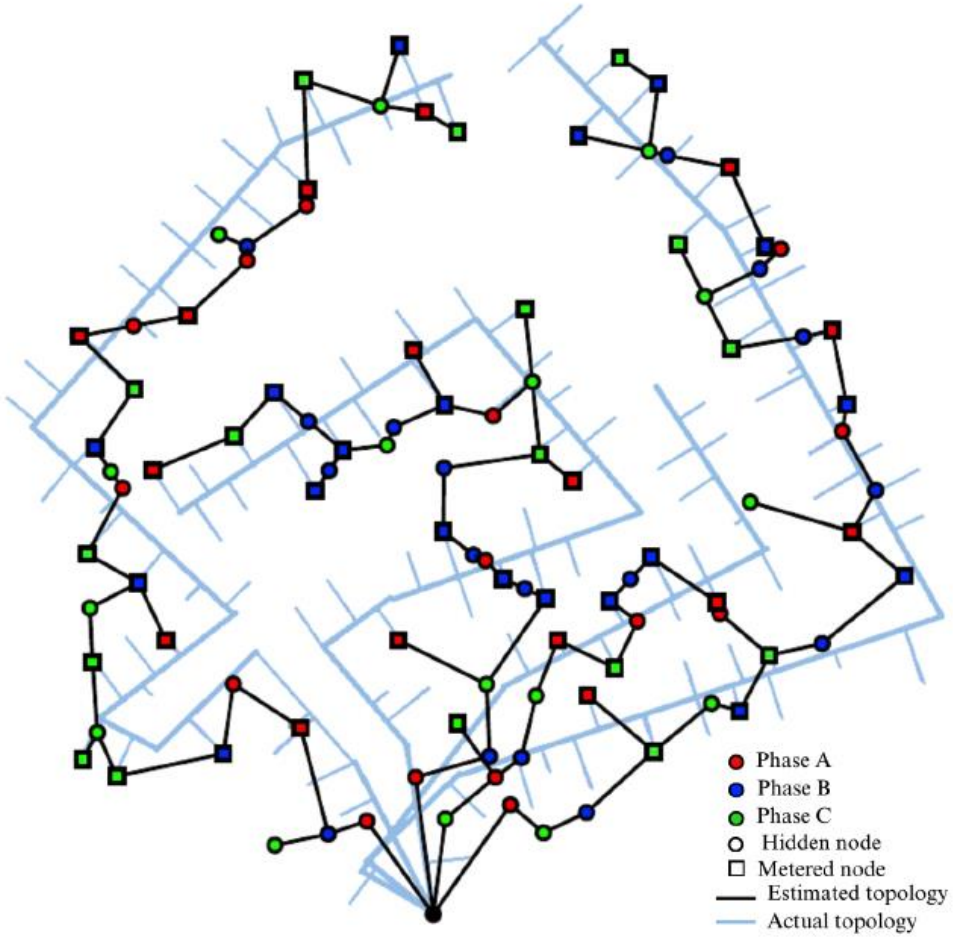
Phase A



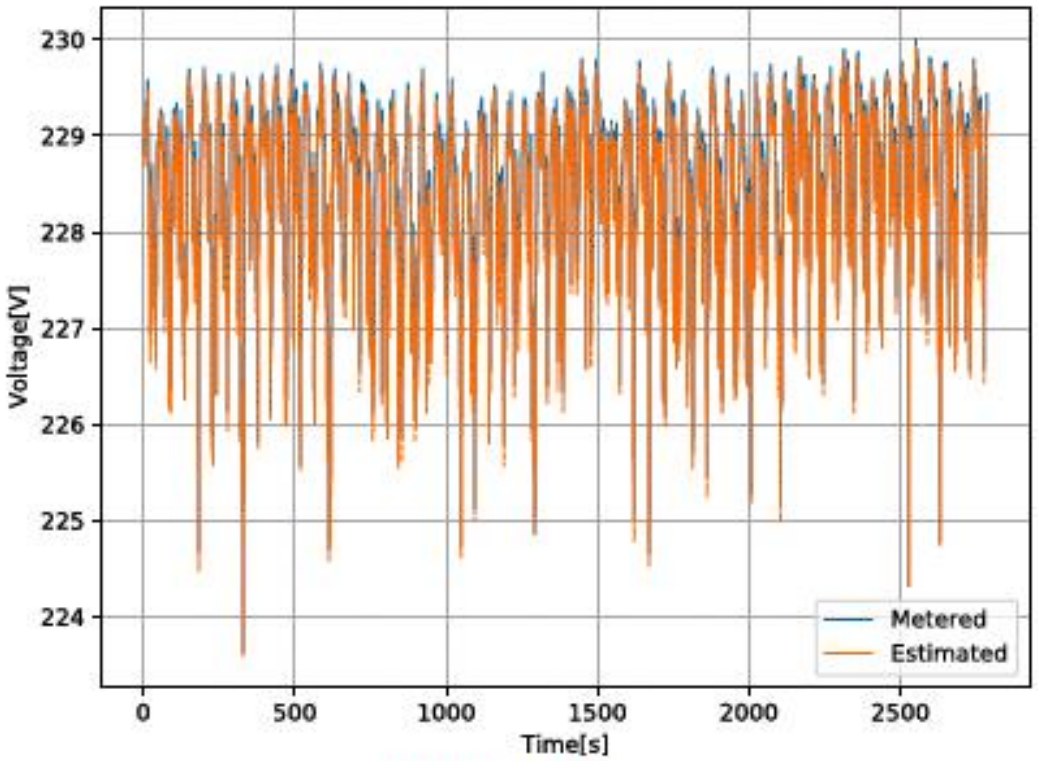
Phase B



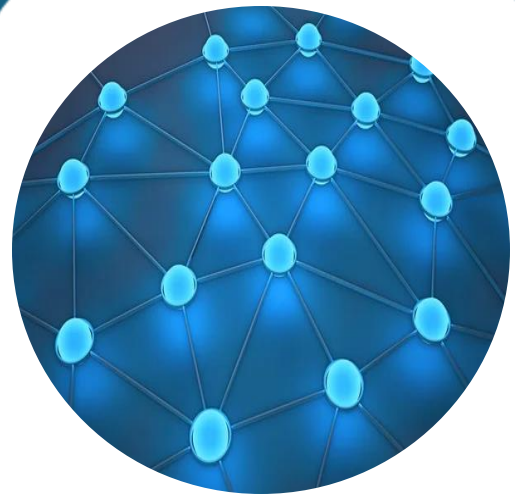
Phase C



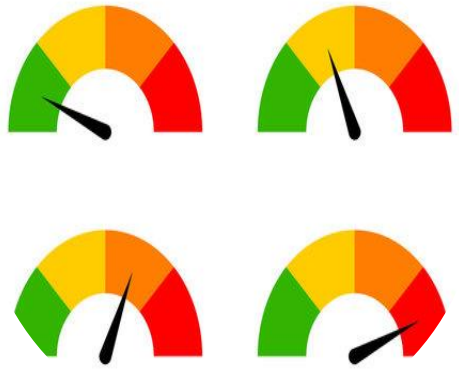
# Results validation




(a) Node 180



Topology identification



Single technology HC


Unified HC definition

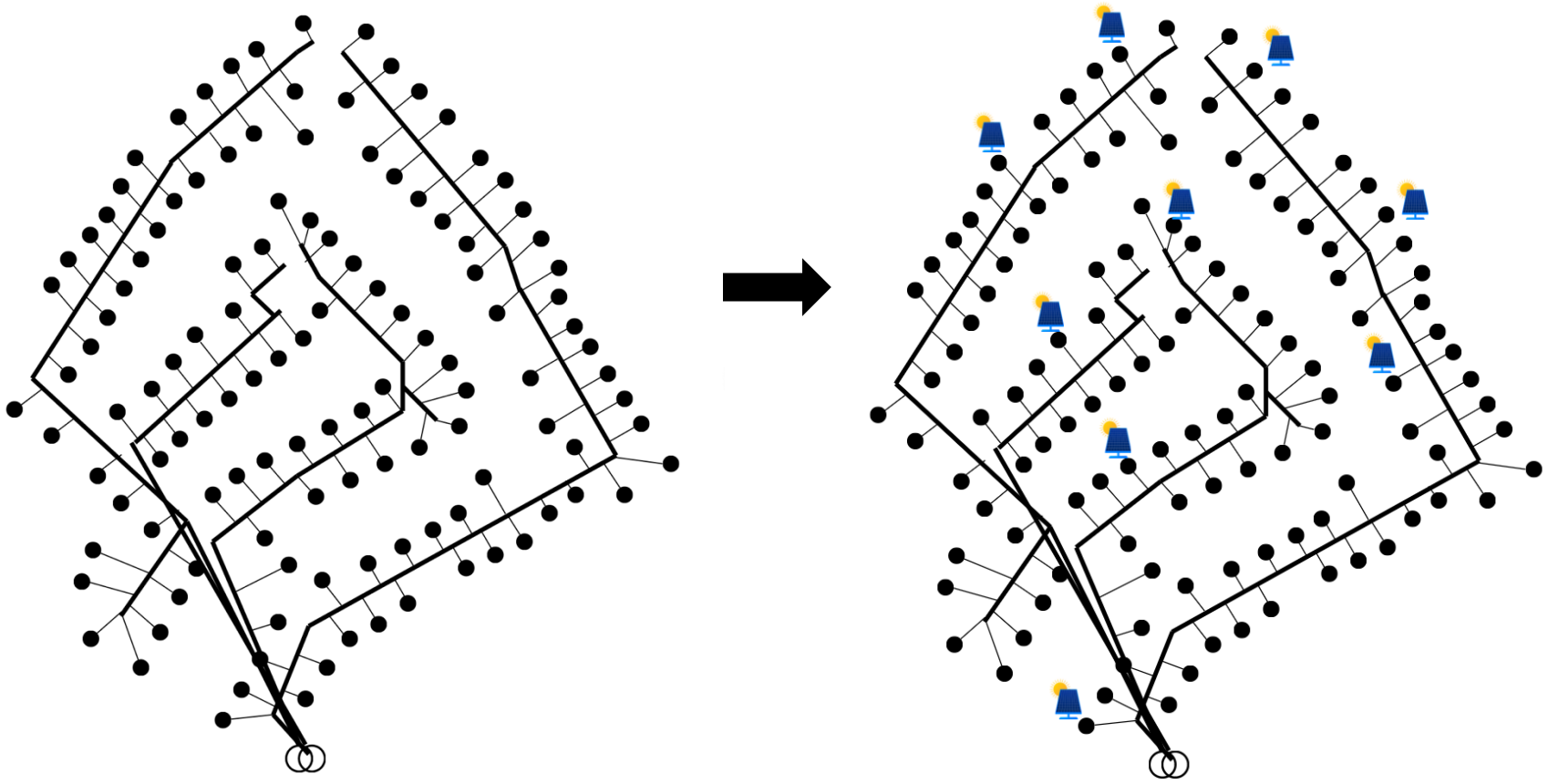
Combined HC

# Determining a Hosting Capacity

# Single technology hosting capacity

For a given technology, how many of that technology can we install before facing any issues?

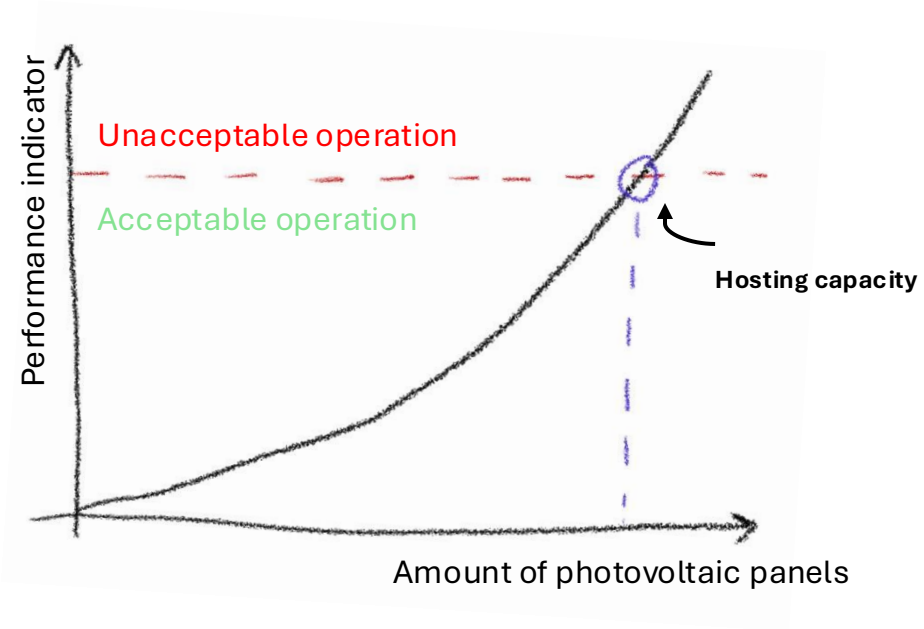
# Methodology idea



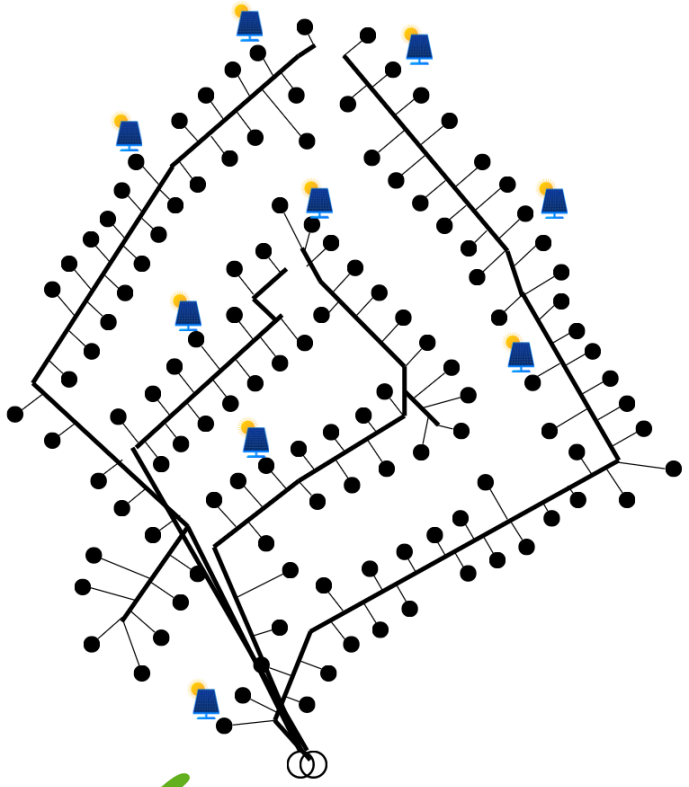
Add new technologies (e.g. PV, EV) to a network and simulate over time and see what happens !

# Key performance indicators

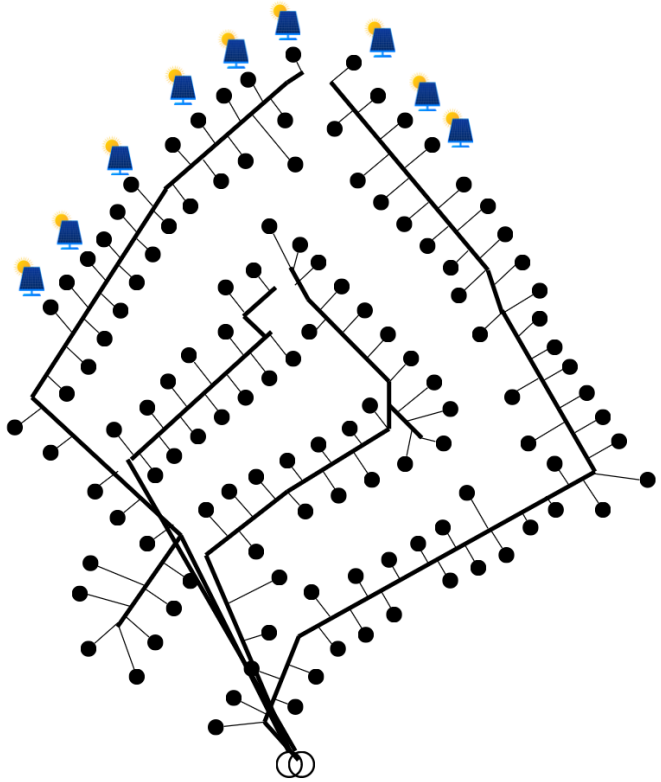
Measure of the performance of the network.



# Configurations

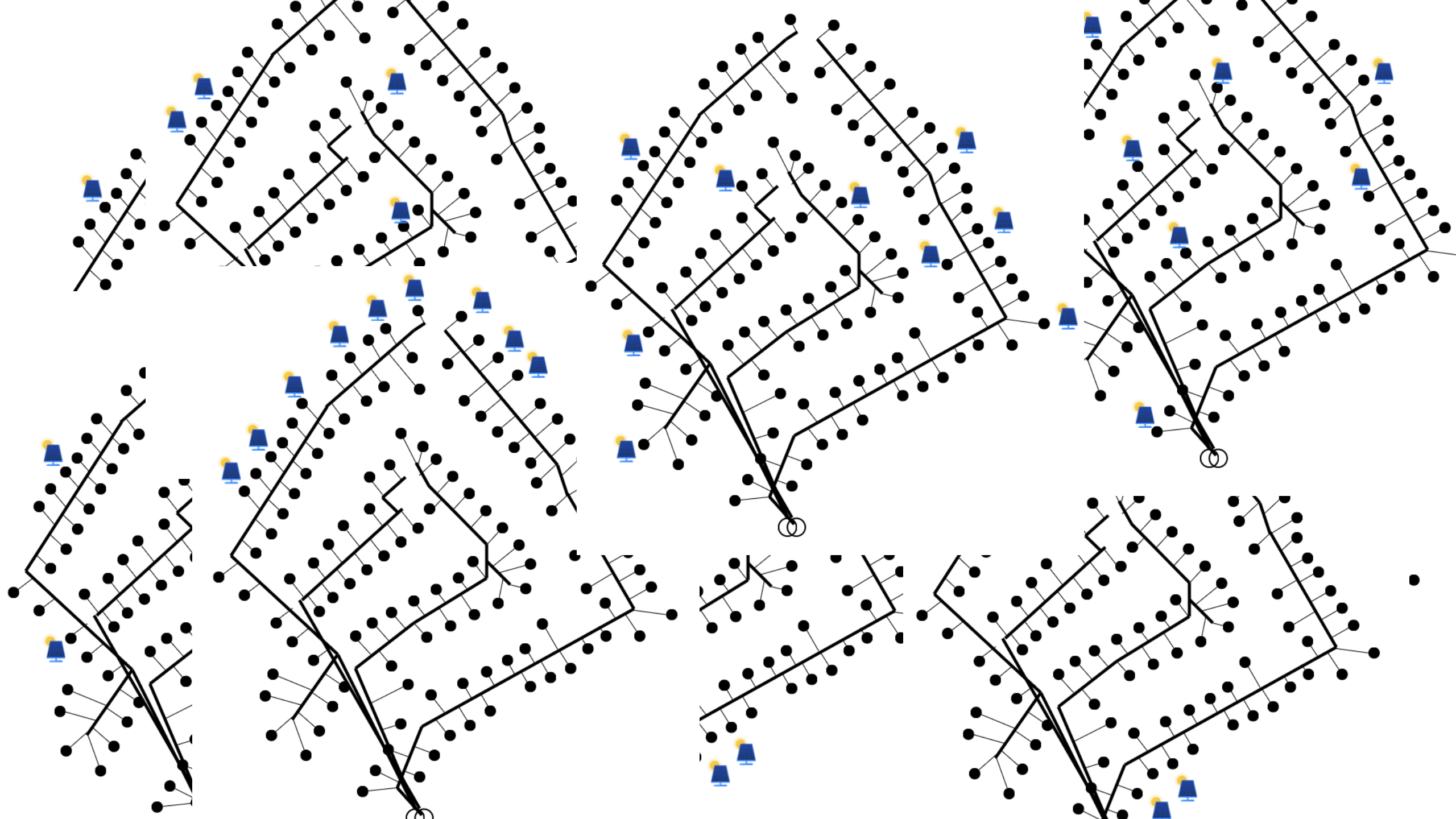


12 Photovoltaic panels



No issues

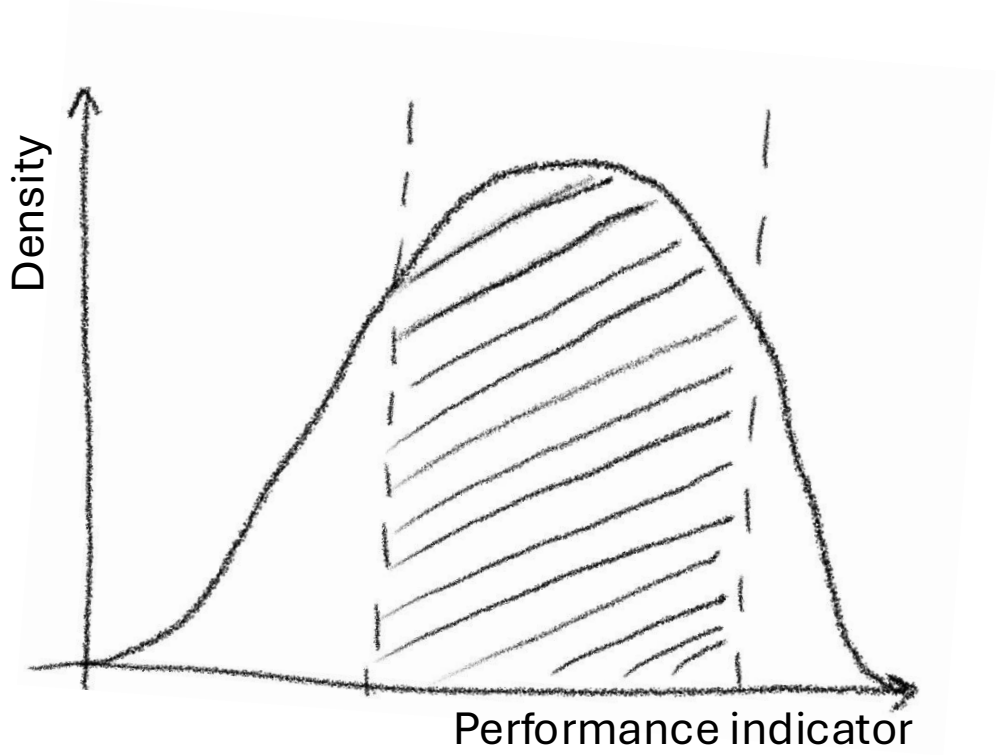
Issues



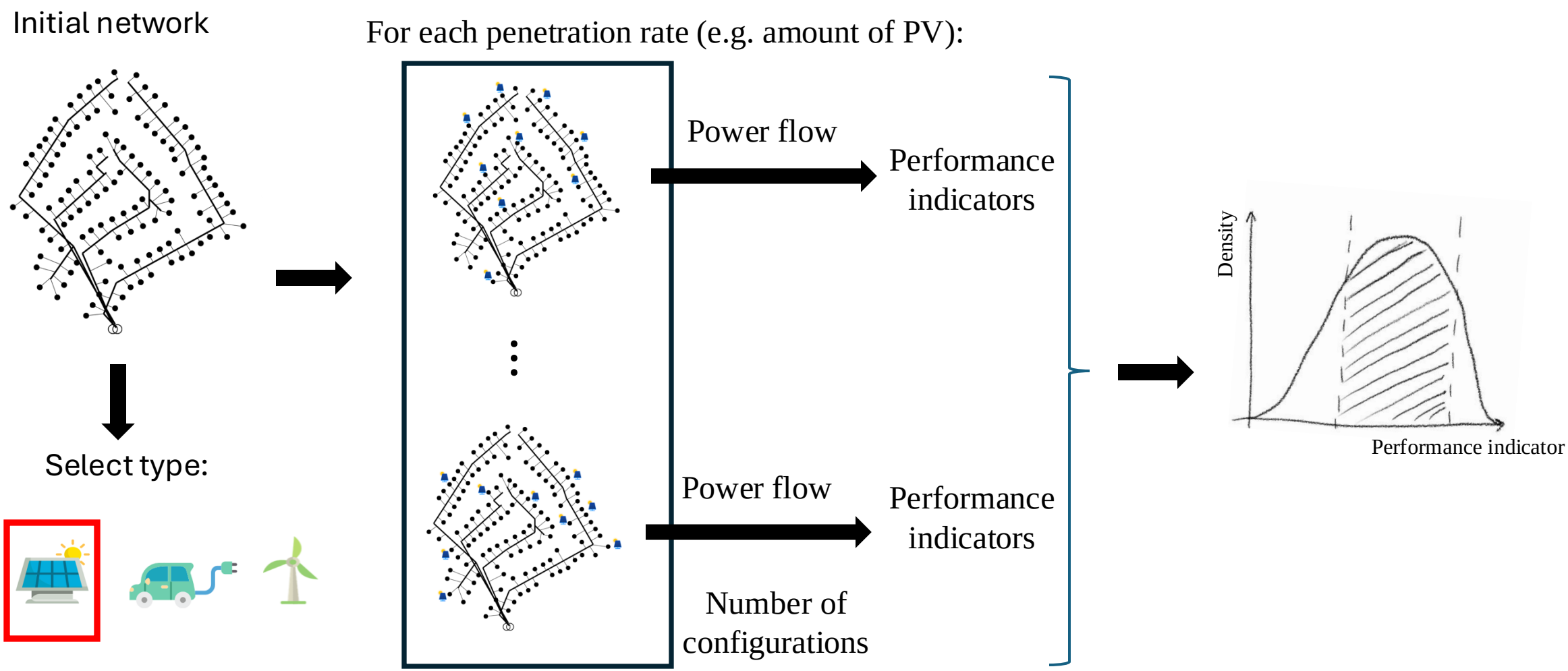
# Configurations (2)

For instance, for 40 new installations and 100 customers, there are $C_{100}^{40} = 10^{28}$ possible configurations.

Probability density function (PDF) for the indicators:

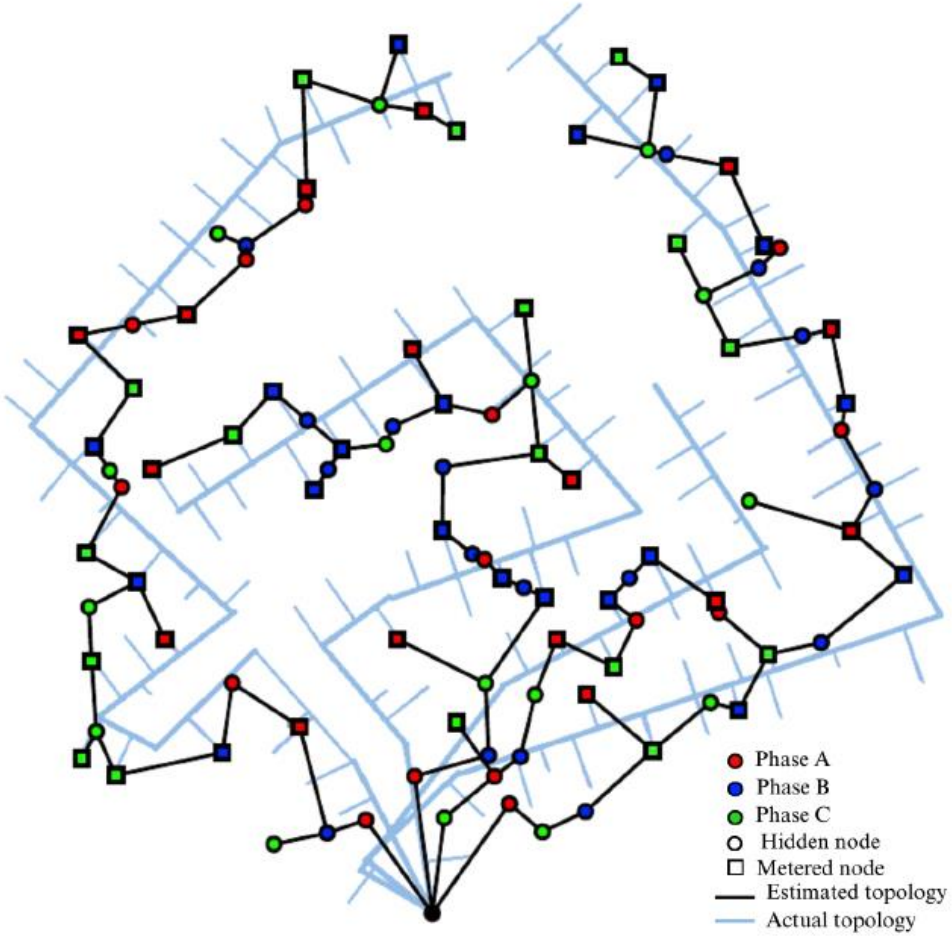


# Methodology - summary

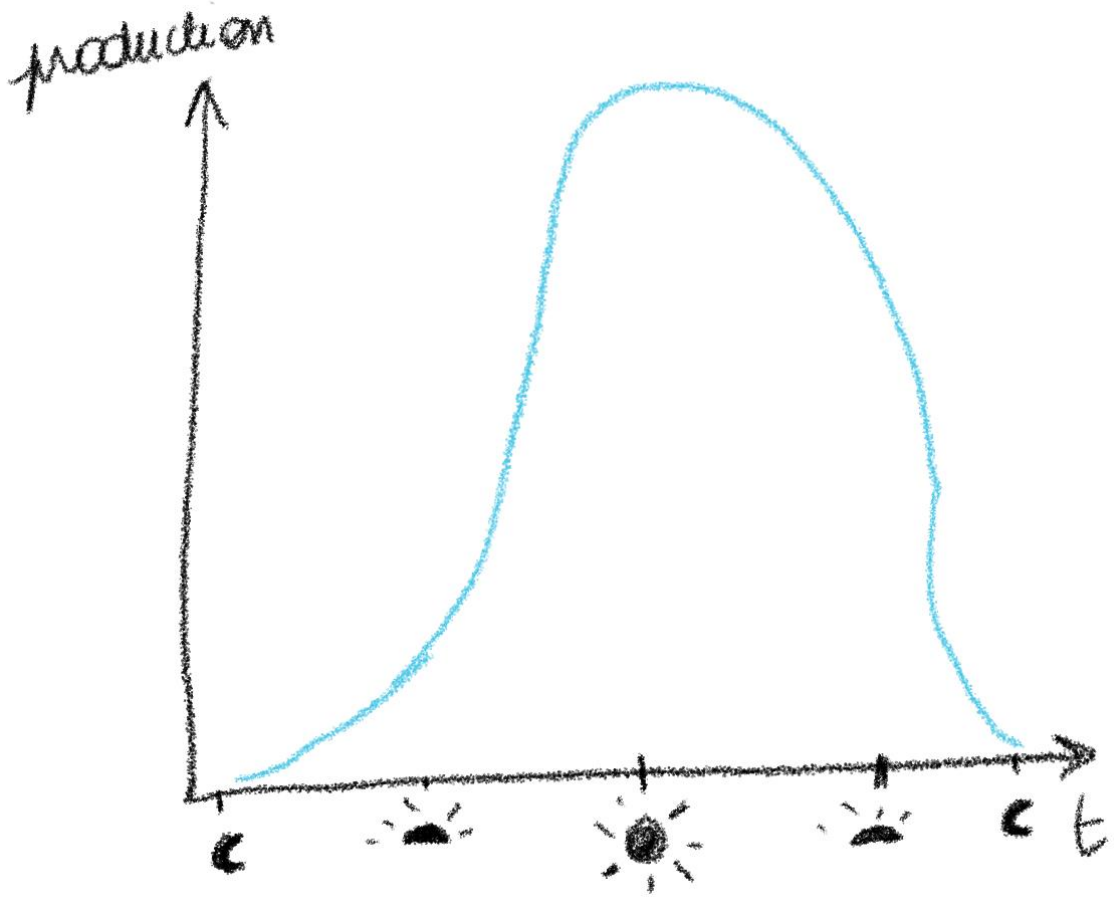


# Test case

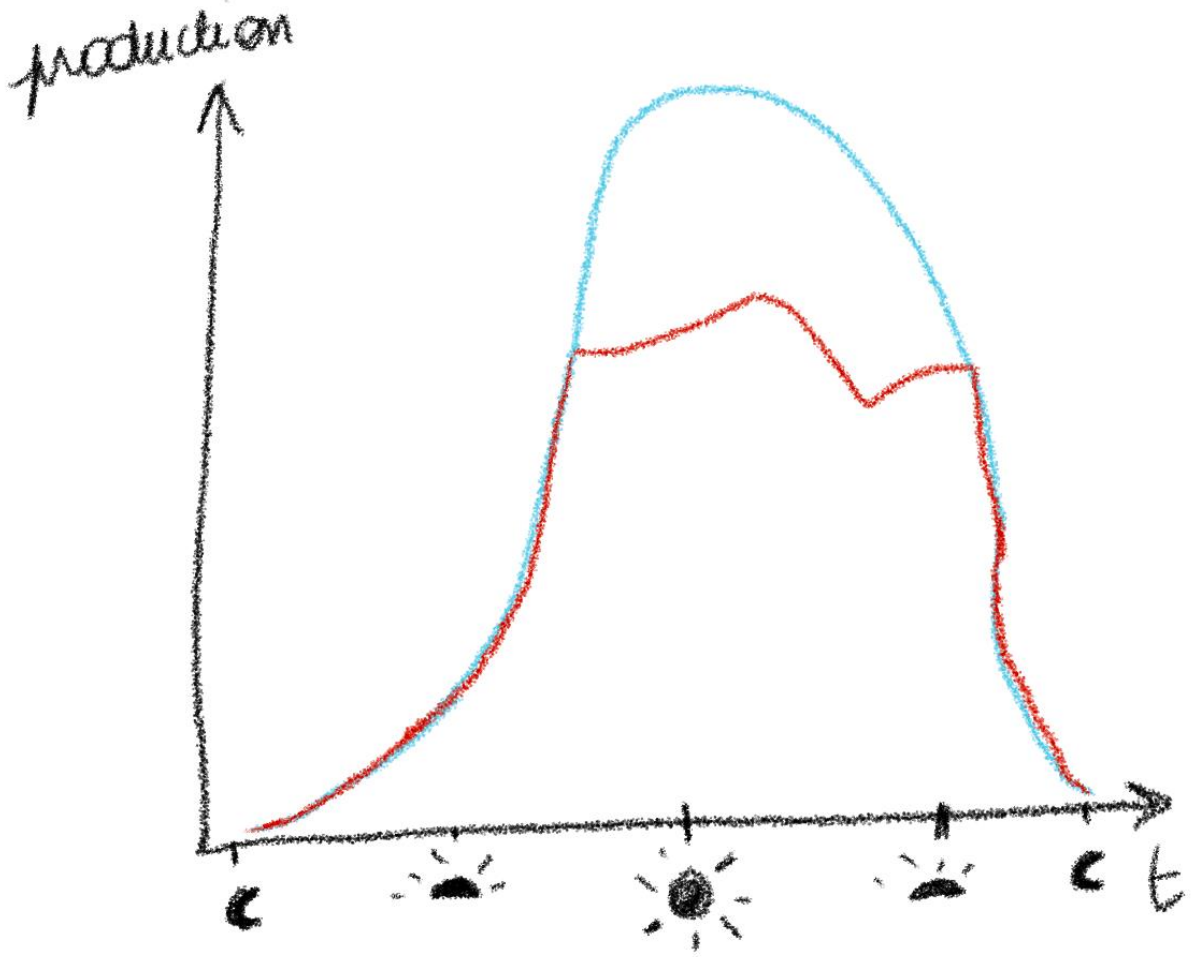
- Topology reconstructed
- 500 configurations per penetration
- 1 week time series
- Penetrations [0, 1, …, 100]
- 13 PVs of 290 $W_{peak}$



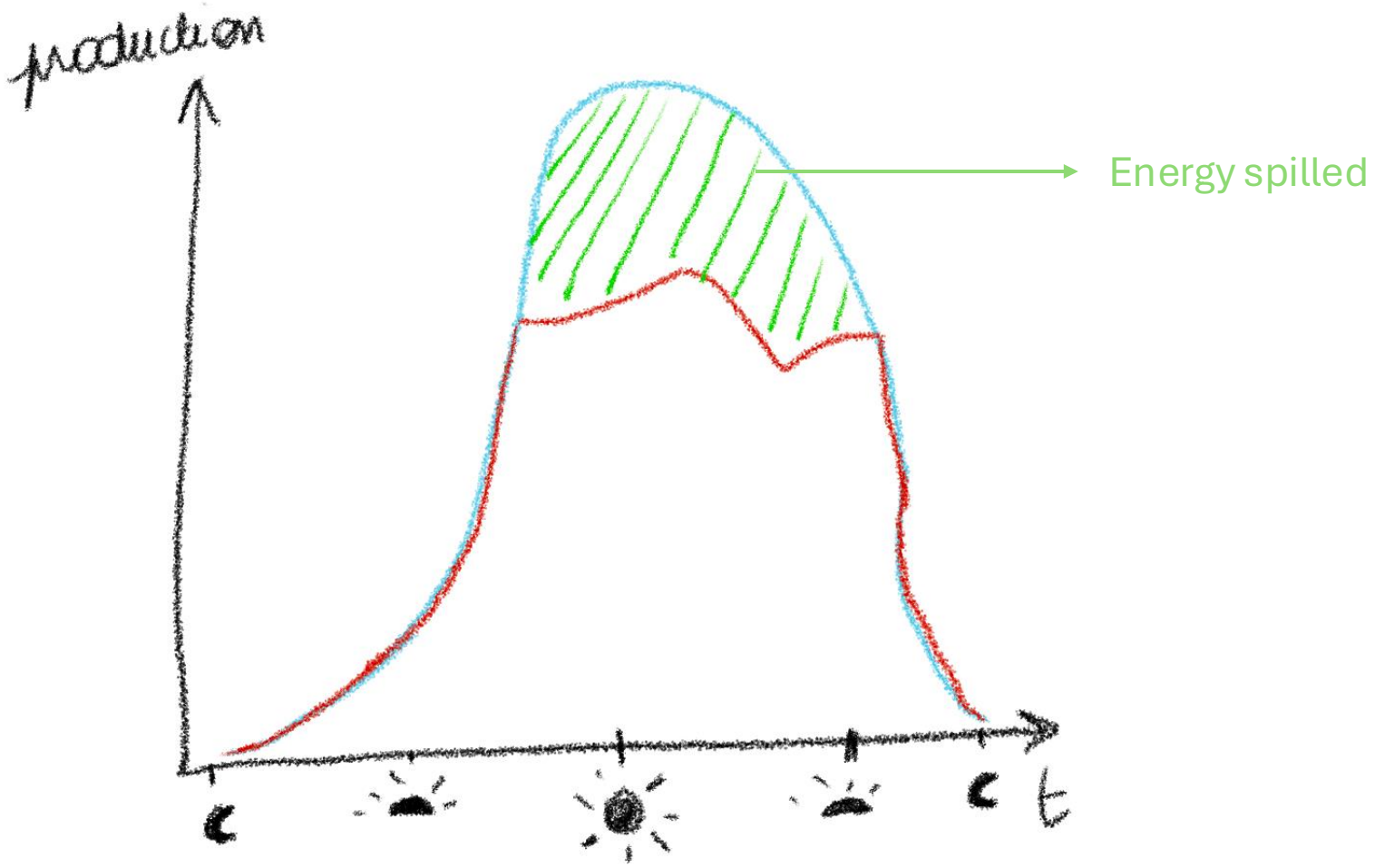
# PV Performance indicator – Energy spilled



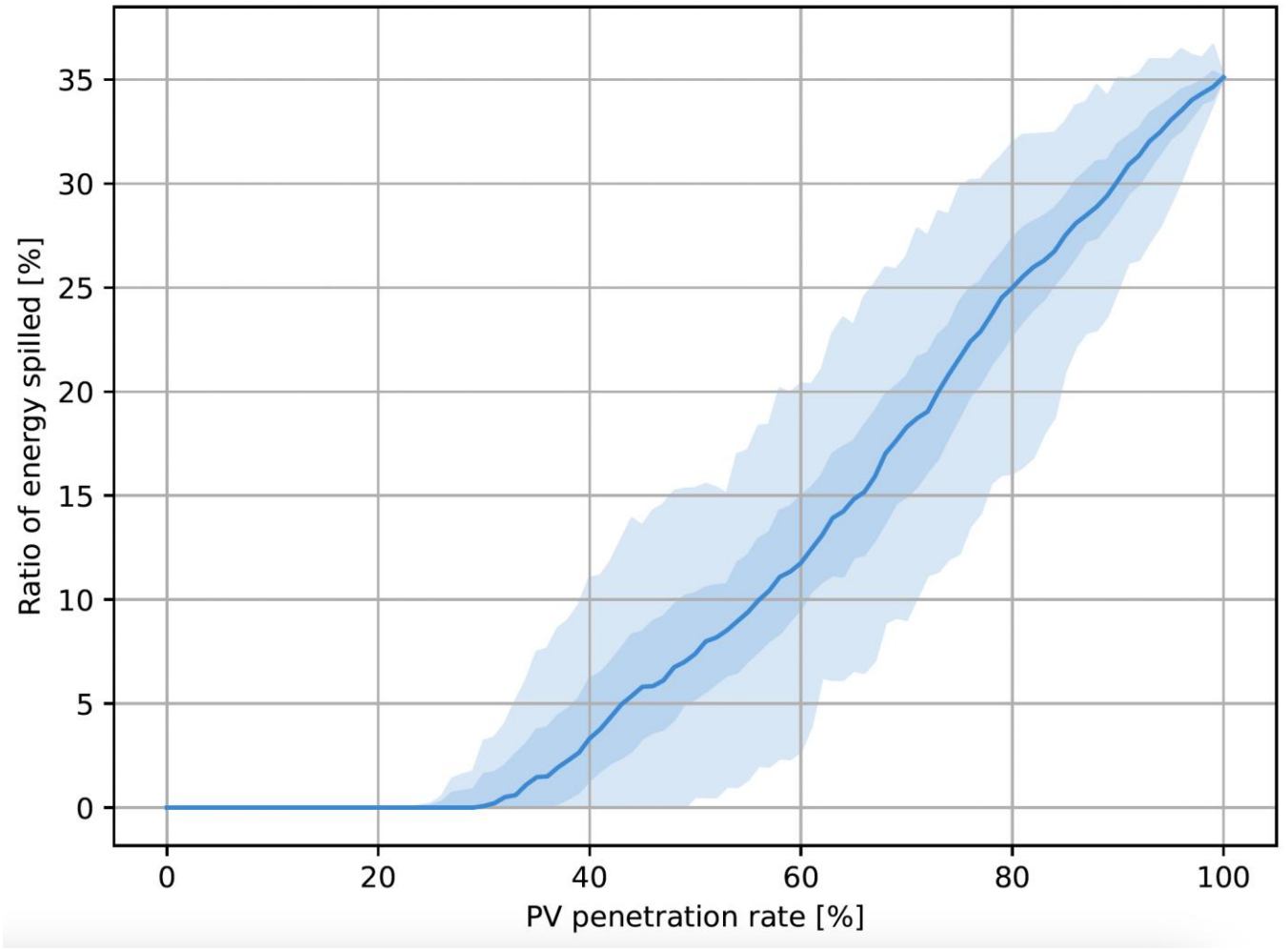
# PV Performance indicator – Energy spilled



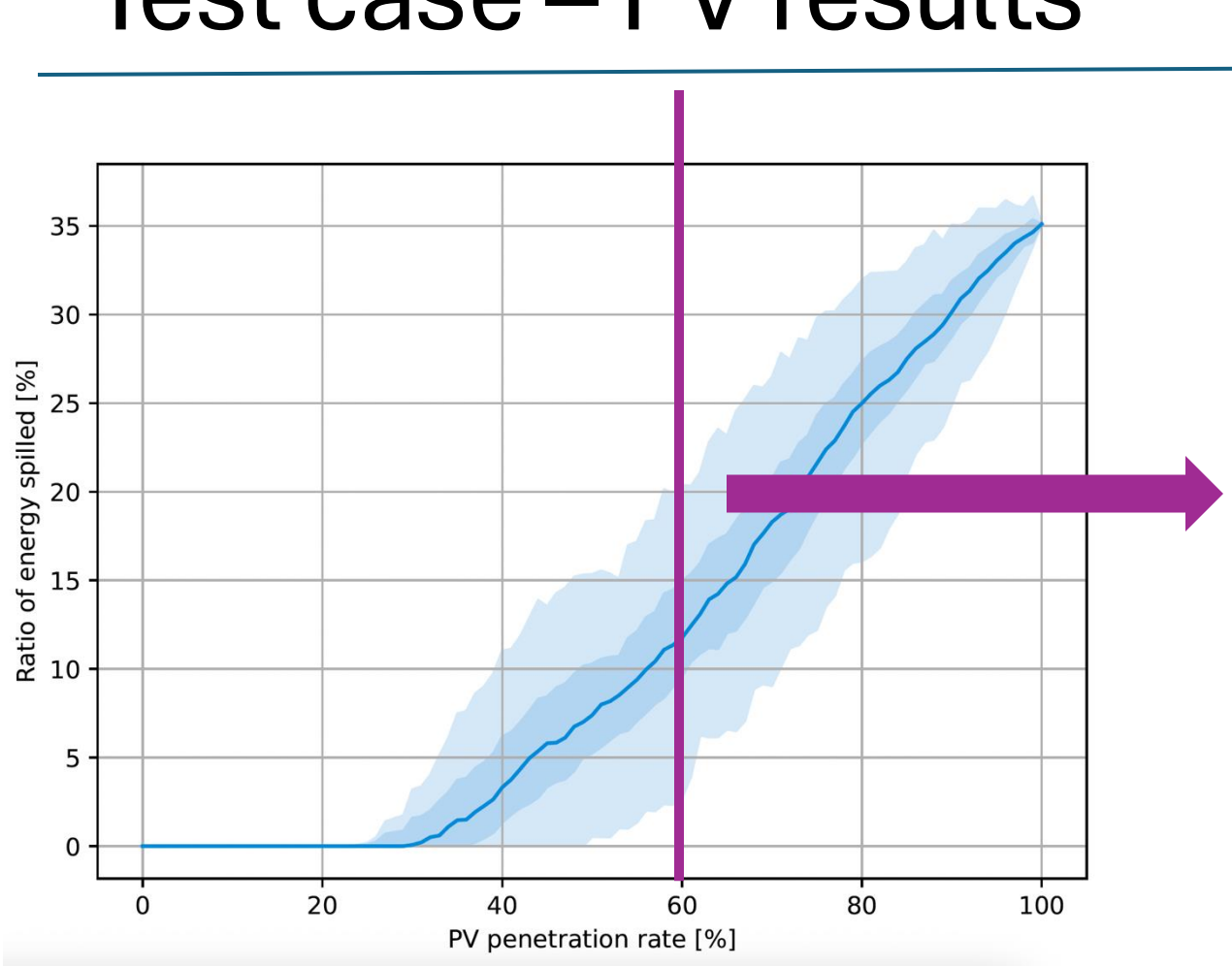
# PV Performance indicator – Energy spilled

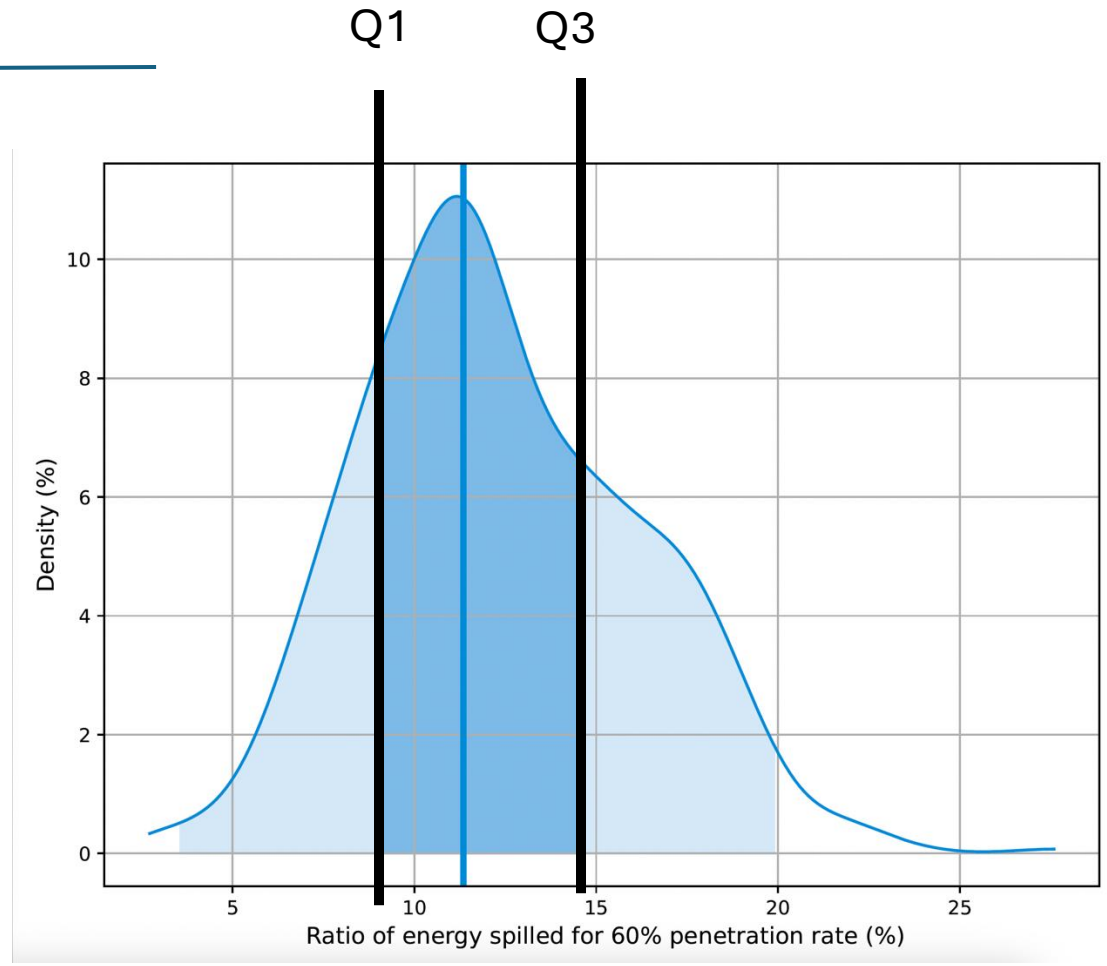


# Test case – PV results

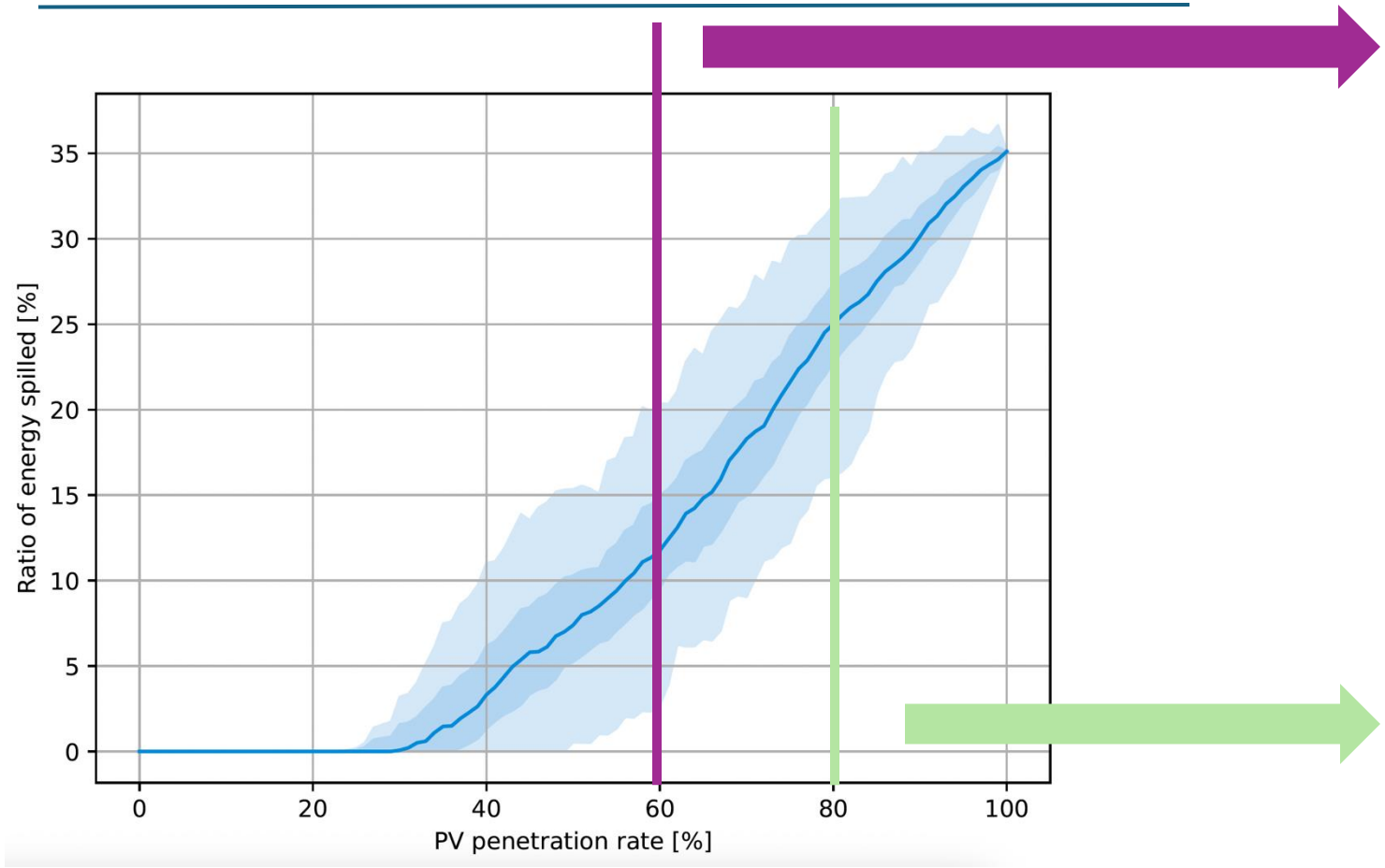


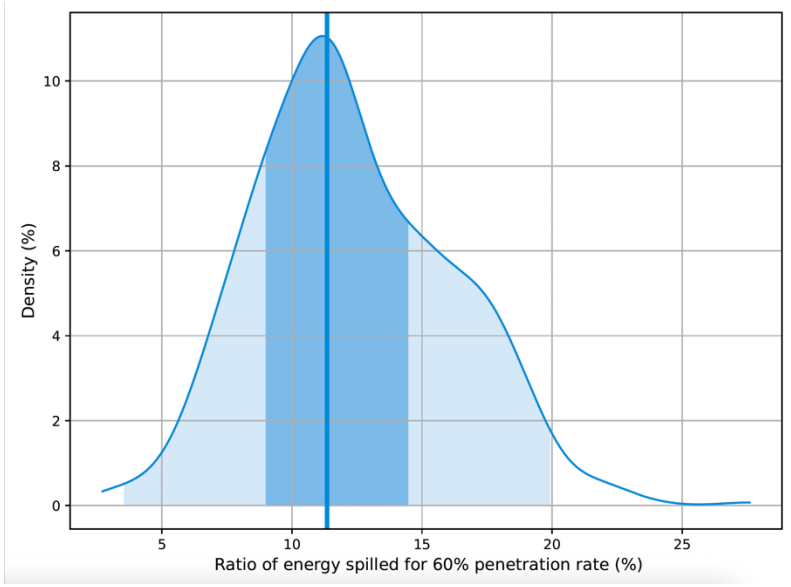
# Test case – PV results

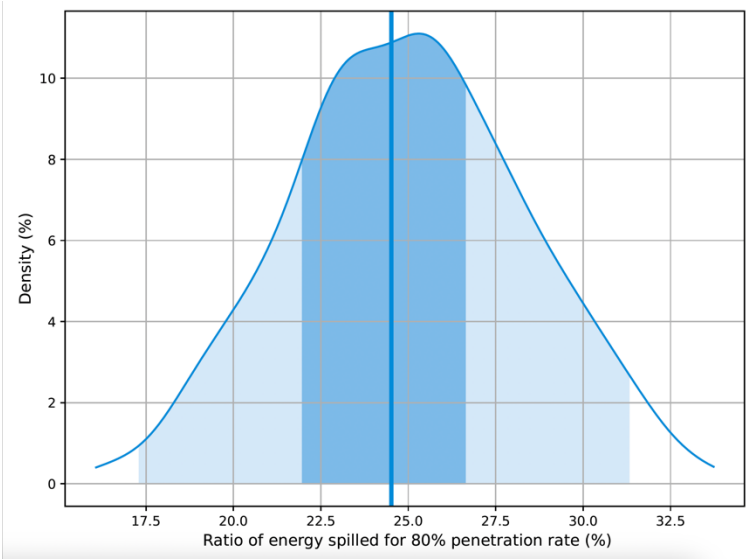


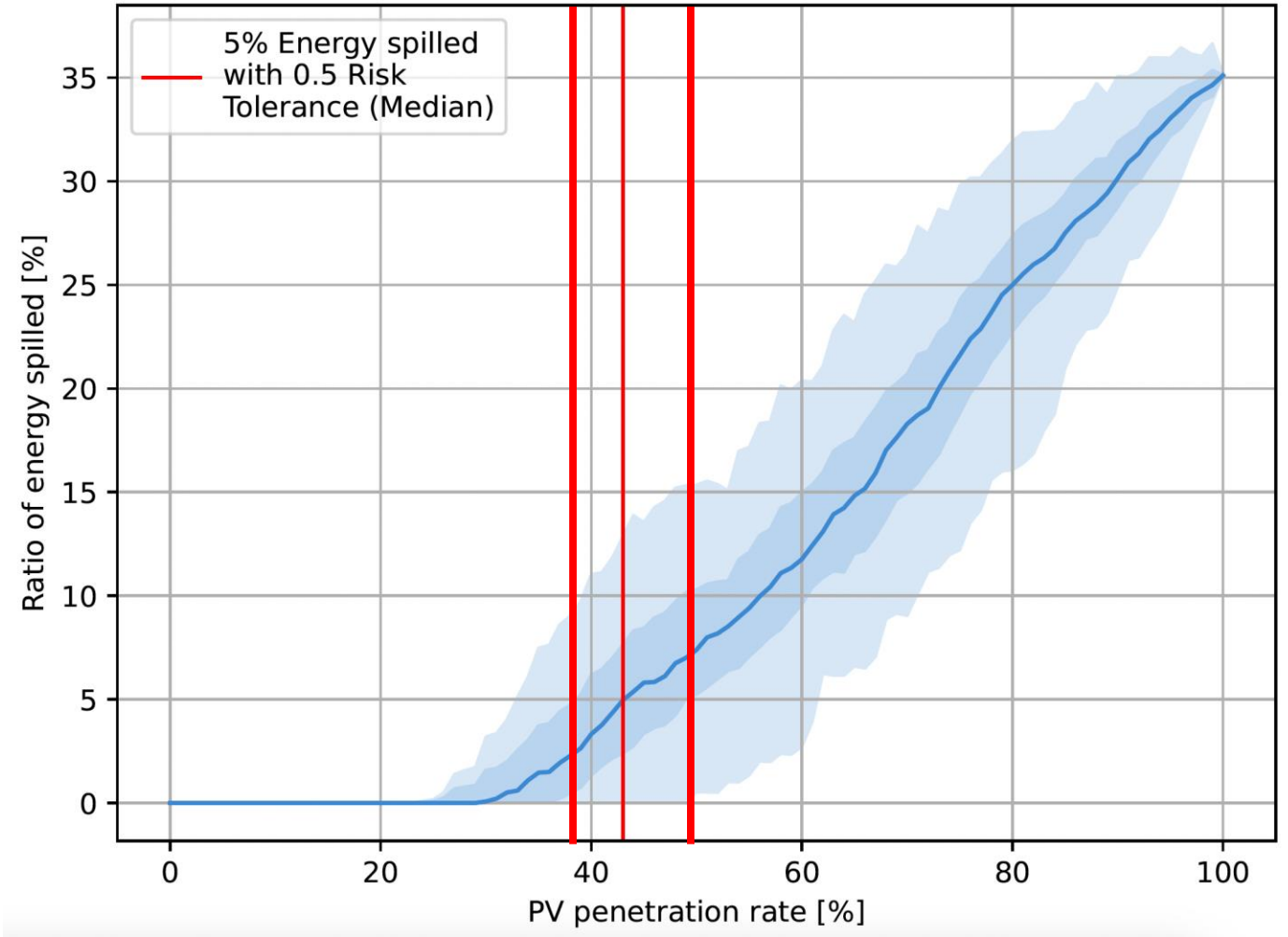
# Test case – PV results

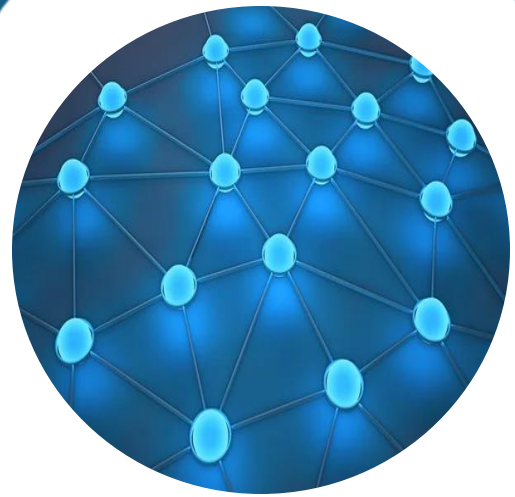


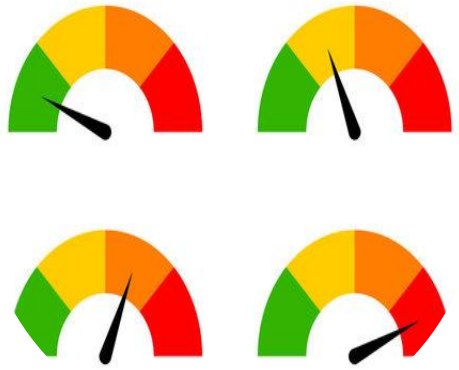



# Test case – PV results

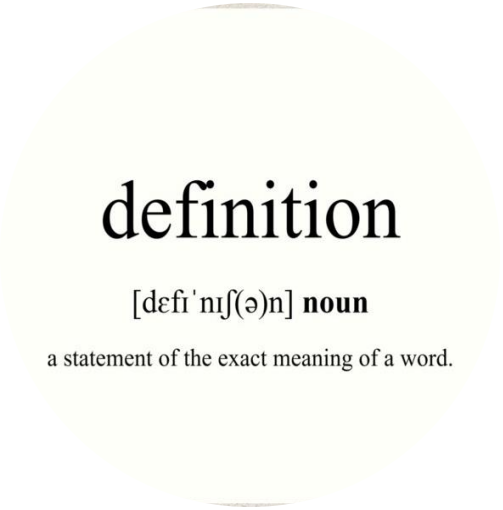




Topology identification



Single technology HC



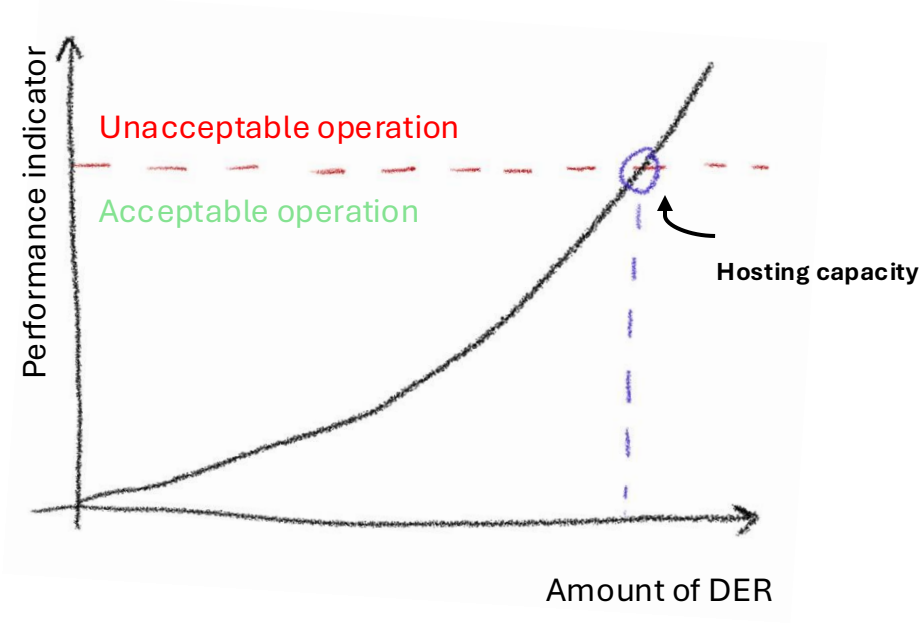

Unified HC definition

Combined HC

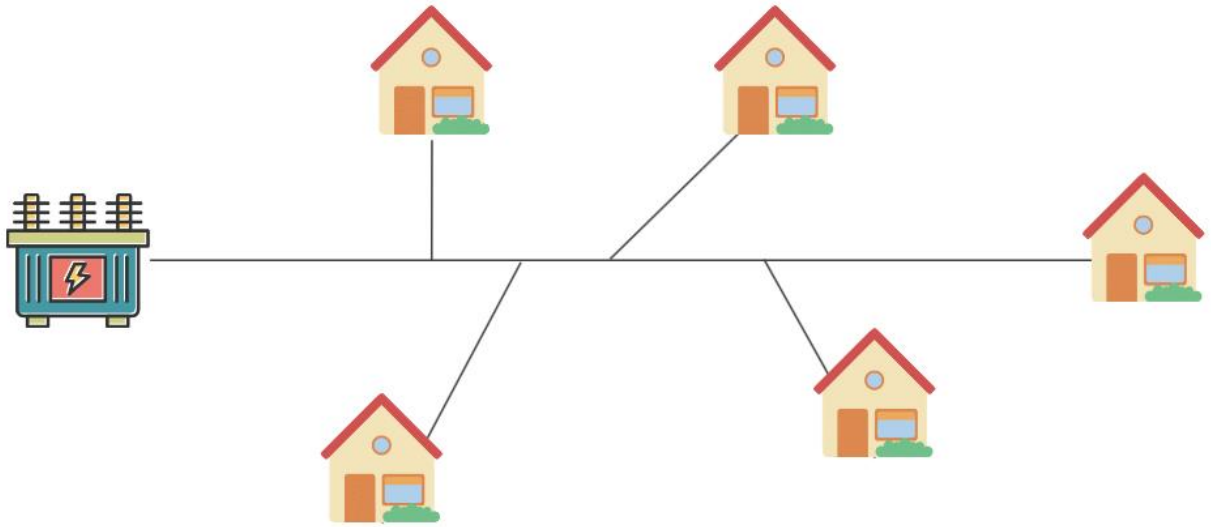
# Hosting Capacity Definition

# Hosting capacity (HC)

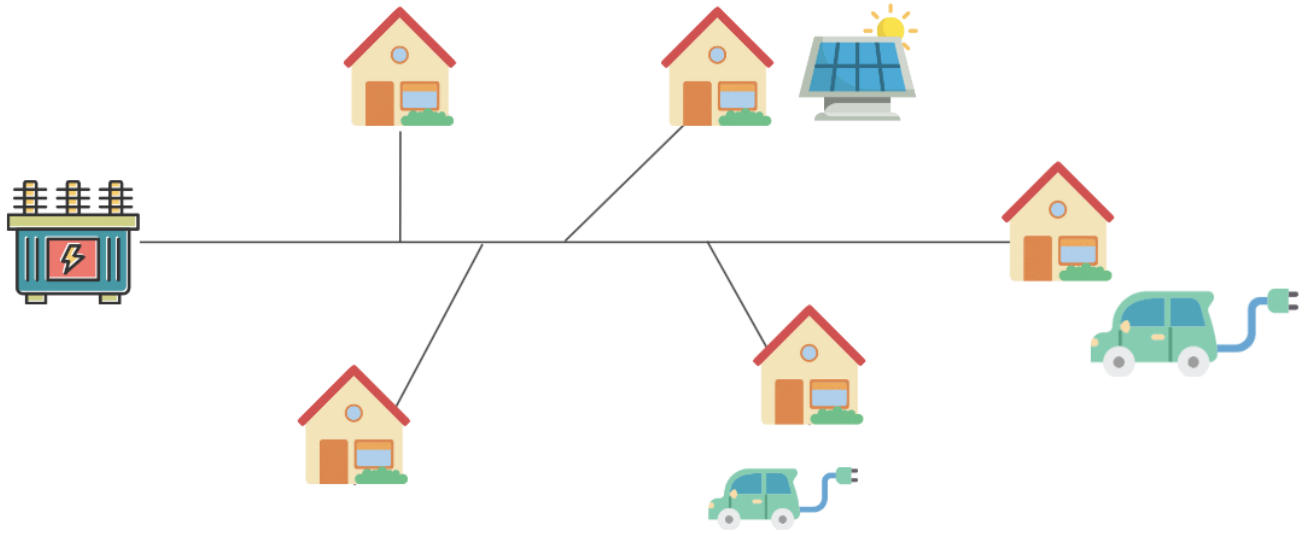
*The HC is the amount of new resources (DER) that can be hosted by a network before facing any issues, i.e., compromising its operational limits or violating safety constraints.*



For a given network, with customers

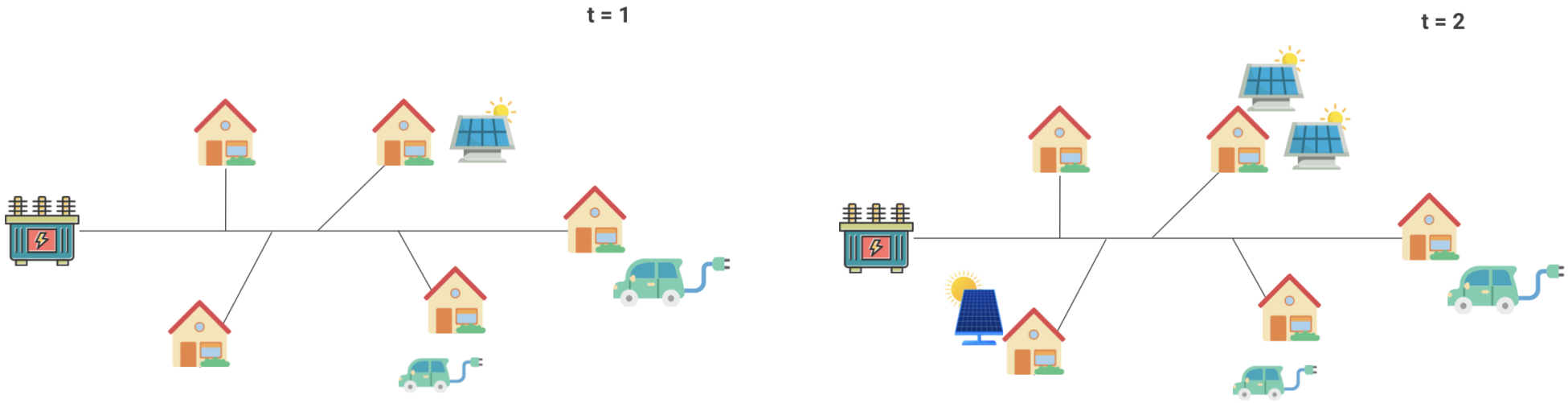


State:



These customers can add different types of DERs with different options, for instance their size.

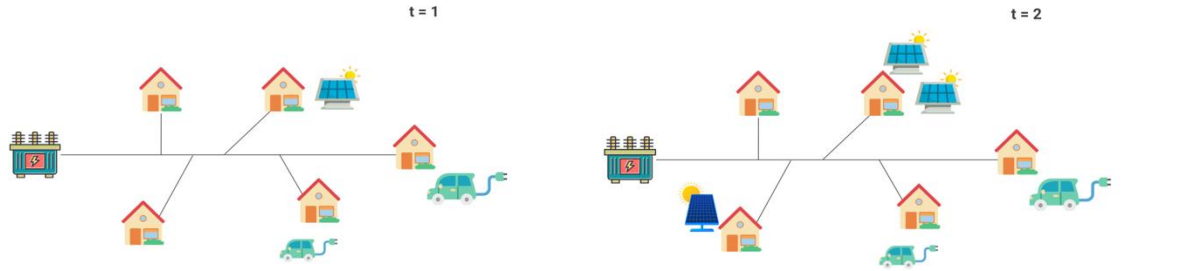
Scenario:



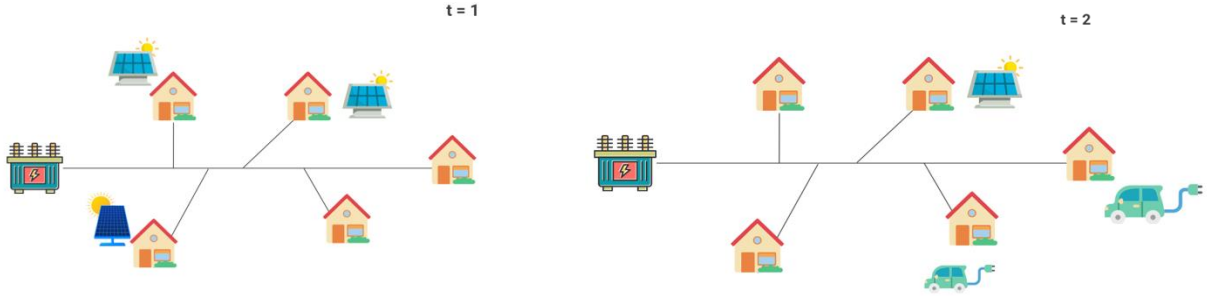
Set of scenarios :

Set of considered scenarios :

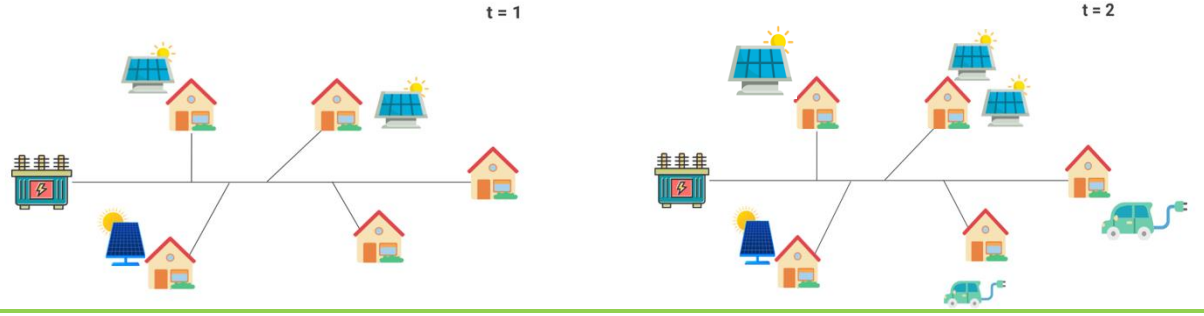
Scenario 1:




Scenario 2:

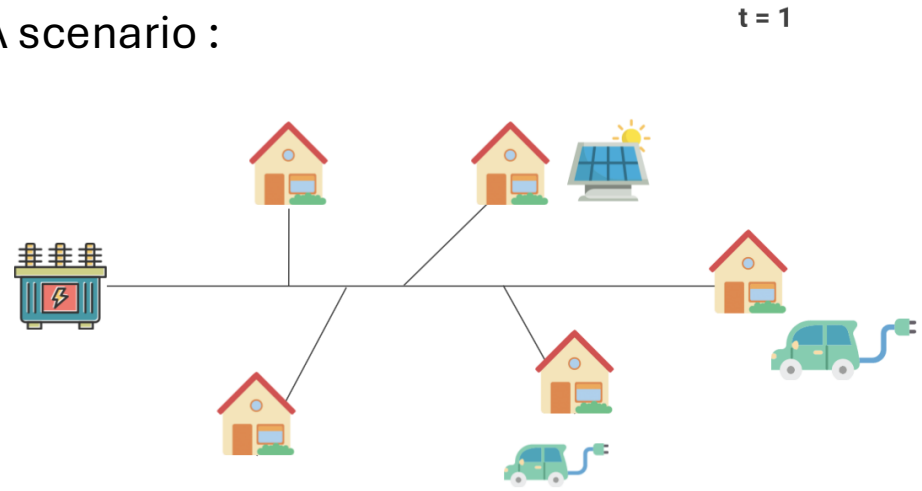


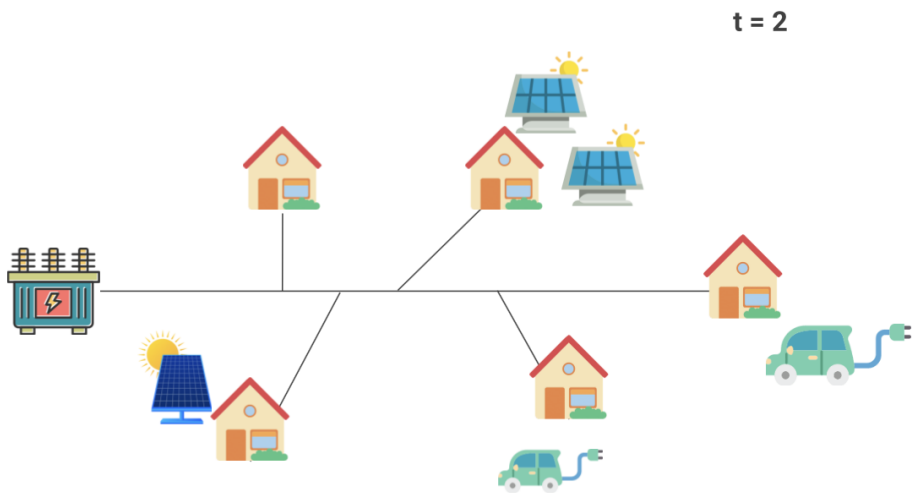

Scenario 3:




Scenario ….:

A scenario :

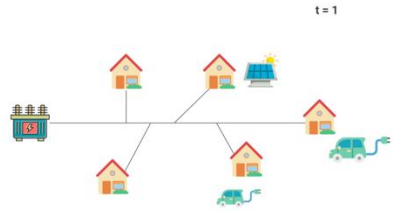


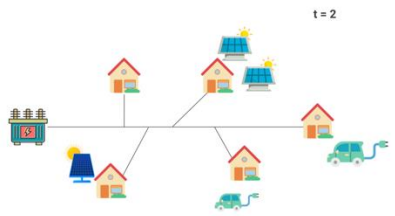




Penetration :

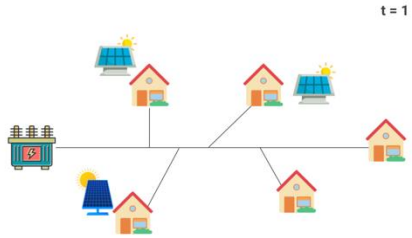
Set of scenarios :

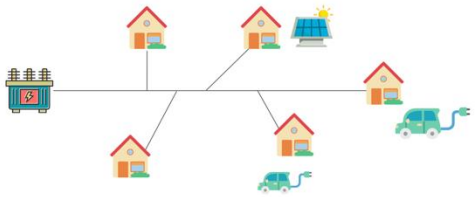
Scenario 1:



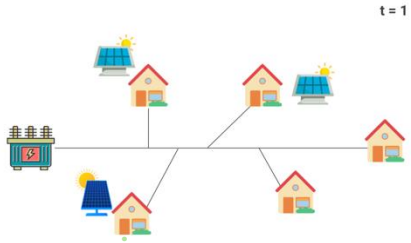



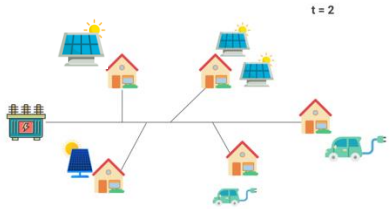

Scenario 2:



Scenario 3:




Set of considered scenarios :

Scenario ....:

Set of penetrations

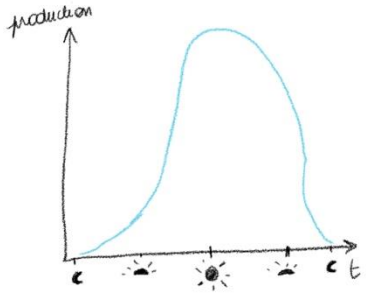
Set of considered penetrations

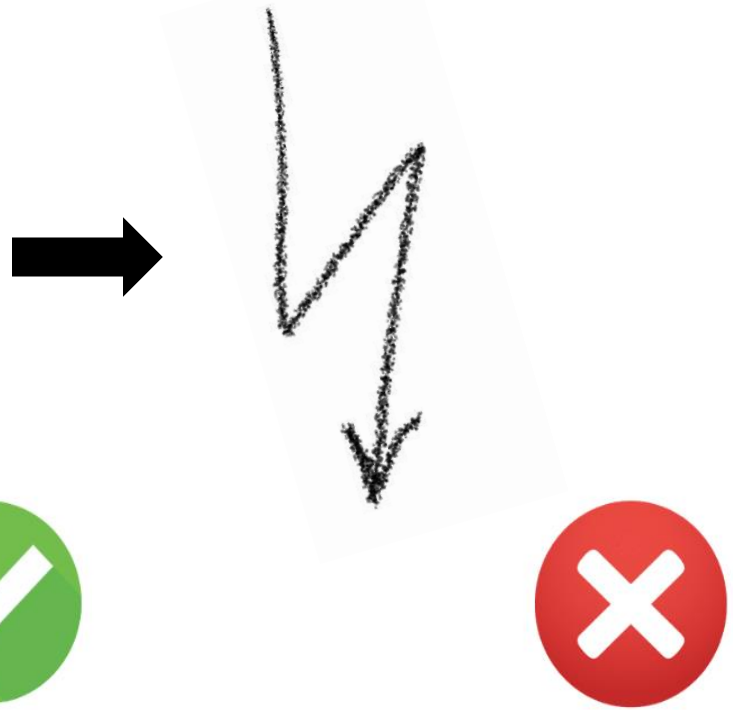
...

...

Scenario

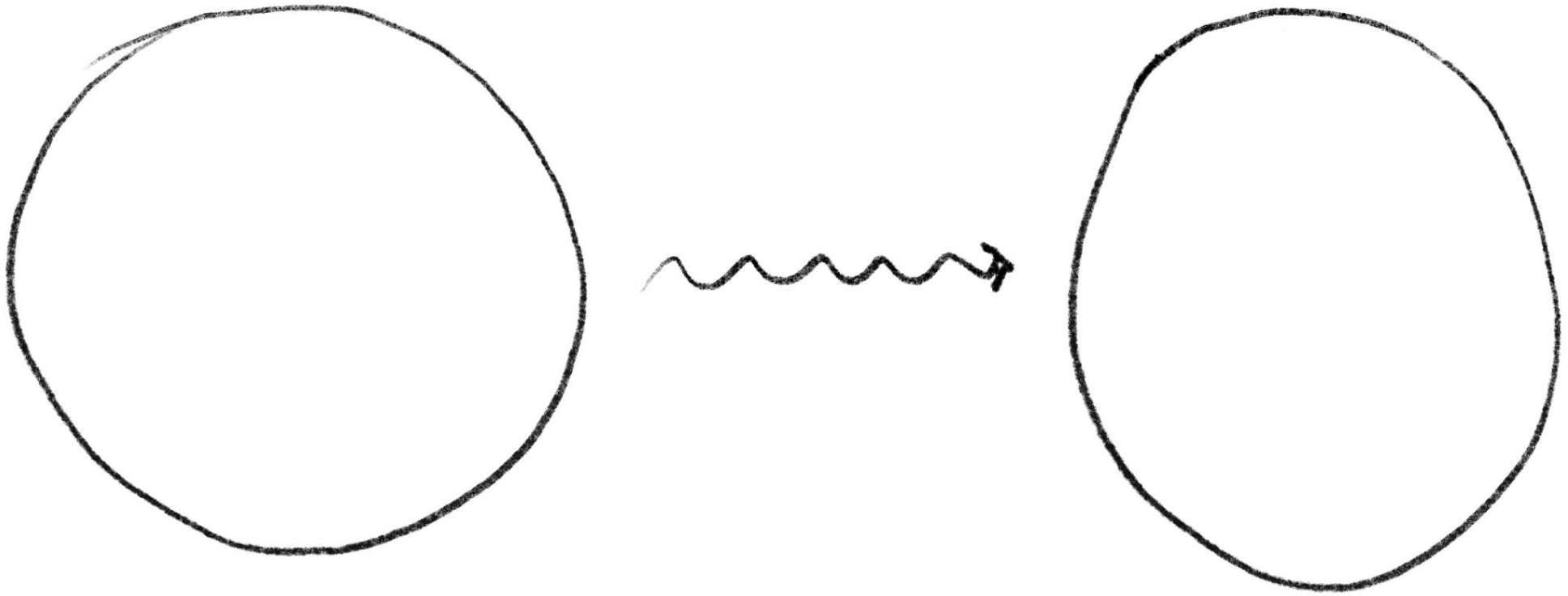

Exogenous data



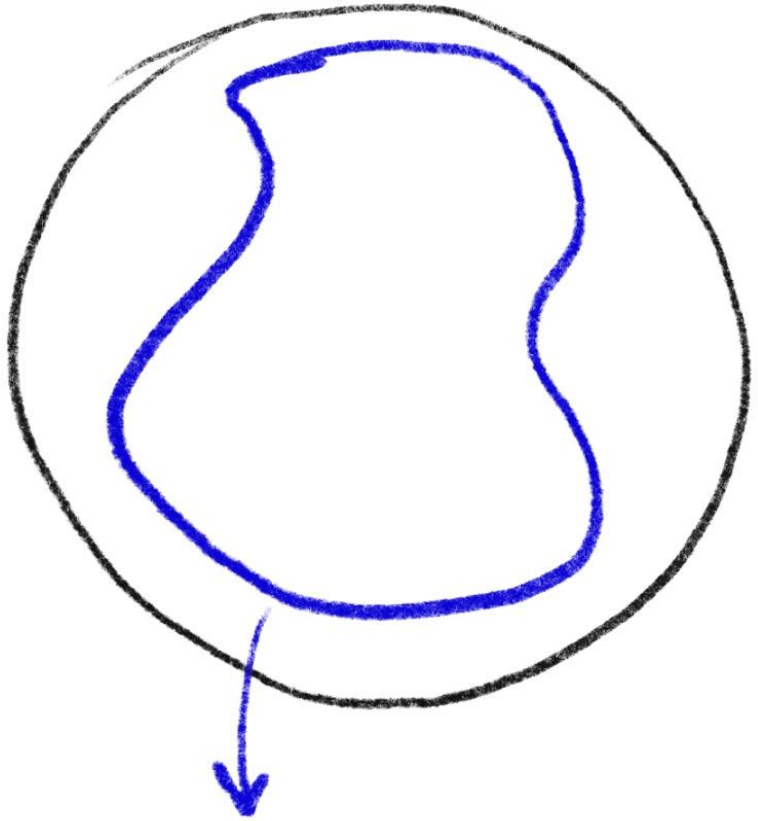



Scenarios

Penetrations

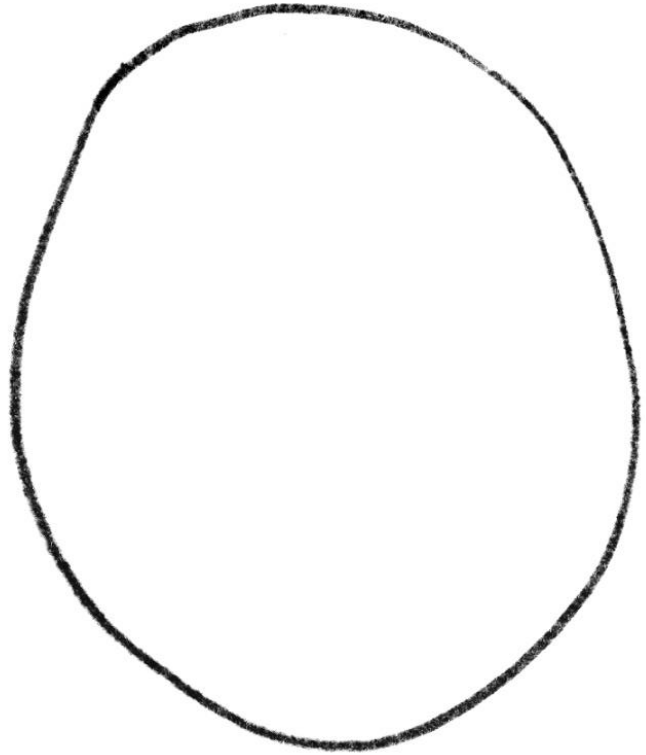


# Scenarios



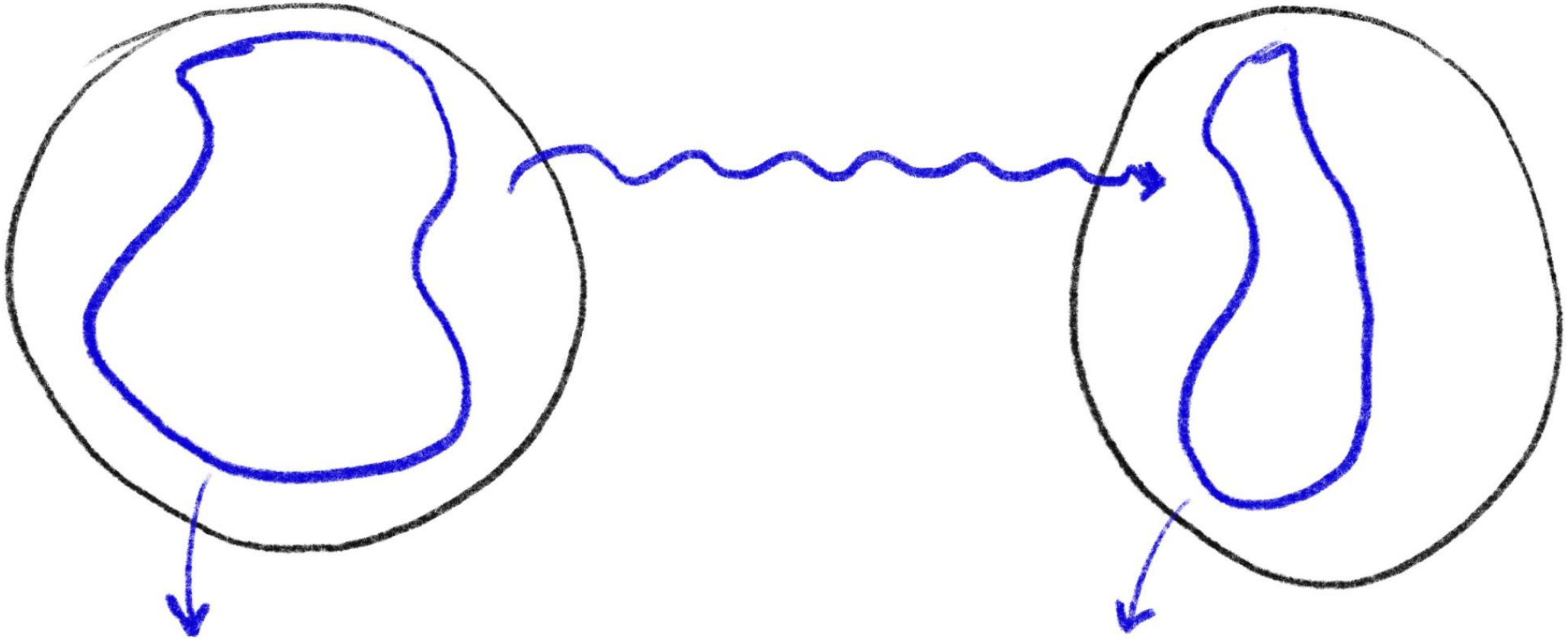
Considered Scenarios

# Penetrations



Scenarios

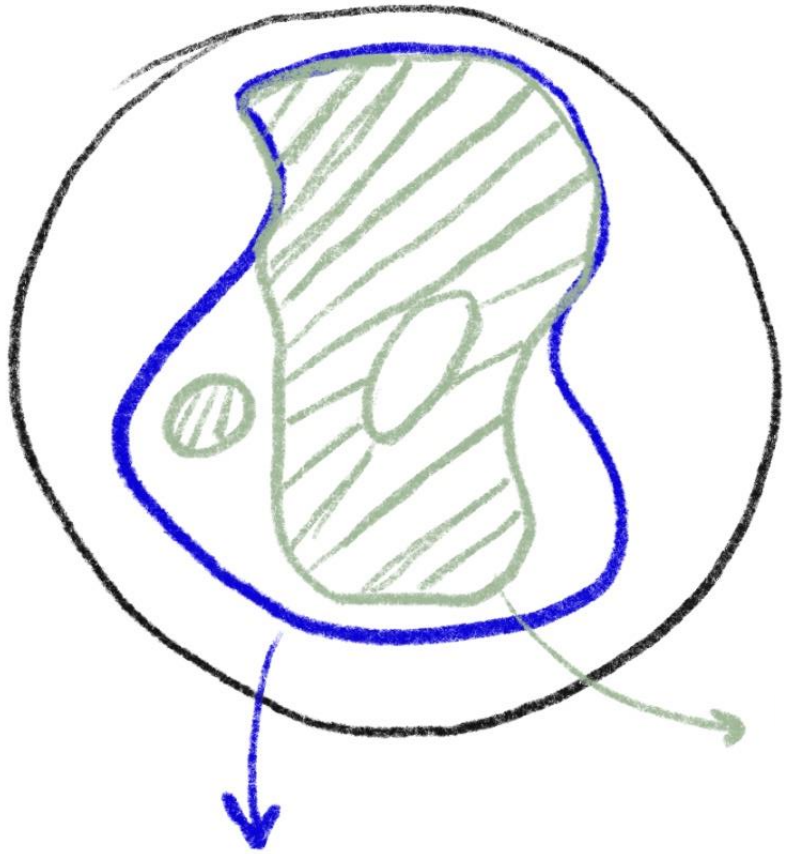
Penetrations



Considered scenarios

Considered penetrations

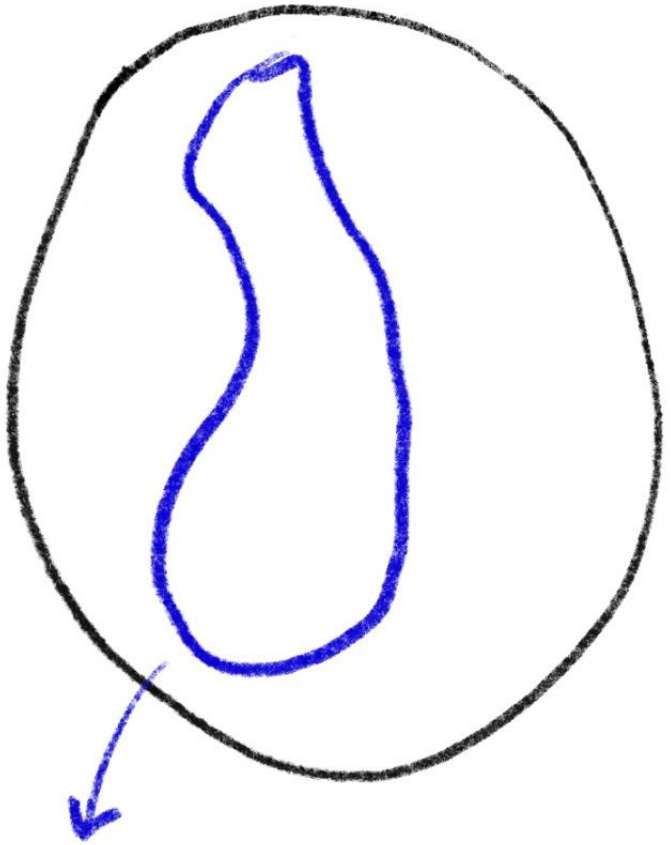
# Scenarios



Valid scenarios

Considered scenarios

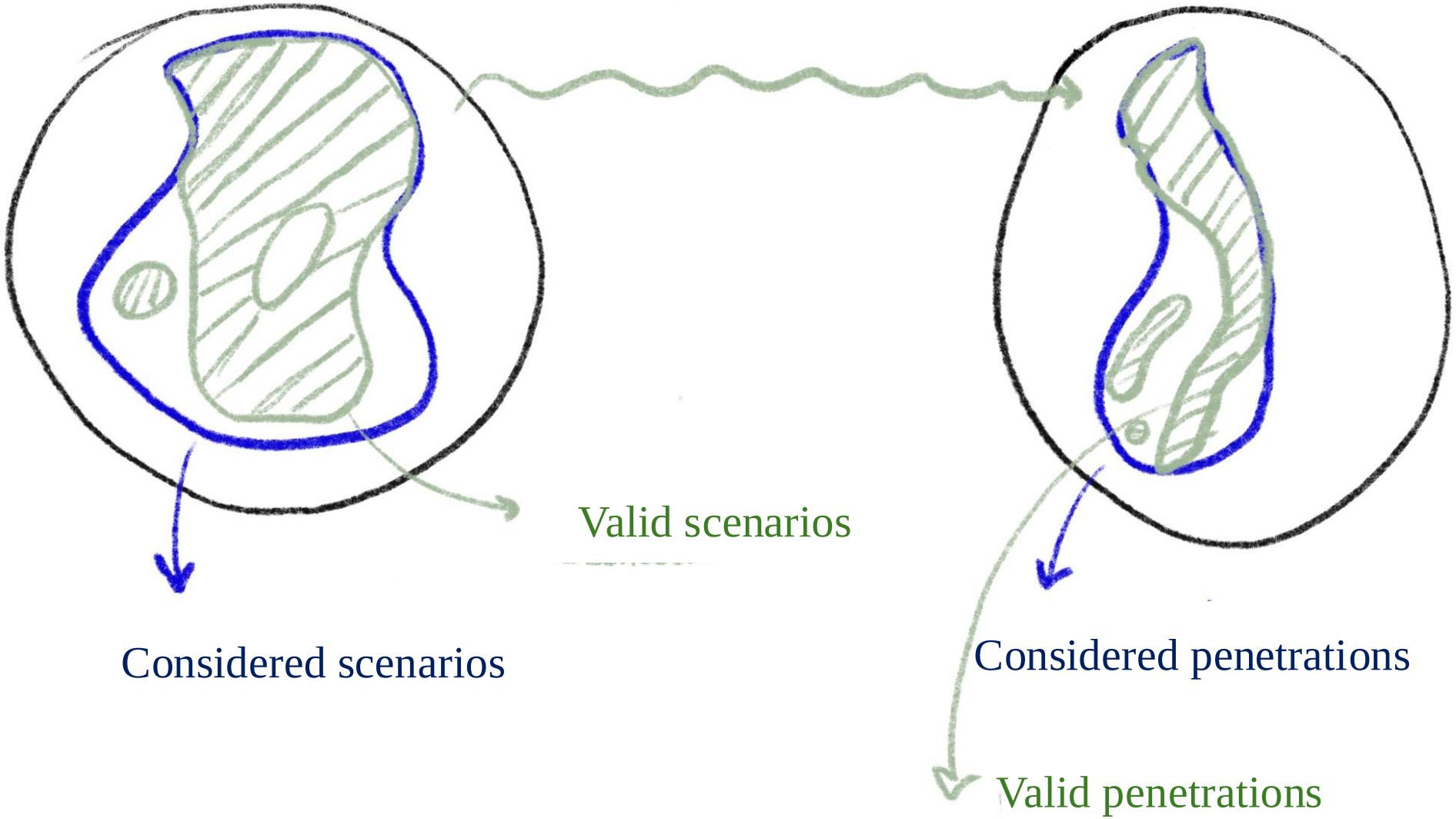
# Penetrations



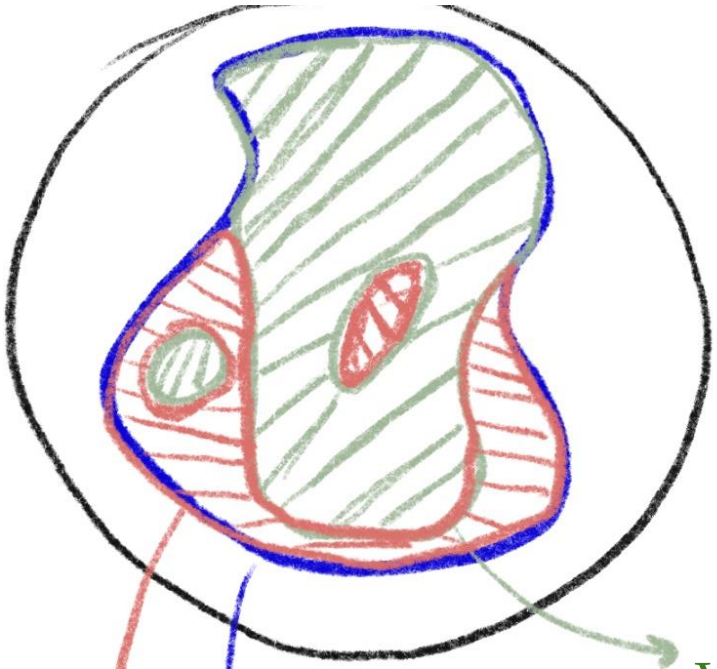
Considered penetrations

# Scenarios

# Penetrations



# Scenarios

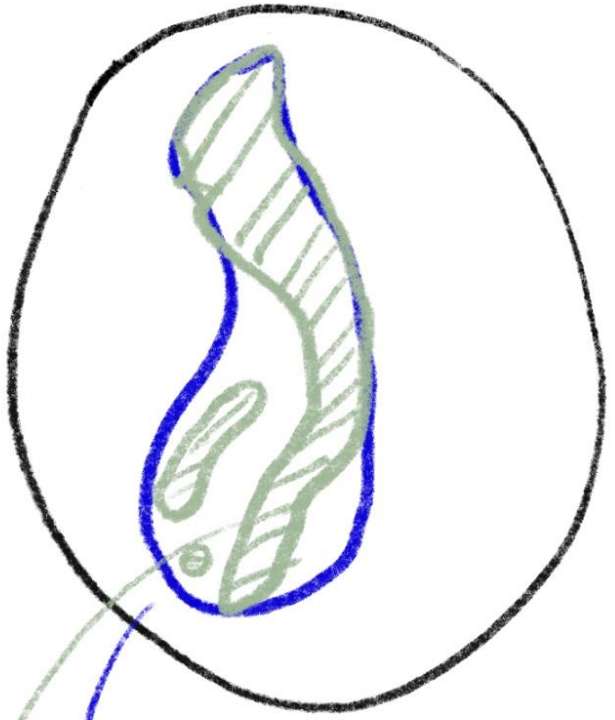


Valid scenarios

Considered scenarios

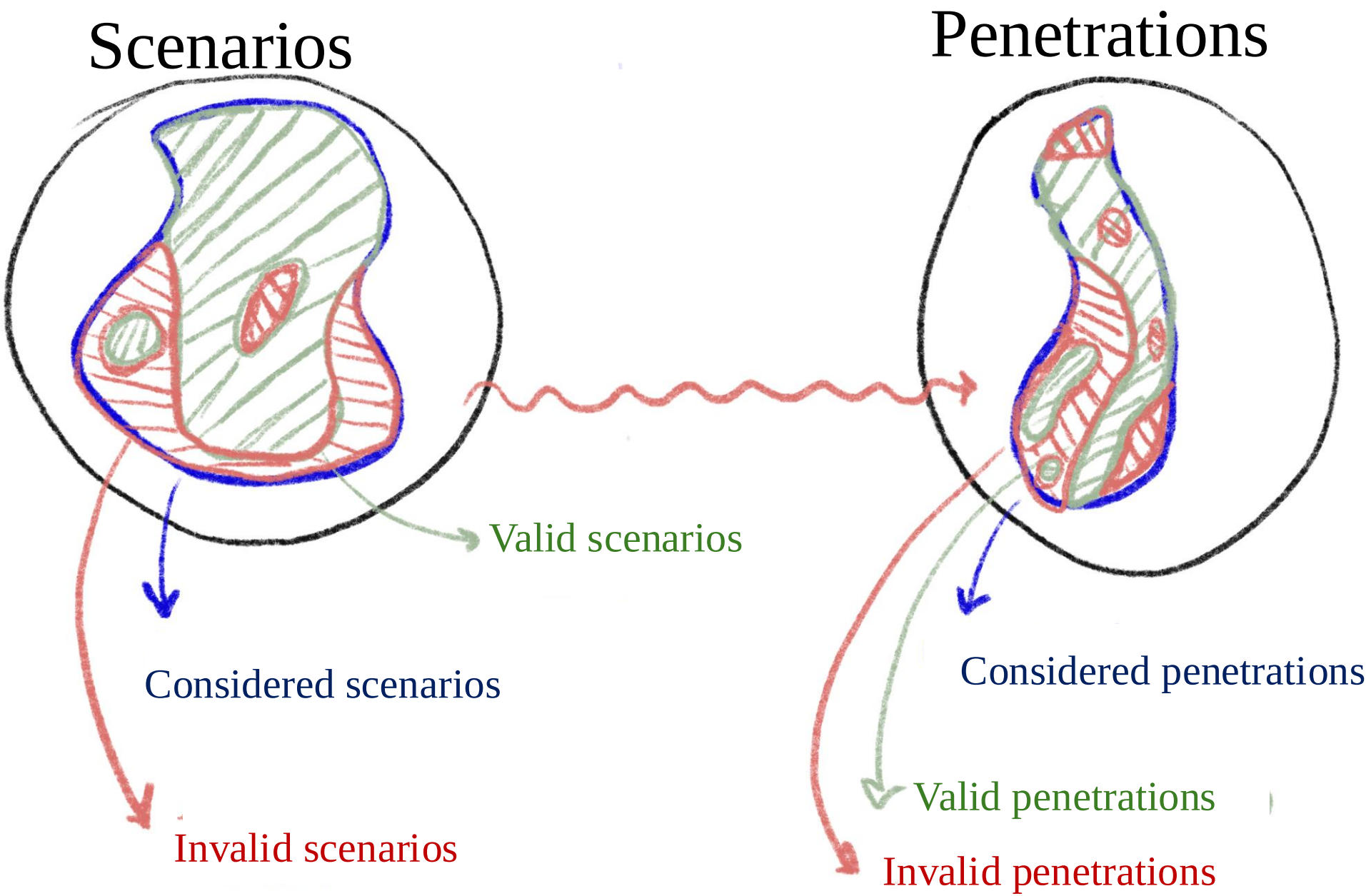
Invalid scenarios

# Penetrations

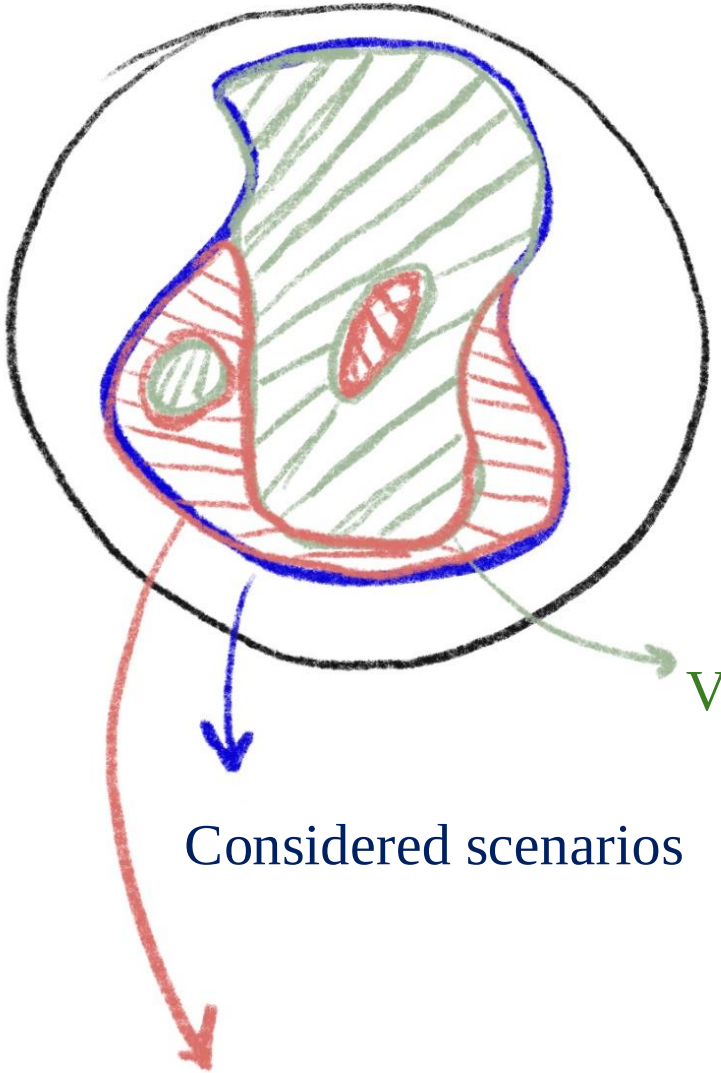


Considered penetrations

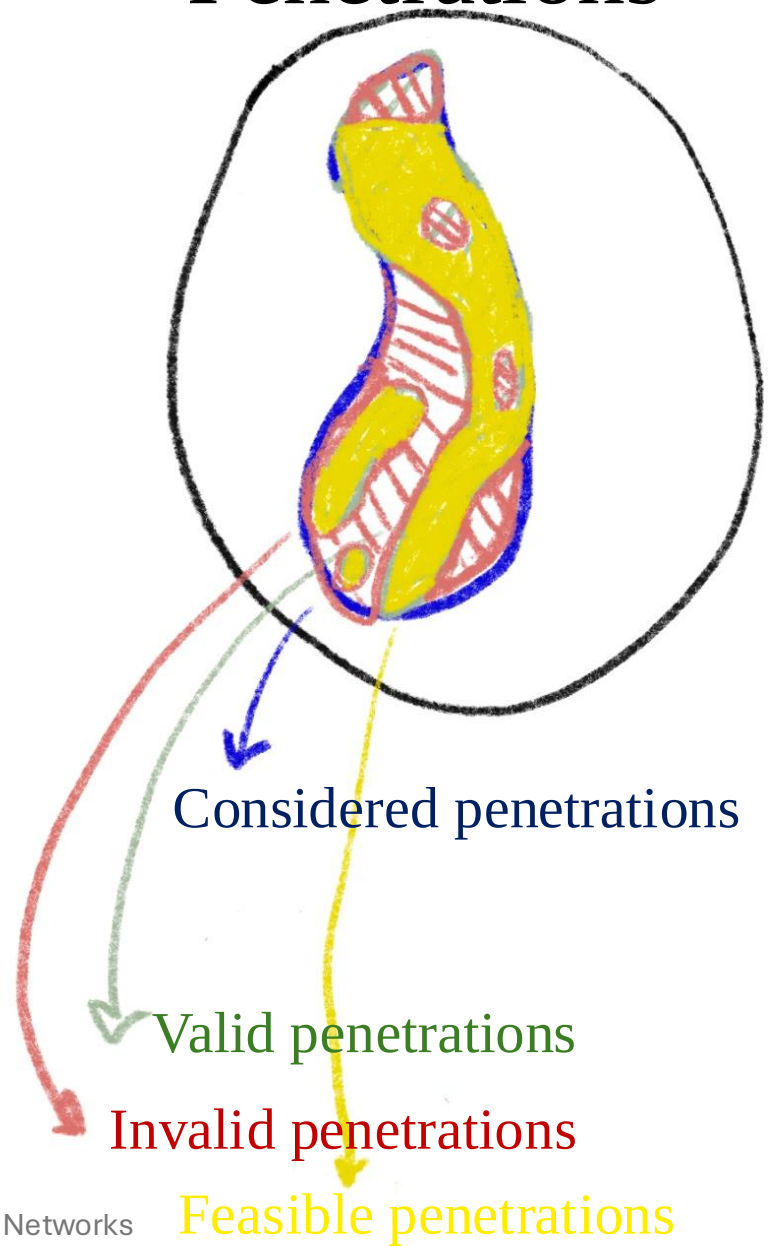
Valid penetrations

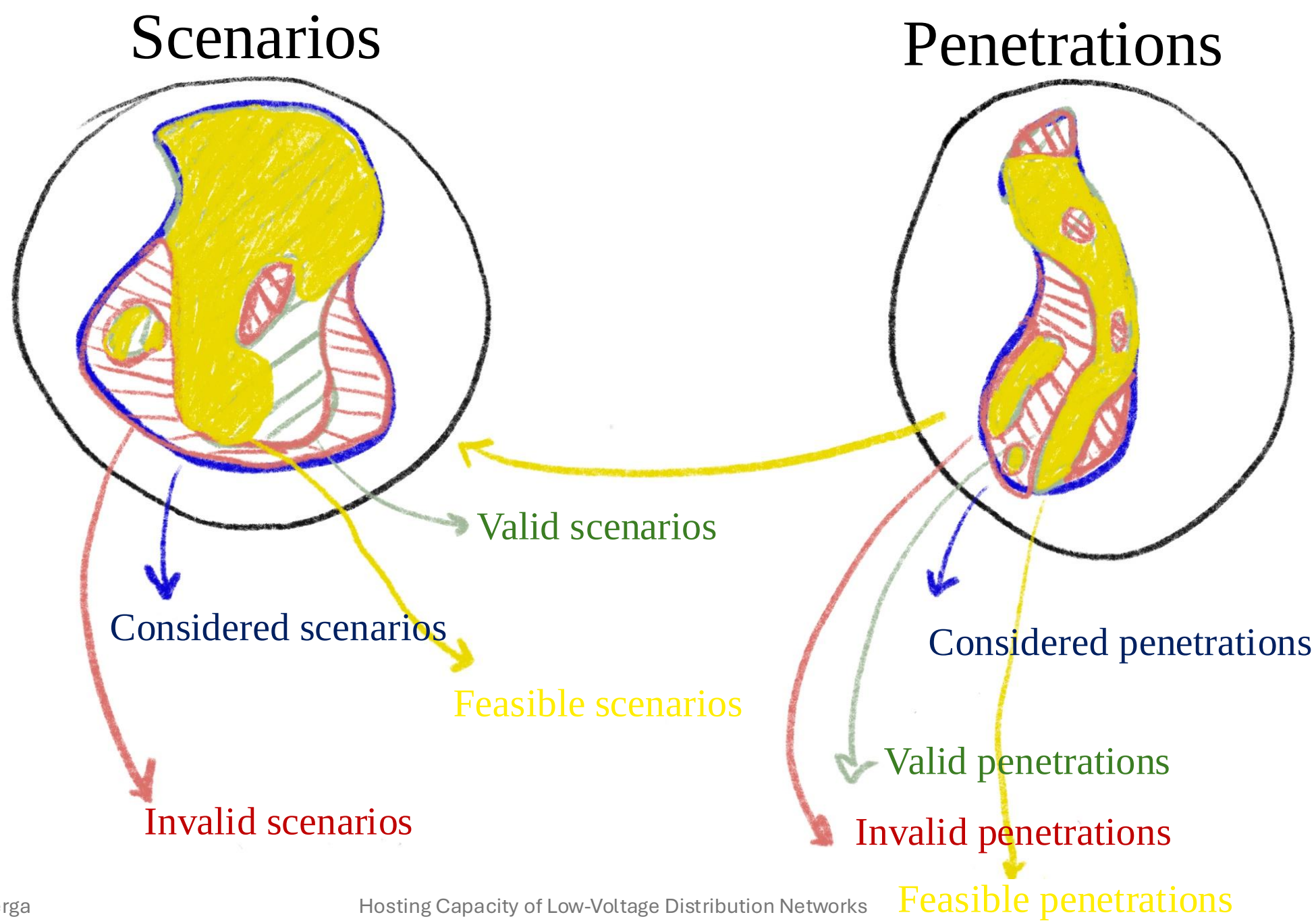

Scenarios
Penetrations
Valid scenarios
Considered scenarios
Considered penetrations
Valid penetrations
Invalid scenarios
Invalid penetrations

# Scenarios



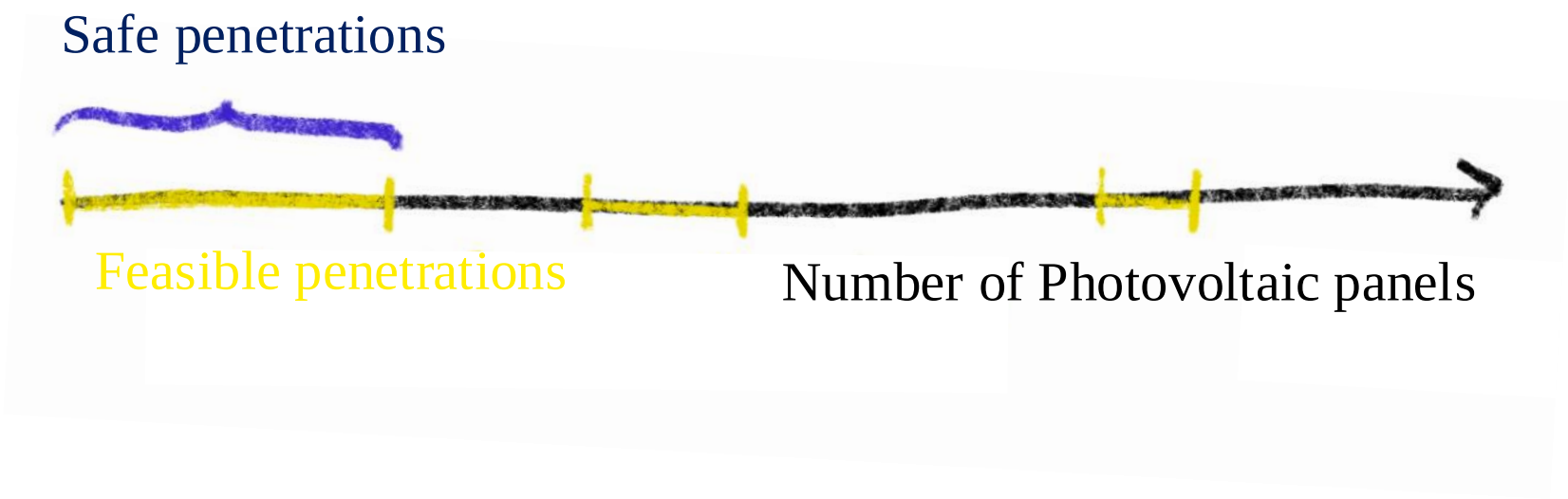

# Penetrations




Scenarios
Penetrations
Valid scenarios
Considered scenarios
Feasible scenarios
Invalid scenarios
Considered penetrations
Valid penetrations
Invalid penetrations
Feasible penetrations

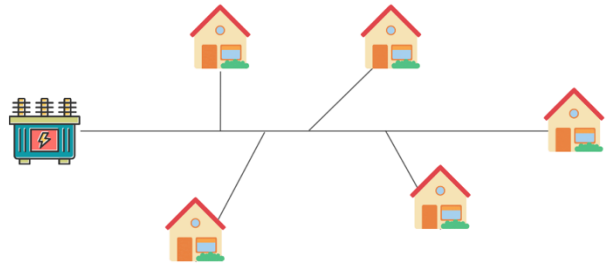
# N-dimensional hosting capacity

# One Dimensional Hosting capacity



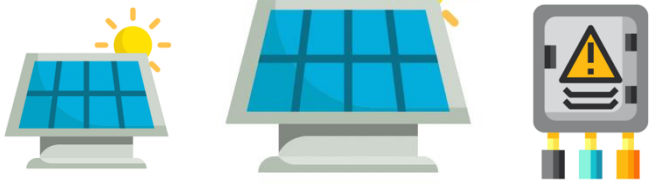
# Summary of the formalism

A network



Technologies

Options for the technologies



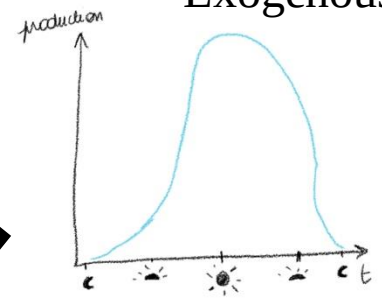
Penetrations

t=...

State

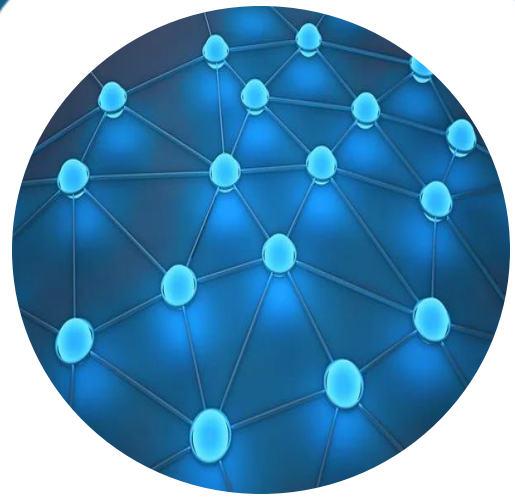
Scenario

Exogenous data

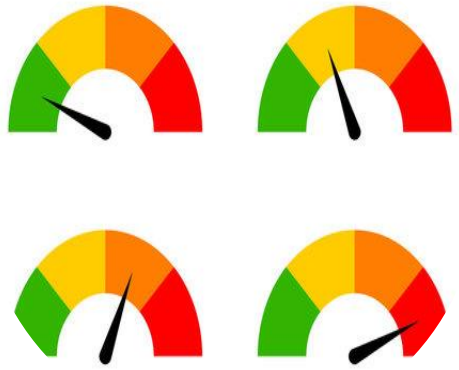



Valid / invalid sets

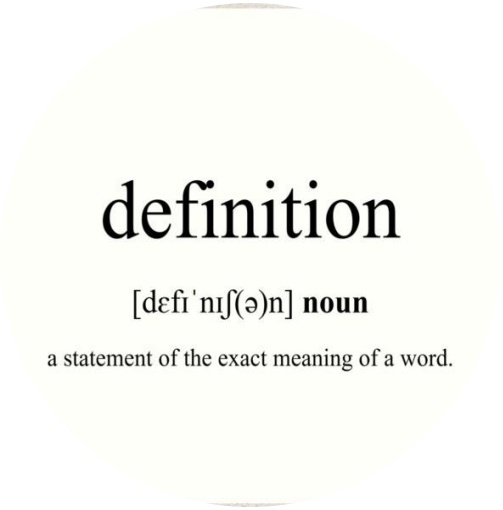
Feasible/safe penetrations
Hosting capacity



Topology identification



Single technology HC




Unified HC definition

Combined HC

# Combined PV-EV-HP Hosting Capacity

# Methodology

- Considered scenarios
- Penetrations
- Issues

# Case study – considered scenarios

- Technologies size:

  Photovoltaic size: 20 x 290$W_{peak}$
  Electric vehicle charger sizes: 3kW and 7kW
  Heat pump sizes: 7.5kW and 15kW

- Probability of installing a technology:

Use a probability to install a new technology for each customer and technology type.

| Household size ($m^2$) | Probability (%) |
|---|---|
| [0,50) | 20 |
| [50, 75) | 40 |
| [75, 100) | 50 |
| [100, 125) | 60 |
| [125, Inf) | 80 |

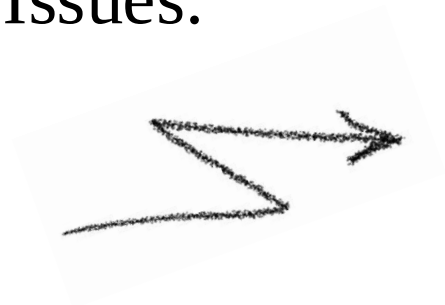
# Case study

- Representative days:
  Reduce the number of time steps considered

| Day | # similar days | Day | # similar days |
|---|---|---|---|
| **1** | 33 | **7** | 20 |
| **2** | 42 | **8** | 42 |
| **3** | 13 | **9** | 23 |
| **4** | 24 | **10** | 3 |
| **5** | 51 | **11** | 10 |
| **6** | 55 | **12** | 50 |

# Case study – Functions

Issues:



$$\text{Under-voltage limit} < \text{Node voltage} < \text{Over-voltage limit}$$

$$\text{Loads of a line} < \text{Line capacity}$$

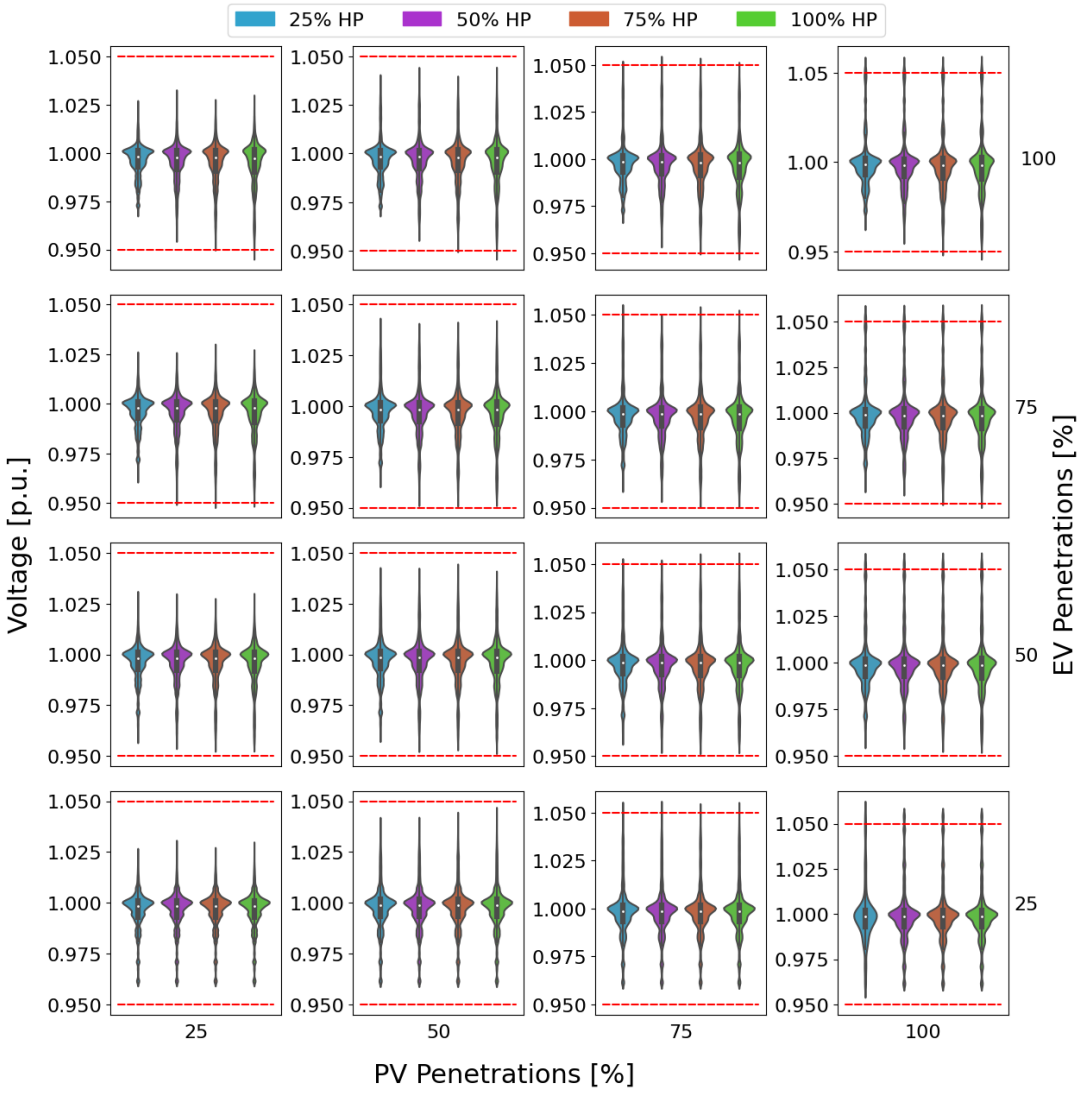
Penetrations:

$$\frac{\text{Number of customers with new technologies (DERs)}}{\text{Total number of customers}}$$

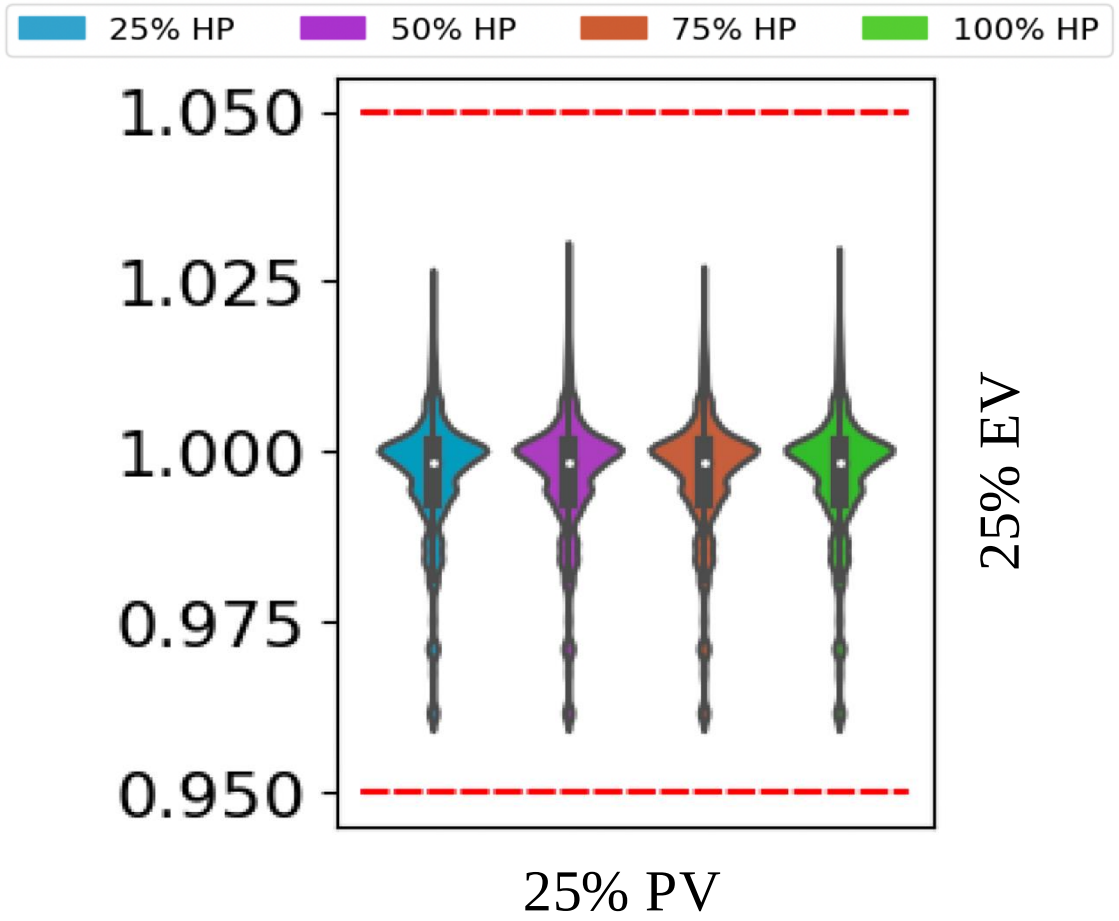
# Case study – Belgian network

- 1 substation
- 2 feeders
- 23 customers
- 15 customers with Smart Meters
- Penetration levels:
  [25%, 50%, 75%, 100%]
- 100 scenarios per penetration level

# Results - Voltage

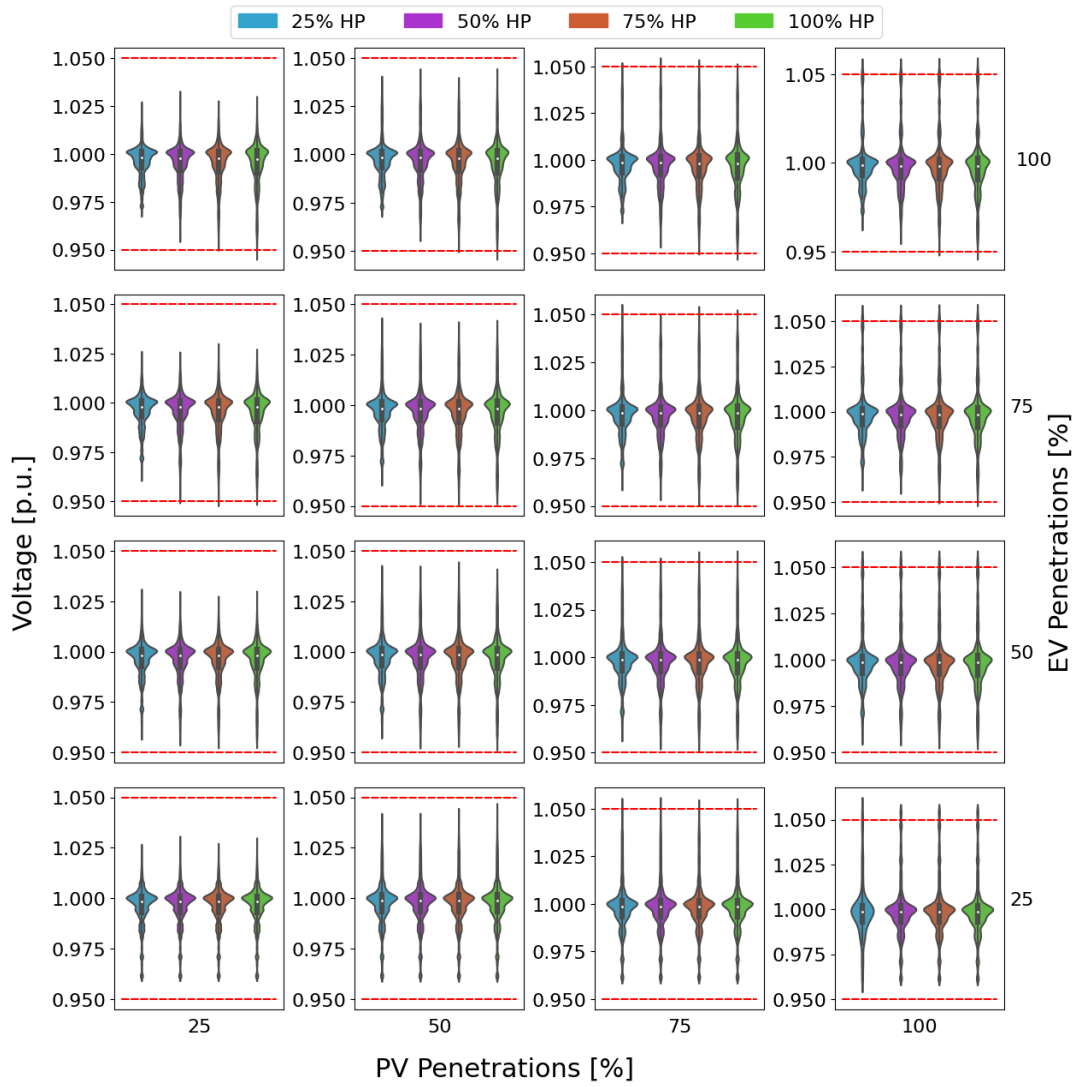


# Results - Voltage



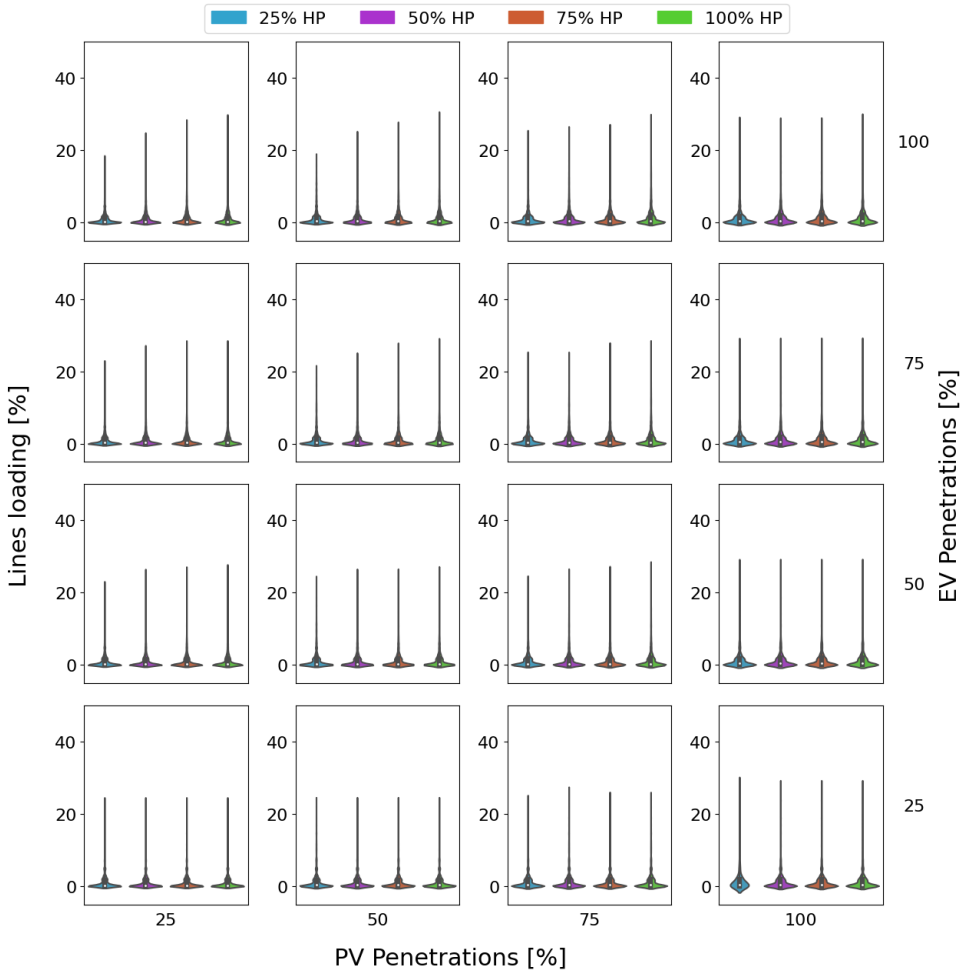
# Results - Voltage

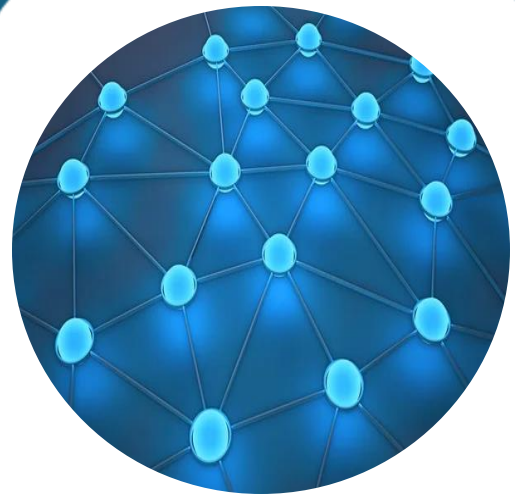
- Acceptable for a penetration around 50% for all technologies
- Under-voltage is encountered rapidly for both EV and HP penetrations higher than 50%.
- Over-voltage is not faced before 75% of PV penetration.



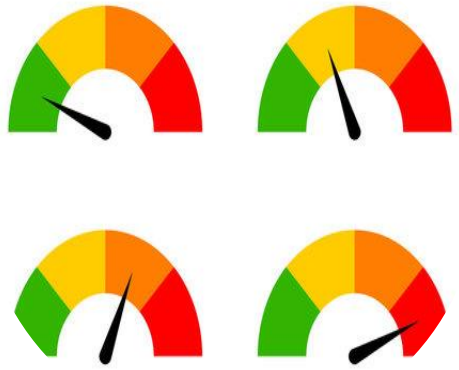
# Results – Loads

Even with high penetration rates for all three technologies, the lines of the case study network are not overloaded.

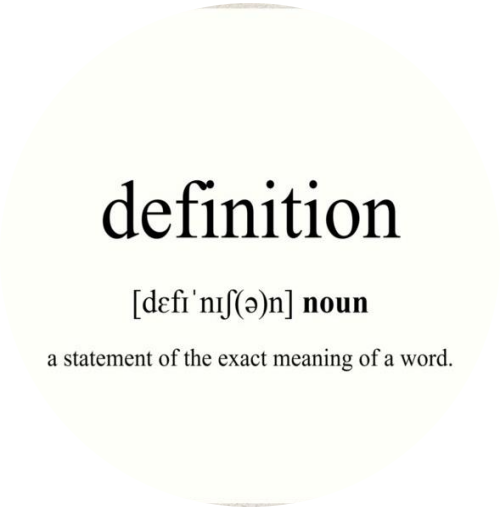




Topology identification



Single technology HC




Unified HC definition

Combined HC

# Conclusion – Journey summary

In this presentation:

- Reconstruction of the topology of distribution network using smart meter data
- Single technology hosting capacity methodology with application on a Belgian inspired network with photovoltaic panels.
- Definition of the hosting capacity
- Combined hosting capacity of PV-EV-HP

In addition, in the manuscript:

- Impact of optimal phase connection on HC

# Future work

- Representative days
- Socio-economic behaviour
- Coupling the HC formalism with investment strategies and active network management.

# Further information

In the thesis:

- A. Benzerga, “Hosting Capacity of Low-Voltage Distribution Networks”, **https://hdl.handle.net/2268/323245**

And the corresponding papers:

- Benzerga, A., Maruli, D., Sutera, A., Bahmanyar, A., Mathieu, S., & Ernst, D. (2021, June). Low-voltage network topology and impedance identification using smart meter measurements. In 2021 IEEE Madrid PowerTech (pp. 1-6). IEEE.
- Marulli, D., Mathieu, S., Benzerga, A., Sutera, A., & Ernst, D. (2021, October). Reconstruction of low-voltage networks with limited observability. In 2021 IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe) (pp. 1-5). IEEE.
- Benzerga, A., Mathieu, S., Bahmanyar, A., & Ernst, D. (2021, July). Probabilistic capacity assessment for three-phase low-voltage distribution networks. In 2021 IEEE 15th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG) (pp. 1-6). IEEE.

# And more


- Benzerga, A., Bahmanyar, A., Derval, G., & Ernst, D. (2024). A unified definition of hosting capacity, applications and review. ORBi-University of Liège. https://orbi.uliege.be/handle/2268/315915.
- Benzerga A., Vassallo M., Gerard S., Vandeburie J., and Ernst D. (2024). Combined PV-EV-HP Hosting Capacity Analysis of a Belgian Low- Voltage Distribution Network. In Proceeding of the 34th Australasian Universities Power Engineering Conference (AUPEC). 2024.
- Benzerga, A., Bahmanyar, A., & Ernst, D. (2022). Optimal Connection Phase Selection of Residential Distributed Energy Resources and its Impact on Aggregated Demand. arXiv preprint arXiv:2207.05059.
- Benzerga, A., Gérard, S., Lachi, S., Garnier, Q., Bahmanyar, A., & Ernst, D. (2022). Optimal connection phase selection for single-phase electrical vehicle chargers.
- Vassallo, M., Benzerga, A., Bahmanyar, A., & Ernst, D. (2023, June). Fair reinforcement learning algorithm for pv active control in lv distribution networks. In 2023 International Conference on Clean Electrical Power (ICCEP) (pp. 796-802). IEEE.

“Happiness can be found, even in the darkest of times, if one only remembers to turn on the light.”

- Albus Dumbledore