Pathways to Positive Energy Districts:

A Comprehensive Techno-Economic and Environmental Analysis

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Citizens 4PED

PED definition

- **Definition** in SET-Plan Action 3.2 :
  - Energy balance
  - Carbon neutrality

*A PED is seen as a district with **annual net zero energy import**, and **net zero CO2 emission** working towards an **annual local surplus production of renewable energy**.*

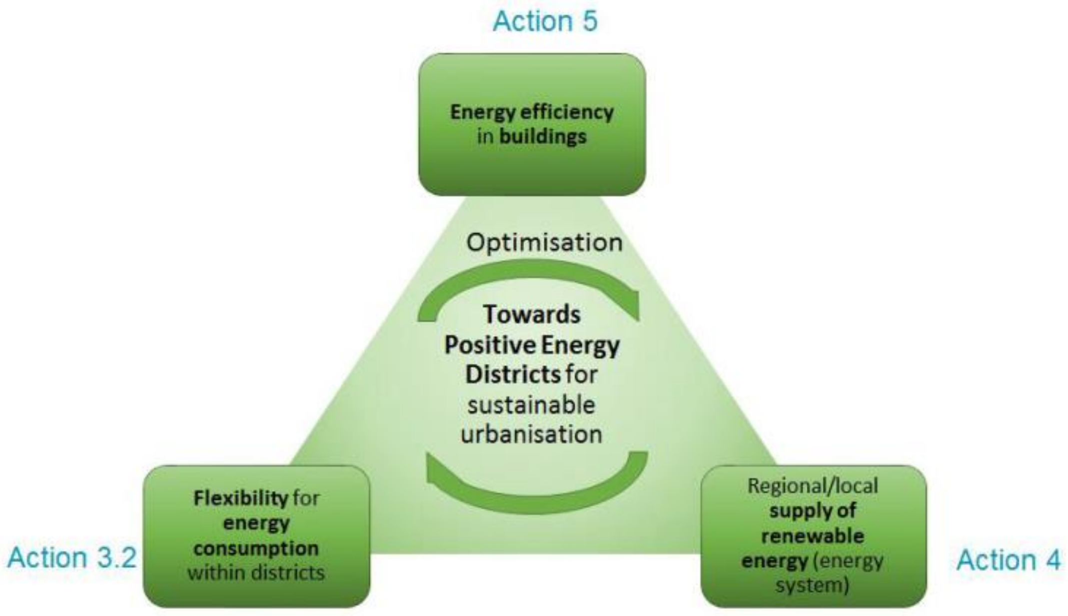
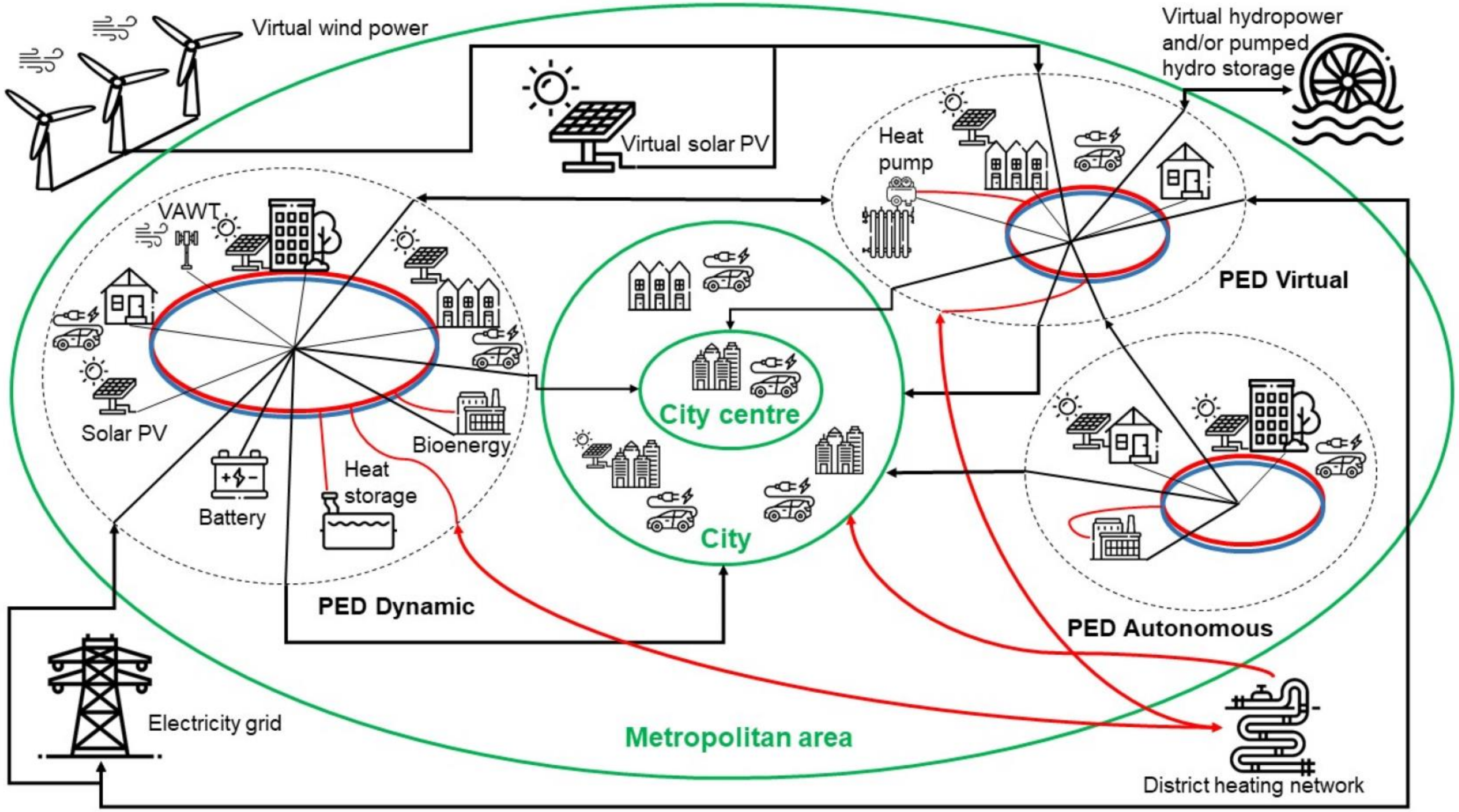


Figure 5: Definition of Positive Energy Districts

Source: SET-Plan Action 3.2

PED boundaries

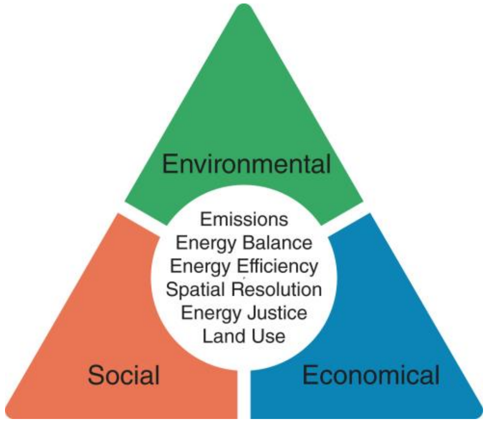
- PED autonomous
- PED dynamic
- PED virtual



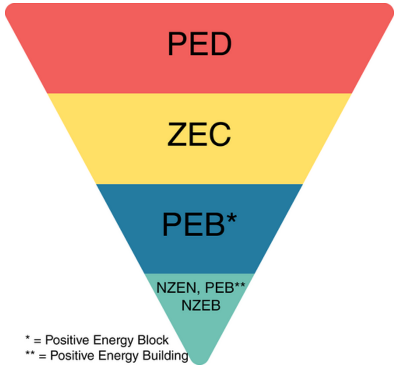
Source: Lindholm, O.; Rehman, H.u.; Reda, F. Positioning Positive Energy Districts in European Cities. *Buildings* **2021**, *11*, 19. https://doi.org/10.3390/buildings11010019

PEDs: Tools and methods

- Key factors:
  - Transition NZEB to PEDs
  - Environmental to multifaceted analyses
  - Multi-stakeholder engagement
- KPIs:
  - Energy
  - Economic
  - Environmental
  - Social
  - …



The triangle of sustainability,

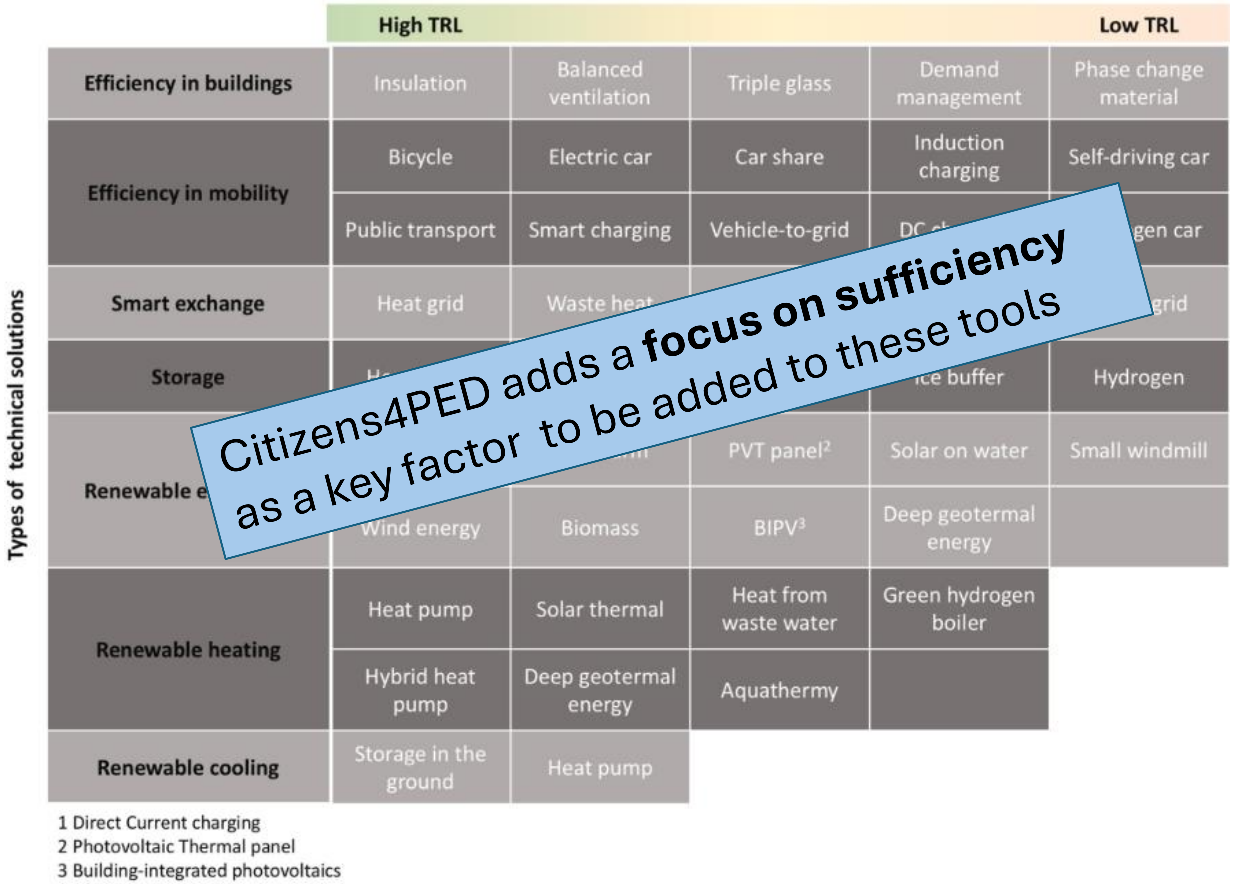


Hierarchical of the concepts (**Casamassima et al.,2022**)

PEDs: design & solutions

- Metrics[1]:
  - CO2 emissions
  - Primary energy
  - Final energy
  - Exergy,...

- Type of solutions[1]:
  - Retrofit
  - Electrification
  - RES (renewable energy sources)
  - DHN (district heating)
  - Storage



Common technologies for urban districts, from high technology readiness levels (TRLs) to low TRLs.[1]

[1] Sassenou, L-N., L. Olivieri, and F. Olivieri. "Challenges for positive energy districts deployment: A systematic review." *Renewable and Sustainable Energy Reviews* 191 (2024): 114152

Pareto optimisation model Framework

- How, when?

  Multi-objective optimization

  Pre-design, planning

- Why?
  - bottom-up & top-down synergies.
  - Need multiple solutions with diverse evaluation metrics:

    --To final solution meet different stakeholders.

Model Evaluation metrics & KPIs

Objective functions:

- Total Annual cost(TAC)
- Annual carbon emissions(CE)

Evaluation metric:

$$CNC = \frac{CO_2^{Dis} - CO_2^{Cred}}{max\left(CO_2^{Dis}, CO_2^{Cred}\right)}$$

$$CO_2^{Dis} = CO_2^{PG} + CO_2^{BO}$$

$$CO_2^{Cred} = CO_2^{El,Exp} + CO_2^{Th,Exp}$$

Carbon Neutrality Check(CNC)

- CNC<0, Carbon neutral, PEDs.
- CNC>0, not PED.
- CNC = 1, no RES.
- CNC = -1, 100% RES.

KPIs:

- Internal rate of return(IRR)
  - IRR> Discount rate, Profitable
  - IRR<Discount rate, Not Profitable
- LCOEx
- Self-Sufficiency Ratio
- Self-consumption Ratio

Source: **Elisa Marrass, 2024**

- **Link:**https://doi.org/10.1016/j.apenergy.2024.123374

Cast study : La Roue

Low temp DHN: 55°C/35°C

Nombre de bâtiments
1041 bâtiments

Demande
34 GWh/an : donnée Sibelga

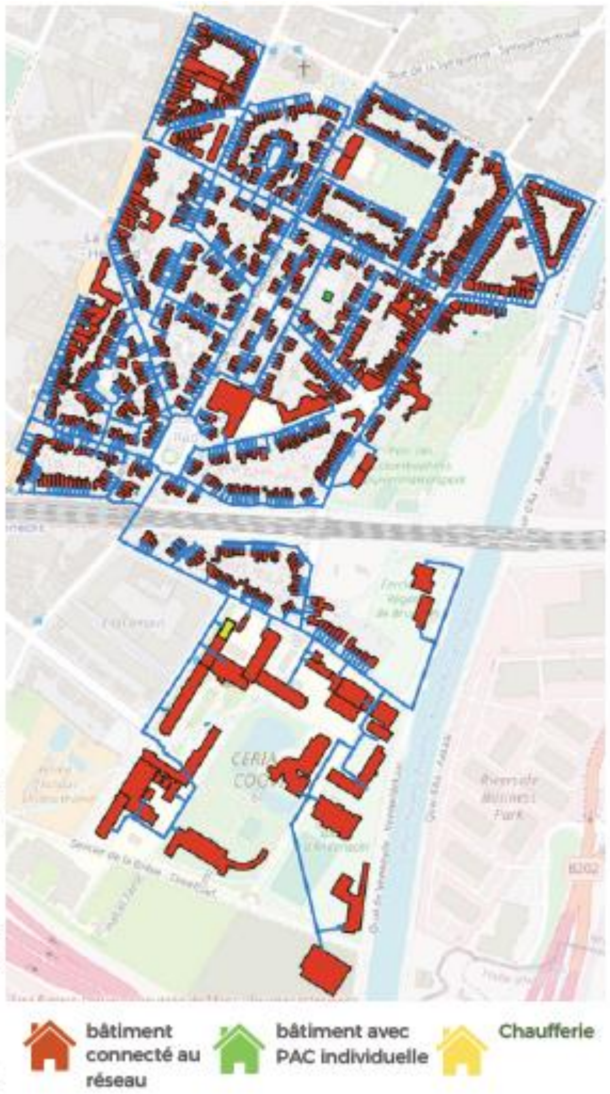
Puissance
14.3 MW

Temps de retour analysé
20 ans

Prix fuel
38 c/kWh_électricité

Potentiel sources locales moyenne température
Géothermie 2MW, Aquathermie 3MW, Aérothermie

Source: RESOLIA



Preliminary results

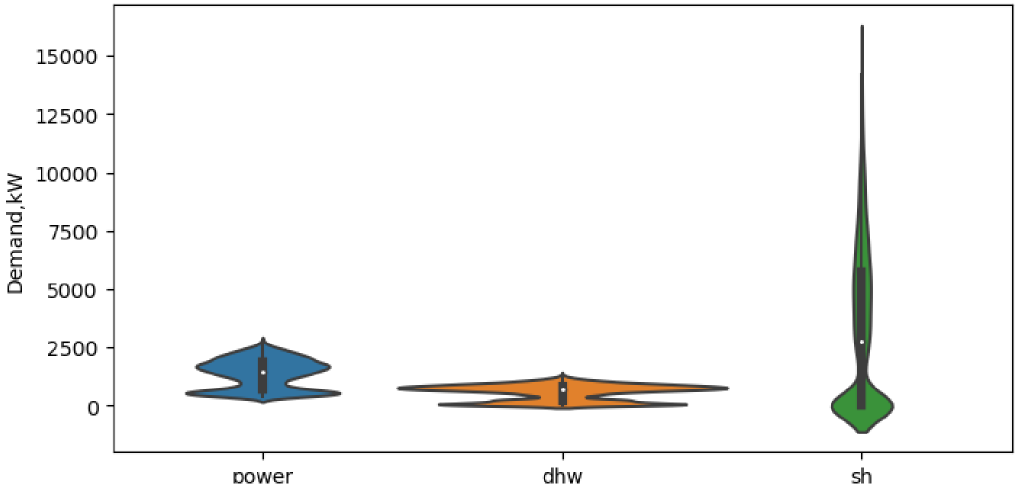
LaRoue Living lab

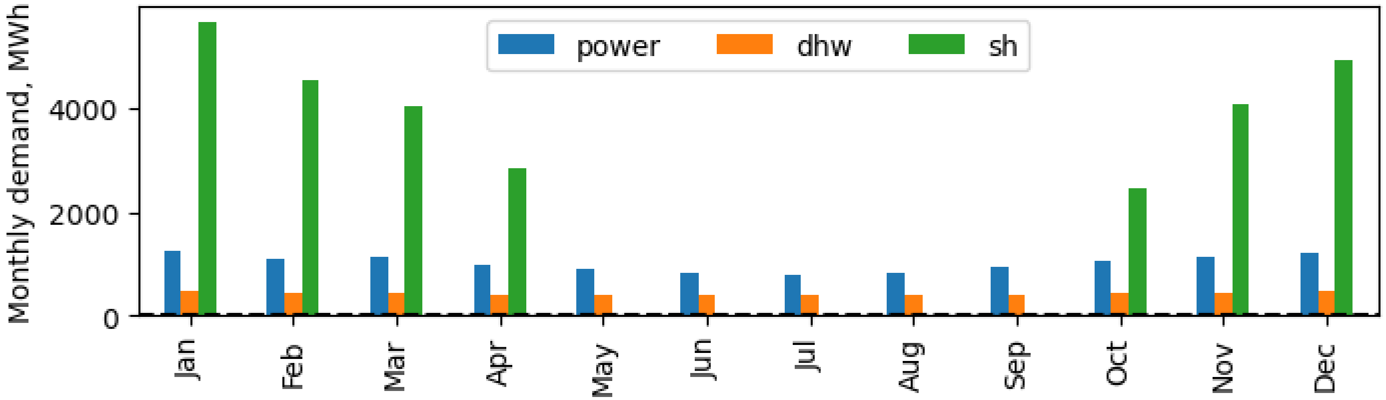
- Input data (low temp scenario)

55/35 degree, 34 GWh heat demand

Parameter	Annual demand [MWh]	Peak demand [kW]
Electrical	12140	2727
Cooling	592	468
heat	33616	
-SH	28525	15189
-DHW	5091	1329
dhn loss	1892	

Annual Heat/ elec = 3.5





CO_2 emission factor: 257 g/kWh (source: Resolia)

NB: could be lower (~150), see https://www.nowtricity.com/country/belgium/

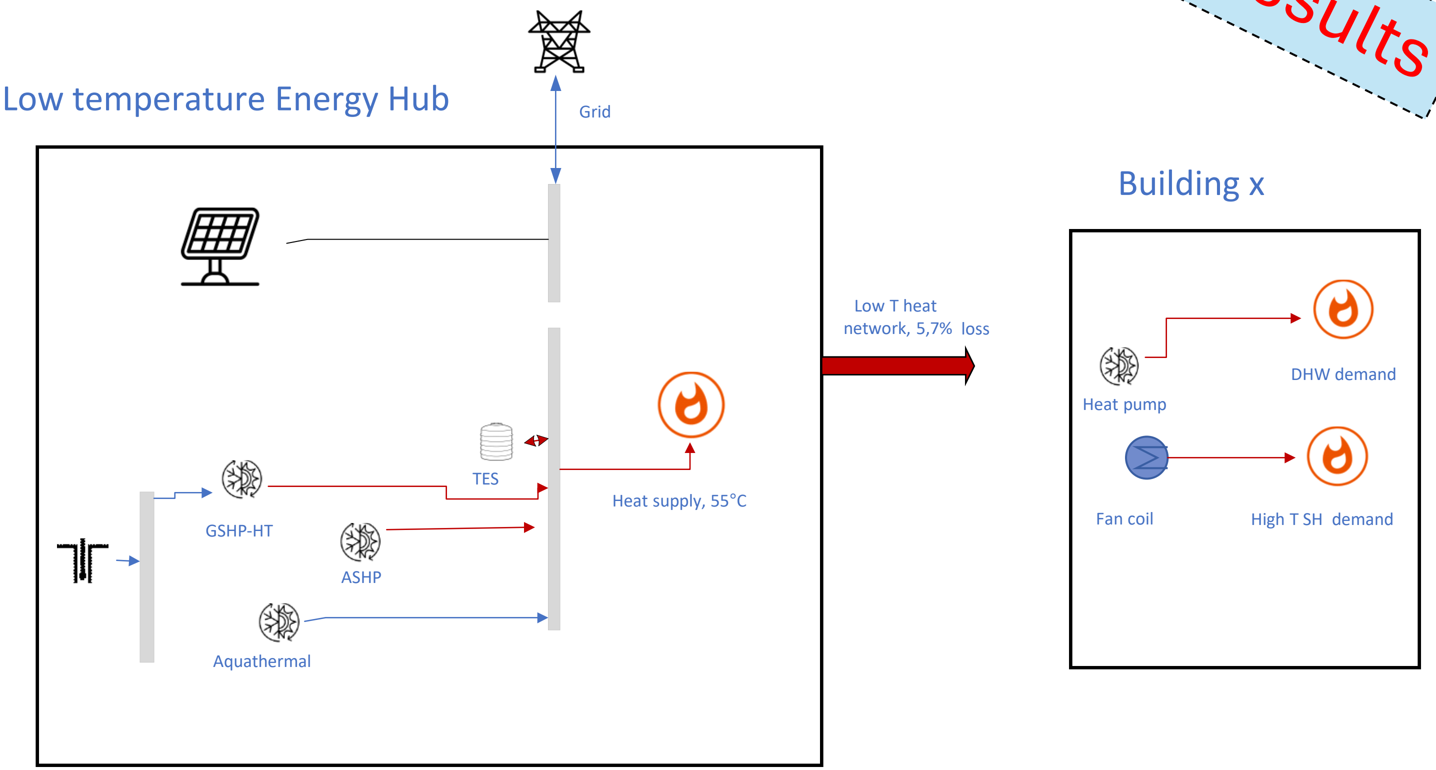
Case study scenarios

Preliminary results

Scenario	
Base	Resolia LT scenario (s0) **
PV10	Increase pv capacity x10
PV10_BAT	Add pv +Battery

- Reduced Needs (sufficiency)

  20 /18 /15 degree scenarios



** boundary conditions extended to allow more possibilities in optimization:

- Add PV panels (no PV in Fiche3)
- max ASHP capacity = 8880 * 2 kW (3880 kW in Fiche3)
- max ATHP = 3000 * 2 kW (3000 kW in Fiche3)
- max GSHP = 4000 * 2 kW (2000 kW in Fiche3)

Preliminary results

Pareto fronts - Base scenario (s0)

- System description
  - PV Area: 18083 m2, 5624 MWh.
  - Electrification: Geothermal, Aquathermal, air-source
  - Heat storage
  - Low-T DHN(Heat Loss 5.7%).
  - Grid connection(cap 2727 *2 kW)

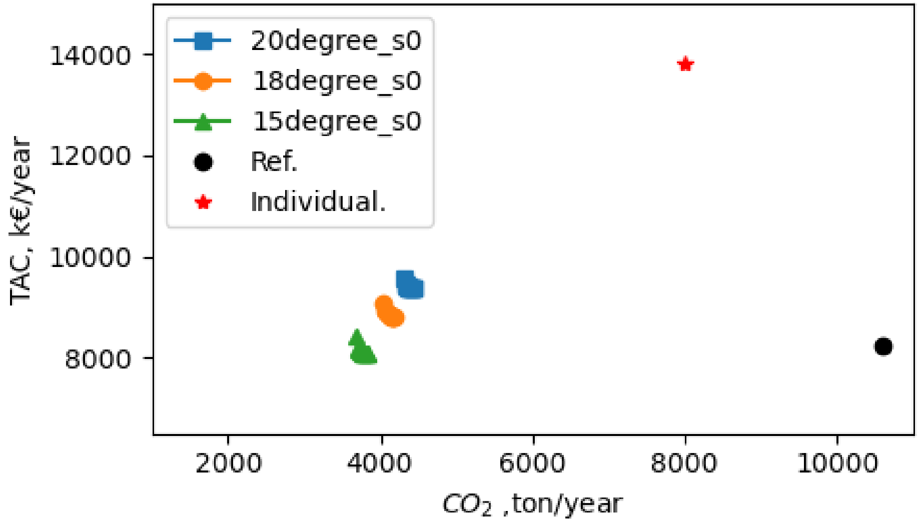
“Ref.” scenario = current situation

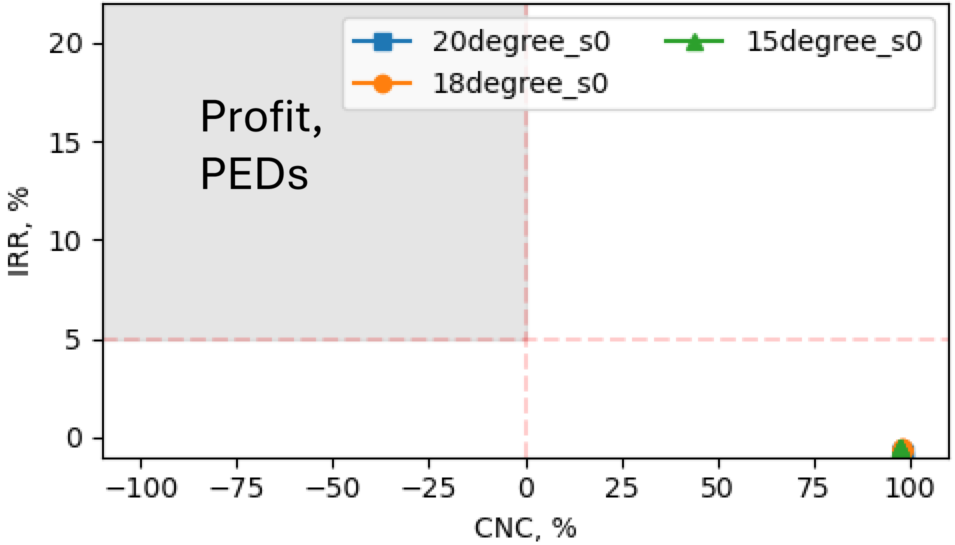
Electricity: Grid. Heat & DHW: NG boiler.

“Individual” scenario = air/air HP for heating

Electricity: Grid. Space heating: HP. DHW: NG boiler.

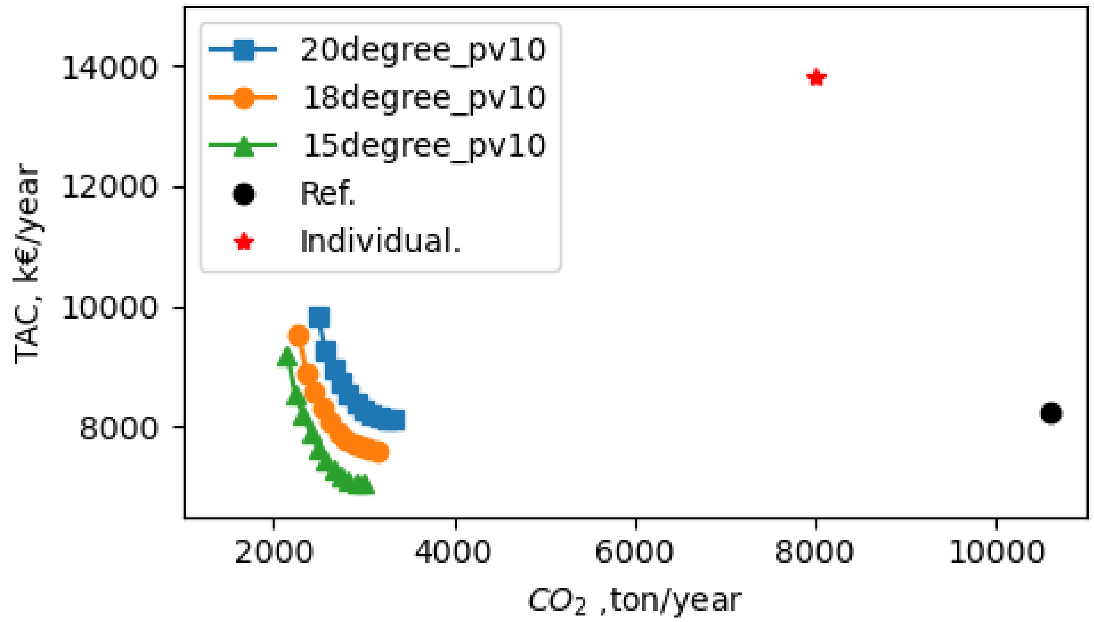
		Ref	Individual
TAC	KEUR/y	8220	13824
CO2	ton/y	10590	8006

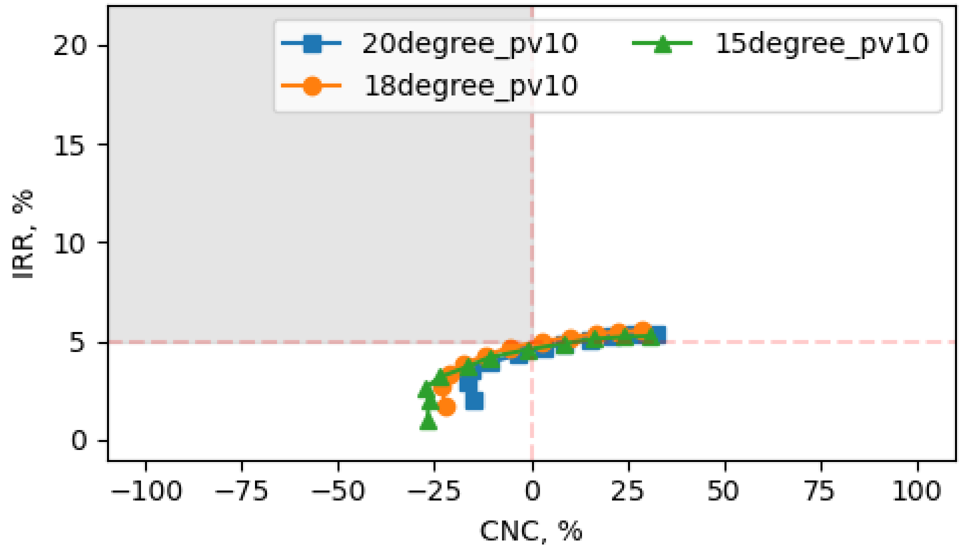




Pareto fronts – Add PV (PV10 scenario)

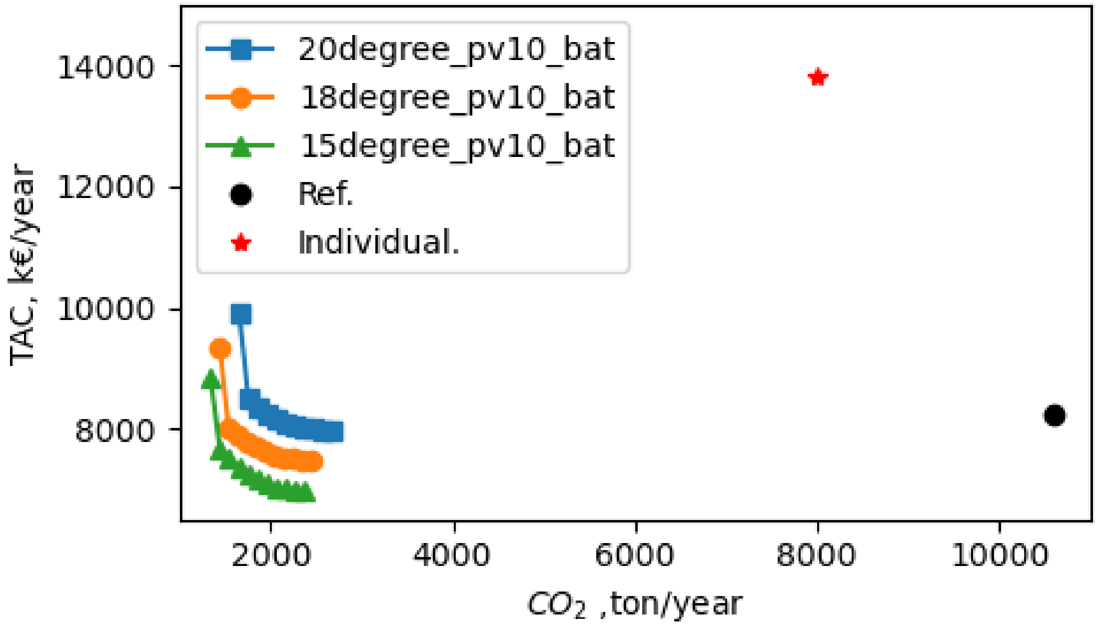
Preliminary results

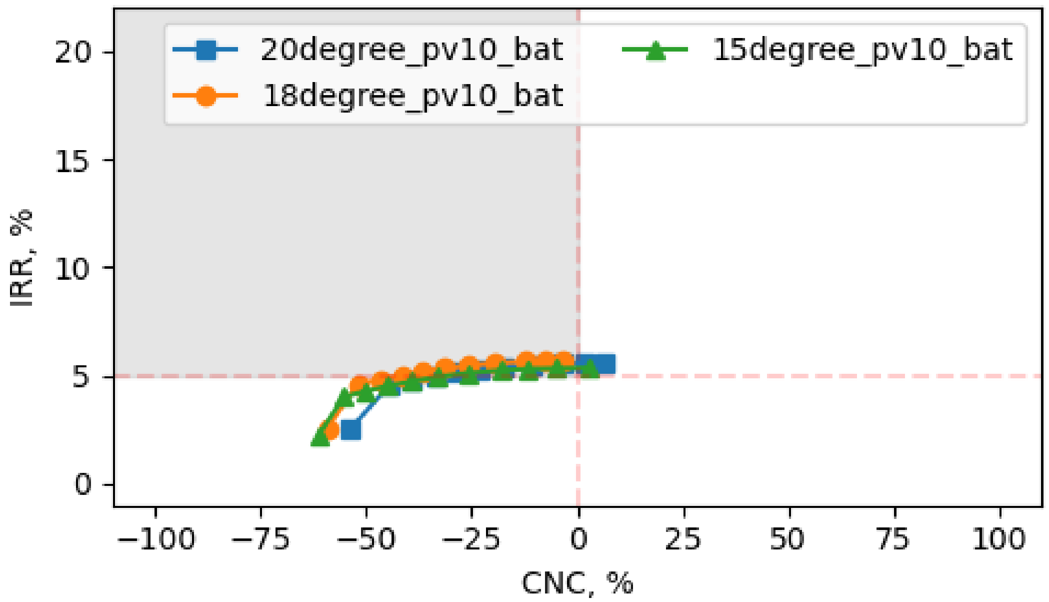




Pareto fronts- Add battery (PV10_BAT)

Preliminary results

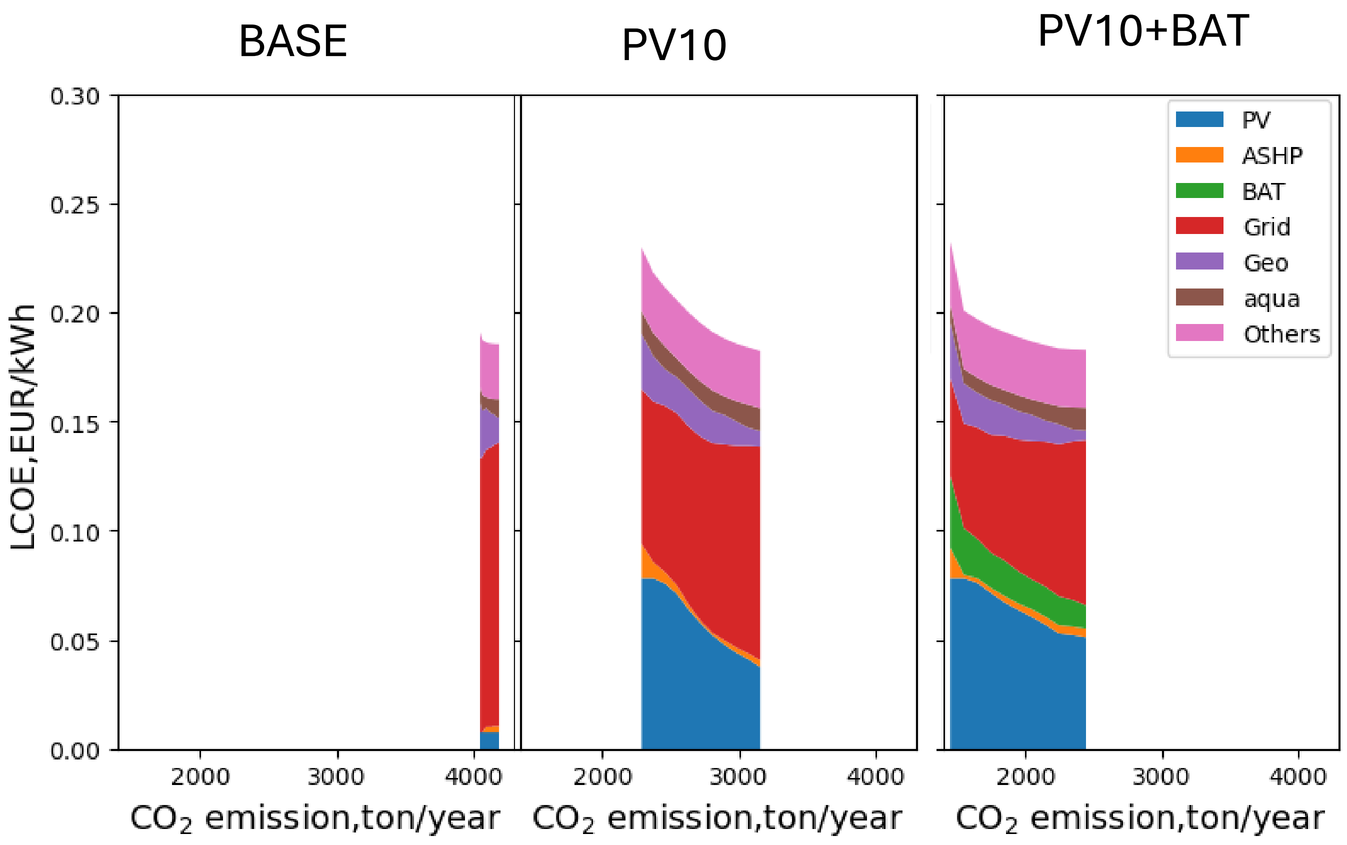




LCOE breakdown (18 degree)

Preliminary results

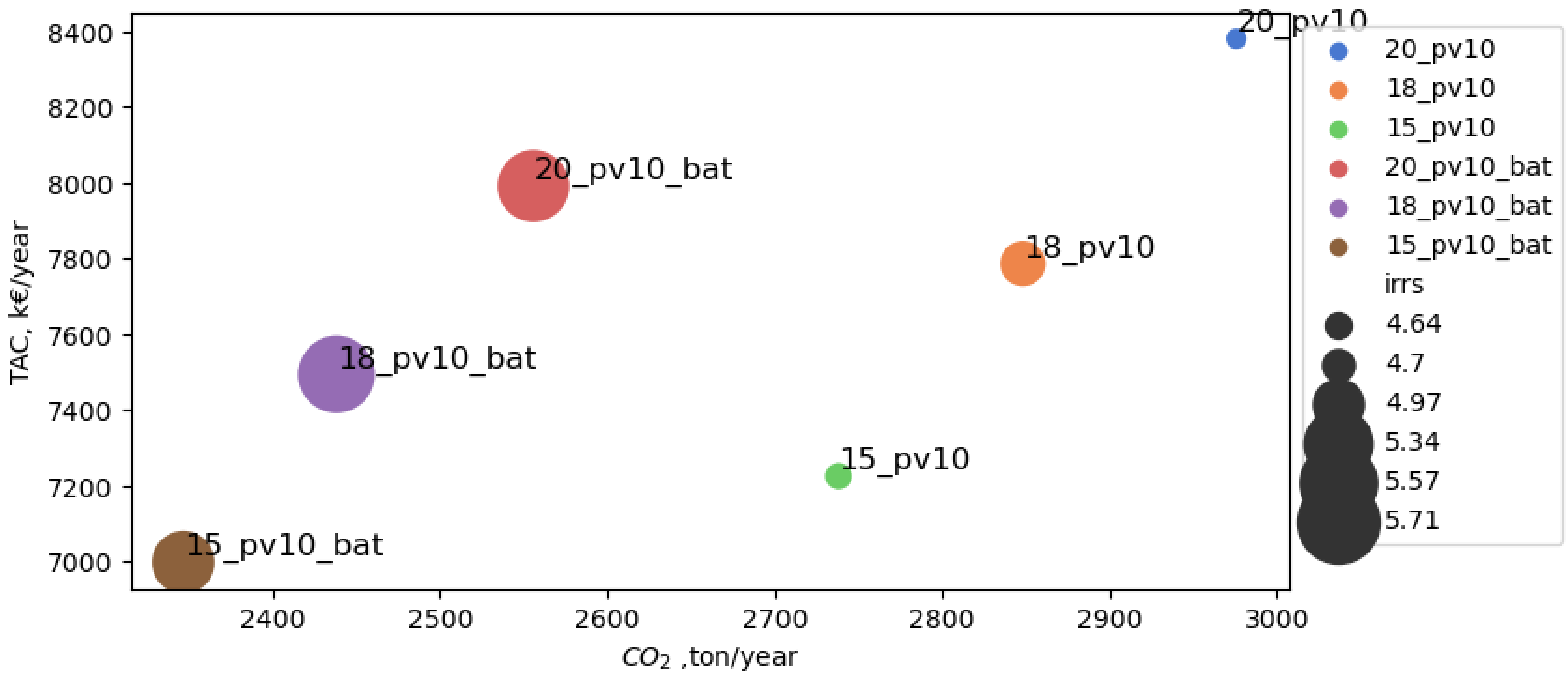
- CO_2 emission decrease.
- From grid, decrease
- RES source, Increase.



Comparison of carbon neutral scenarios

Preliminary results

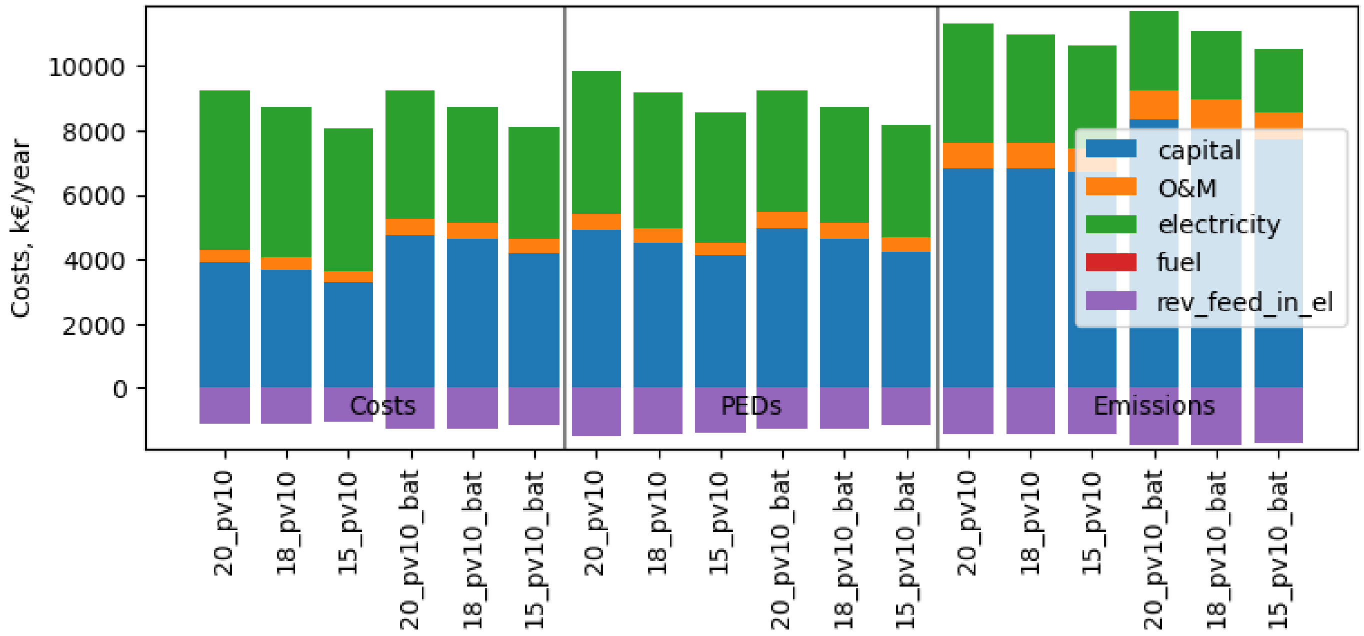
- Points when CNC =0



Cost Breakdown

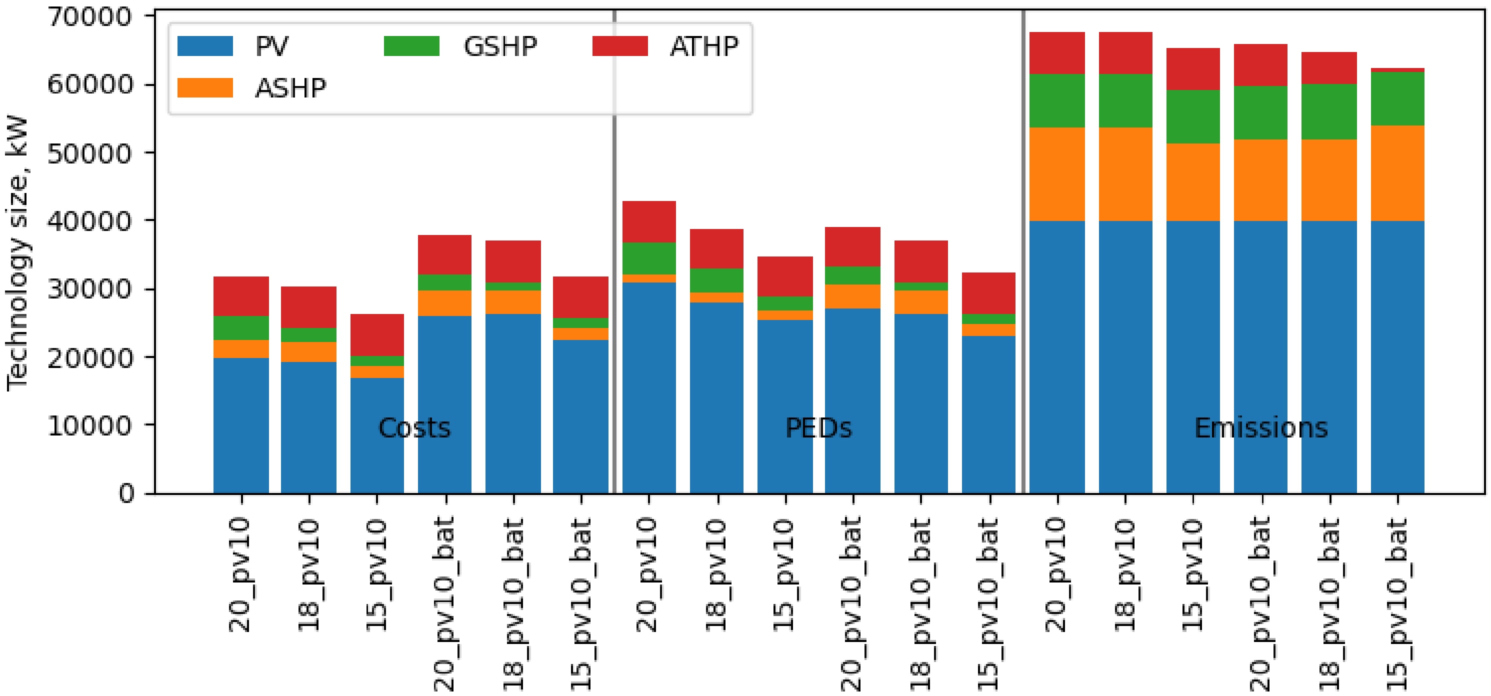
Preliminary results

- Cost-optimal points
- PED points
- CO2-optimal points



Capacity Breakdown

- Generation/Conversion tech



Discussions

Road to PEDs:

- Boundaries : Virtual PED
- Potential Solutions:
  - Add RES resource.
  - Energy flexibility- battery storage.
  - Energy efficiency:
    - Reduce needs.
    - Retrofit, **EPB**: F-> D or C or better (Local policy?)

      need strategies to incentivize participation in renovation

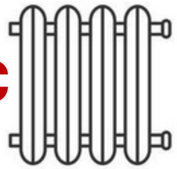
It’s an iterative process

Thanks!

How to adapt demand curves to reduced needs ?

Classic heat demand curve (per hour)

20°C



Domestic hot water (kW)	
13,76	51,67
8,1	30,41
4,31	16,19
1,95	7,31
4,31	16,19
4,45	16,71
5,9	22,15
12,07	45,35
31,76	119,29
62	232,88
66,72	250,62
65,51	246,07
57,72	216,81
45,12	169,47
43,46	163,24
37,5	140,85

Space heating part

Space heating (kW)		
9,63	24,79	32,06
10,72	27,59	34,65
10,43	26,85	34,48
10,75	27,69	35,37
13,23	34,07	33,58
17	43,75	32,64
19,13	49,25	33,65
20,04	51,58	32,02
21,33	54,91	33,34
20,44	52,63	33,67
19,92	51,29	35
17,44	44,89	32,06
16,73	43,08	32,06
15,35	39,52	30,18
16,28	41,9	32,95
14,74	37,94	31,3
12,41	31,95	31,11
10,67	27,47	30,7
10,64	27,4	31,63
11,45	29,47	36,56
12,01	30,92	37,85
13,21	34,01	39,16
12,98	33,41	41,29
13,34	34,35	39,66
15,23	39,22	43,92
16,33	42,05	46,42
15,67	40,34	46,6
19,18	49,38	53,09
26,69	68,71	53,43

Local outside temperature

Air temperature (°C)
7,5
7
6,7
7
7
7
7
7,2
7,2
7,4
7,1
7,5
7,4
7,8
7,9
8,3
7,7
7,2
7
6

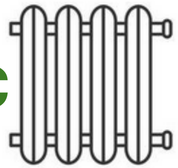
New target T° > Outside T° ?

Space heating demand is reduced proportionally to the target T° vs outside T°

$$24{,}79 \times \frac{18 - 7{,}5}{20 - 7{,}5} = 20{,}82$$

New heat demand curve (per hour)

18°C



New values - Space heating (kW)			
8,0892	20,8236	26,9304	6
9,070769	23,34538	29,31923	7,64
8,861579	22,81241	29,29504	7,28
9,096154	23,43	29,92846	7,08
11,19462	28,82846	28,41385	7,21
14,38462	37,01923	27,61846	8,82
16,18692	41,67308	28,47308	11,8
16,90875	43,52063	27,01688	17,2
17,99719	46,33031	28,13063	18,8
17,19556	44,27603	28,32556	17,1
16,83163	43,33806	29,57364	16,4
14,6496	37,7076	26,9304	14
14,07444	36,2419	26,97111	14,5
12,83361	33,04131	25,23246	13,5
13,58909	34,97438	27,50372	15,0
12,22034	31,45453	25,94957	14,5
10,39211	26,75488	26,05146	14,5
9,002813	23,17781	25,90313	14,2

How to adapt demand curves to reduced needs ?