Multi-objective optimization algorithm coupled to EnergyPLAN software: the EPLANopt model

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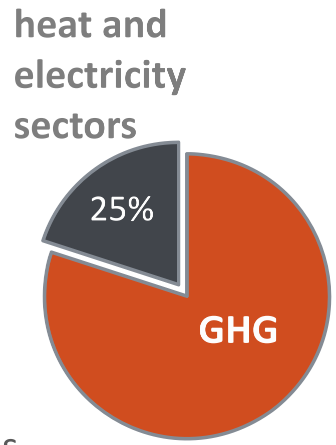
Motivation

One of the **greatest challenges** of the international community is to **lower** anthropogenic greenhouse gas (**GHG**) emissions in order to tackle climate change.



Heat and electricity sectors produce the **25%** of the overall amount of GHG

In order to address the **climate change problem** and to increase **security of the energy system**, an always larger number of countries have set **strict energy targets** and increased their share of renewables. European union adopted the **2020 climate and energy package** in 2007 and **2030 climate and energy framework** in 2014.

The **energy planning** is therefore acquiring a central role **for simulating the future energy system** and thus helping policy makers in setting targets and subsidizing mechanism.

The **optimization** problem of an **energy system** is a complex **multi-objective problem**. The ability of an electricity system to balance demand and supply may for instance be in opposition to its efficiency, as higher flexibility typically requires higher fuel consumption.

Originality and objectives

Similar approach of coupling EnergyPLAN to an optimization algorithm:

- *Bjelic et al. [1] have realized a methodology of soft-linking of EnergyPLAN software with a generic optimization program (GenOpt – single objective).*
- *Mahbub et al. [2] have coupled EnergyPLAN to a multi-objective evolutionary algorithm written in Java to evaluate the Pareto front of best configurations of the energy system.*

We have further developed this methodology:

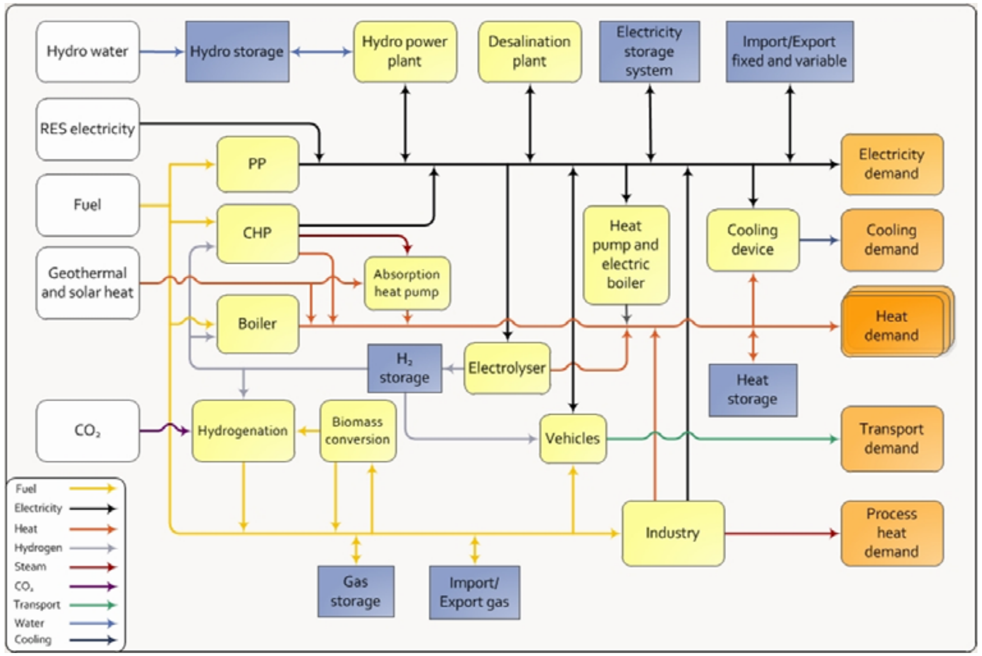
- **Open-source** tool written in **python** based on DEAP library
- Multi-objective evolutionary algorithm with the possibility to set **n-objectives**
- Possibility to run **simulation in parallel** to reduce computational time
- Analysis of the input variables of the optimization algorithm, introducting the **energy efficiency** variable connected to building refurbishment

[1] I. Batas Bjelić and N. Rajaković, "Simulation-based optimization of sustainable national energy systems," Energy, vol. 91, pp. 1087–1098, Nov. 2015.

[2] M. S. Mahbub, M. Cozzini, P. A. Østergaard, and F. Alberti, "Combining multi-objective evolutionary algorithms and descriptive analytical modelling in energy scenario design," Appl. Energy, vol. 164, pp. 140–151, Feb. 2016.

Methodology: the energy model, EnergyPLAN

- **Deterministic**, analytically programmed energy system **simulation model**
- Particularly designed for the analysis of energy systems with **high degrees of renewable** energy sources (RES)
- It simulate one-year periods with a **temporal resolution** of one **hour** to adequately reflect the fluctuations in the various RES
- EnergyPLAN considers the **integration** of **three** primary **sectors** of any national energy systems.
- The **results** developed using EnergyPLAN are constantly being **published** within academic journals.
- Possibility to launch it from command prompt line. And so the **possibility** to create an **external code** in order to run serial simulations.



Methodology: the energy model, EPLANopt

Model n objectives

Simulation model

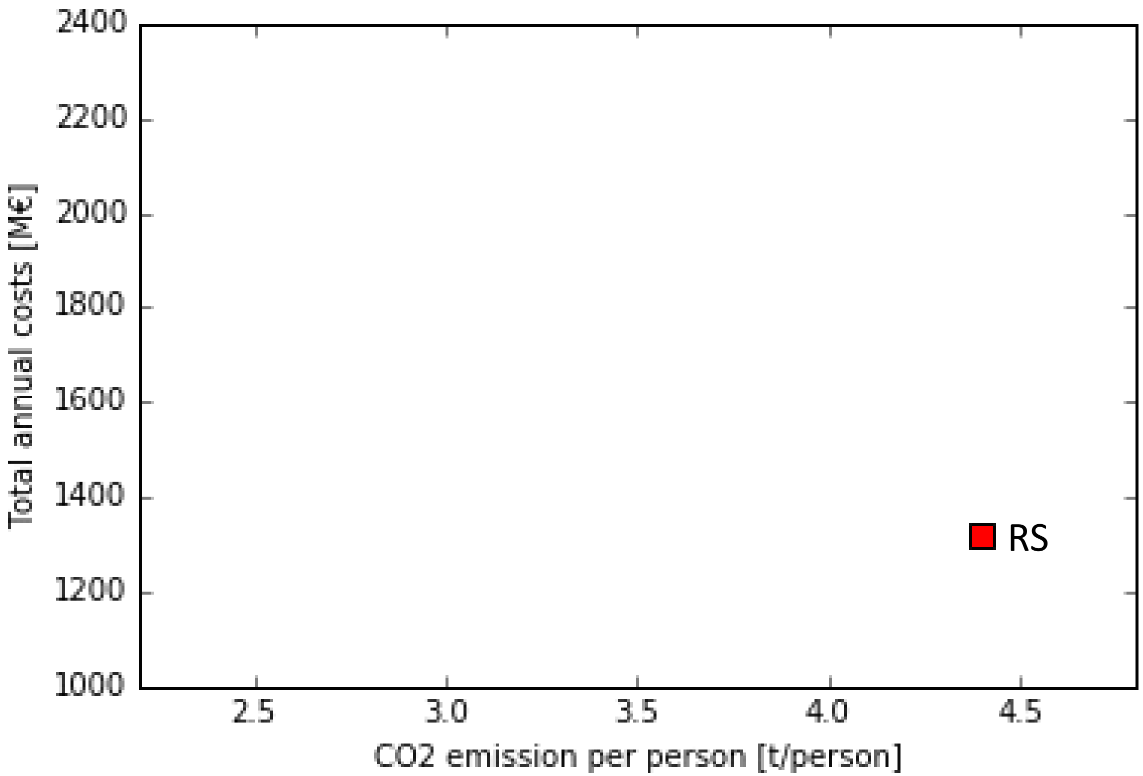
EnergyPLAN
(Aalborg
University)

+

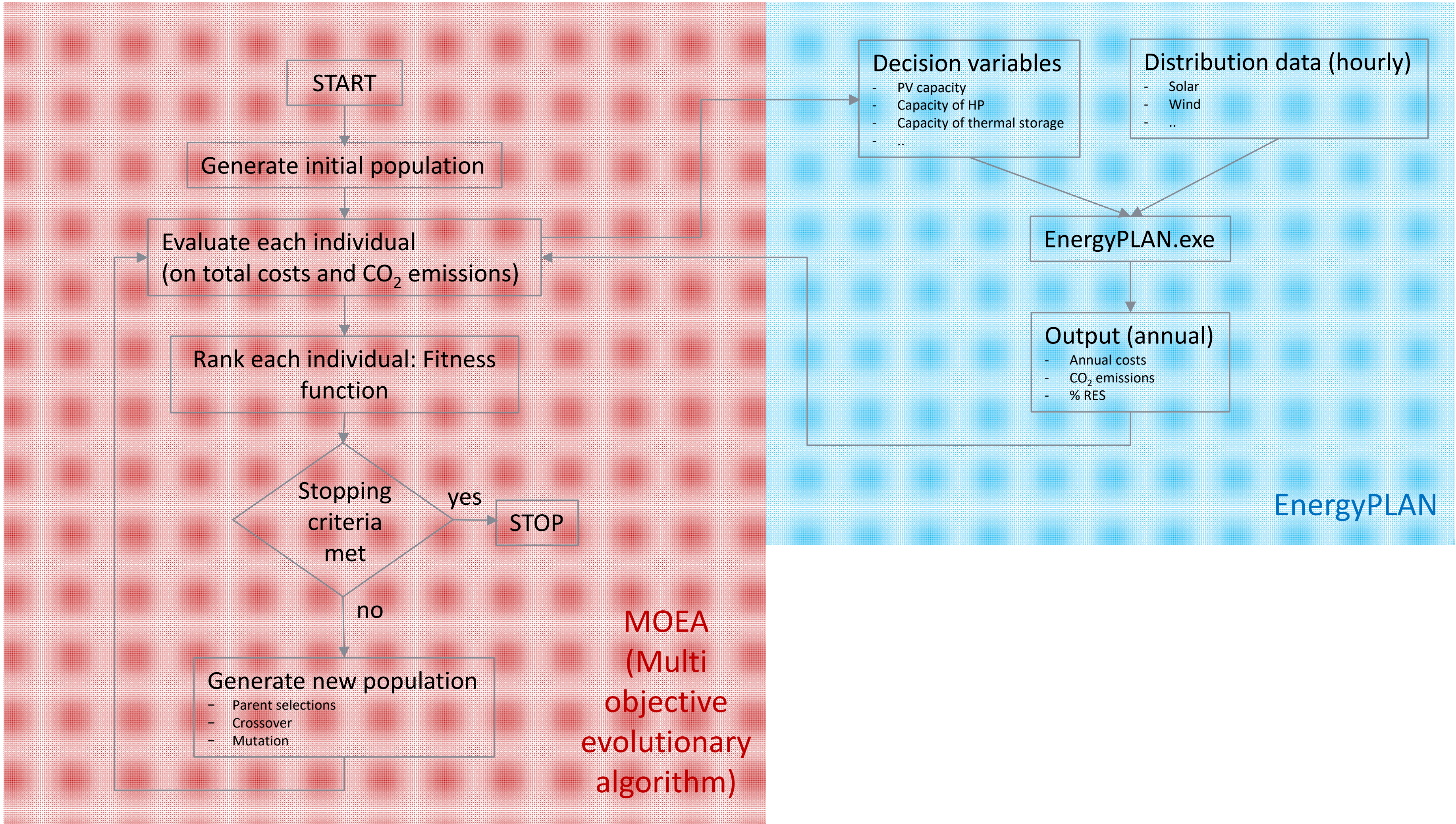
Optimization model

python

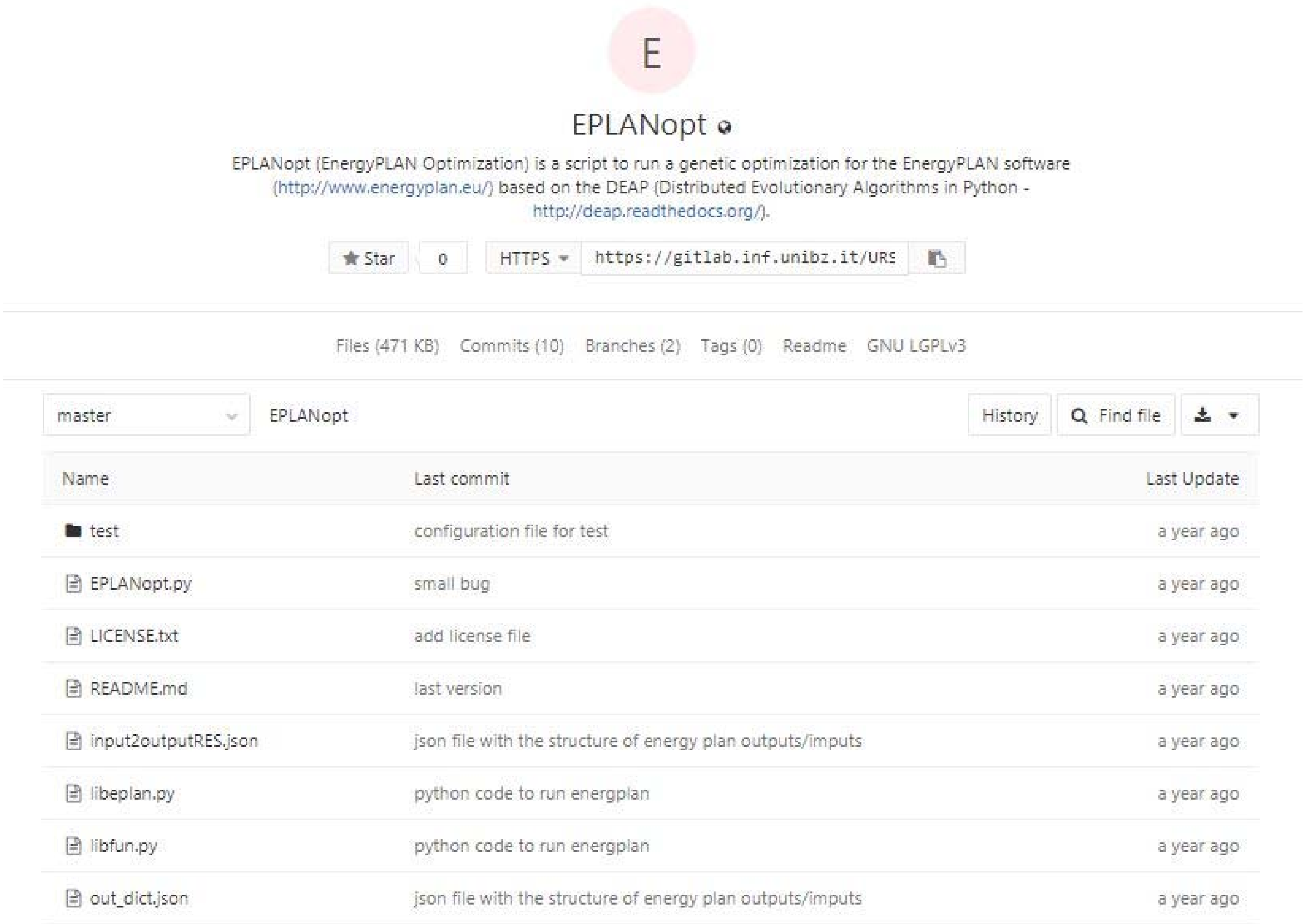
Multi objective
evolutionary algorithm
MOEA (DEAP)



Methodology: the energy model, EPLANopt



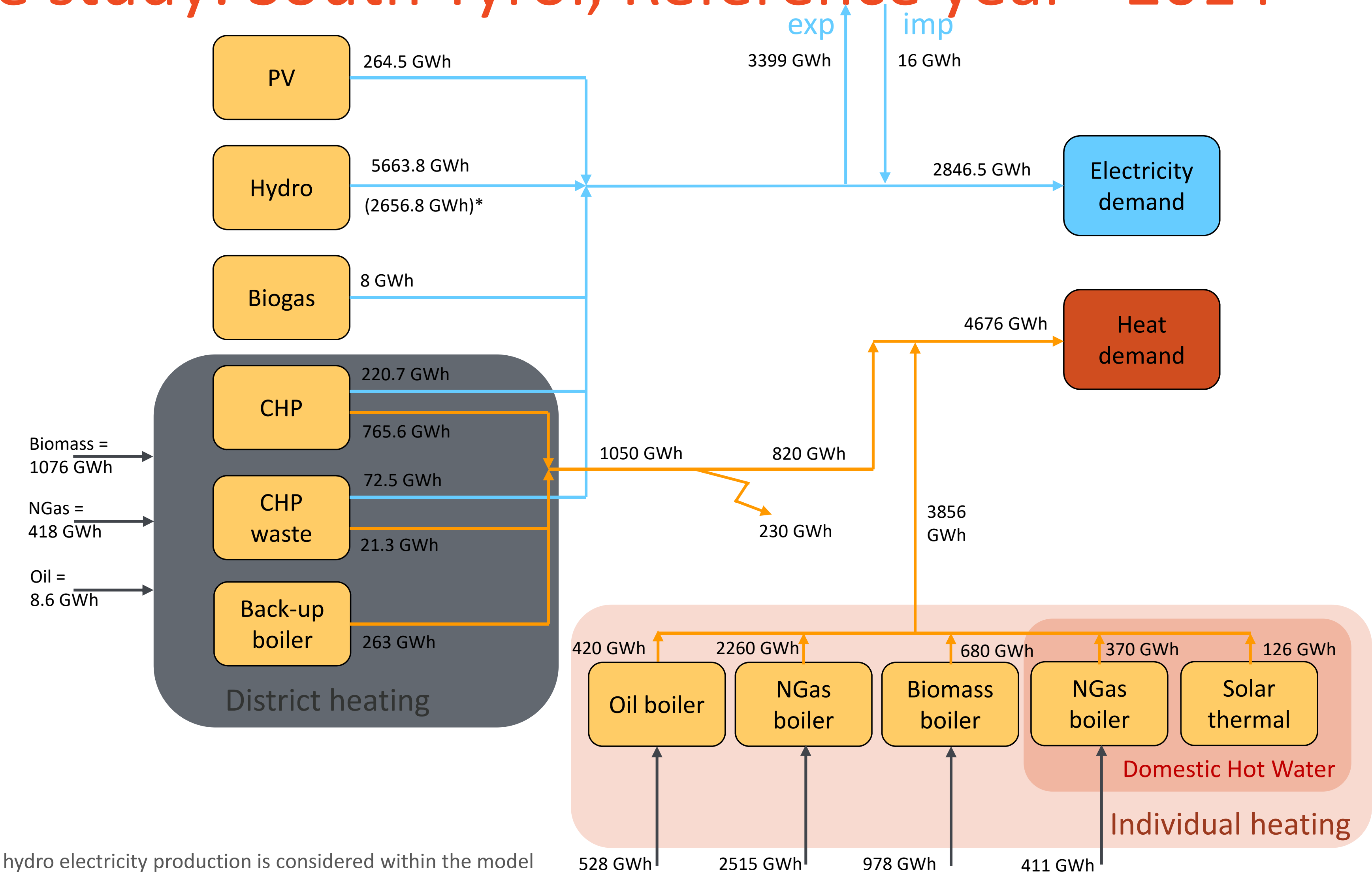
Methodology: the energy model, EPLANopt



https://gitlab.inf.unibz.it/URS/EPLANopt

Main characteristics:
- **Open source**
- Multi-objective optimization with **n-objectives**
- Possibility to **easily change operators and parameters** of the genetic algorithm (type of crossover, mutation, mutation rate,..)
- Possibility to **initialize** part of the population **with known solution** (seeding the population)
- Easy parameters and **data setting** through **.json file**
- Possibility of **parallelization**
- **Documentation** and simple **example provided**

Case study: South Tyrol, Reference year - 2014

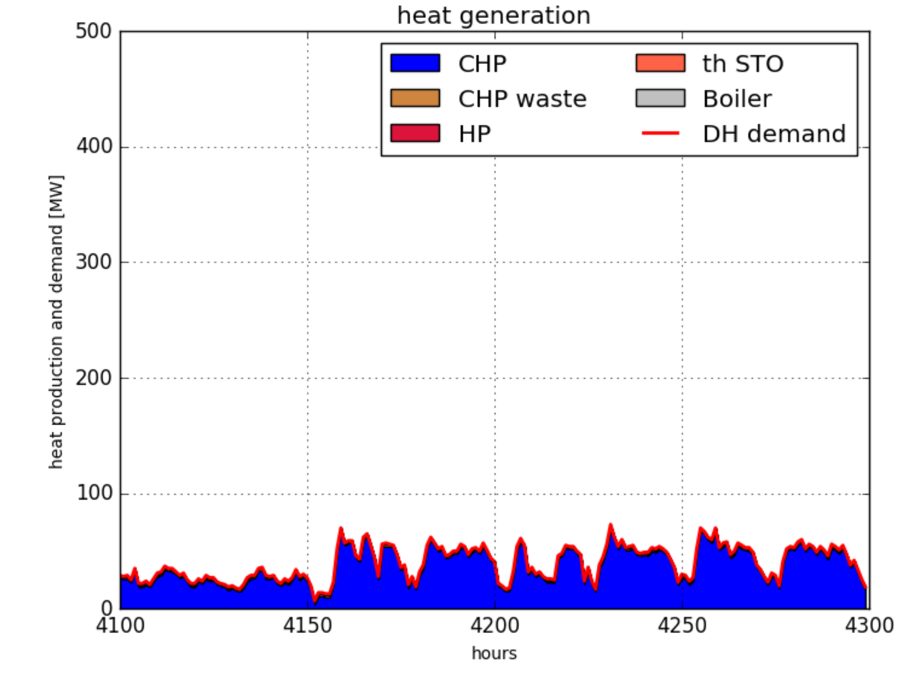


*if only River hydro electricity production is considered within the model

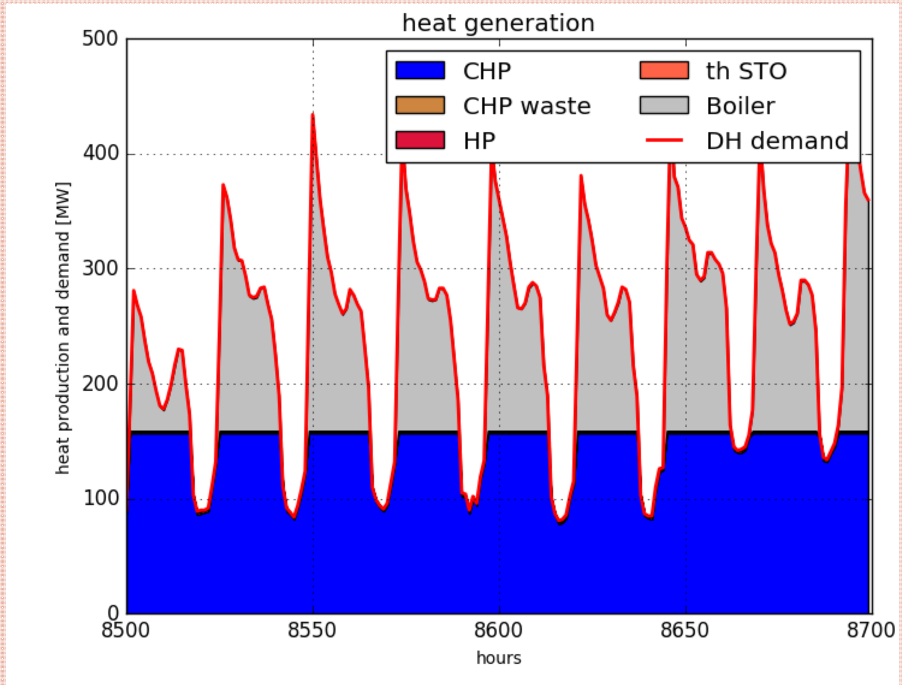
Reference scenario – district heating production

District heating

Week in summer



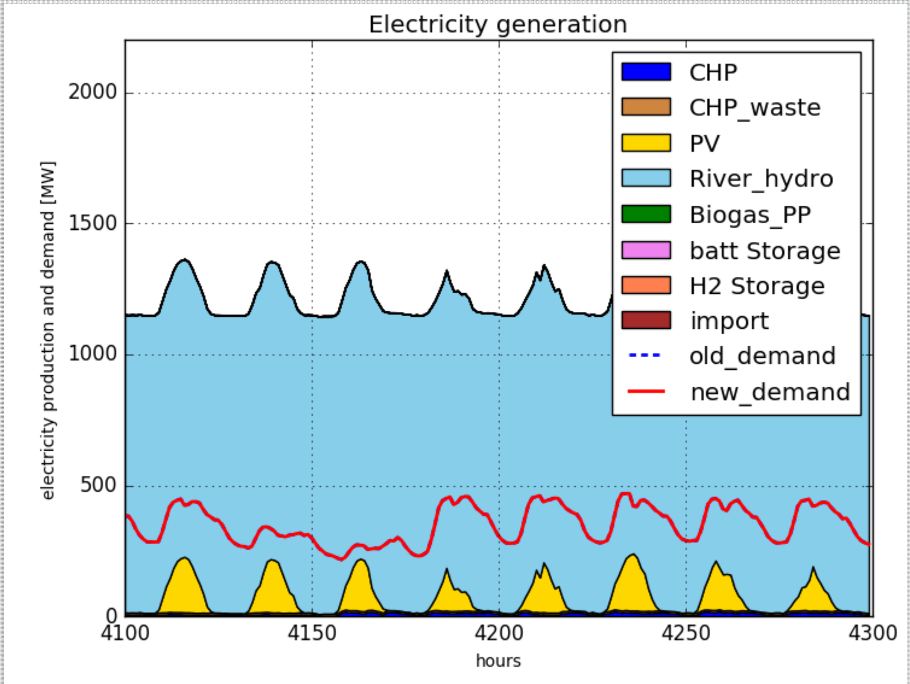
Week in winter



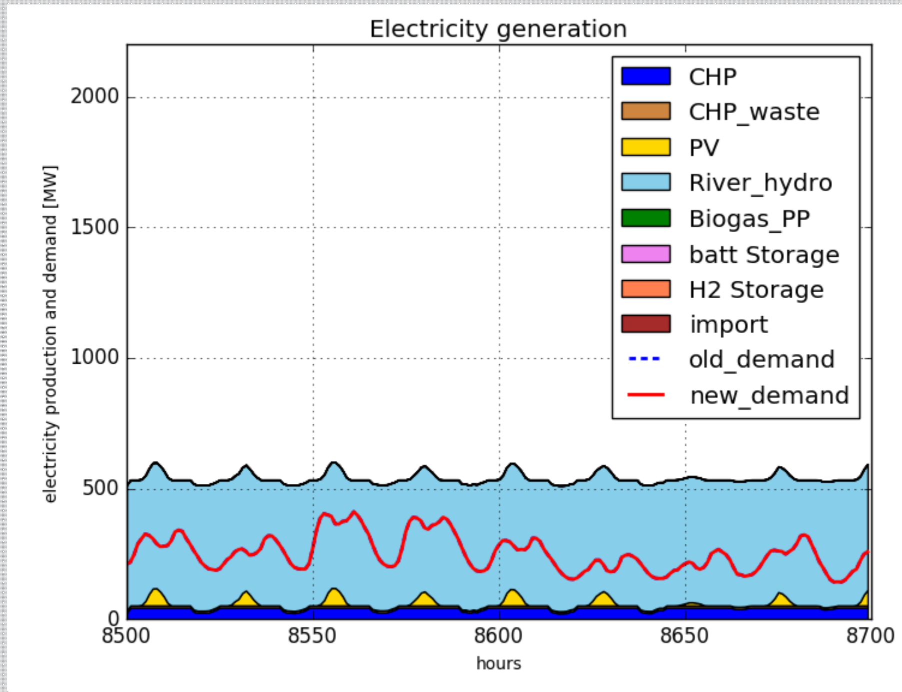
Reference scenario – Electricity production

Electricity

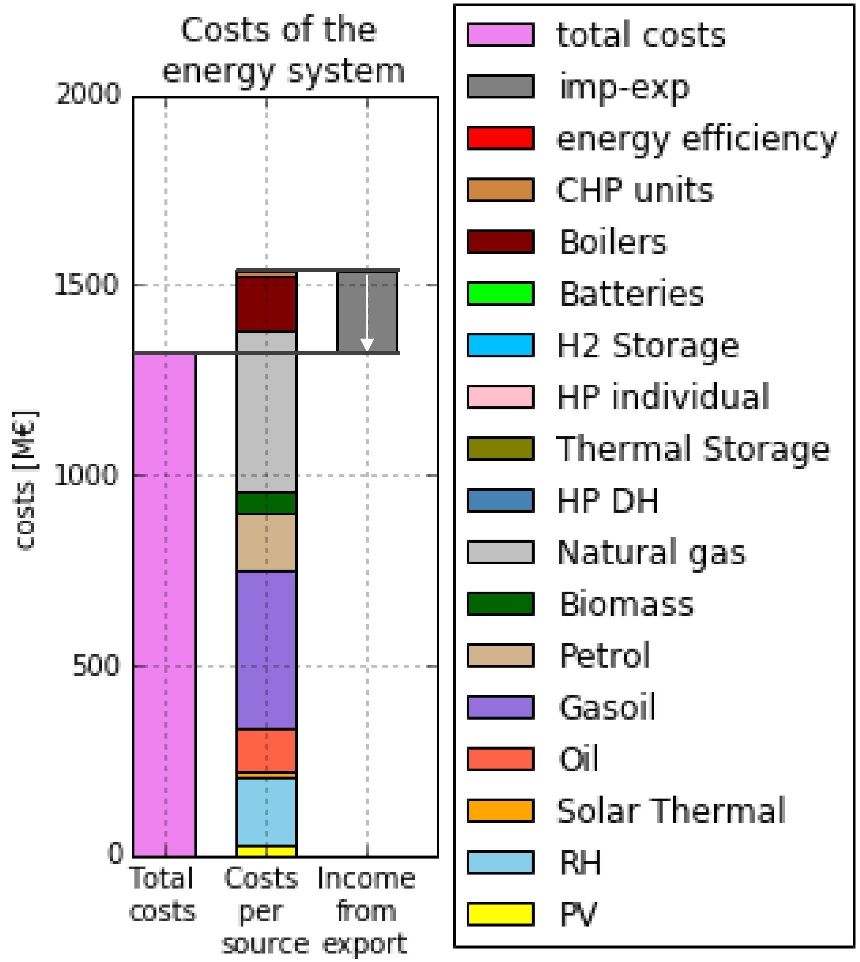
Week in summer



Week in winter



Reference scenario – financial data



Total annual costs include investment costs, operation and maintenance costs and fuel costs for each technology.

Key assumptions and constrains

Which technology might be applied on which scale?

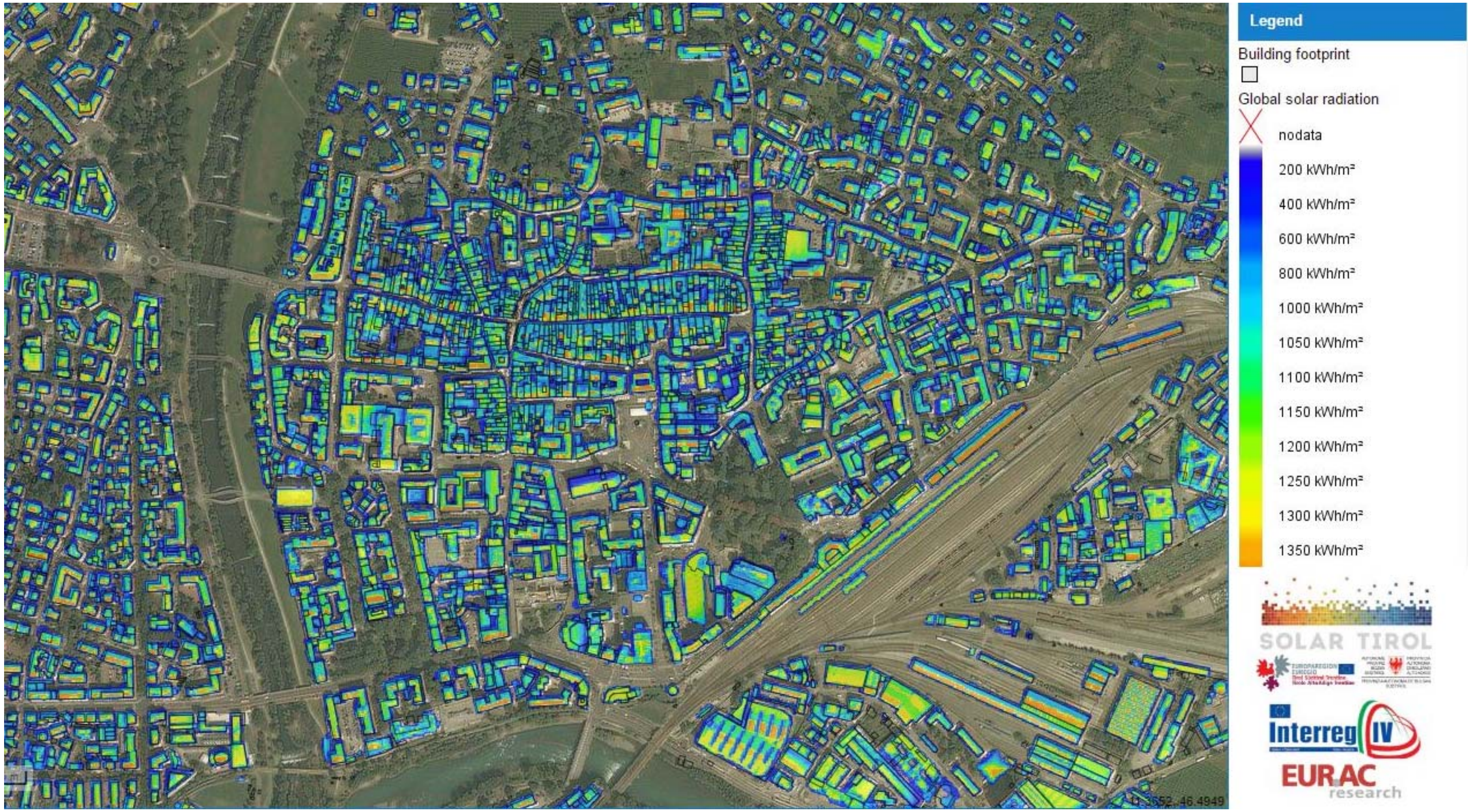
Key assumptions and constrains for a possible application of single technologies are listed in the table. PV assumptions are based on the simulations carried out within the SolarTirol project

It is shown in which steps the range of application of a single technology has been considered in the single simulation iterations.

	Simulation range (step)
PV [MW]	250 – 1250 (25)
Biogas power plants [MW]	0- 10 (10)
Electric storage Batteries [GWh]	0 – 10 (1)
Electric storage Hydrogen [GWh]	0 – 500 (10)
Electrolyser [MW]	0 – 1500 (100)
Fuel cell [MW]	0 – 1500 (100)
Large heat pumps [MW]	0 – 30 (5)
Seasonal thermal storage [GWh]	0 – 100 (10)
Solar thermal [GWh_th]	126 -500 (50)
Heat pumps individuals [%]	0 – %Energy Eff.
Energy efficiency [%]	0 – 75 (5)

Application of heat pumps in the building stock has been allowed in the model only after deep energy refurbishment of the building.

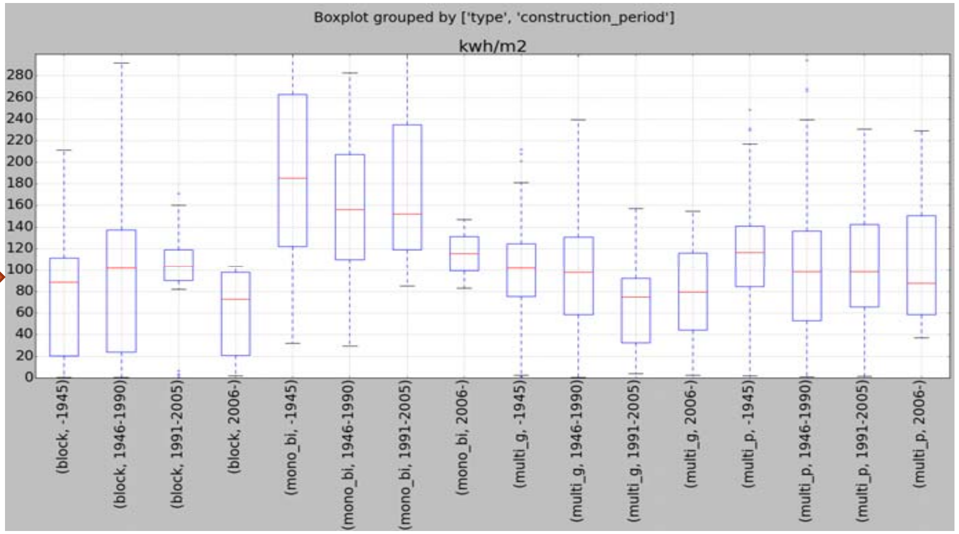
PV potential [240 - 1250] MW

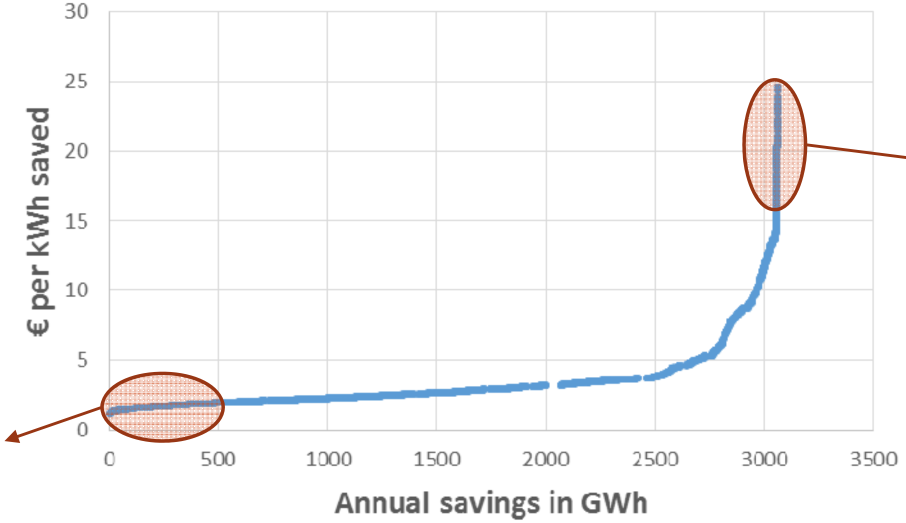


Through the Solar tyrol project is possible to estimate the maximum rooftop PV potential for the South Tyrol area that is equal to 1250 MW (while the current installed power is equal to 240.5 MW).

Energy efficiency

1. **Analysis and classification** of the provincial residential **building stock: construction period**, the **types of buildings** (single family house, multi family house, detached, block) and the heating degree days (**HDD**).
2. **Evaluation** of the **specific heat consumption** for each municipality, construction period, and type of buildings.
3. **Assessment of the cost of retrofit** and the **actual energy savings** associated to retrofit measures (through Passive House Planning Package (**PHPP**) **simulations** launched to evaluate the thermal energy consumption in post-retrofit conditions)
4. **Assumption** that the **energy saving percentage** is **the same regardless** of the **municipality** and the **construction period** of the buildings.
5. Possible to calculate the **annual thermal energy savings** for each construction period and type of building and also the value of the **euro per kWh saved**. The results obtained show therefore higher values of energy savings for municipalities with colder climates.

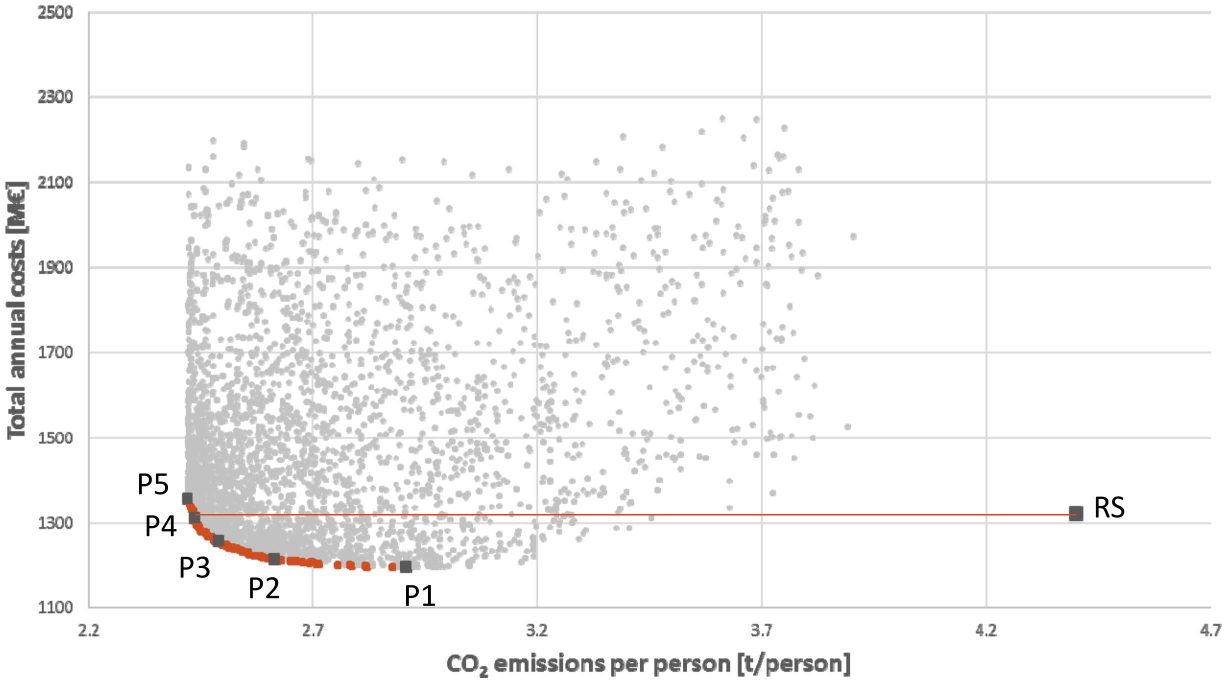




Measures that produce low energy savings compared to the costs (window replacement for new houses)

Measures that produce high energy savings compared to the costs (roof insulation for old SFH built before 1946, façade insulation and basement insulation)

Simulation result clowd – Hydro tot

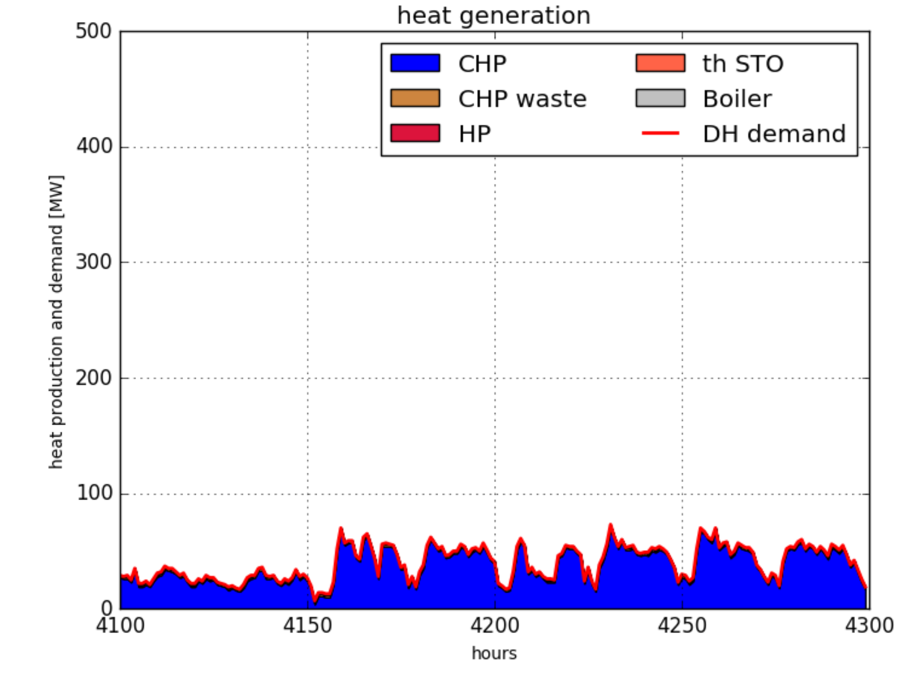


	PV [MW]	*Biogas [MW]*	*Batteries [GWh]*	*H2 [GWh]*	*H2 electrolyser [MW]*	*H2 fuel cell [MW]*	*HP DH [MW]*	*th STO DH [GWh]*	*Solar thermal [TWh]*	*HPs ind [GWh_th]*	*En. Eff. [%]*	*CO2 emissions per person [t/person]*	*Total annual costs [M€]*	*100 - %RES*
RS	250	0	0	0	0	0	0	0	0.1	0	0	4.40	1323	45.5
P1	250	10	0	0	0	0	0	10	0.3	420	47	2.90	1196	27.3
P2	275	10	0	0	0	0	0	10	0.3	582	65	2.61	1215	18.0
P3	400	10	0	0	0	0	0	10	0.3	653	73	2.49	1258	13.1
P4	800	10	0	0	0	0	0	10	0.5	671	75	2.43	1312	10.6
P5	875	10	0	20	100	100	0	10	0.5	671	75	2.42	1359	10.2

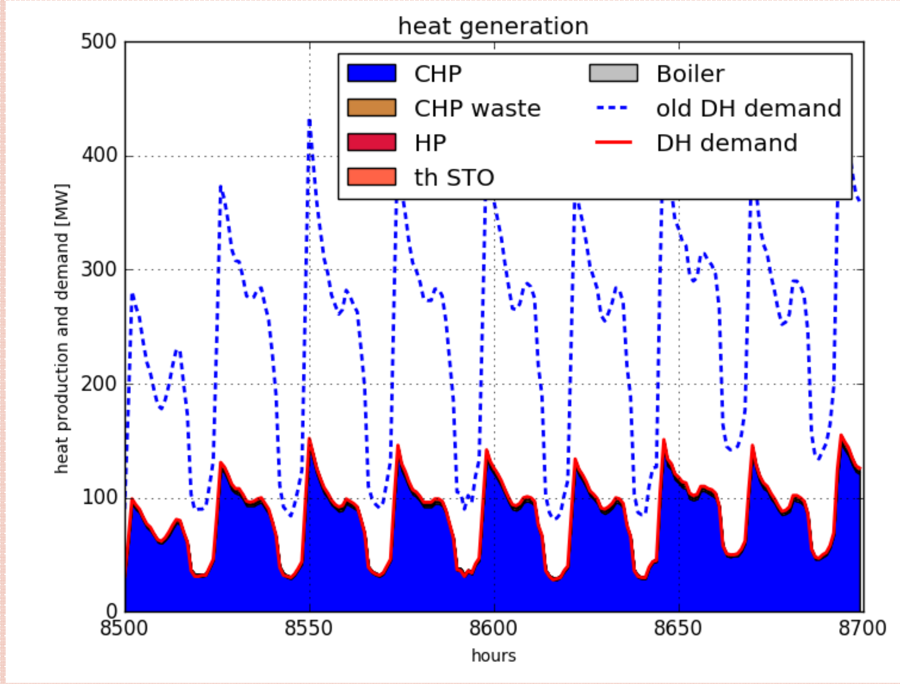
P4 – district heating production

District heating

Week in summer



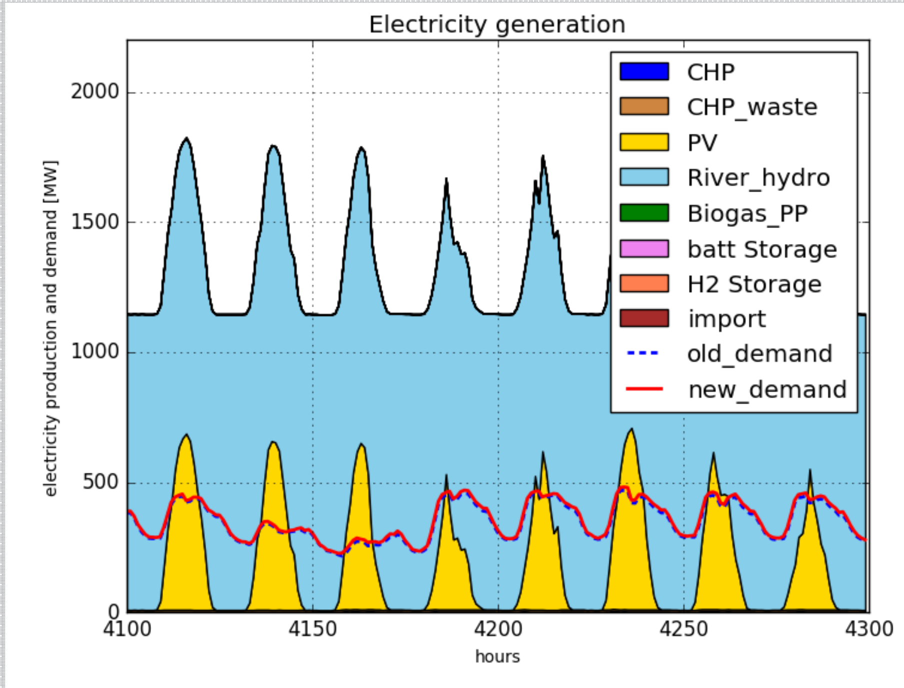
Week in winter



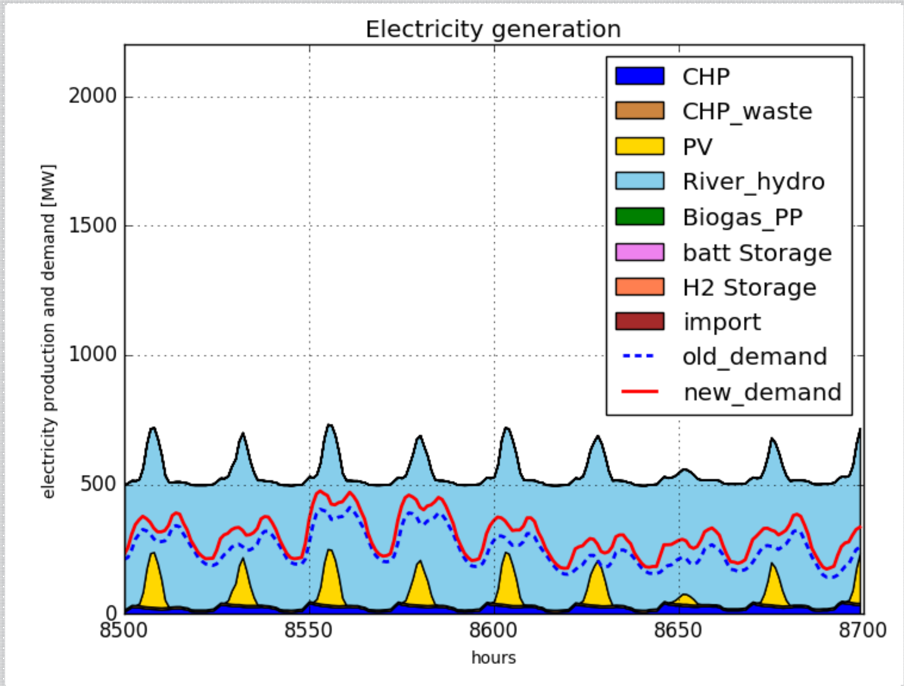
P4 – Electricity production

Electricity

Week in summer

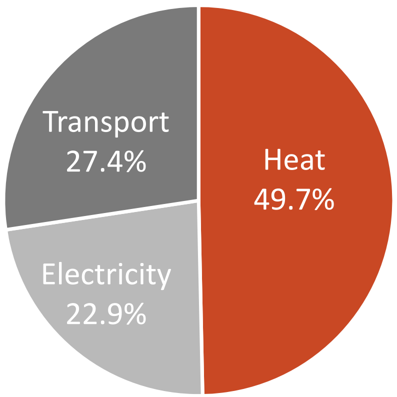


Week in winter

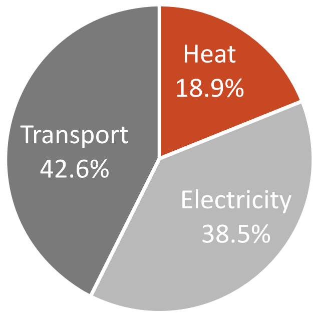


P4– energy consumption

Reference scenario



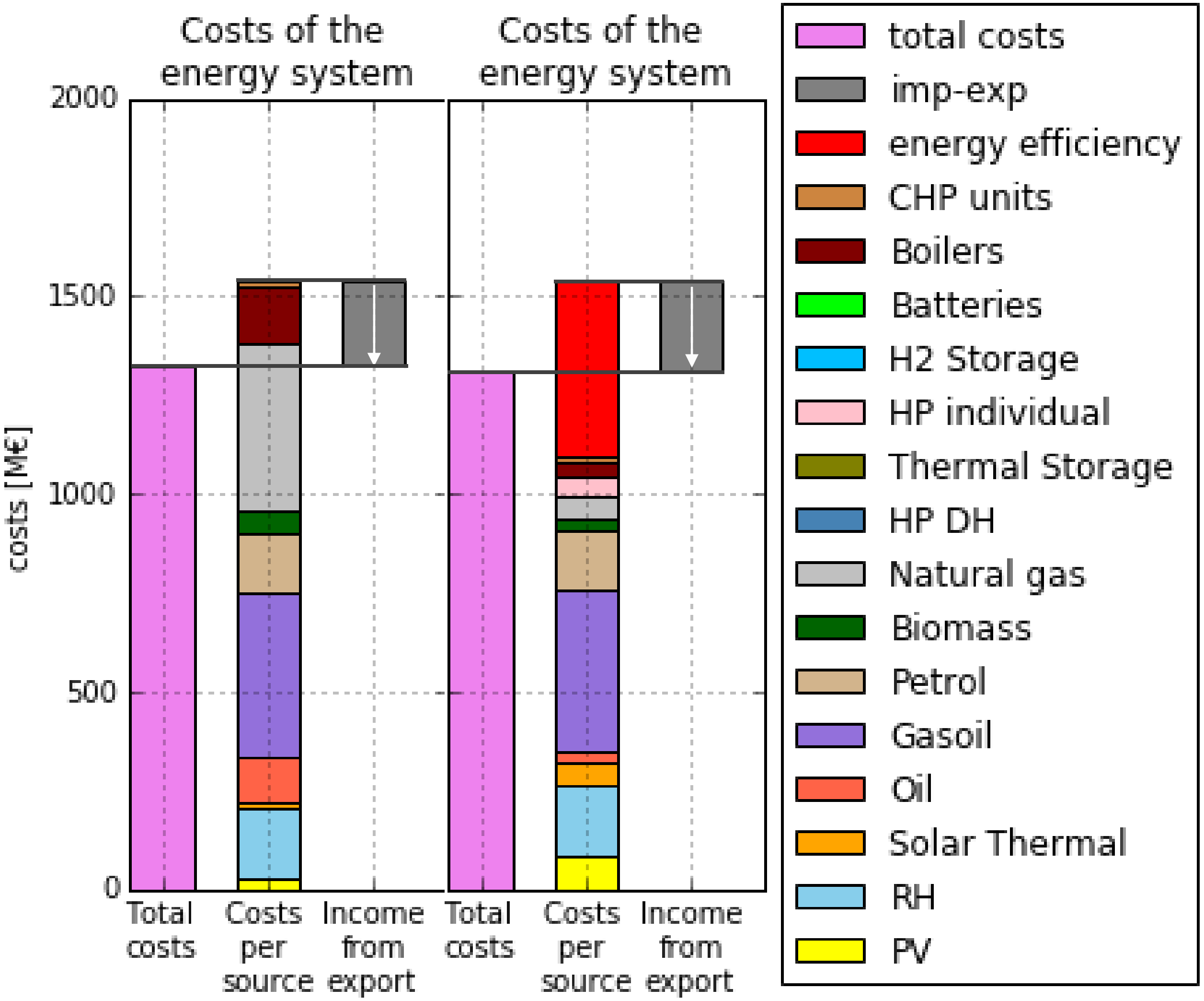
P4



Overall energy consumption:	12.4 TWh	7.9 TWh

P4– financial data

RS



P4

Conclusions

- **EPLANopt** model couples energyPLAN software with a multi-objective evolutionary algorithm
  - Open source
  - n-objectives
  - Parallelization of the code, low computational time
- Through an external code has been possible to consider **energy efficiency variable** within energyPLAN simulation tool and adding a constraint on individual heat pumps
- The methodology has been applied to a case study, the provincial area of **South Tyrol**, and the final results presented
- The following methodology allows for identifying the **future optimal mix** configuration of an energy system starting from the **current situation** and **potentials of renewables** or different sources.
- Multi-objective optimization approach provides more informations to the decision makers or policy makers if compared to single-objective approach.

Thanks for your attention

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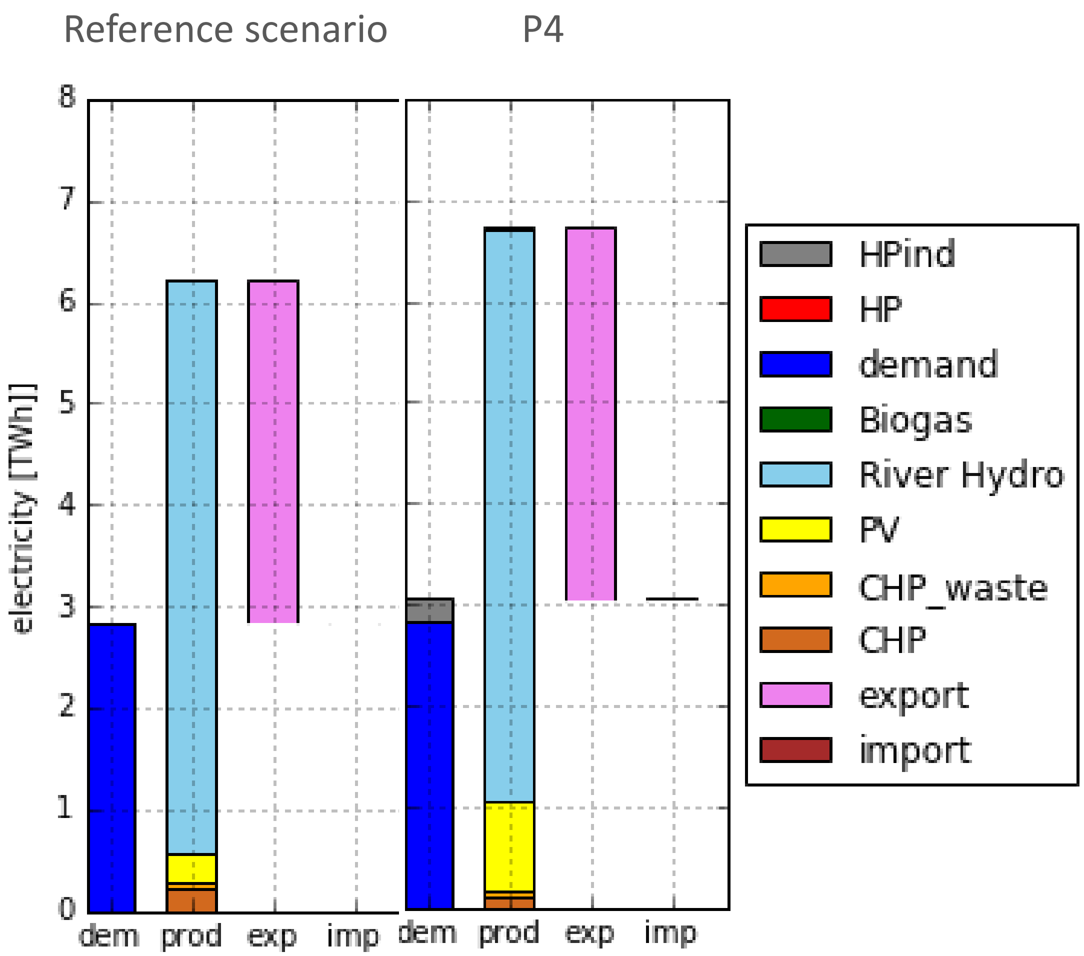
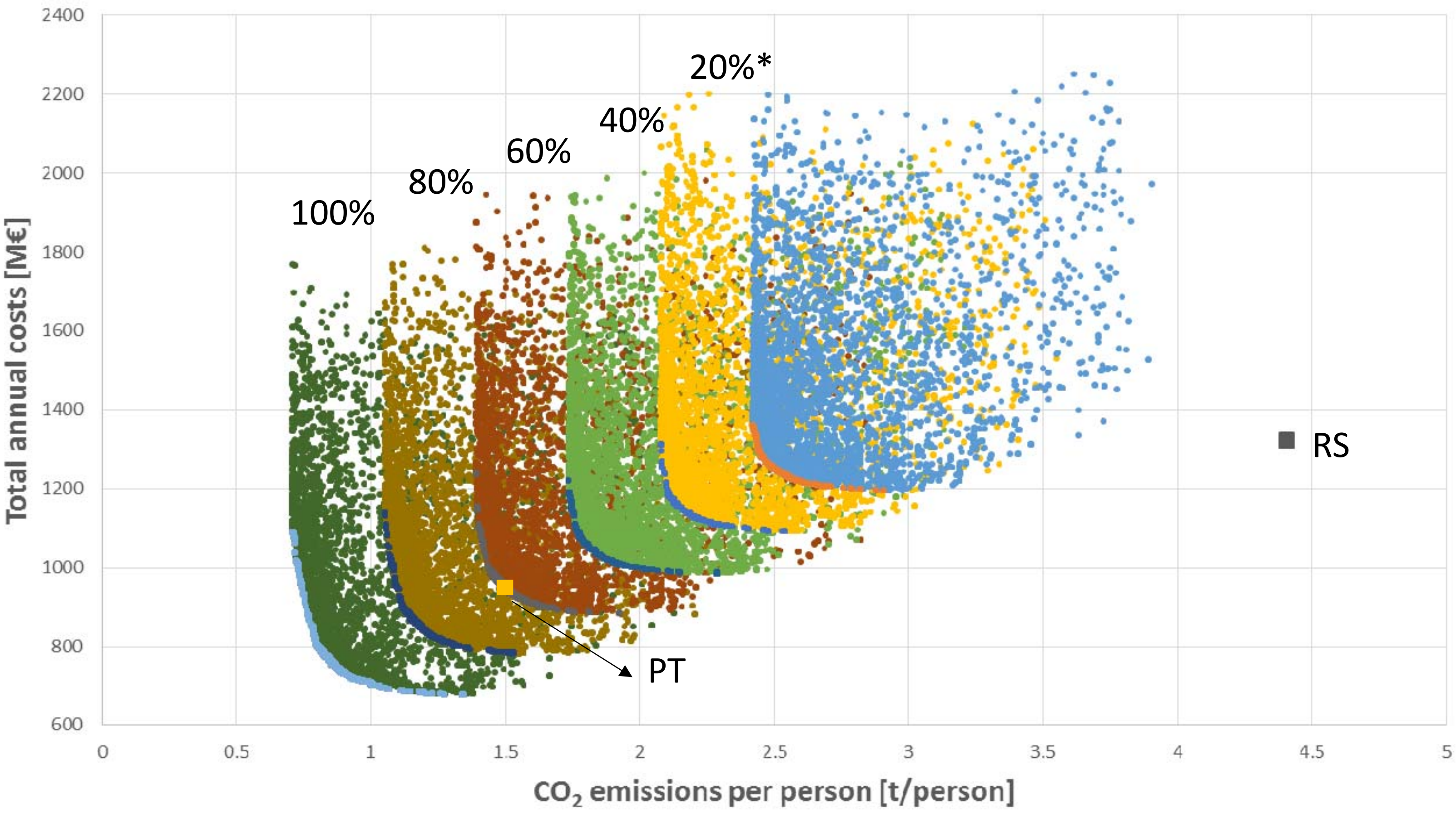
P4 – Electricity annual balance



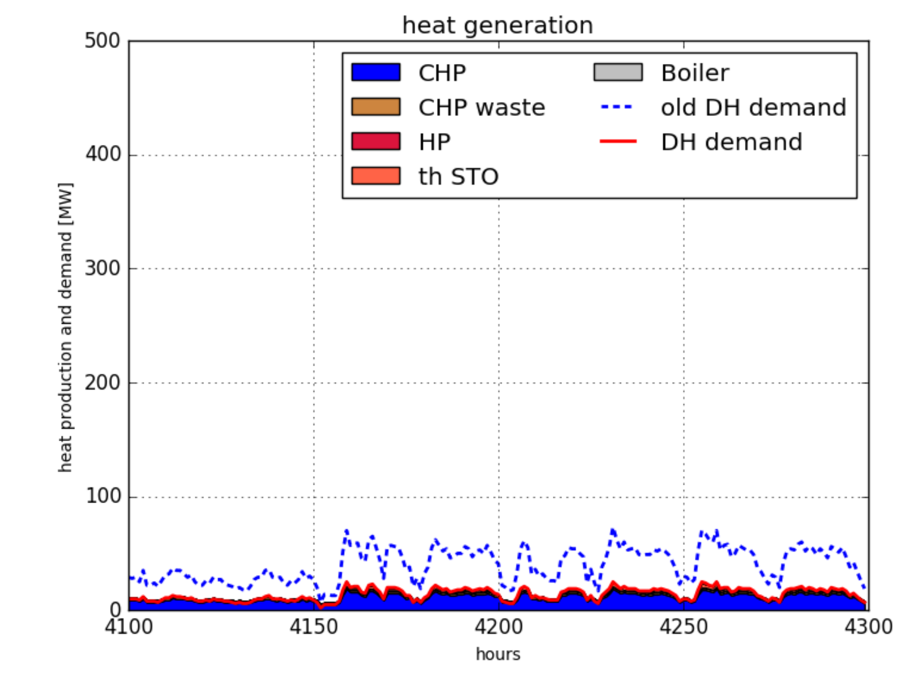
Zero emission transports



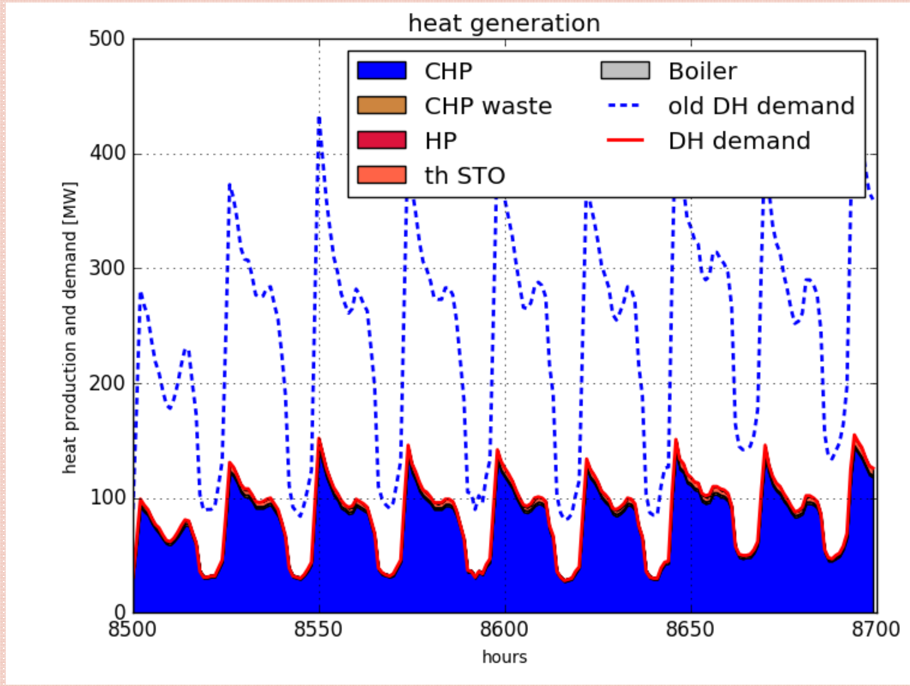
PT – district heating production

District heating

Week in summer



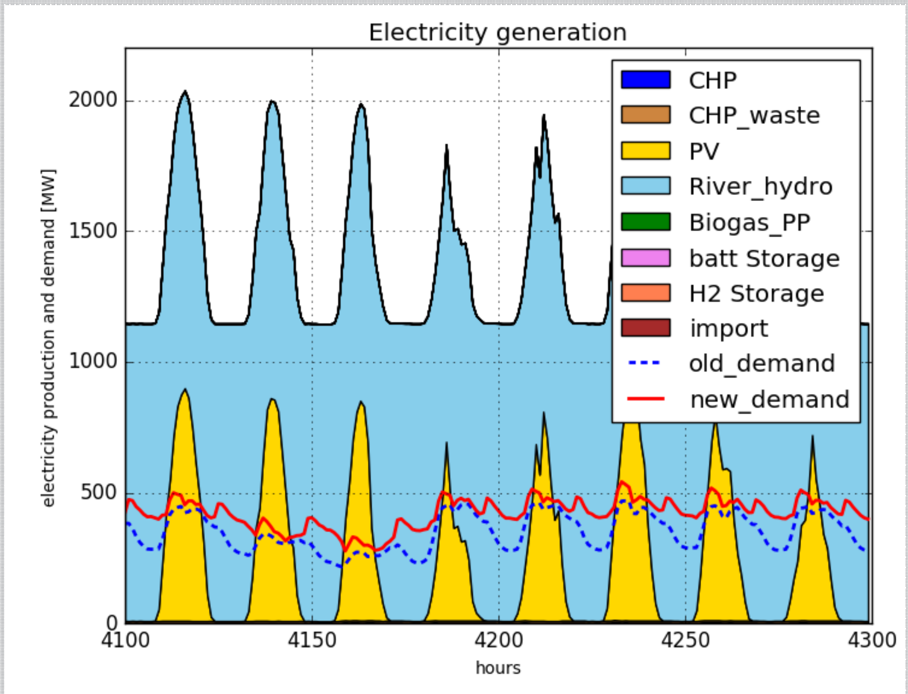
Week in winter



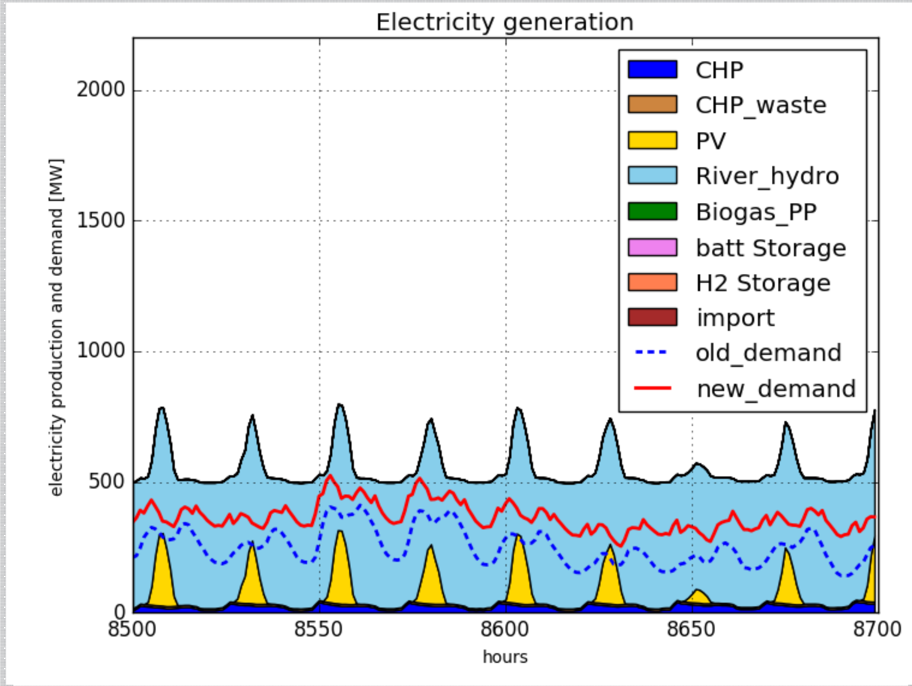
PT – Electricity production

Electricity

Week in summer

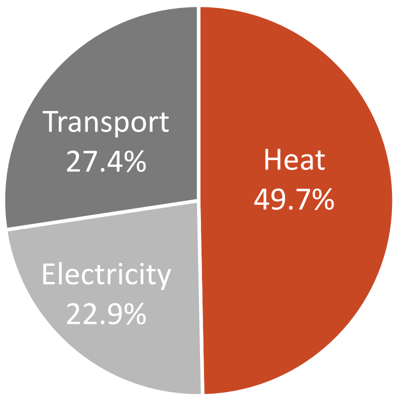


Week in winter

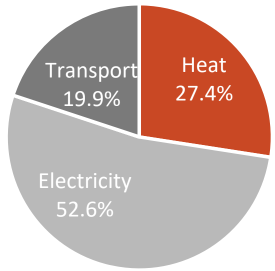


PT – energy data

Reference scenario

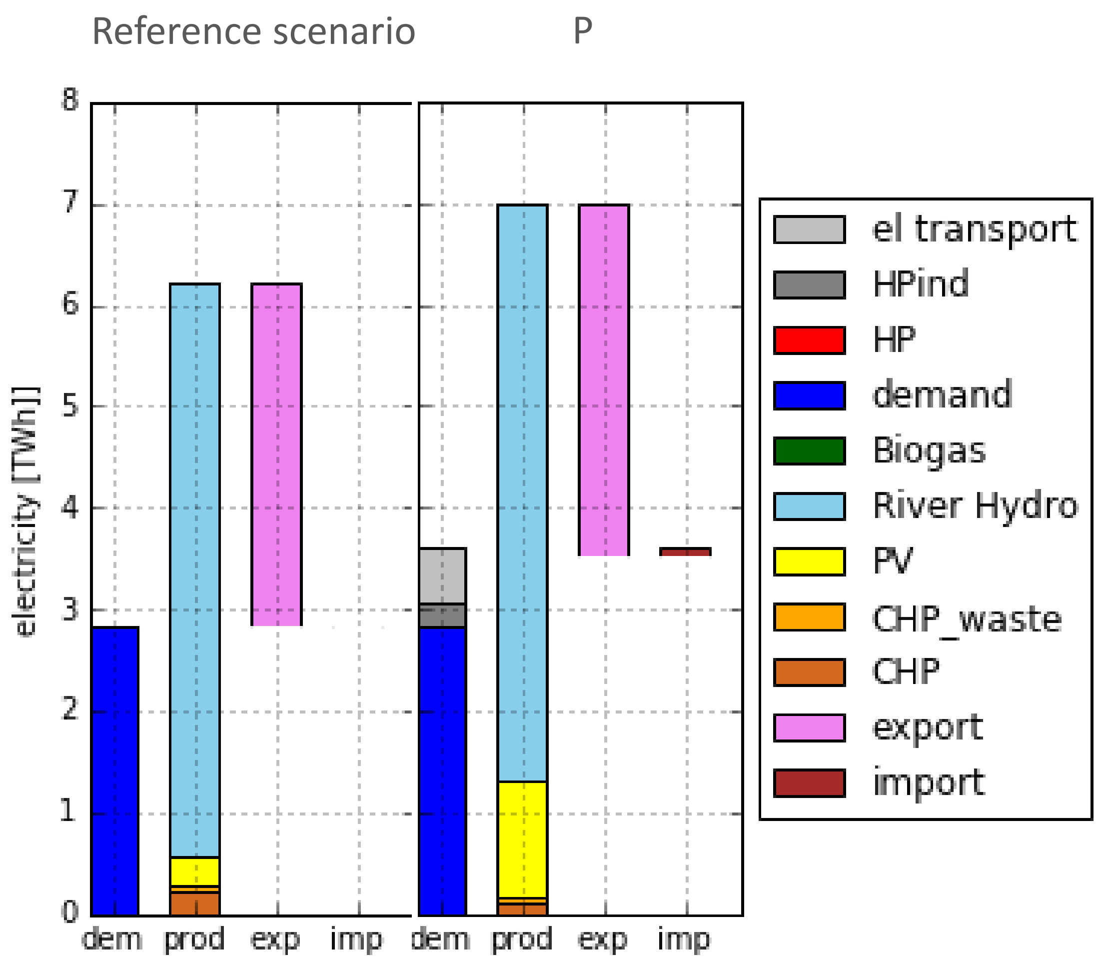


PT



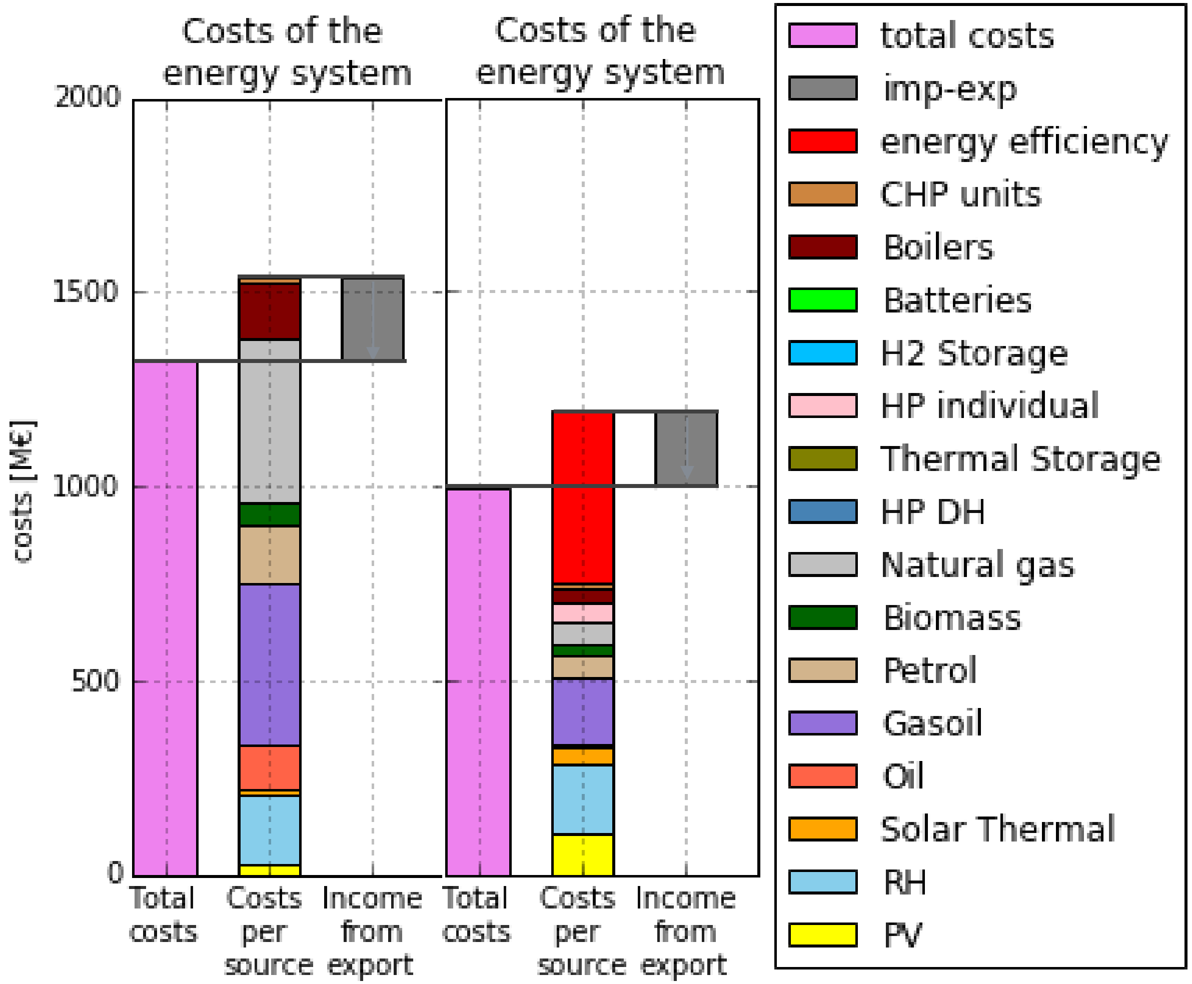
Overall energy consumption:	12.4 TWh	6.8 TWh

PT – Electricity annual balance



PT – financial data

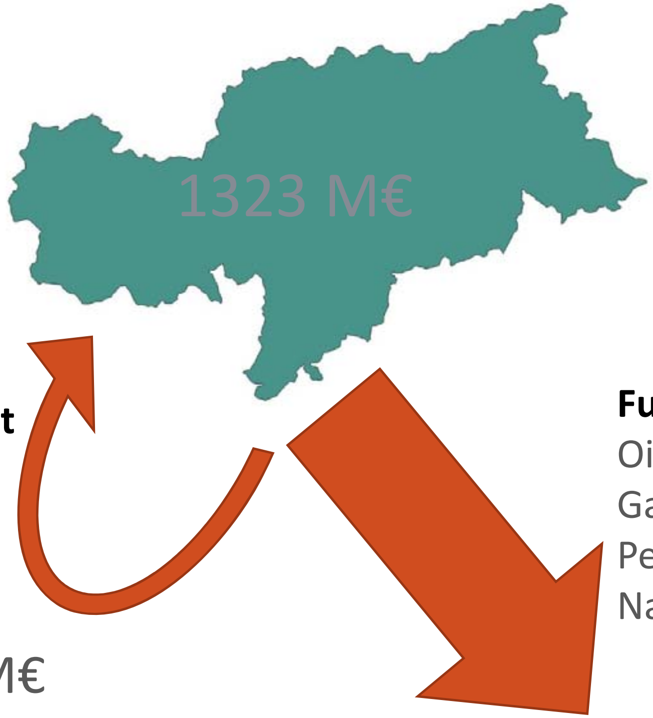
RS



PT

financial data

Reference scenario



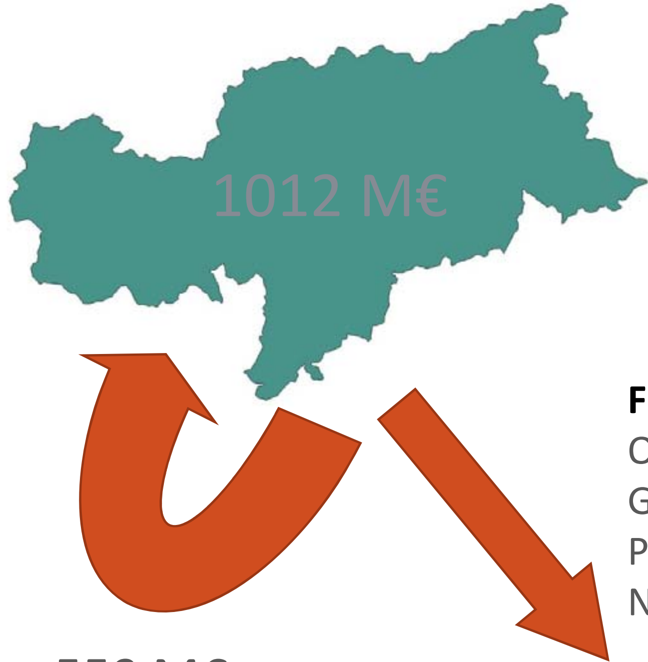
Local investment and O&M costs

220 M€

Fuel costs:
Oil
Gasoil
Petrol
Natural gas

1103 M€

Point PT



Local investment and O&M costs

+

Energy efficiency costs

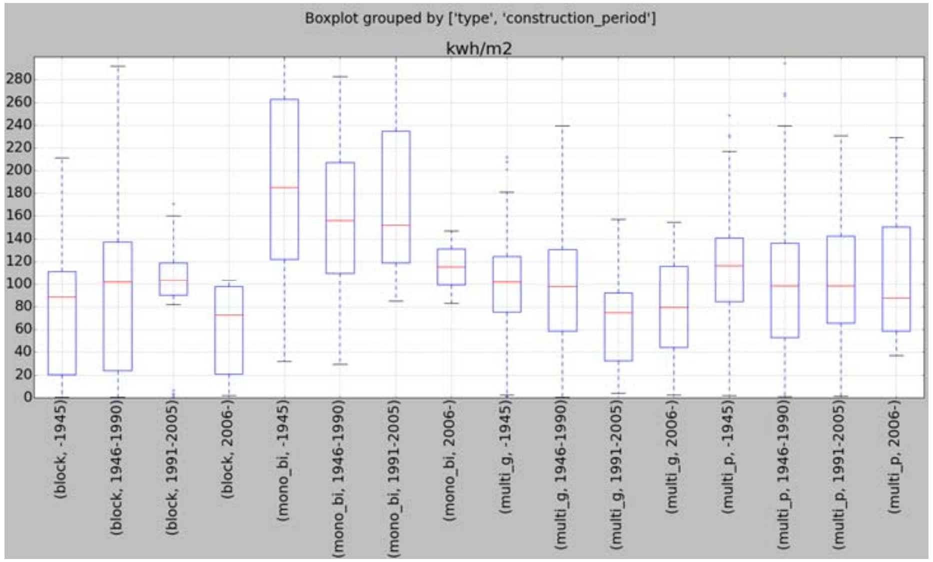
559 M€

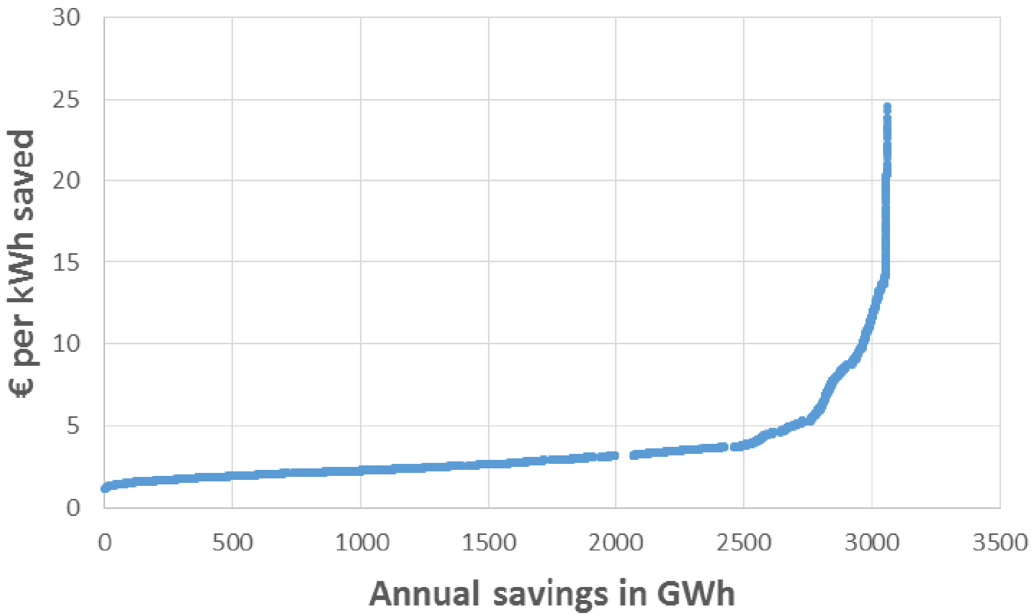
Fuel costs:
Oil
Gasoil
Petrol
Natural gas

453 M€

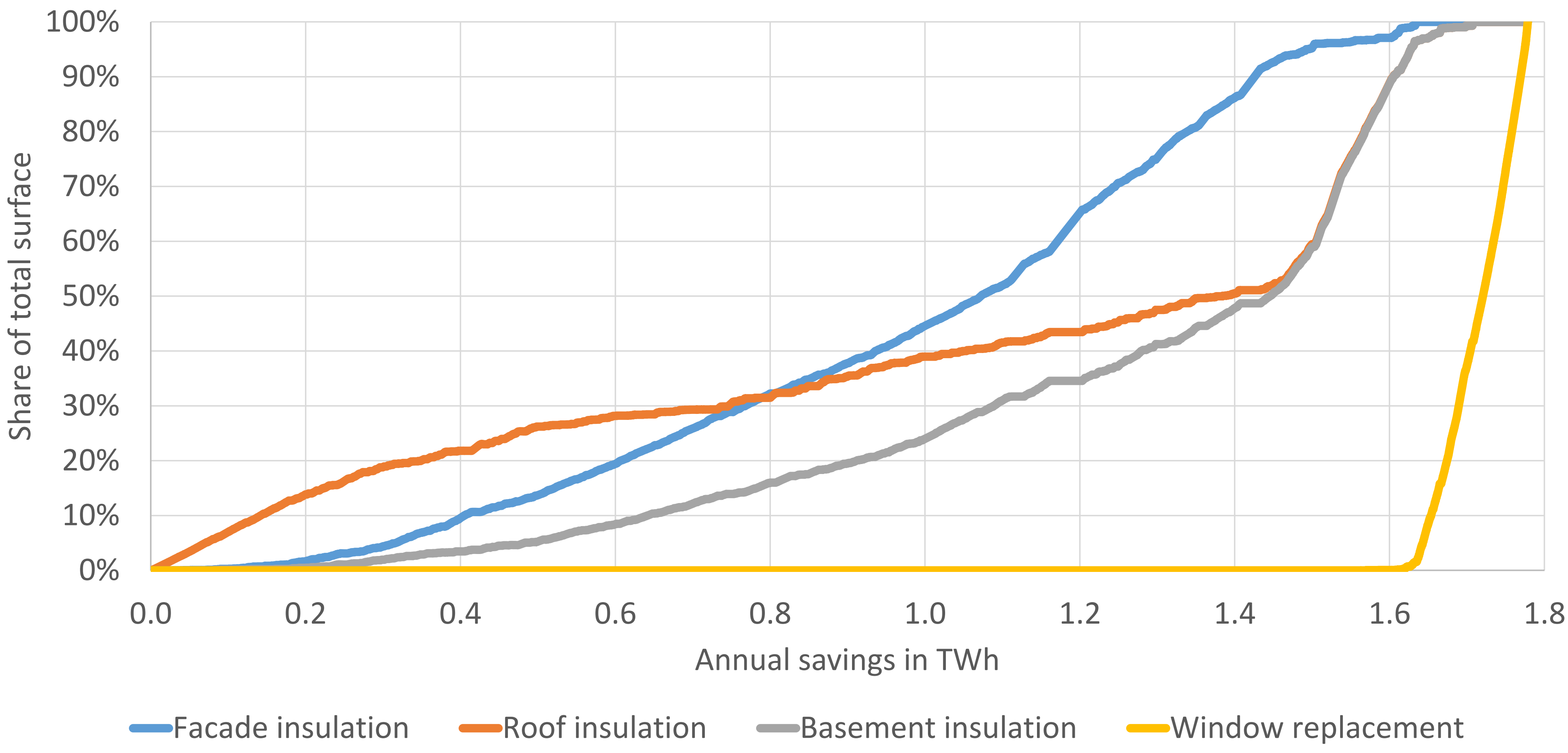
Energy efficiency

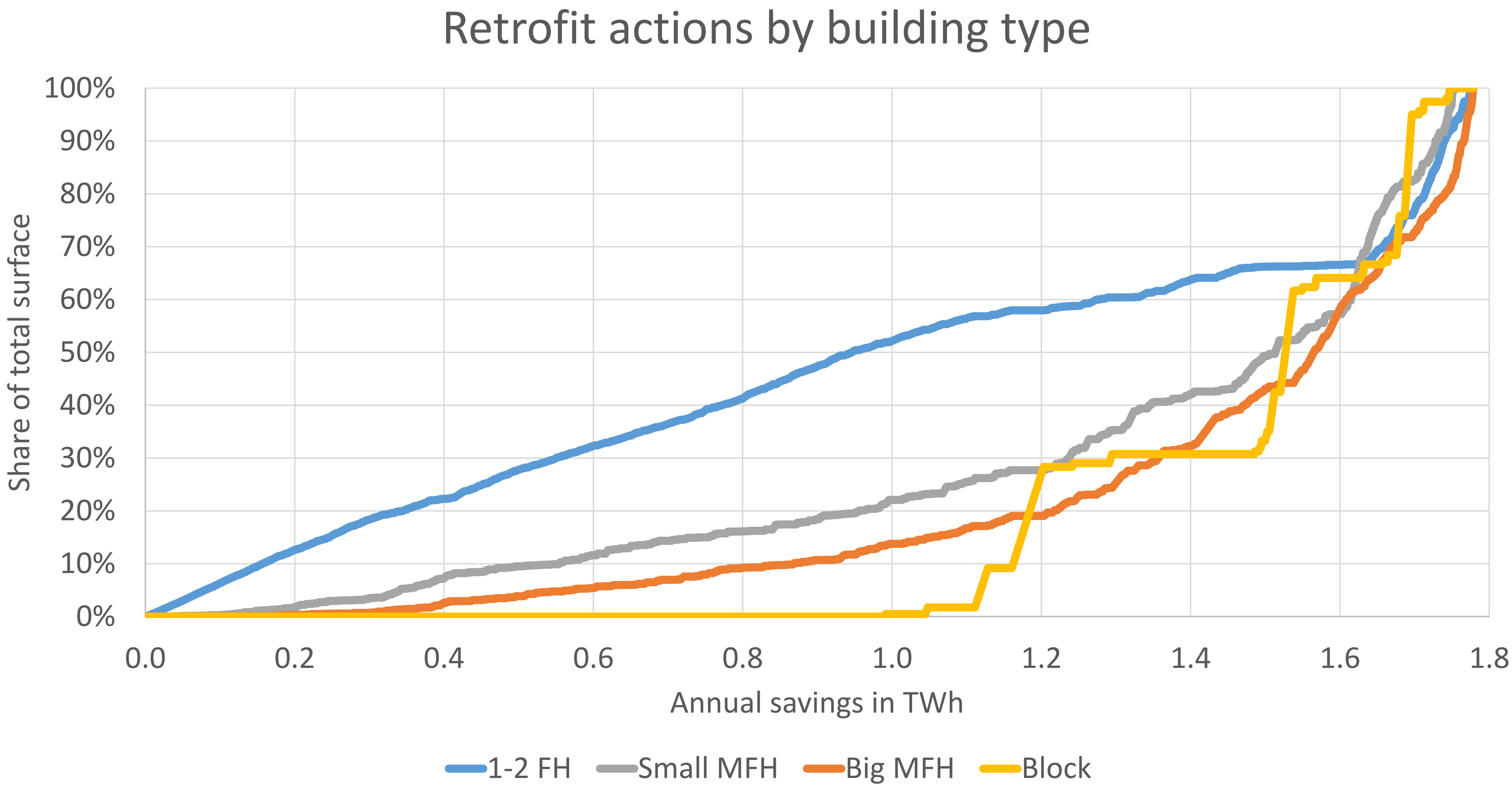
1. **Analysis** of the provincial residential **building stock** and **classification** according to the **construction period**, the **types of buildings** (single family house, multi family house, detached, block) and the heating degree days (**HDD**).
2. **Evaluation** of the **specific heat consumption** for each municipality, construction period, and type of buildings.
3. **Assessment of the cost of retrofit** and the **actual energy savings** associated to retrofit measures. Passive House Planning Package (**PHPP**) **simulations** have been carried out for the following four types of housing: single family house (SFH) 250 m², multi family house (MFH) 904 m², detached 1363 m² and block 2308 m². PHPP simulations were launched to evaluate the thermal energy consumption in post-retrofit conditions with the aim of quantifying actual energy savings.
4. Assumption that the **energy saving percentage** is **the same regardless** of the **municipality** and the **construction period** of the buildings.
5. Possible to calculate the **annual thermal energy savings** for each construction period and type of building and also the value of the euro per kWh saved. The results obtained show therefore higher values of energy savings for municipalities with colder climates.





Retrofit actions – all residential buildings





Retrofit actions by building type
Share of total surface
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
Annual savings in TWh
1-2 FH
Small MFH
Big MFH
Block

Retrofit actions by construction period