4DH
4th Generation District Heating Technologies and Systems

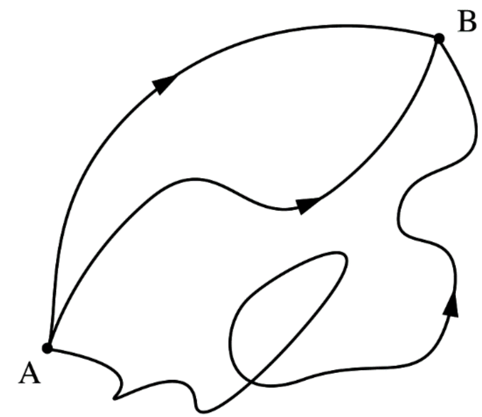
4th International Conference on Smart Energy Systems and 4th Generation District Heating
Aalborg, 13-14 November 2018

eurac research
POLITECNICO MILANO 1863
AALBORG UNIVERSITY DENMARK

Creating optimal transition pathways from 2015 to 2050 towards low carbon energy systems using the EnergyPLAN software: methodology and application to South Tyrol

Matteo Giacomo Prina, Marco Cozzini, Federica Lombardi, Henrik Lund, Giampaolo Manzolini, David Moser, Ulrich Filippi Oberegger, Poul Alberg Østergaard, Roberto Vaccaro, Wolfram Sparber
Institute for Renewable Energy, EURAC Research, Viale Druso 1, I-39100 Bolzano, Italy
Dipartimento di energia, Politecnico di Milano, Via Lambruschini, 4, 20156 Milano (MI), Italy
Department of Planning, Aalborg University, Rendsburggade 14, 9000 Aalborg, Denmark

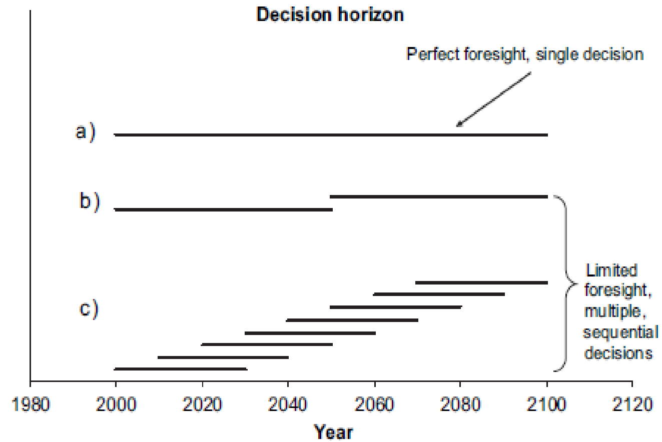
Introduction



Energy system models

- Top-Down models
- Bottom-up models
  - Static or short-term models
  - Long-term models
    - Perfect foresight
    - Myopic

- «Perfect-foresight» optimization
  - Assumes decision maker is provided full information about future costs and constraints
  - The optimization problem is solved once, considering the whole timeframe
- «Myopic» optimization
  - The decision maker has a limited view of the future
  - A set of optimization problems has to be solved, where solution of previous problems is used as input for the latter ones



Keppo, Strubegger - "Short term decisions for long term problems – The effect of foresight on model based energy systems analysis"

State of the art

Model and references	*Time-horizon*	*Time-step*	*Scope*	*Objective function*	*Critical aspects*
MARKAL/TIMES,	Long-term (perfect foresight)	Time-slices	Optimization	Min. cumulated costs	Poor time-discretization Uses proprietary software
OSeMOSYS	Long-term (perfect foresight)	Time-slices	Optimization	Min. cumulated costs	Poor time-discretization
Temoa	Long-term (perfect foresight)	Time-slices	Optimization	Min. cumulated costs	Poor time-discretization Heavy computational burden
EnergyPLAN	Static	Hours	Simulation	-	Cannot perform optimization
I. Batas Bjelić et al.	Static	Hours	Optimization	Min. annual costs	Static model
M. S. Mahbub et al.	Static	Hours	Optimization	Min. annual costs Min. Annual CO_2 emissions	Static model
M. S. Mahbub et al.	Long-term (myopic approach)	Hours	Optimization	Min. annual costs Min. Annual CO_2 emissions	Myopic approach
EPLANopt	Static	Hours	Optimization	Min. annual costs Min. Annual CO_2 emissions	Static model
EPLANoptTP	Long-term (perfect foresight)	Hours	Optimization	Min. cumulated costs Min. cumulated CO_2 emissions	Heavy computational burden at the increasing of decision variables number

NOVELTY:

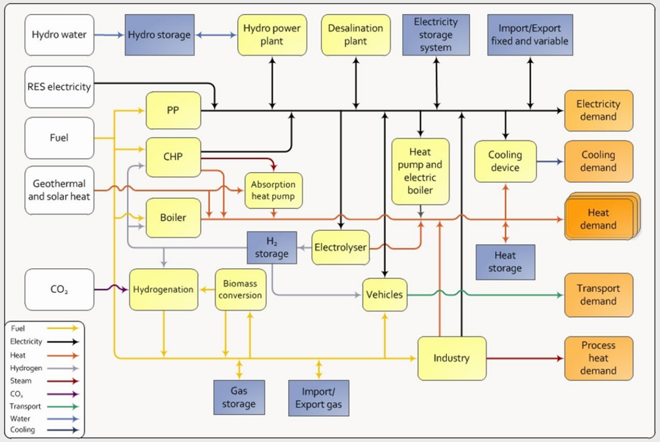
- High time resolution
- Multi-objective optimization including cumulated CO_2 emissions

EPLANopt

M. G. Prina, M. Cozzini, G. Garegnani, G. Manzolini, D. Moser, U. F. Oberegger, R. Pernetti, R. Vaccaro, W. Sparber, "Multi-objective optimization algorithm coupled to EnergyPLAN software: The EPLANopt model," Energy, vol. 149, pp. 213–221, Apr. 2018.

Already implemented

- **Deterministic simulation model**
- Future scenarios with **high degrees of renewable** energy sources (RES)
- It simulate one-year periods with a **temporal resolution** of one **hour**
- **Integration** of **three** primary **sectors** of any national energy systems.
- Possibility to launch it from command prompt line. And so the **possibility** to create an **external code** in order to run serial simulations.



What is new?

Model n objectives

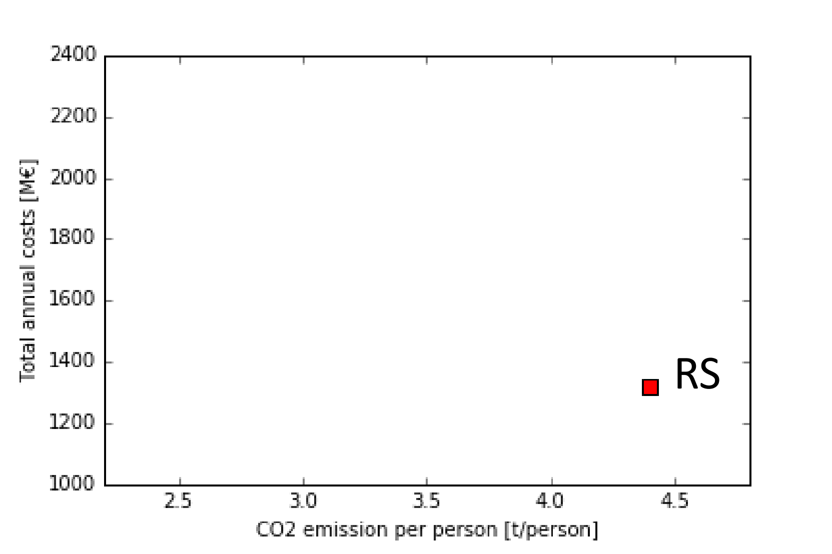
Simulation model

EnergyPLAN (Aalborg University)

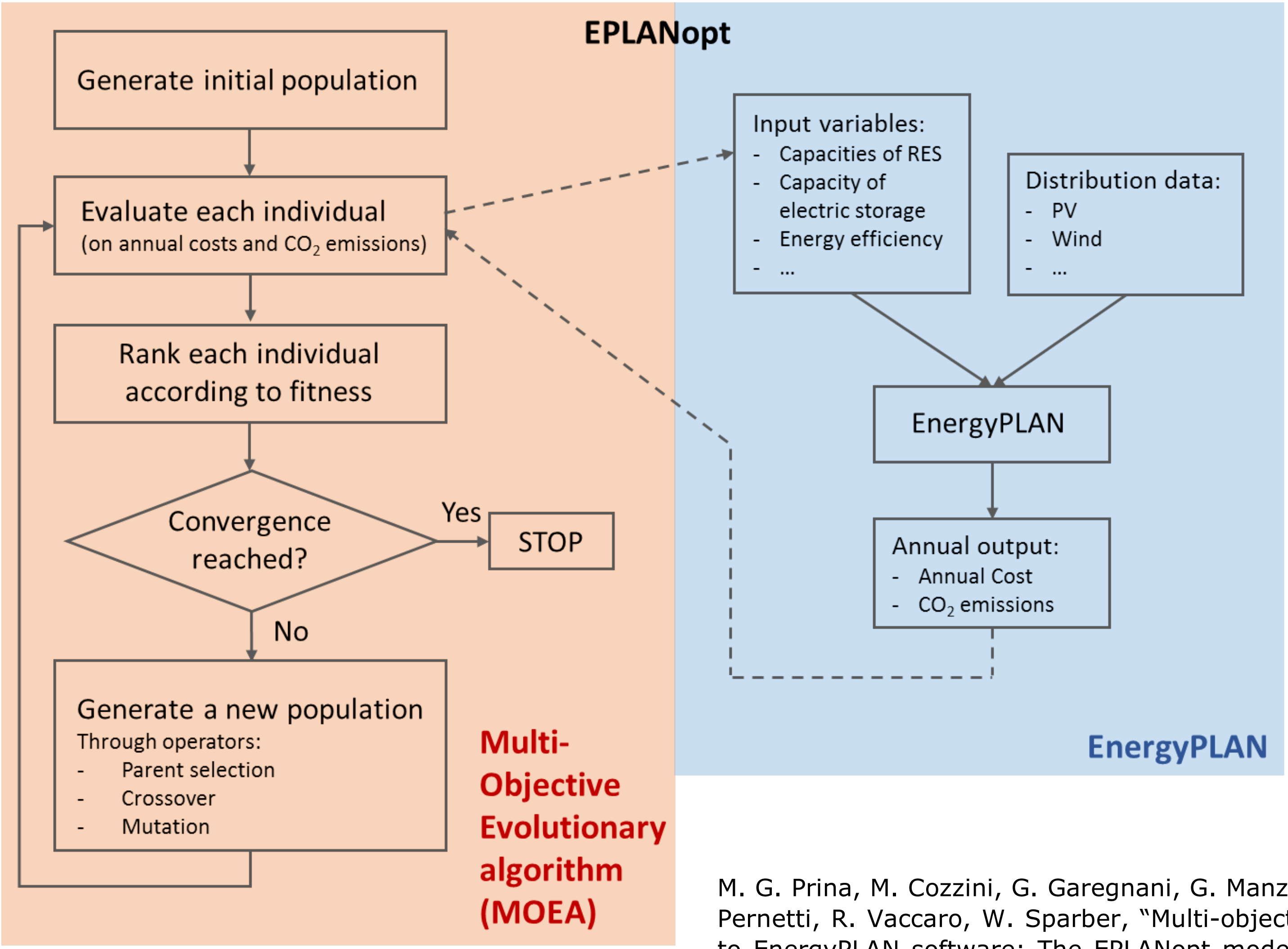
+

Optimization model

Multi objective evolutionary algorithm MOEA (DEAP)

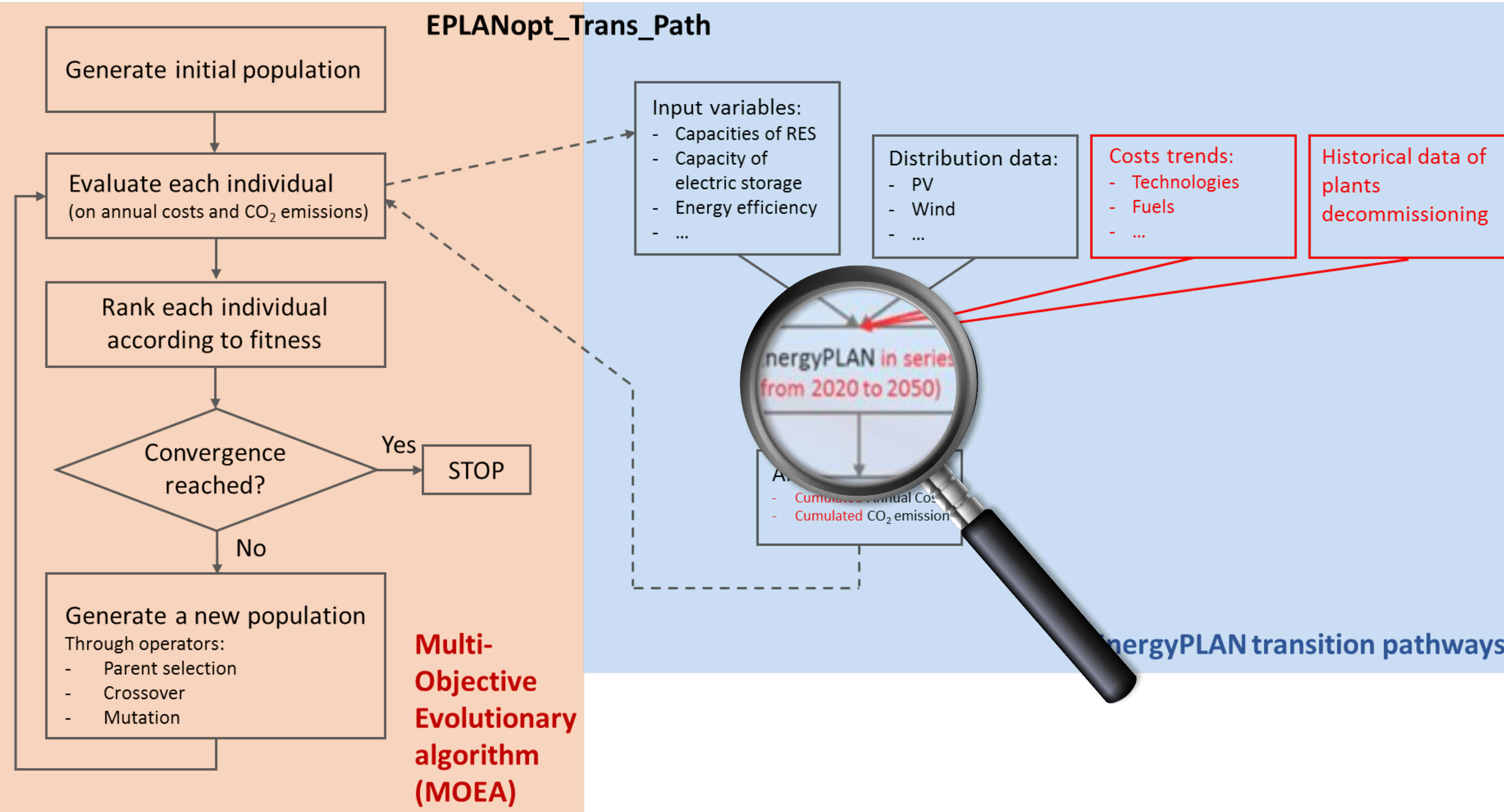


EPLANopt

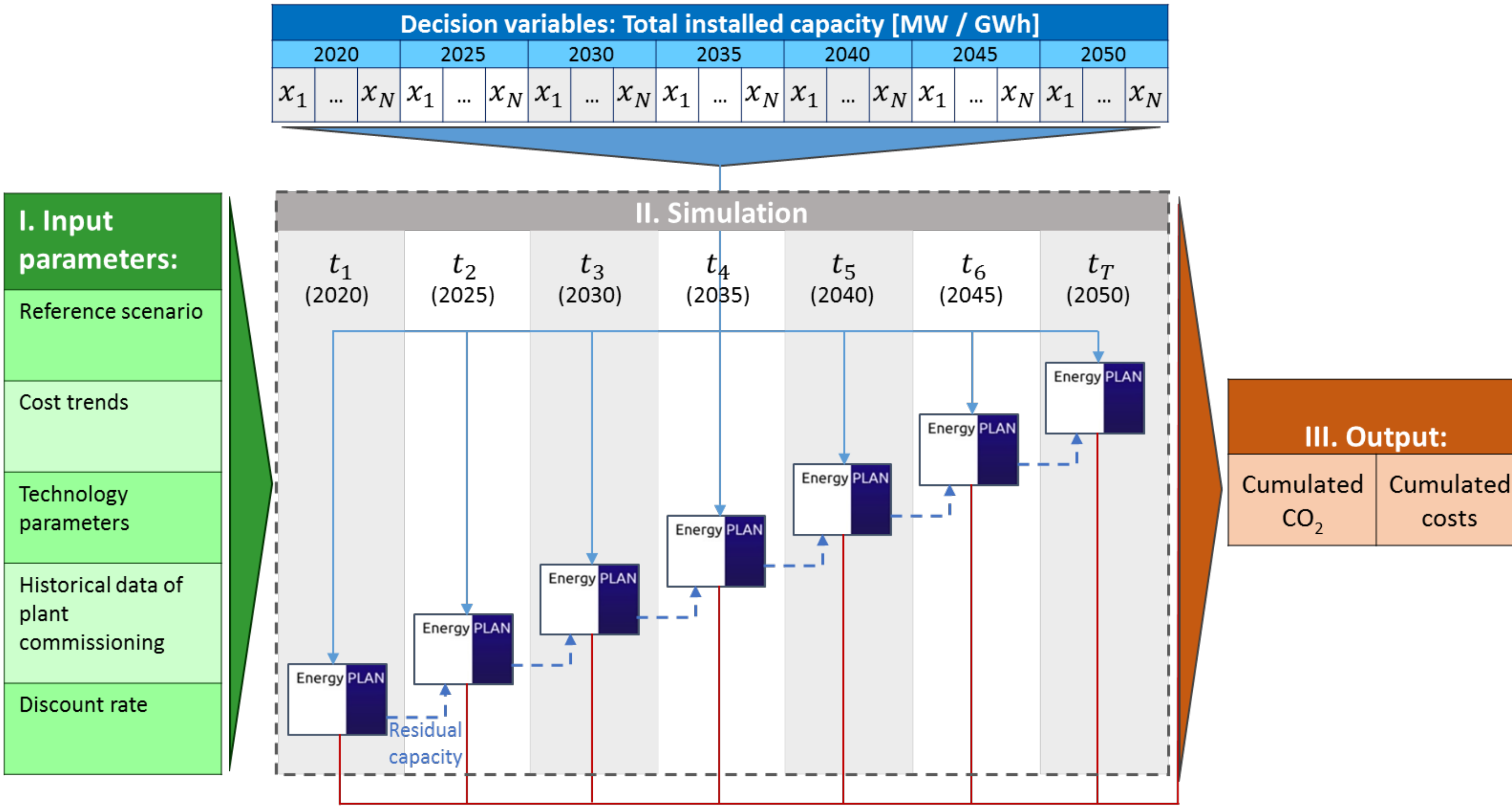


M. G. Prina, M. Cozzini, G. Garegnani, G. Manzolini, D. Moser, U. F. Oberegger, R. Pernetti, R. Vaccaro, W. Sparber, "Multi-objective optimization algorithm coupled to EnergyPLAN software: The EPLANopt model," Energy, vol. 149, pp. 213–221, Apr. 2018.

EPLANoptTP - EPLANopt for transition pathways



EPLANoptTP - Transition optimization model



I. Collects all the input data

II. Performs a capacity conservation balance
Runs EnergyPLAN with the reference scenario modified according to the input data related to the current period, to compute the yearly operation & Maintenance (O&M) costs and the CO2 emissions.

III. Integrates all the time-period costs and emissions to calculate their cumulated values

eurac research

EPLANoptTP - variables

- Capacity (t,k) [optimization variable]:
  - A (*K* x *T*) matrix representing the total installed capacity of all considered technologies *k* in each timestep *t*
- CO_2 emissions (t):
  - Emissions related to the whole energy system (considering thermal and transport) in each timestep *t*, computed by EnergyPLAN and then multiplied for the number of years in that timestep
- O&M costs (t):
  - Fixed and variable operation costs related to the whole energy system in each timestep *t*, computed by EnergyPLAN, discounted to the first year in the timestep

$$O\&M(t) = O\&M'(t) \cdot \sum_{y=1}^{Y} (1+r)^{(1-y)}$$

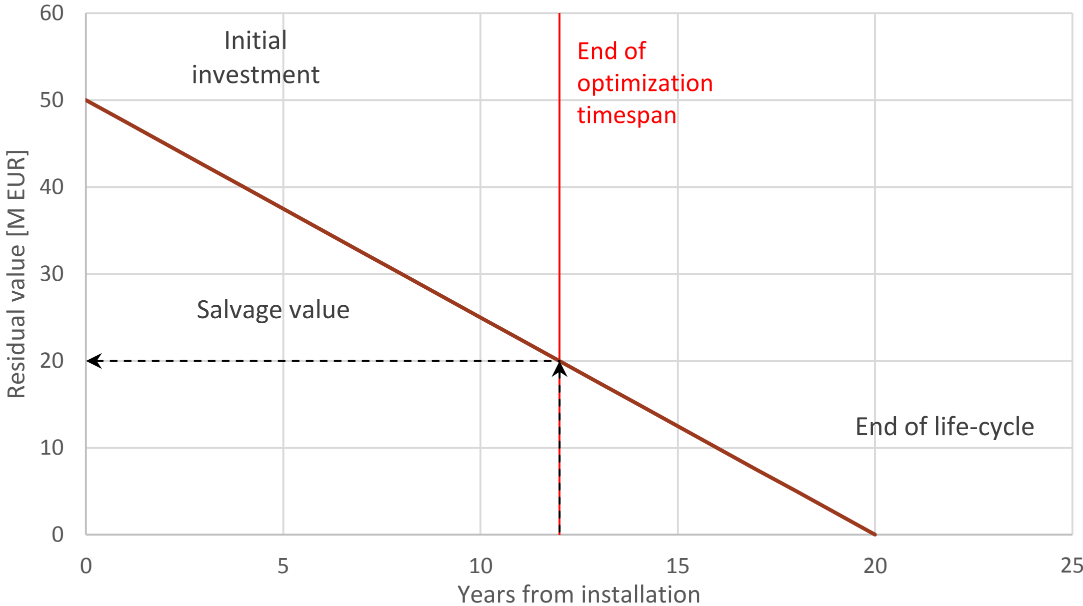
O&M'(t): *O&M costs as computed by EPLAN (just for one year)*
Y: *number of years* y *in each timestep*
r: *discount rate*

EPLANoptTP - variables

- Investment costs (t,k):
  - Costs related to the installation of new capacity
  - Lump-sum payment in the first year of the same timestep the capacity is installed
  - Unit costs [EUR/kWh] are an input parameter, varying with time

- Salvage value (k):
  - Residual value of capacity of technology *k* still available after the optimization timespan
  - Calculated assuming constant linear depreciation

$$\begin{cases} Salvage(k) = \sum_{t\,=\,T-Life(k)}^{T} salvage(t,k) \\ salvage(t,k) = Inv(t,k) \cdot \left[1 - \frac{T-t}{Life(k)}\right] \end{cases}$$



EPLANoptTP - variables

- Cumulated CO2 emissions & discounted cumulated costs:
  - Objective functions, to be minimized by the genetic algorithm

$$\begin{cases} CO2_{cumulated}\,[OBJ_1] = \sum_{t=1}^{T} CO2(t) \\ Costs_{cumulated}\,[OBJ_2] = \sum_{t=1}^{T} \left[(1+r)^{Y(1-t)} \cdot \left(\sum_{k=1}^{K} Inv(t,k) + O\&M(t) \right) \right] - (1+r)^{Y(1-T)} \cdot \sum_{k=1}^{K} Salvage(k) \end{cases}$$

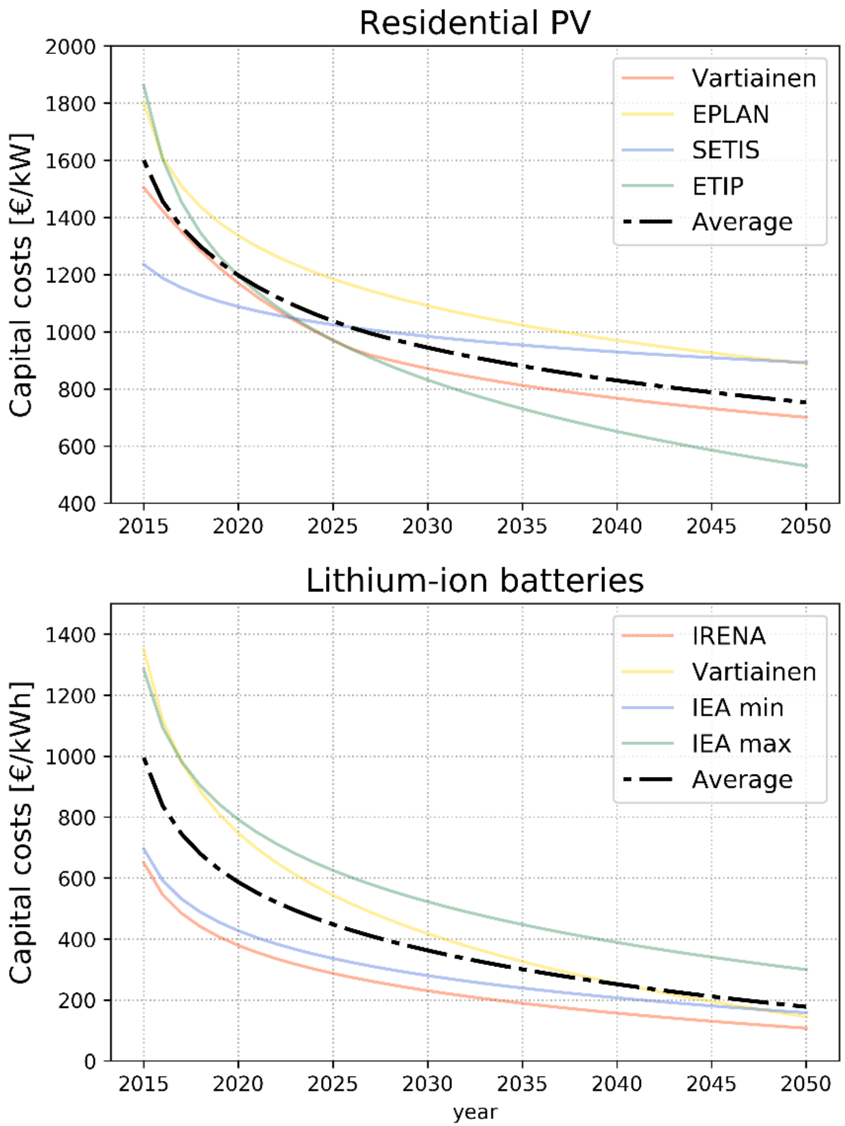
T: *number of timesteps* t
K: *number of technologies* k
Y: *number of years* y *in each timestep* t
r: *discount rate*

CO2(t): *CO2 emissions of the whole energy system in timestep* t
Inv(t,k): *investment costs for technology* k *in timestep* t
O&M(t): *O&M costs for the whole energy system in timestep* t
Salvage(k): *Salvage value of residual capacity of technology* k

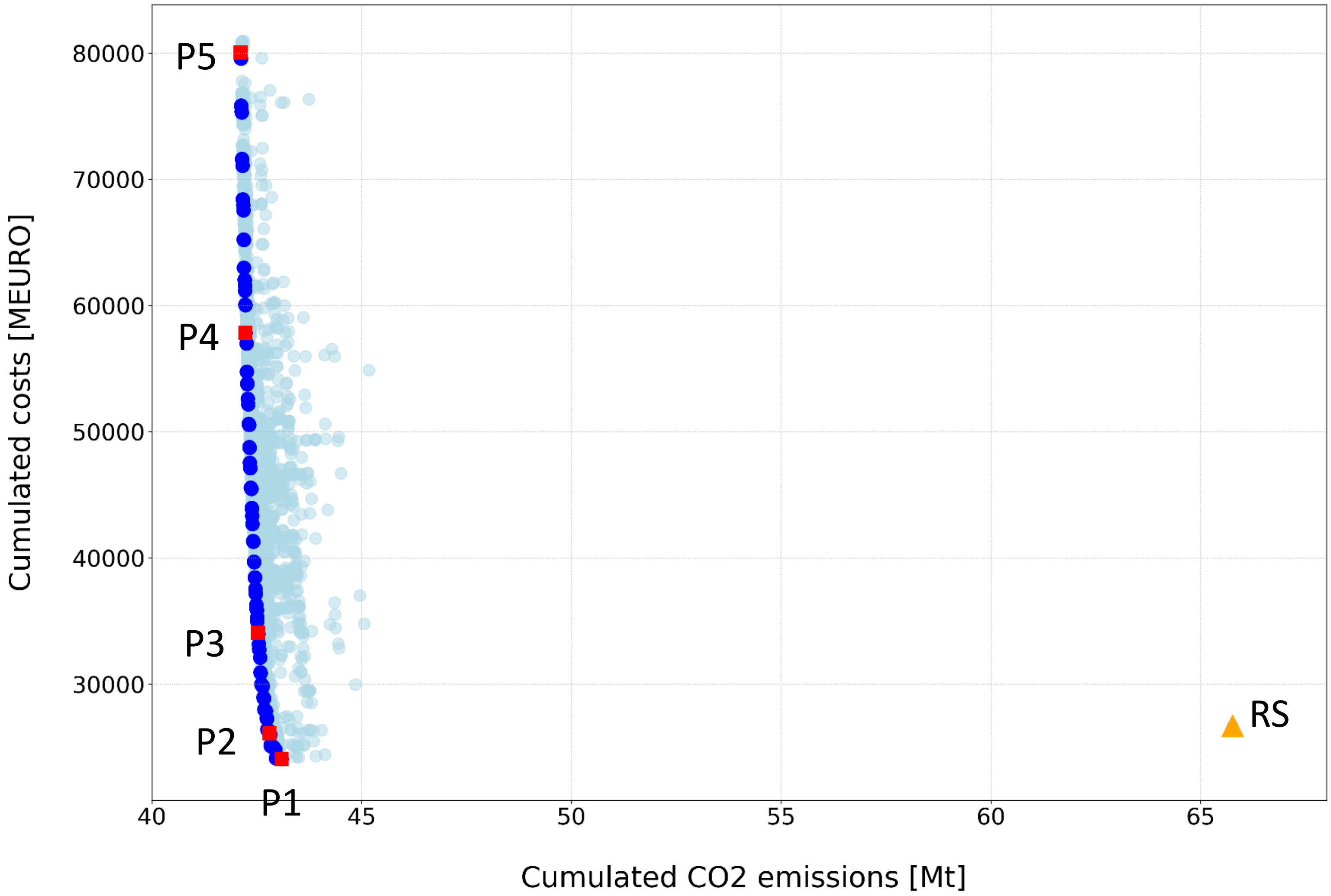
EPLANoptTP – South Tyrol

- 4 decision variables:
  - PV
  - PV+Li-ion battery storage
  - Hydrogen storage
  - Energy effciency in buildings
- Installed capacity of other technologies is assumed to remain constant (replaced at null cost)
- 7 timesteps of 5 years each, ranging from 2015 until 2050
- Linear decrease of electricity production from Hydro due to climate change
- Constant electric demand
- PV+Li-ion battery storage: costs on 3 kW PV and 4kWh battery
- Growth constraints on
  - PV = 65 MW/year
  - Energy effciency in buildings = 6%/year

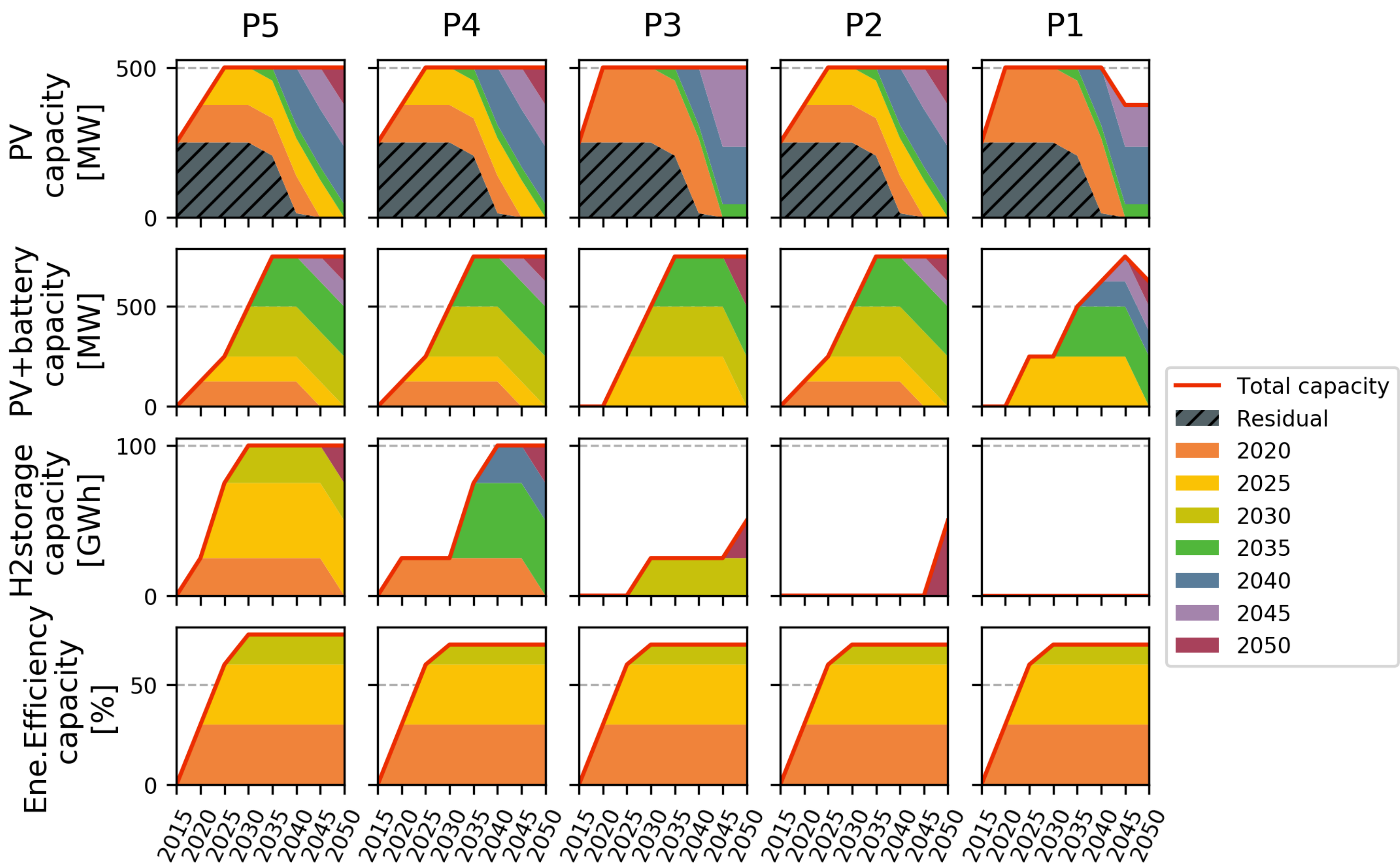
EPLANoptTP – cost trends



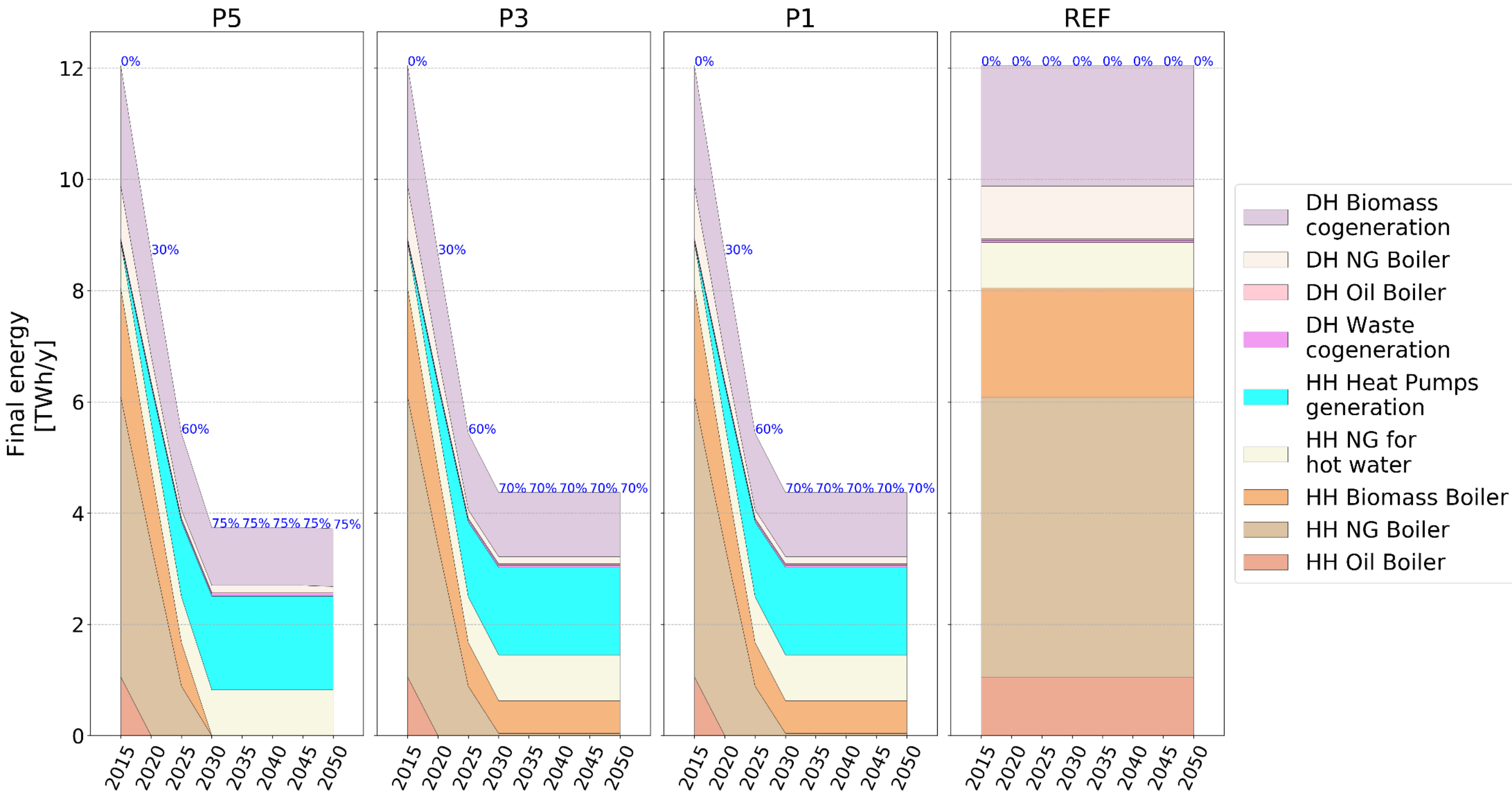
EPLANoptTP – results



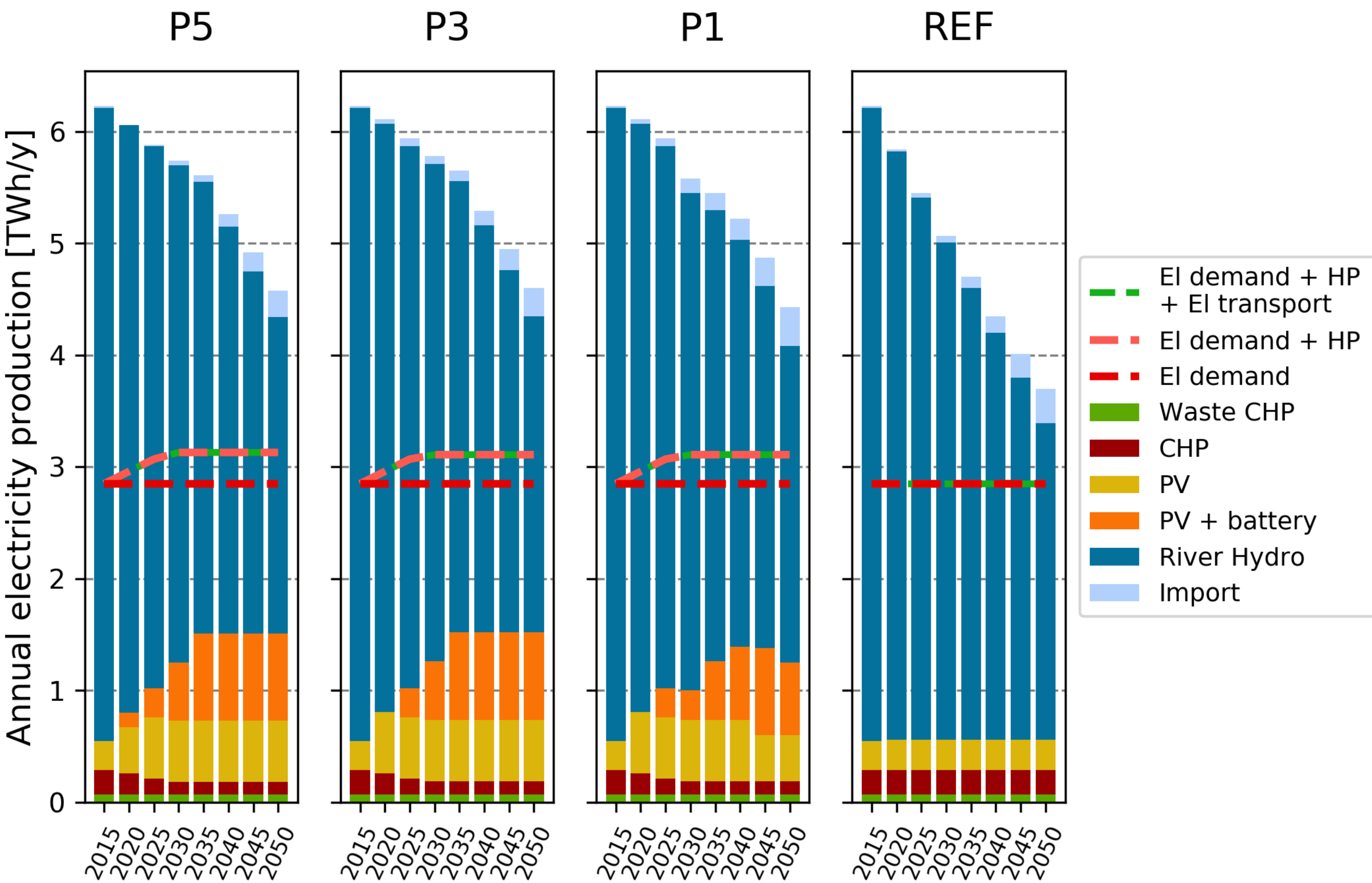
EPLANoptTP – results



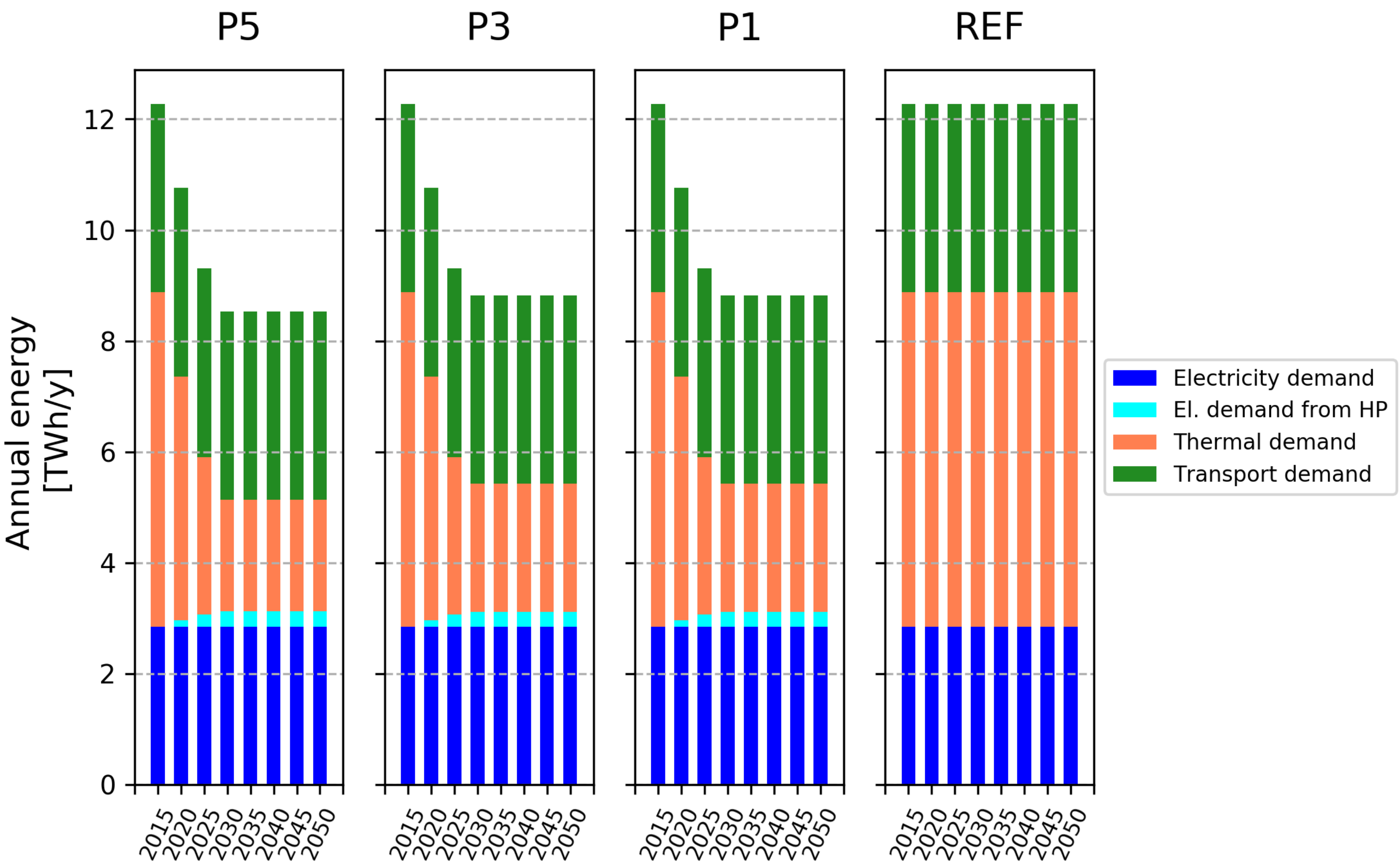
EPLANoptTP – results



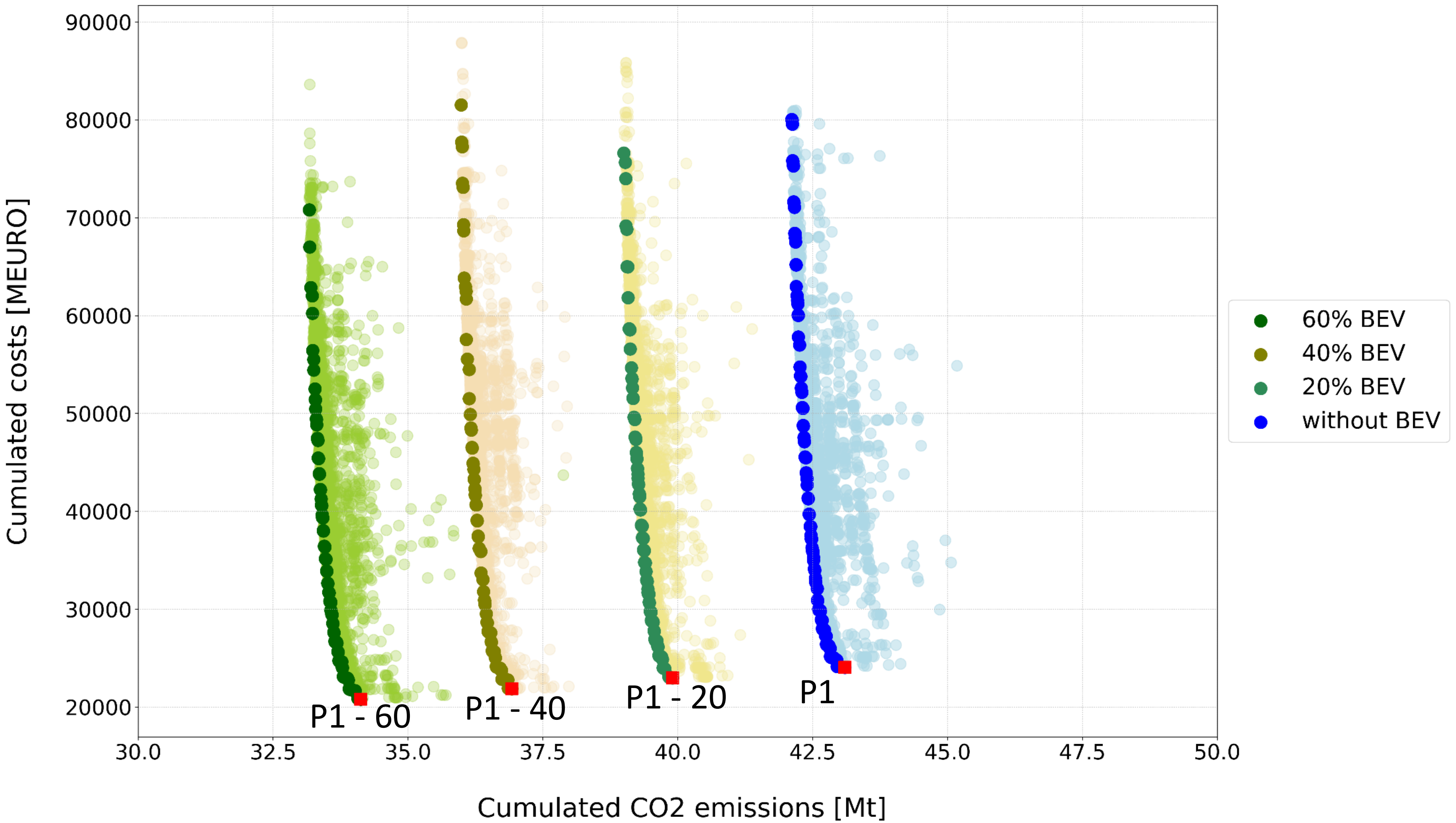
EPLANoptTP – results



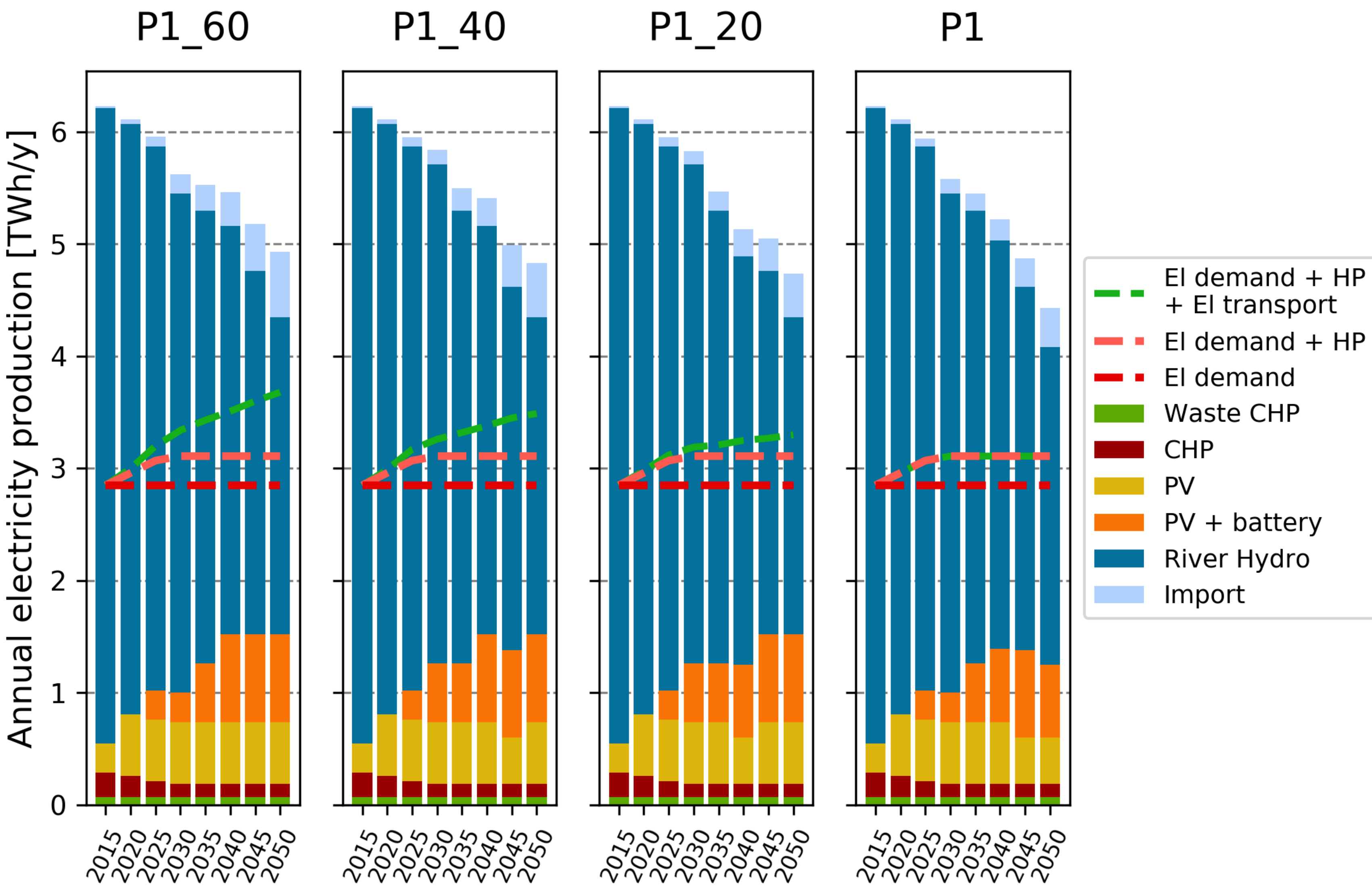
EPLANoptTP – results



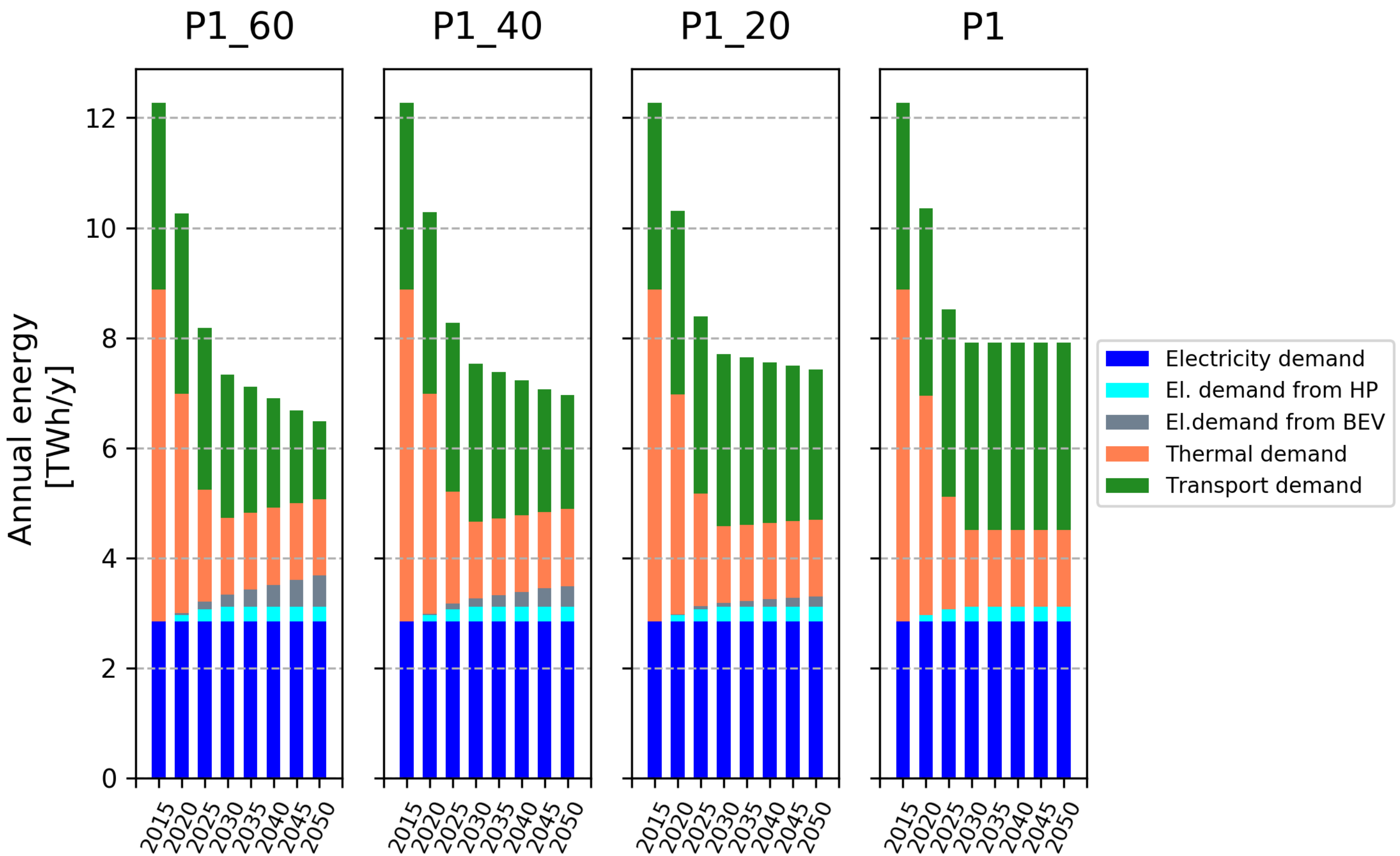
EPLANoptTP – results



EPLANoptTP – results



EPLANoptTP – results



Conclusions

- An optimization methodology of energy transition pathways has been developed starting from the simulation software EnergyPLAN (very large community)
- It allows to simulate the energy system with one year horizon and hourly time-step. Improvement if compared to the time-slice approach of existing methodologies (K. Poncelet, E. Delarue, D. Six, J. Duerinck, and W. D'haeseleer, "Impact of the level of temporal and operational detail in energy-system planning models," Appl. Energy, vol. 162, pp. 631–643, Jan. 2016.)
- It highlights the importance to consider cumulated CO_2 emissions as objective function and not only the CO_2 emissions of the year 2050
- The advantage of using a genetic algorithm is the possibility to parallelize the code to save computational time

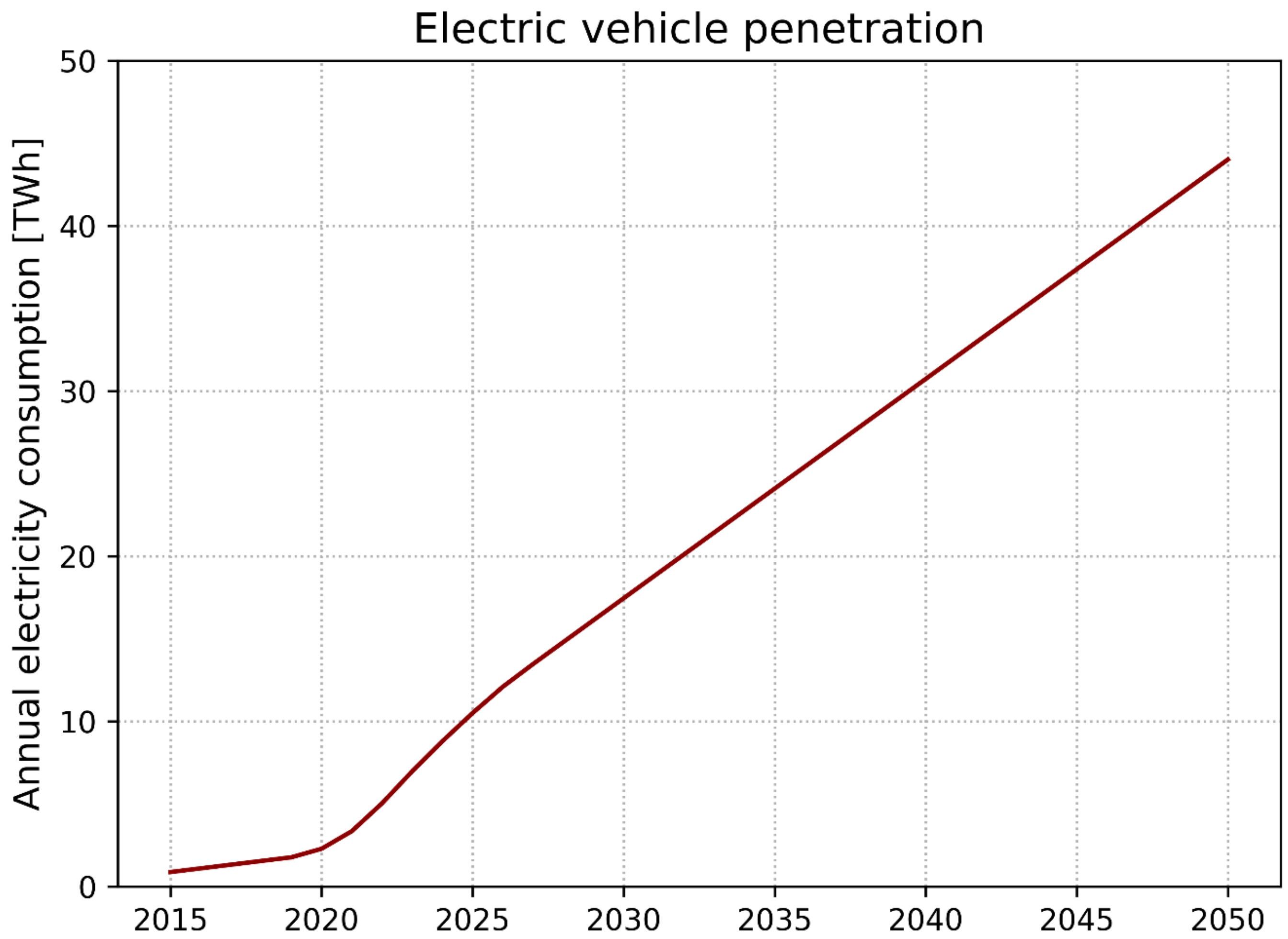
Thanks for your attention

Contact us:

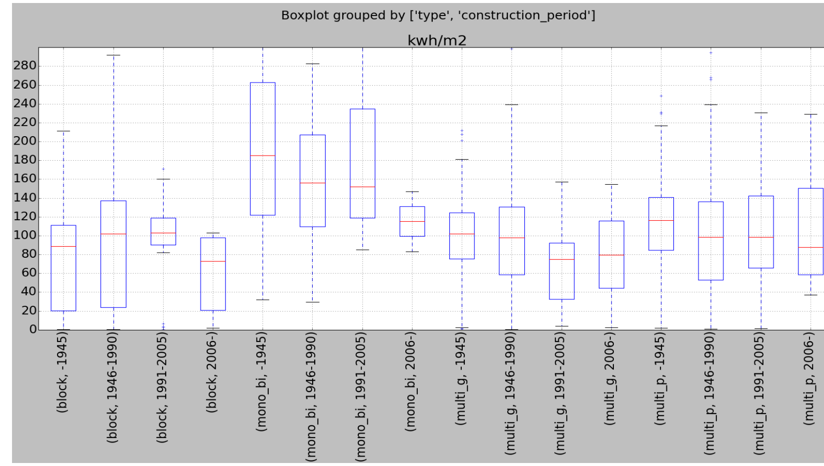
www.eurac.edu
MatteoGiacomo.prina@eurac.edu

Tel. +39 0471 055587

eurac research

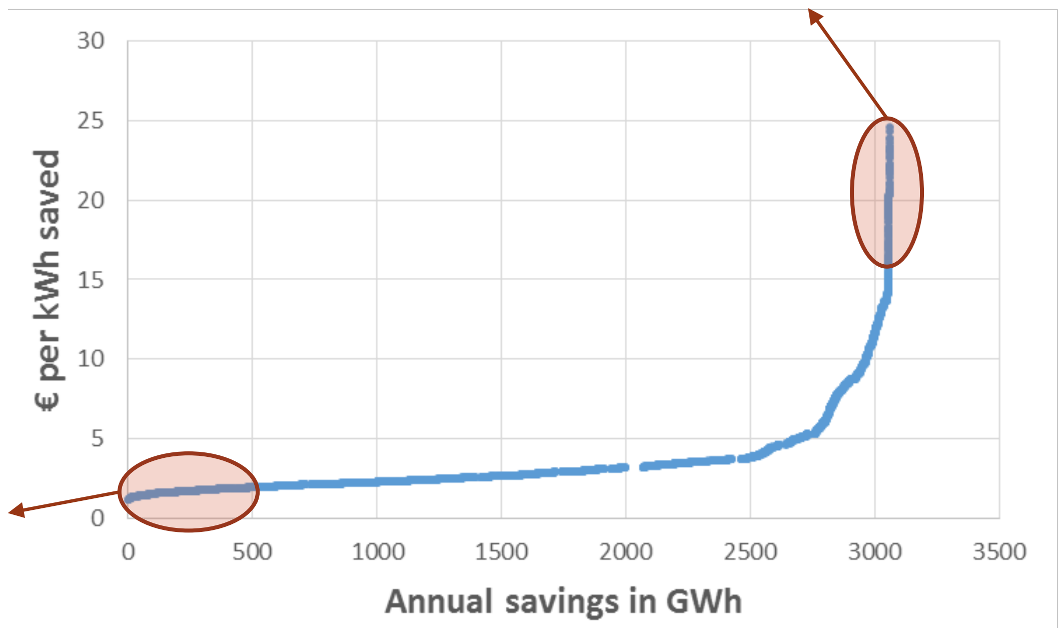

Electric vehicle penetration
Annual electricity consumption [TWh]
0
10
20
30
40
50
2015
2020
2025
2030
2035
2040
2045
2050

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)