Multi-Objective Investment Optimization of Energy Systems for Residential Quarters Considering Costs and Life-cycle Environmental Impacts

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Agenda

- Energy system model LAEND
- Case study
- Conclusions and outlook

Aim of Energy system model LAEND

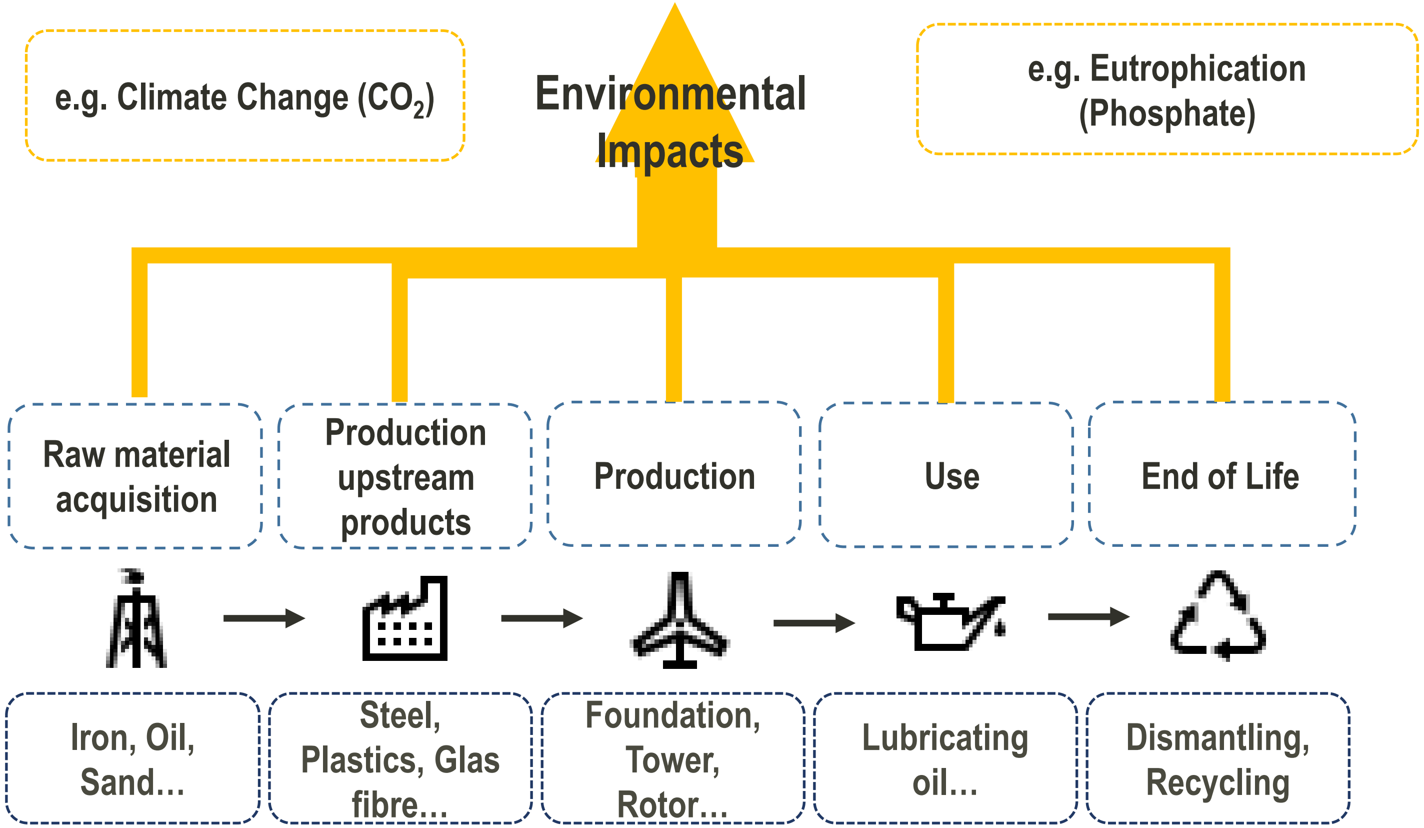
Decision support concerning the configuration of an integrated energy system that compensates for costs and environmental impacts

- Prevention of burden shifting, which occurs in single objective optimization
- System boundary: communities, quarters or neighborhoods
- Transformation of energy system over time: investment planning

→ LAEND = **L**ife-cycle **A**ssessment based **En**ergy **D**ecision support

Life Cycle Assessment (LCA)

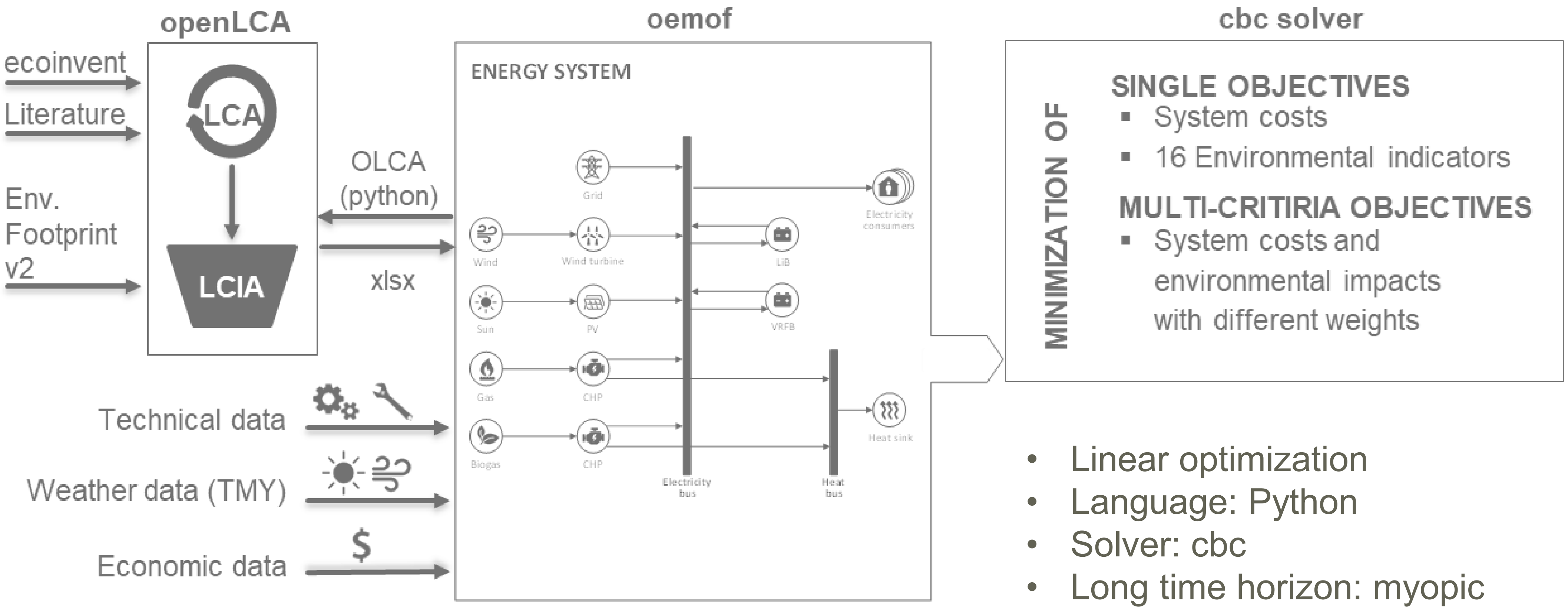
- Aggregation of environmental impacts over the whole life-cycle of a product



Environmental Indicators/Possible optimization objectives

Single objective			
Climate change	Ozone layer depletion	Acidification	Minerals and metals
	Carcinogenic effects	Terrestrial eutrophication	Fossils
	Non-carcinogenic effects	Freshwater eutrophication	Dissipated water
	Respiratory effects, inorganics	Marine eutrophication	Land use
	Ionizing radiation	Eco toxicity	
	Photochemical ozone creation		
Costs			
Multi criteria objective (weighted sum)			
EU Environmental Footprint v2 (Normalization and weighting of single indicators)			
EU Environmental Footprint + costs (case study: 70:30)			
Equilibrium (equal weighting of all env. indicators and costs)			

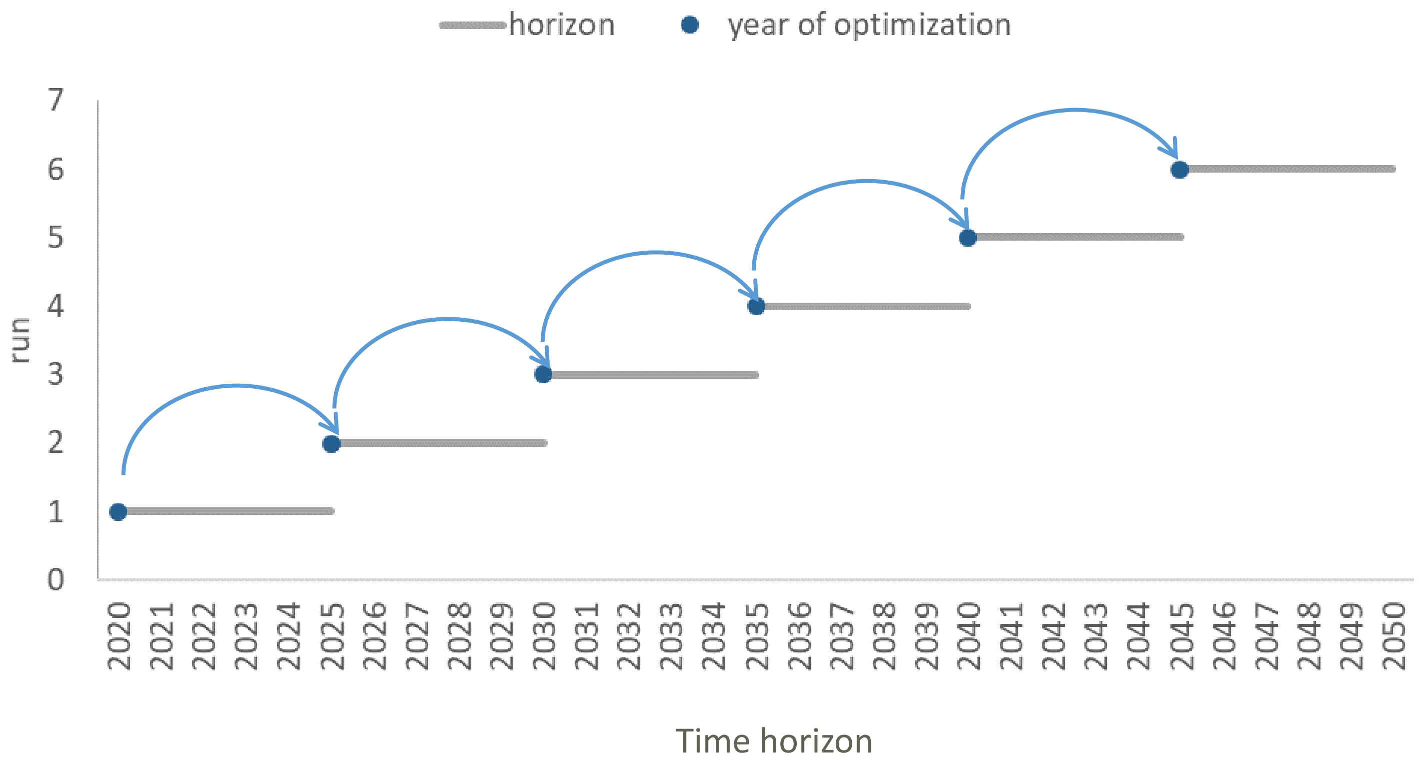
Methods Coupling in LAEND: Energy system optimization + LCA



- Linear optimization
- Language: Python
- Solver: cbc
- Long time horizon: myopic optimization every 5 years
- hourly resolution within years

Application of myopic optimization

- First year of a time period (here 5 years) is optimized
- Results are transferred to next period
- Impacts per year are aggregated for full period



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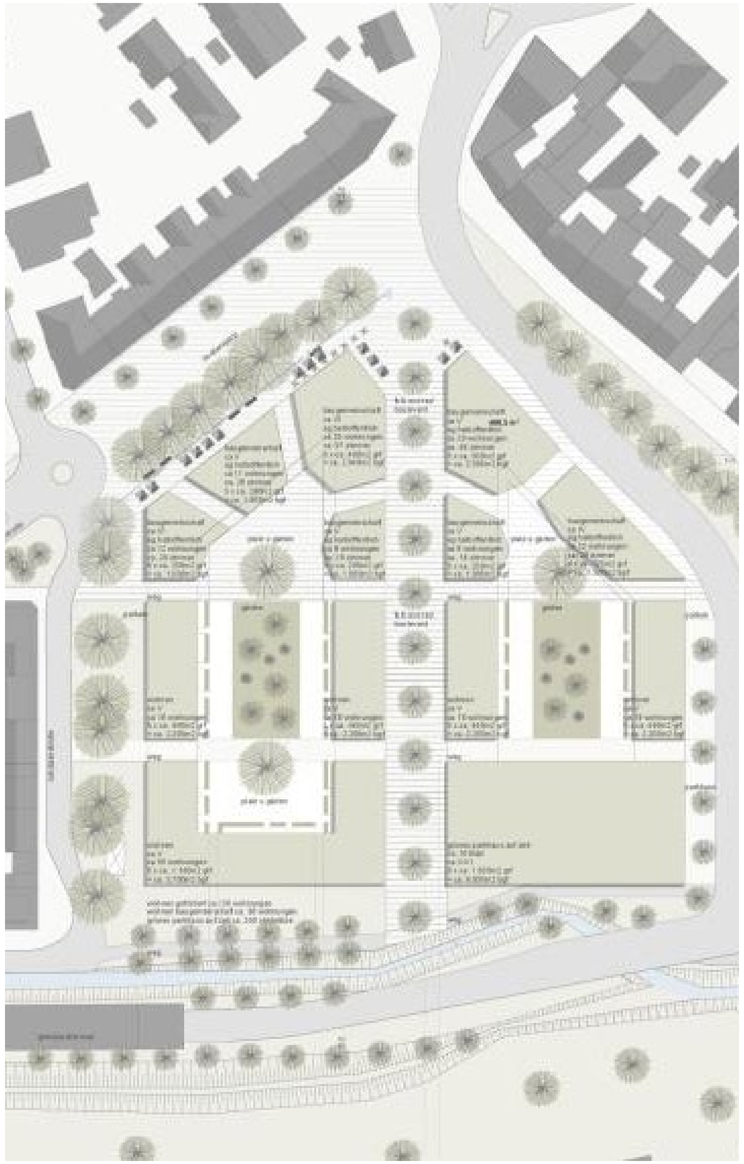
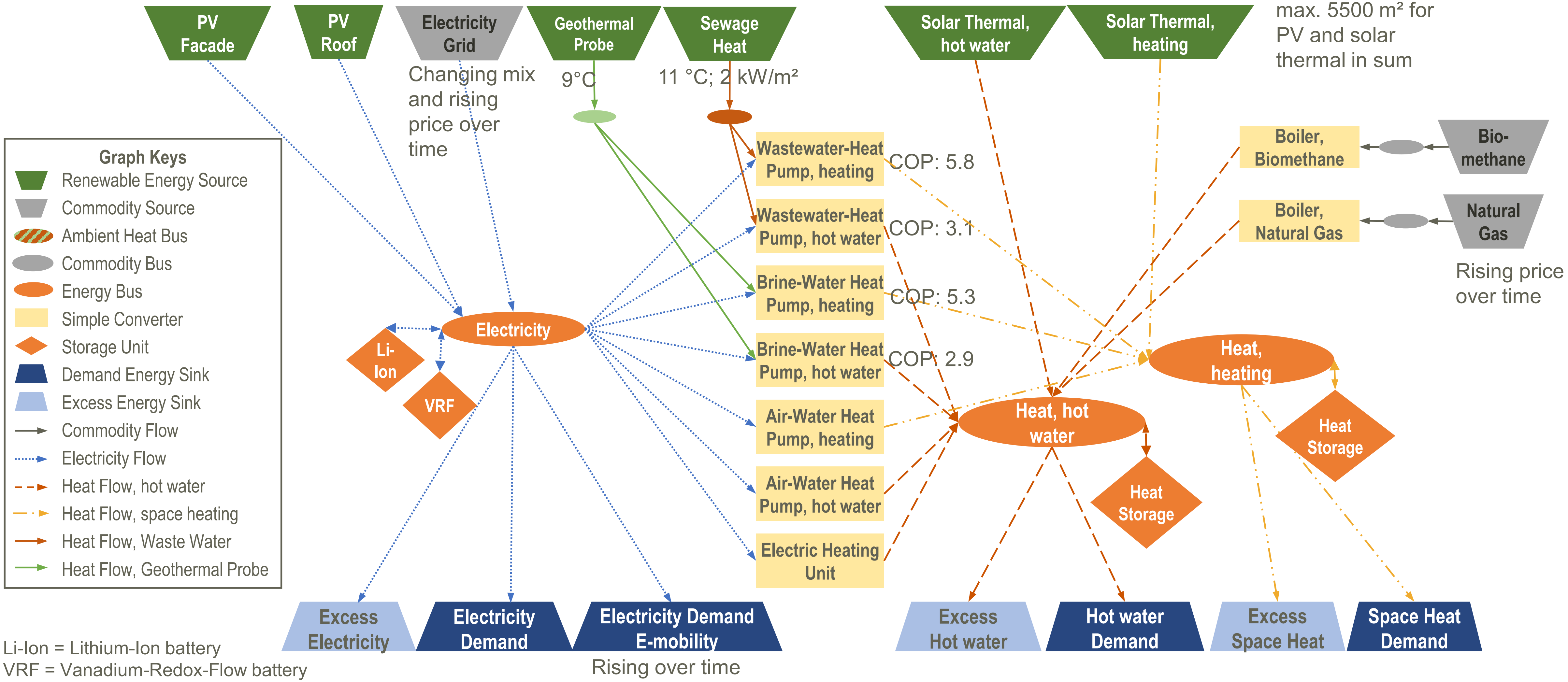
Case Study

Case Study

- Inner-city quarter in Constance (city in South-Western Germany)
- Newly built multiple-family dwellings
- Electricity demand approximation:
  ≈ 500 MWh/a
  + Charging stations: 50 in 2023 and 500 in 2038
- Heat demand:
  ≈ 1000 MWh/a (space heat + hot water)
- Time horizon: 20 years

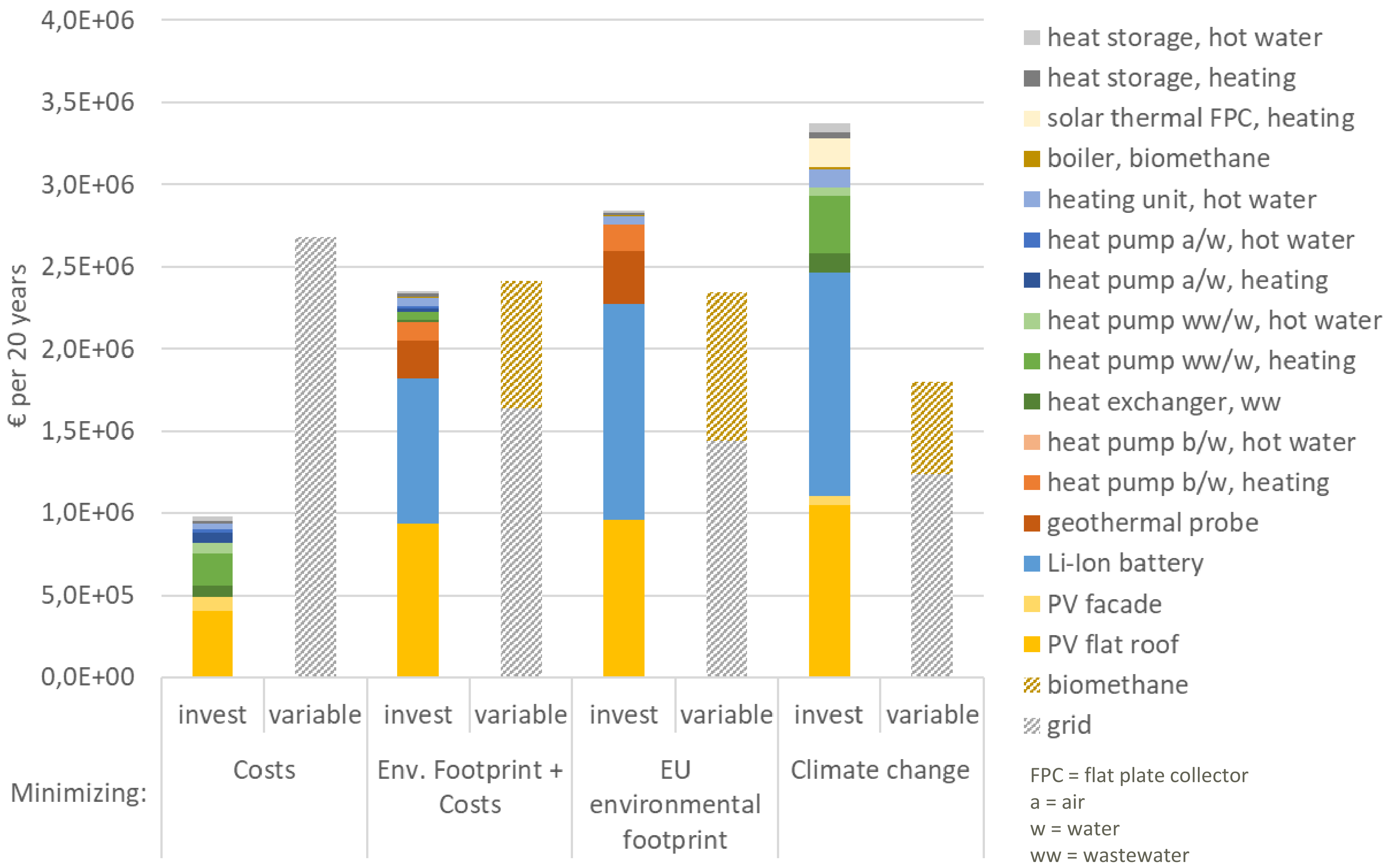


Model structure/technologies and parameters used



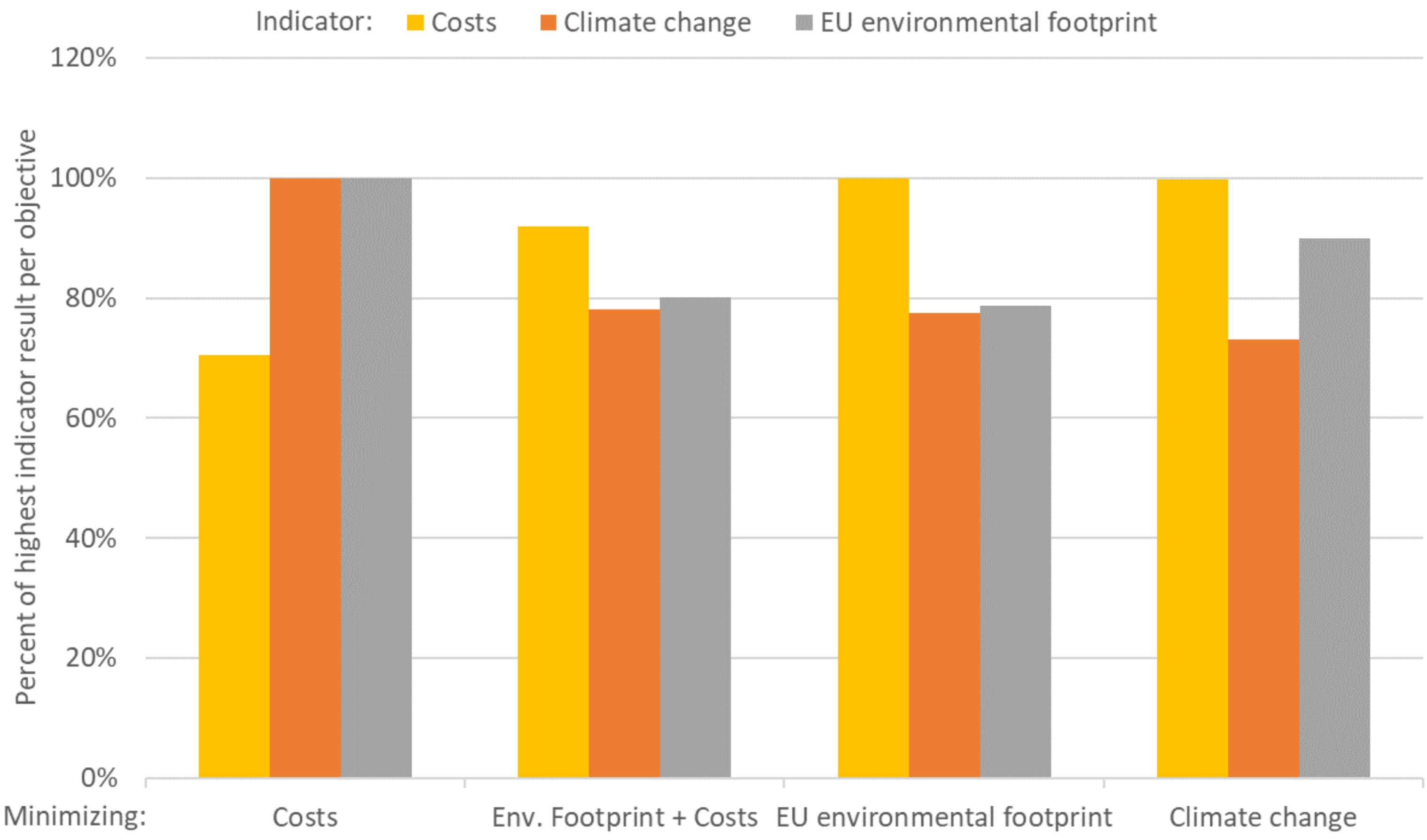
Costs over 20 years per objective

- High investments if environmental and climate impacts are minimized; mainly due to batteries and PV



Impacts over 20 years per objective

- Minimal climate impacts, high costs and vice versa
- Minimal climate impacts, high overall env. impacts (due to infrastructure)
- Compromise solutions exists



Conclusions and Outlook

Conclusions and Outlook

- System configuration differs for different objectives
- Single-objective optimization leads to burden shifting
- Compromise solutions exist which **prevent from burden shifting** from one impact to another
- Minimizing **costs and climate impacts are opposing objectives**
- Including environmental and climate objectives leads to higher costs but prevention costs are internalized
- Aiming at sustainability also **other indicators** like security of supply, employment effects, etc. should be taken into account

Thanks for your attention

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https://github.com/inecmod/LAEND_v031

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Literature and Links

- Tietze, I.; Lazar, L.; Hottenroth, H.; Lewerenz, S. (2020) LAEND: A model for multi-objective investment optimisation of residential quarters considering costs and environmental impacts. *Energies*, Band 13, Heft 3, S. 614. doi: 10.3390/en13030614
- https://www.hs-pforzheim.de/forschung/institute/inec/sonstiges/laend
- Documentation und Programme code LAEND v0.3.1 https://github.com/inecmod/LAEND_v031
- European Commission (2019): European Platform on Life Cycle Assessment; EF reference package 2.0 (pilot phase). https://eplca.jrc.ec.europa.eu/permalink/EF_2.0_Complete.zip. Zugegriffen: 07. Juni 2021.

Methodological Approach of Energy System Model

Input data

- Demand
- Weather data
- Technical parameters
- Costs
- Life-cycle impact assessment data

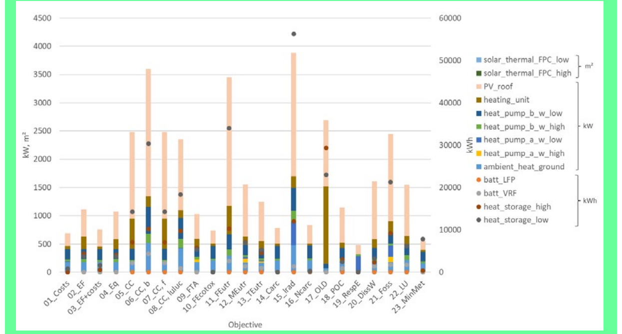
LAEND

Life-cycle Assessment based ENergy Decision support tool

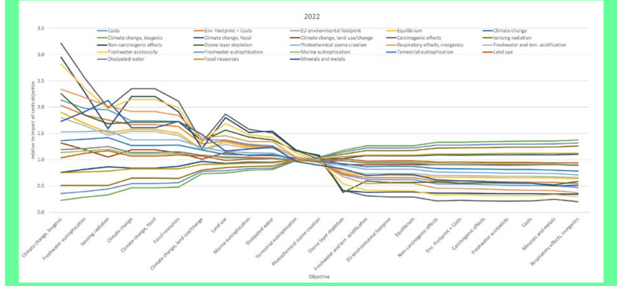
Multi-criteria multi-period investment and dispatch optimization including cost and environmental criteria

Results

Optimal investment and dispatch planning

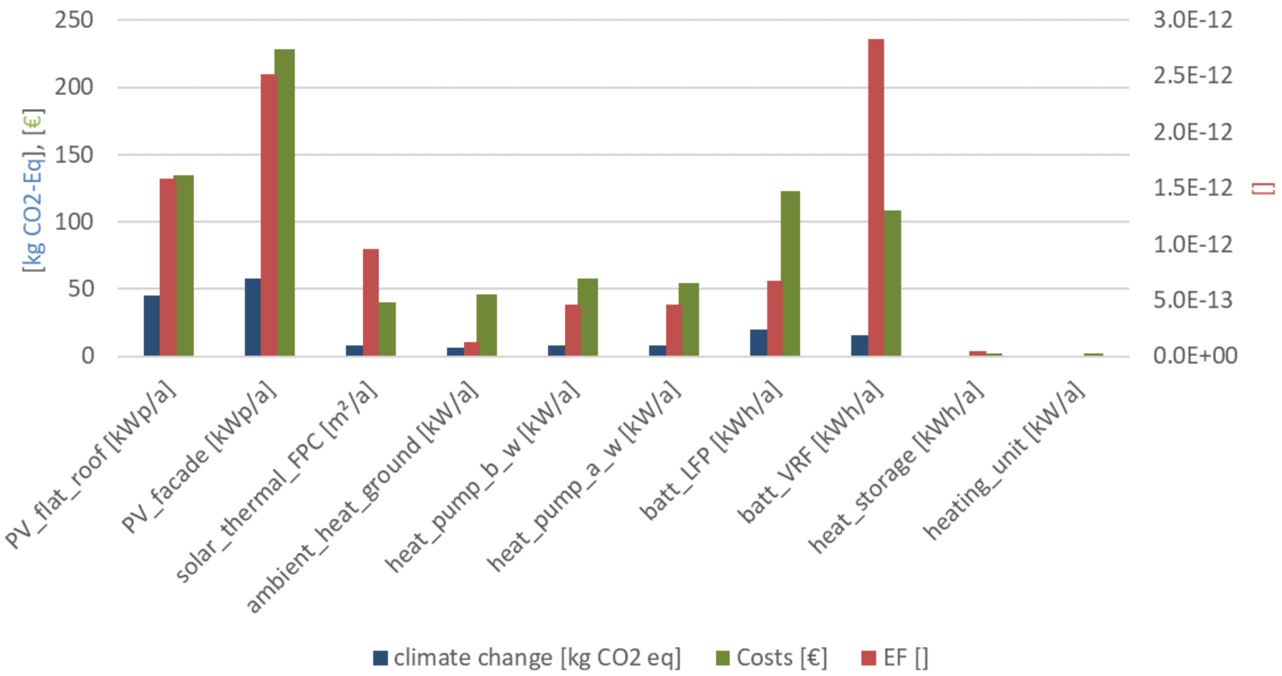


Environmental impacts of planning alternatives



Environmental impacts

- Use of LCIA data in analogy to costs on a yearly basis but without discount rate
  - for plant infrastructure (invest) per kW/kWh (storages)
  - for variable environmental impacts per kWh
  - for commodities/grid electricity per kWh
- LCIA calculation in openLCA is initiated by LAEND, saved as xlsx file and read

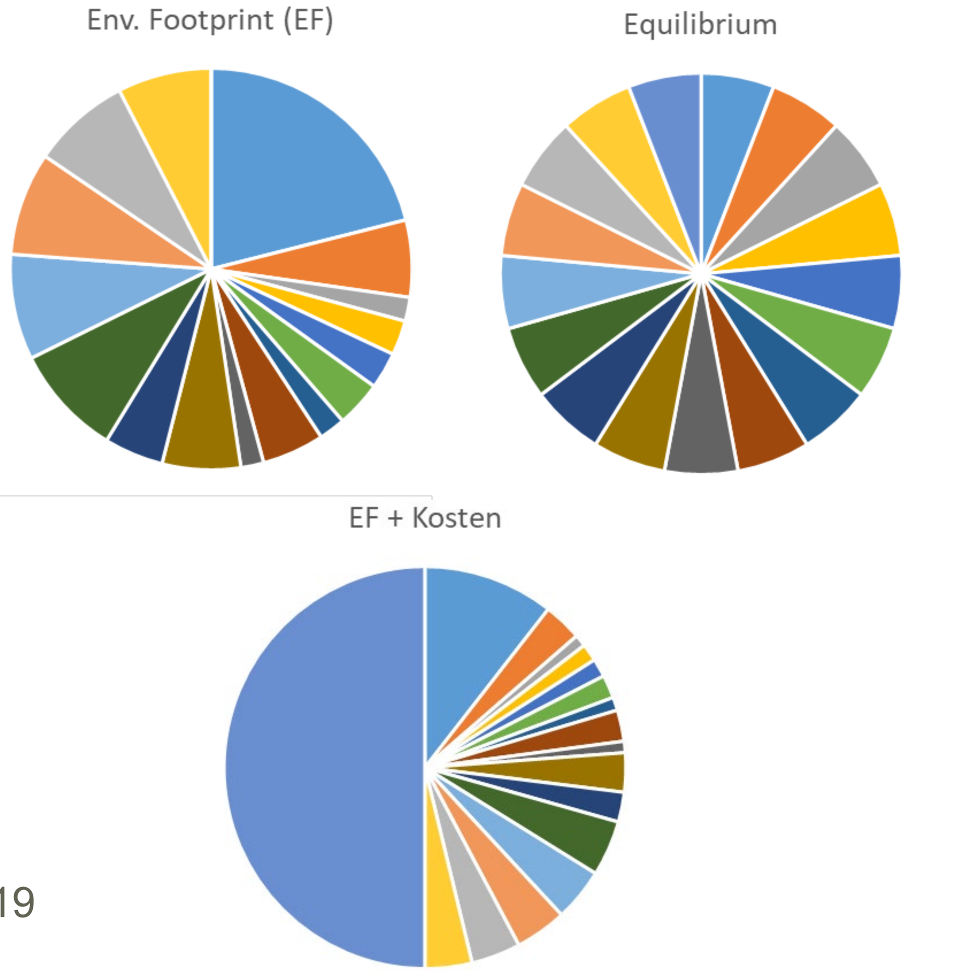


Normalization and Weighting Factors for multi-criteria Optimization

Indicator	Normalization World 2010	
Climate change	8.94E+13	kg CO_2-Äq
Acidification	4.93E+11	mol H^+-Äq
Ecotoxicity	2.66E+13	CTUe
Freshwater eutrophication	1.59E+10	kg P-Äq
Marine eutrophication	1.99E+11	kg N-Äq
Terrestrial eutrophication	1.57E+12	mol N-Äq
Carcinogenic effects	8.67E+04	CTUh
Ionising radiation	2.63E+13	kBq U-235-Äq
Non-carcinogenic effects	1.07E+06	CTUh
Ozone layer depletion	1.86E+08	kg CFC-11-Äq
Photochemical ozone creation	2.85E+11	kg NMVOC-Äq
Respiratory effects, inorganics	7.34E+06	Krankheitsfälle
Dissipated water	7.14E+13	m³ Wasser-Äq
Fossils	5.19E+14	MJ
Land use	8.31E+15	Punkte
Minerals and metals	4.60E+08	kg Sb-Äq
Costs	*4.63E+13*	$€_{2018}$

Environmental Footprint v2.0 according to European Commission 2019

Weighting factors



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Objective function

- graph structure: start nodes and end nodes connected by directed edges

$$min \sum_{t \in T} \sum_{(s,e) \in E} vari_{(s,e)} f_{(s,e)}(t) \cdot \tau$$

$$+ \sum_{(s,e) \in E} epi_{(s,e)}\, x_{(s,e)}$$

$$+ \sum_{n \in N} epi_{(n)} y_{(n)}$$

$vari =$ variable impacts
$epi =$ equivalent periodical impacts
$f =$ flow between nodes
$x =$ power invest
$y =$ energy invest
$s =$ start node
$e =$ end node
$E =$ edge
$n =$ node
$N =$ nodes
$\tau =$ time increment
$t =$ timestep
$T =$ time period

- Minimizing costs and environmental impacts as weighted sum

Multi criteria aggregation

$$vari = \frac{varm}{n_m} w_m + \left(\sum_i \frac{vare_i}{n_i} w_i\right) w_e$$

$$epi = \frac{epm}{n_m} w_m + \left(\sum_i \frac{epe_i}{n_i} w_i\right) w_e$$

$$\sum_i w_i = 1, \qquad w_m + w_e = 1$$

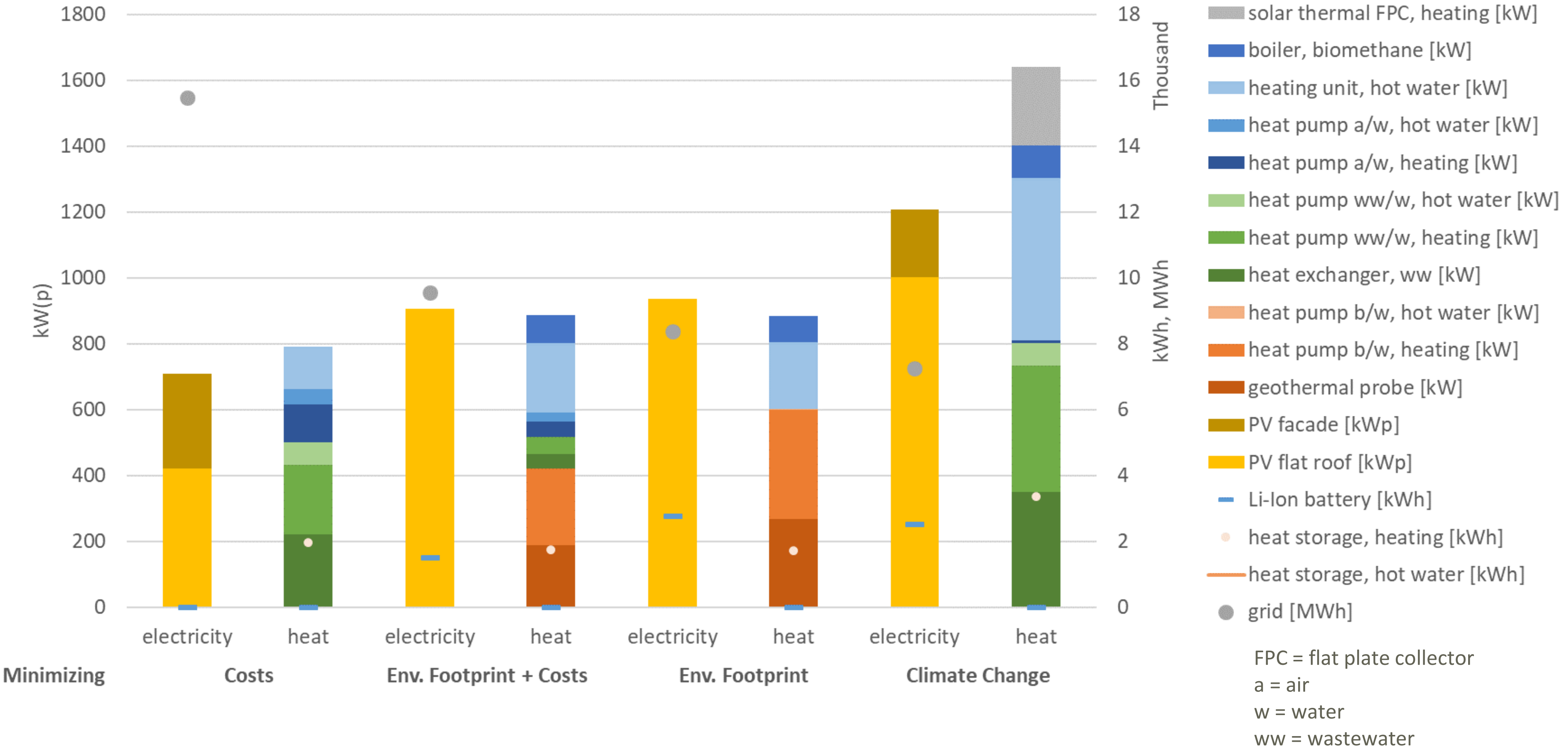
$$epm = c_{om} + annuity, \quad epe = \frac{e}{lifetime}$$

	w_m	w_e	w_i
Single criteria			
costs	1	0	0
Env. Impact i	0	1	1
Multi criteria			
Env. Footprint (EF)	0	1	$\sum_i w_i = 1$ *
EF + costs	w_m (e.g. 0.5)	$1-w_m$	$\sum_i w_i = 1$ *
Equilibrium	1/17	16/17	1/16

* According to European Commission 2019

$vari = variable\ impacts$
$varm = variable\ impact, monetary$
$vare = variable\ environmental\ impact$
$n = normalization\ value$
$w = weight$
$m = monetary$
$e = environmental$
$i = single\ environmental\ impact$
$epi = equivalent\ periodical\ impacts$
$epm = equivalent\ periodical\ impacts, monetary$
$c_{om} = costs, operation\ and\ maintenance$
$epe = equivalent\ periodical\ env.\ impact$
$e = environmental\ impact\ per\ unit$

Results: installed capacities per objective



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- Ergebnis-Diagramme