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oemof User Meeting
Stuttgart

Multi-Objective Investment Optimization of Energy Systems Considering Life-cycle Environmental Impacts



Agenda

- Energy system model LAEND
- Results of a case study
- Conclusions

Aim

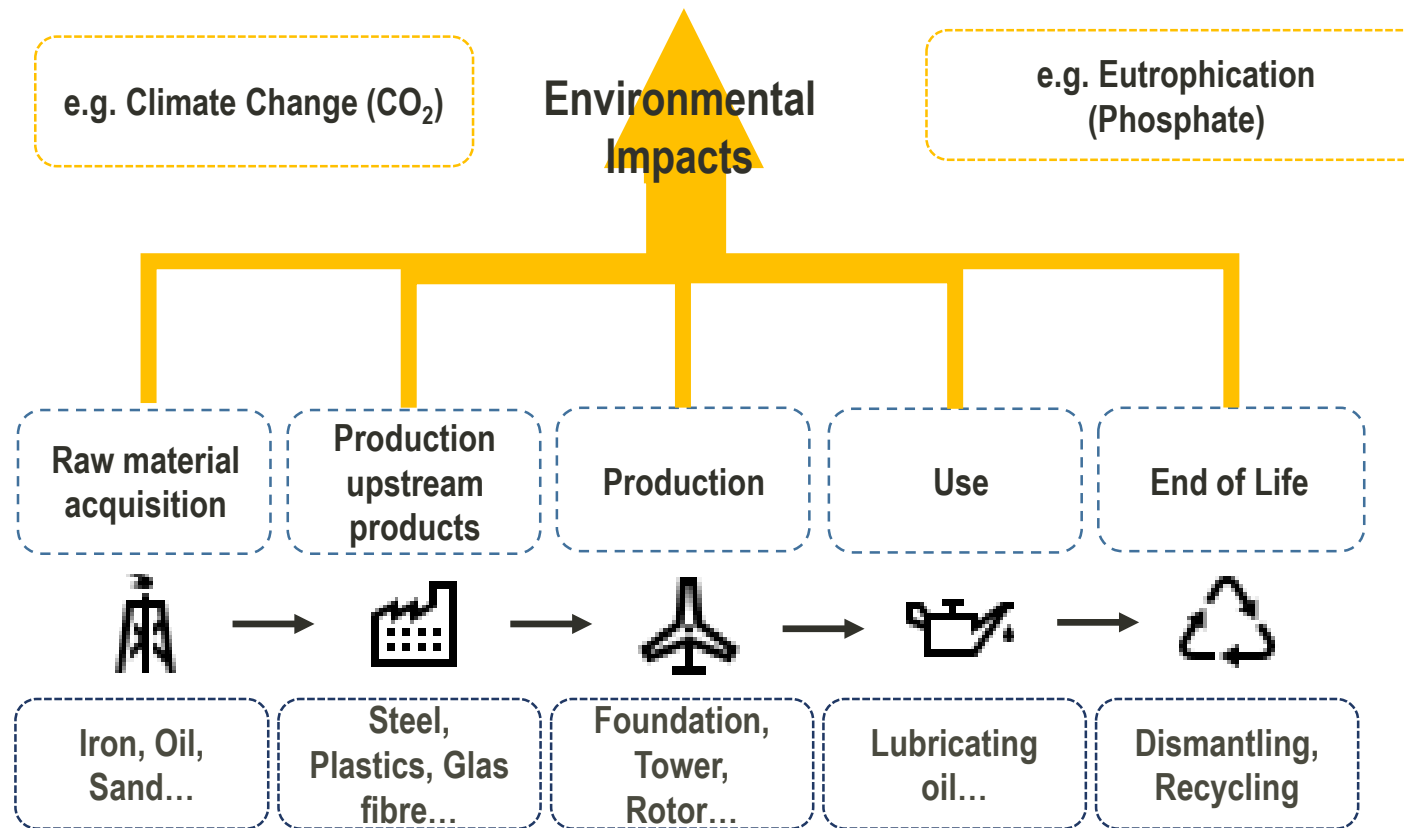
Decision support concerning the configuration of an integrated energy system that compensates for costs and environmental impacts

- Prevention of burden shifting when optimizing only single objective
- System boundary: communities, quarters or neighborhoods
- Transformation of energy system over time: investment planning

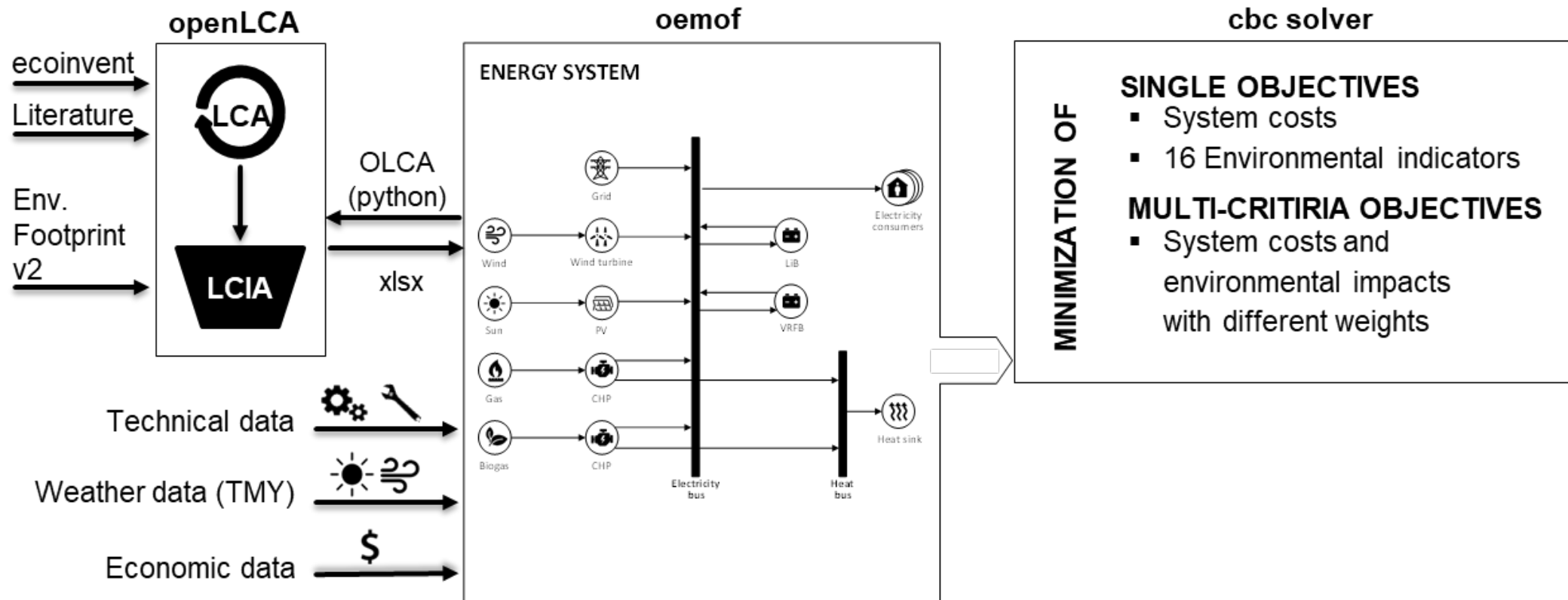
→ LAEND = **L**ife-cycle **A**ssessment based **E**nergy **D**ecision support

Life Cycle Assessment (LCA)

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



Methods Coupling in LAEND

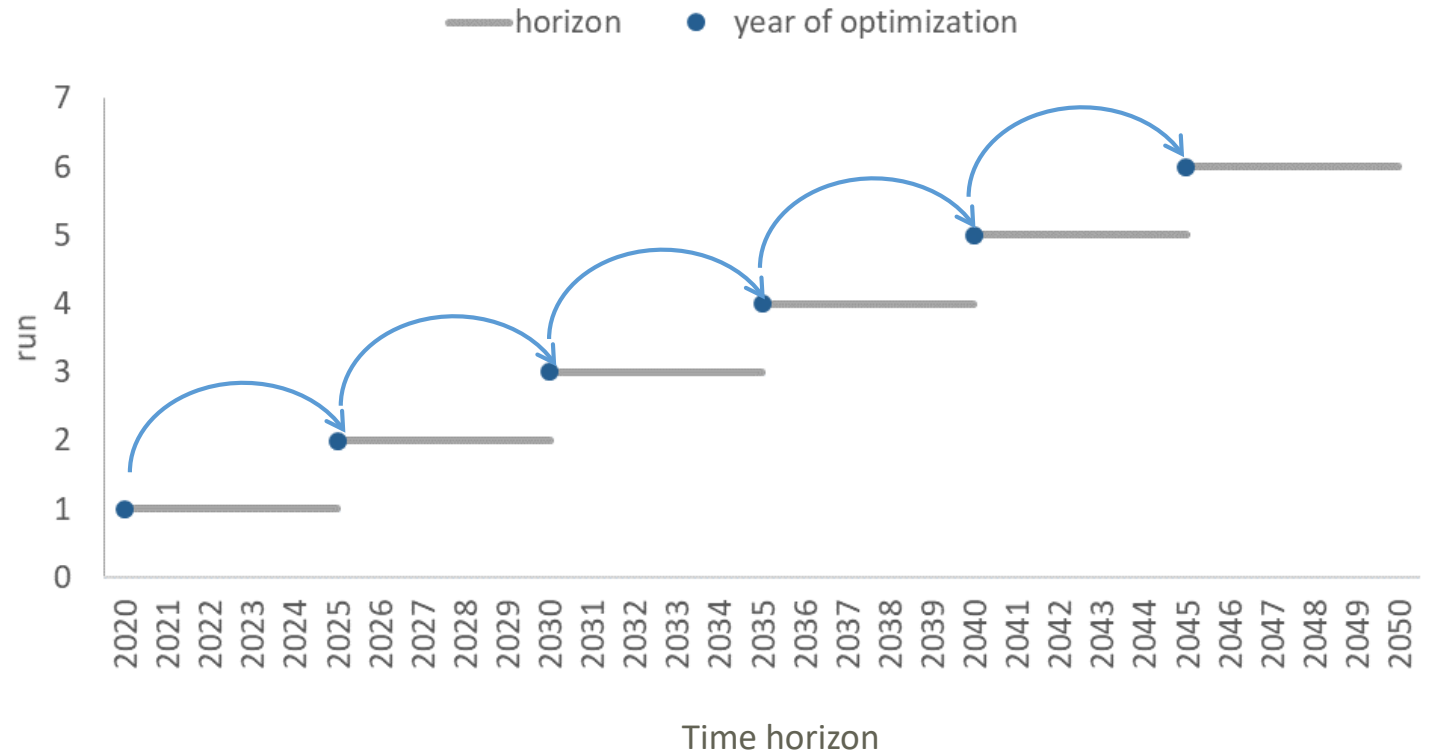


Possible optimization objectives

Climate change	Human health	Ecosystem quality	Resources
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 objectives			
EU Environmental Footprint v2 (Normalization and weighting of single indicators)			
EU Environmental Footprint + costs			
Equilibrium (equal weighting of all env. indicators and costs)			

Multi-period optimization: Application of myopic approach

- First year of a limited time horizon (here 5 years) is being optimized
- Results are given to the next year of optimization (here 6th year)
- Impacts per time period (one year) are aggregated over horizon step and summed up over full time horizon

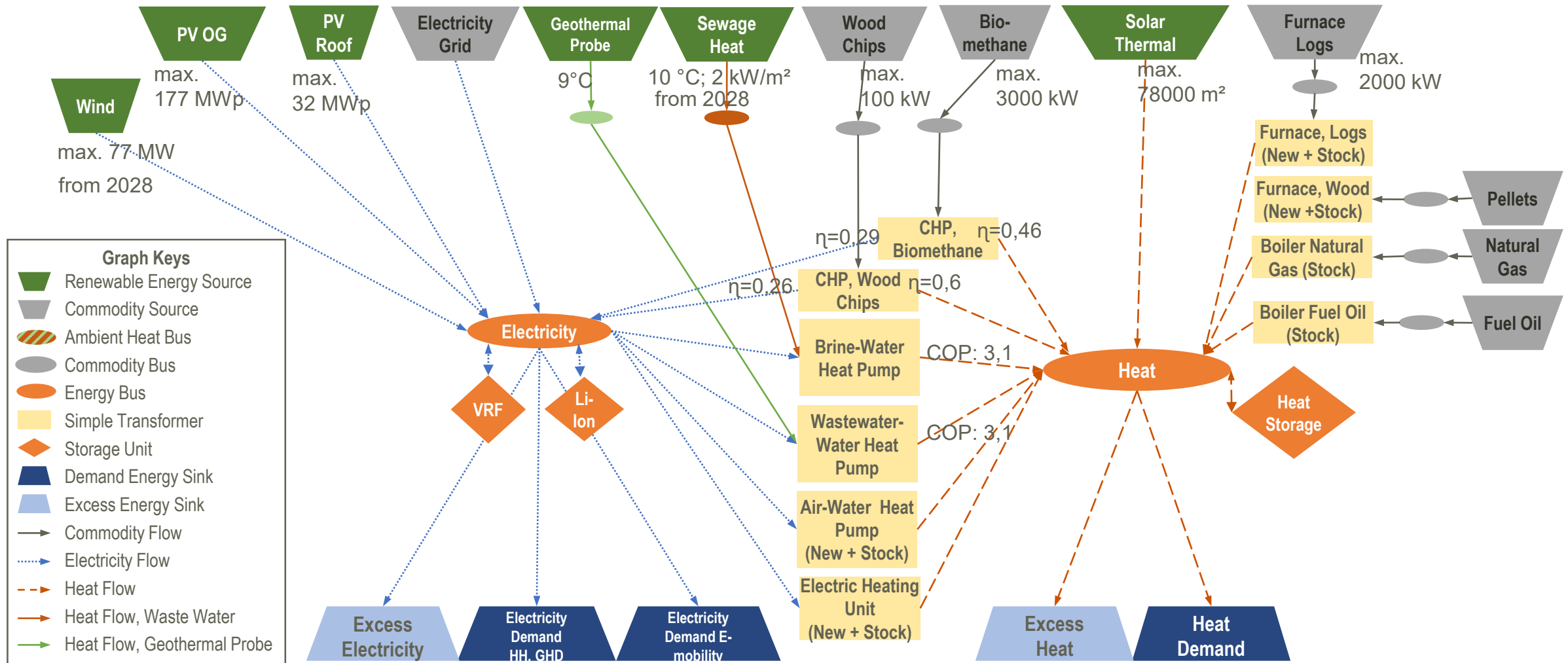


Results of a Case Study

Case Study

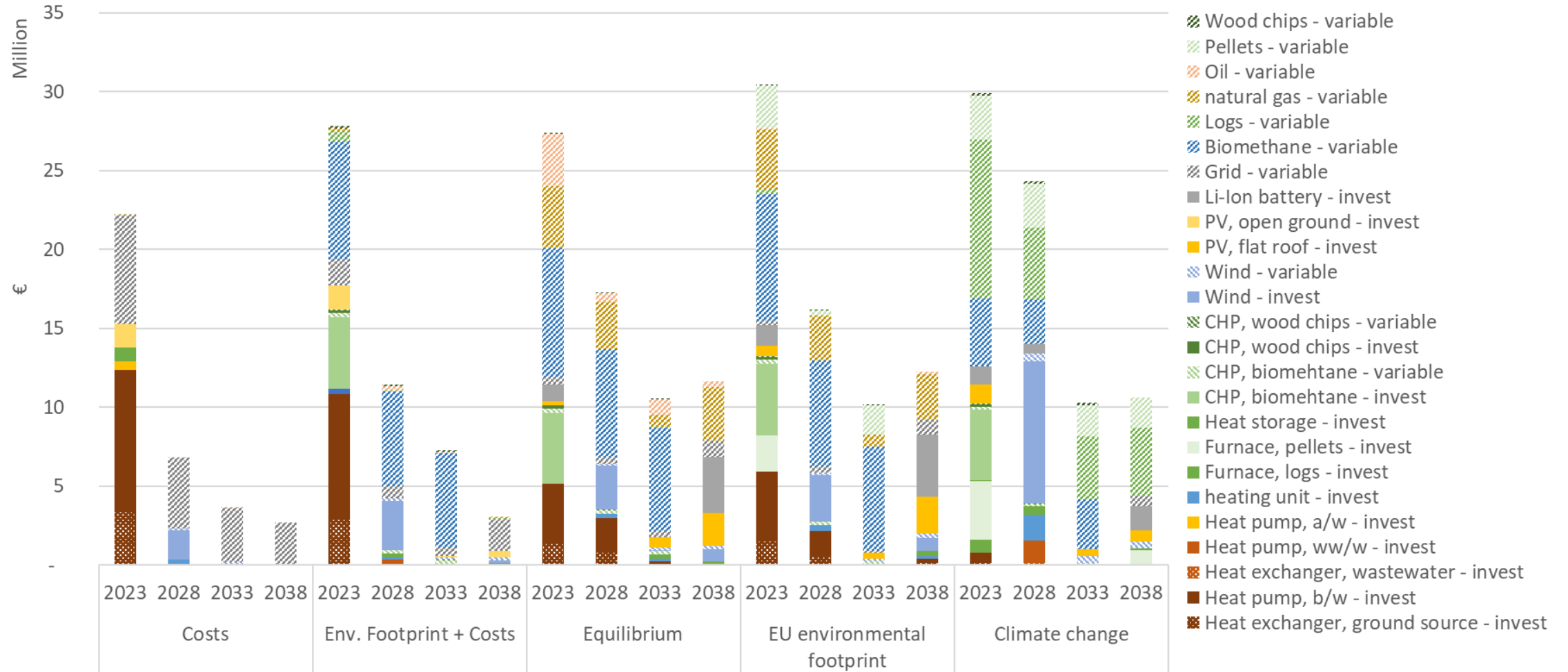
- Village in Southern Germany; merely single-family houses
- Electricity demand: 5.5 GWh, heat demand: 30 GWh
- Time horizon: 20 years
- Changes over time:
 - Charging stations: rising from 50 to 1000 in 2038
 - Decreasing heat demand due to refurbishment
 - Grid electricity mix (costs and LCA)
 - Costs for natural gas and fuel oil
 - Fade-out of existing plants (heat generators, PV)

Model structure/technologies and parameters used



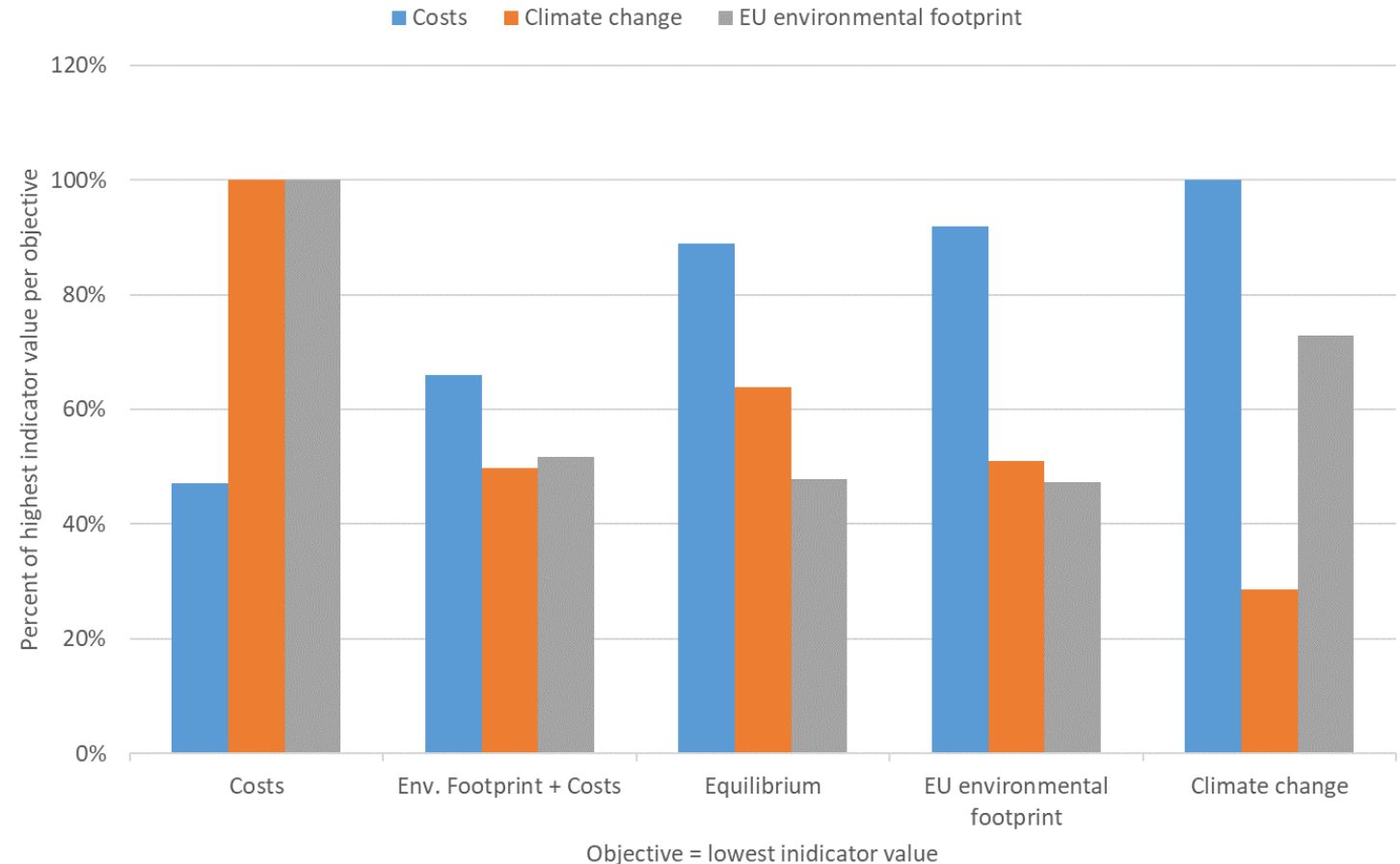
gefördert durch

Costs vs. Climate vs. multi-criteria optimization: Costs over time



Impacts over 20 years per objective

- Minimal climate impacts:
 - high costs and vice versa
 - rel. high overall environmental impacts (due to infrastructure)
- Single objective optimization leads to burden shifting
- Compromise solutions exists



Conclusions

Conclusions

- Single-objective optimization leads to burden shifting; minimizing **costs and climate impacts are opposing objectives**
- Compromise solutions exist which **prevent from burden shifting** from one impact to another
- Aiming at sustainability also **social indicators** like security of supply, employment effects, etc. taken into account



Thanks for your attention

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https://github.com/inecmod/LAEND_v031



Literatur und 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://doi.org/10.3390/en13030614)
- <https://www.hs-pforzheim.de/forschung/institute/inec/sonstiges/laend>
- Dokumentation und Programmcode 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. Zugriffen: 07. Juni 2021.

Methodological Approach of Energy System Model

Input data

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

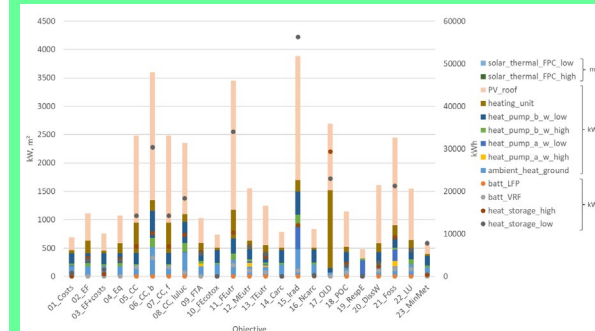
LAEND

Life-cycle Assessment based ENERGY Decision support tool

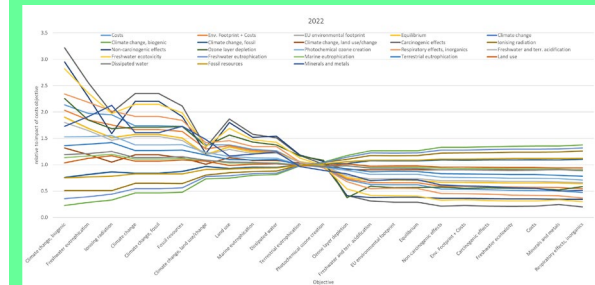
Multi-criteria multi-period investment and dispatch optimization including cost and environmental criteria

Results

Optimal investment and dispatch planning



Environmental impacts of planning alternatives



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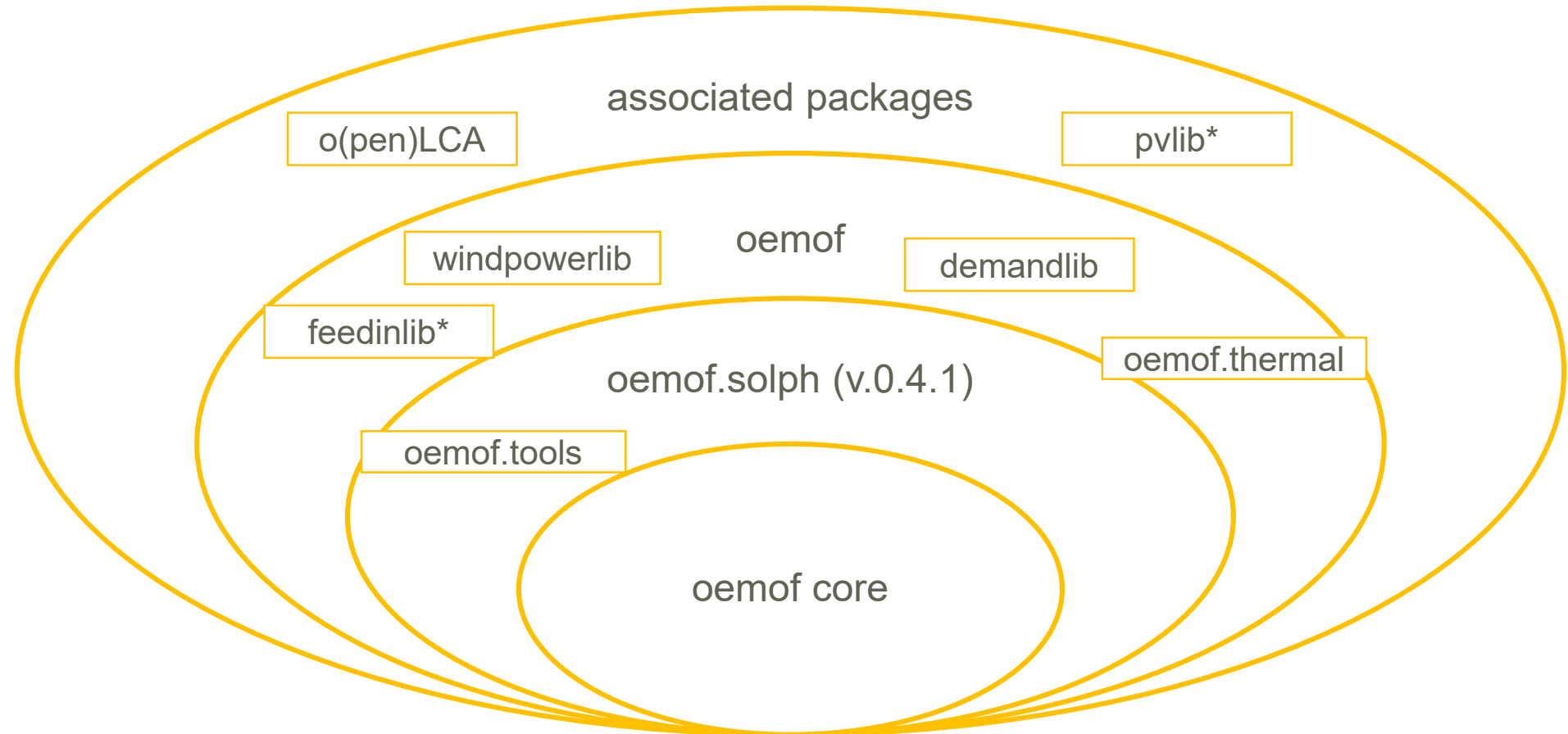
LAEND: Struktur der verwendeten Programmbibliotheken

openLCA:

Use of API to
generate LCA per
used unit

kW for investment
(generation)

kWh for storage
investment and
operation



* (bislang) nicht verwendet

Objective function

- For single environmental objective: environmental impacts are used instead of costs

$$\begin{aligned} \min & \sum_{t \in T} \sum_{(s,e) \in E} \text{vari}_{(s,e)} f_{(s,e)}(t) \cdot \tau \\ & + \sum_{(s,e) \in E} \text{epi}_{(s,e)} x_{(s,e)} \\ & + \sum_{n \in N} \text{epi}_{(n)} y_{(n)} \end{aligned}$$

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

τ = time increment

t = timestep

T = time period

- For multi-criteria objectives: minimizing costs and environmental impacts as weighted sum

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Multi criteria aggregation

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

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

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

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

	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

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

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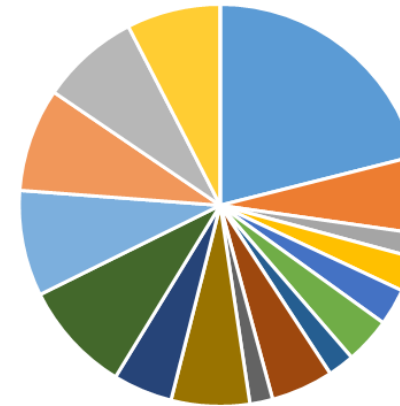
* According to European Commission 2019

Normalization and Weighting Factors for multi-criteria Optimization

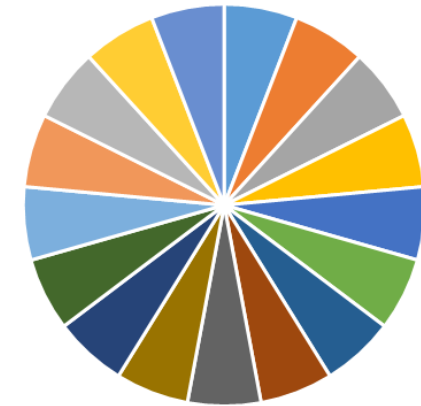
Indicator	World 2010	
Climate change	8.94E+13	kg CO ₂ -Äq
Acidification	4.93E+11	mol H ⁺ -Äq
Ecotoxicity	2.66E+13	CTUe
Freshwater eutrophication	1.59E+10	kg P-Äq
Marine eutrophication	1.99E+11	kg N-Äq
Terrestrial eutrophication	1.57E+12	mol N-Äq
Carcinogenic effects	8.67E+04	CTUh
Ionising radiation	2.63E+13	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	m ³ 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

Weighting factors

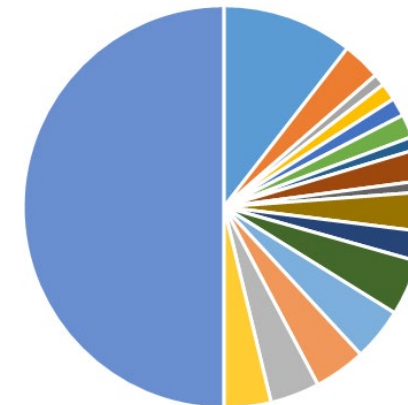
Env. Footprint (EF)



Equilibrium



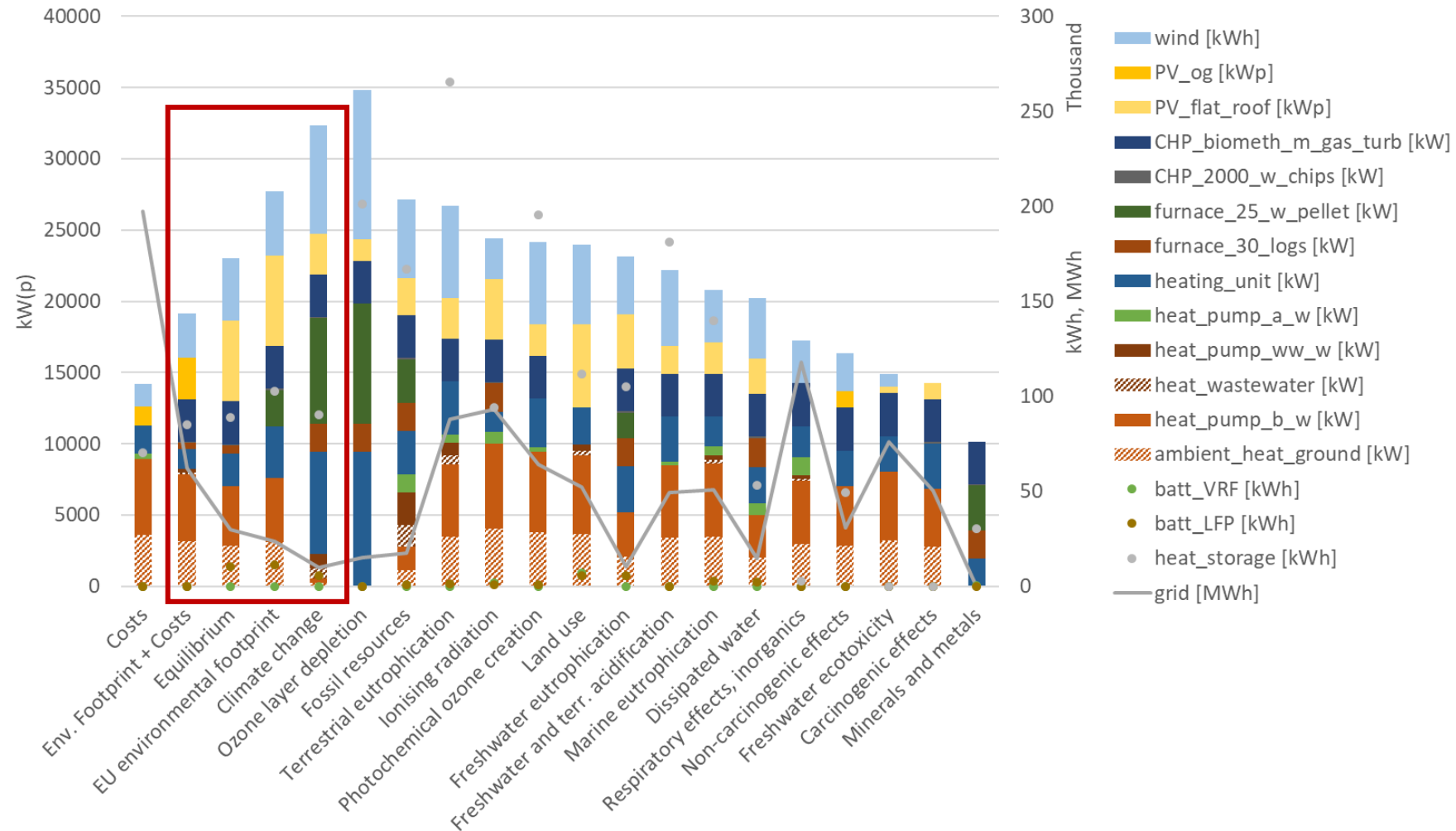
EF + Kosten



Environmental Footprint v2.0 according to European Commission 2019

Results: installed capacities per objective

- Wide range of system configurations
- The higher the weight of climate impacts the higher the installed capacity (red frame)



Objective = minimal indicator value