Combining local preferences and linear optimisation with multi-criteria decision analysis to develop feasible energy concepts in small communities

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1. Introduction & Motivation

- **Buildings**:
  - Account for almost 40% of (German) energy consumption
  - Around 80% for domestic hot water and space heating
- **Decentralised approaches** required as most (~90%) of heat is generated and used decentrally, renewable energy exploitation at least partly decentralised
- Vast majority of renewable generation capacity is in hands of private individuals and farmers but also acceptnace issues

- Various **energy-political criteria and objectives:**
  - Energy policy “target triangle”
  - National: e.g. ambitious targets for renewables in electricity and end energy demand; 80% primary energy demand reduction in residential buildings by 2050
  - Regional/local: differs by location, many communal energy concepts

- Especially smaller, more **rural municipalities lack resources** to carry out extensive energy and climate studies
- **Combination** of quantitavie and qualitative approaches necessary in order to capture both techno-economic and socio-economic aspects

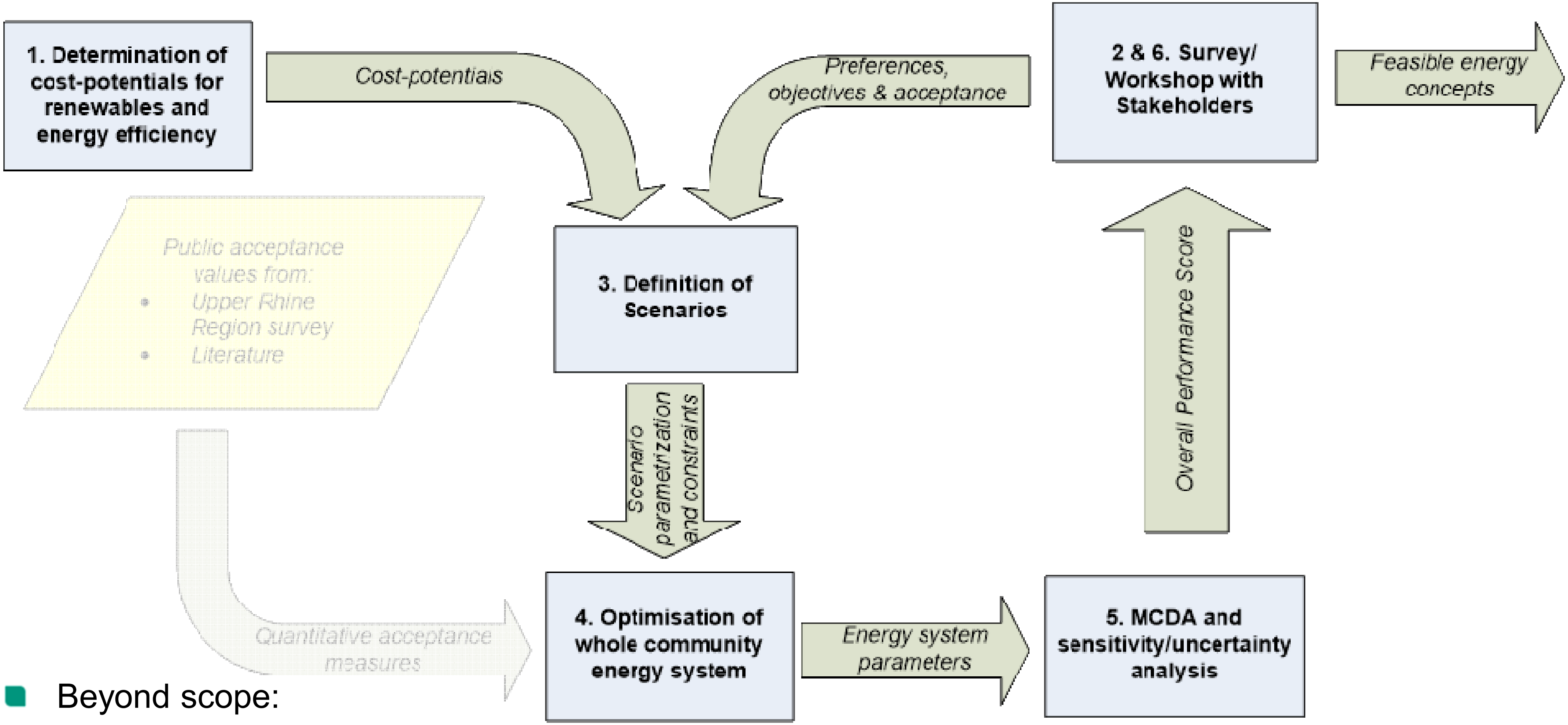
BMWi 2014

2.1 Introduction to Case Study: Ebhausen

- Enquiry to all (around 40) municipalities in Baden-Württemberg involved in European Energy Award (EEA) in February 2016
- Positive feedback from several municipalities
- **Ebhausen** selected on “first come first served” basis:
  - Located around 460 m above sea level, area of 25 km^2
  - Population of about 5000
  - Around 1100 residential buildings
  - Currently around 1.5 MW of PV installed
  - Already quite “active” in energy

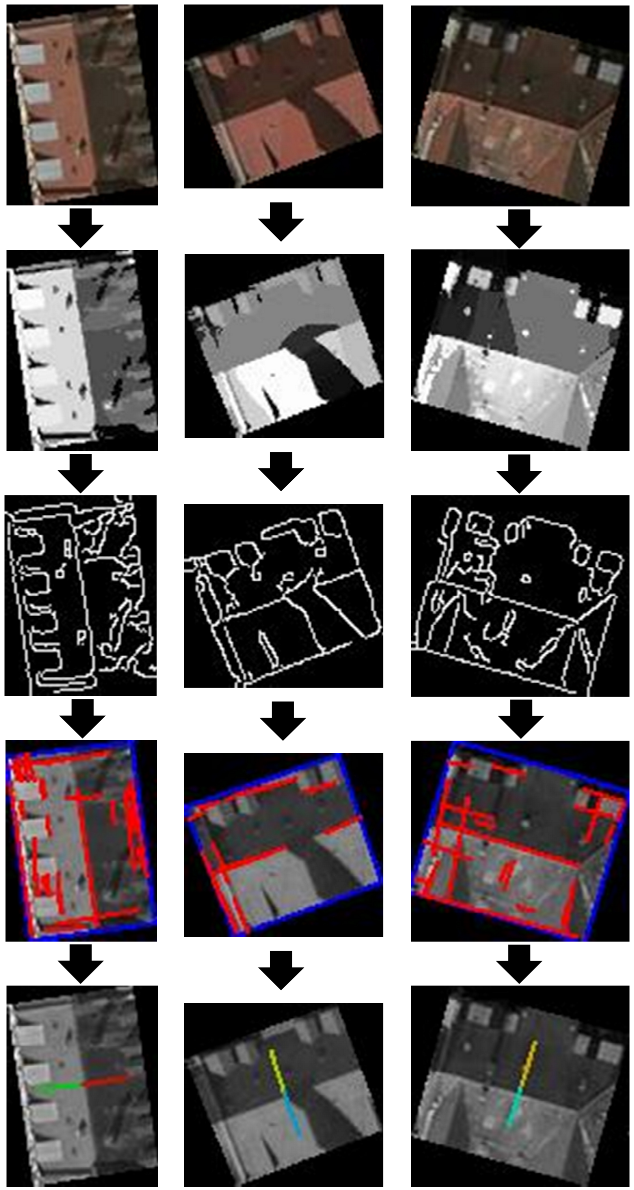

Rotterdam
Paderborn
Göttingen
Halle (Saale)
Leipzig
Dortmund
Essen
Eindhoven
Kassel
Düsseldorf
Antwerp
Bruges
Ghent
Dunkirk
Calais
Germany
Cologne
Jena
Chemnitz
Brussels
Bonn
Aachen
Zwickau
Lille
Liège
Fulda
Belgium
Arras
Koblenz
Karlovy Vary
Frankfurt
Wiesbaden
Mainz
Bayreuth
Amiens
Würzburg
Bamberg
Luxembourg City
Trier
Mannheim
Nuremberg
Heidelberg
Reims
Saarbrücken
Metz
Regensburg
Karlsruhe
Paris
Stuttgart
Straubing
Ingolstadt
Nancy
Versailles
Strasbourg
Ulm
Augsburg
Troyes
Parc Naturel Régional des Ballons des Vosges
Munich
Freiburg
Orléans
Rosenheim
Kempten
Konstanz
Friedrichshafen
Garmisch-Partenkirchen
Berchtesgaden
Basel
Zürich
Parc Naturel Régional du Morvan
Dijon
St Gallen
Innsbruck
Besançon
Liechtenstein
Bourges
Lucerne

2.1 Overall approach

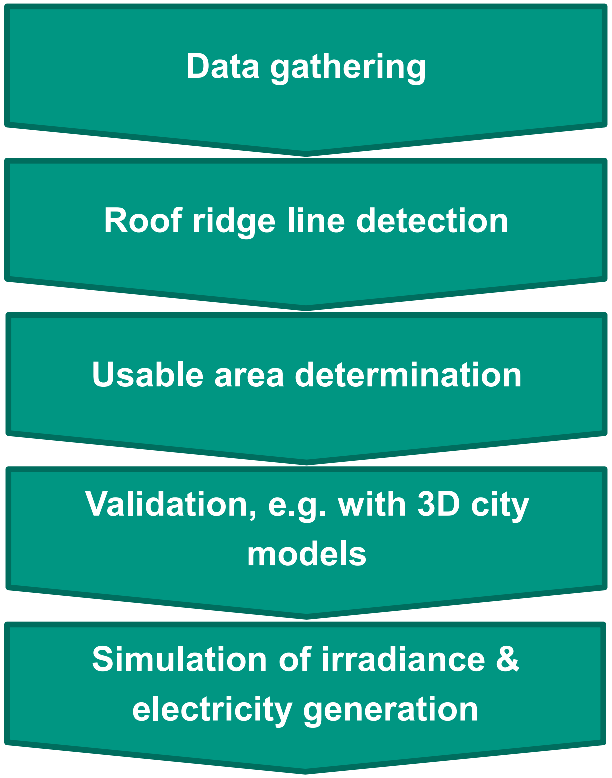


- Beyond scope:
  - Transport
  - Infrastructure and network planning
  - Implementation of measures

2.2 Cost-potential analysis for PV:
Roof area, orientation and ridge line detection

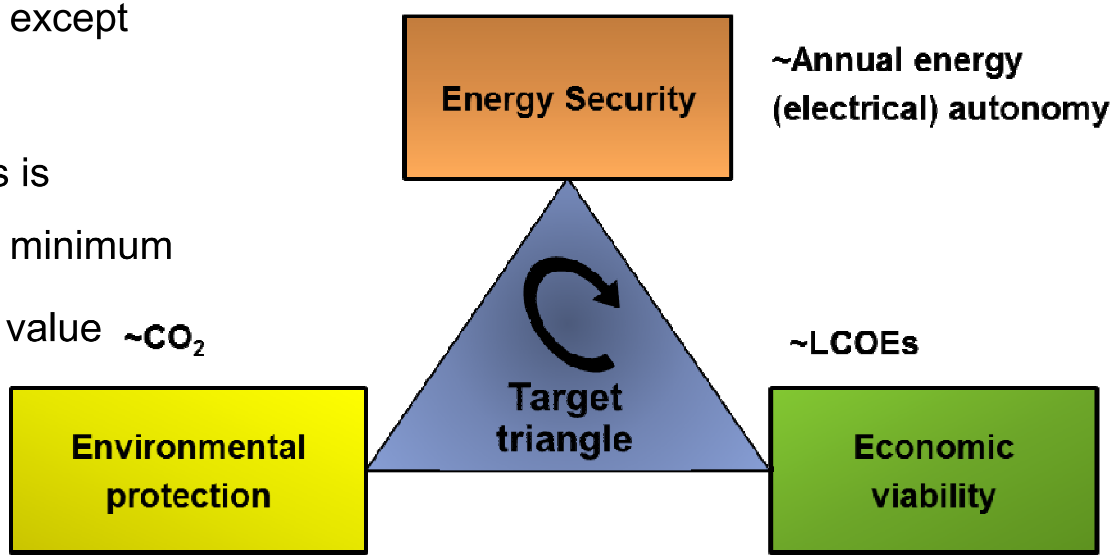


- Data sources:
  - Bing maps
  - Open Street Map
- Pre-processing
  - Noise reduction
  - Colour filtering
  - Contrast enhancement
- Edge detection
- Straight line detection
- Logical analysis: Final roof ridge line has to be in middle corridor of the building, parallel to the walls, separate areas of different brightness in the image
- Validation has shown a good accuracy, with a failure rate of about 12%



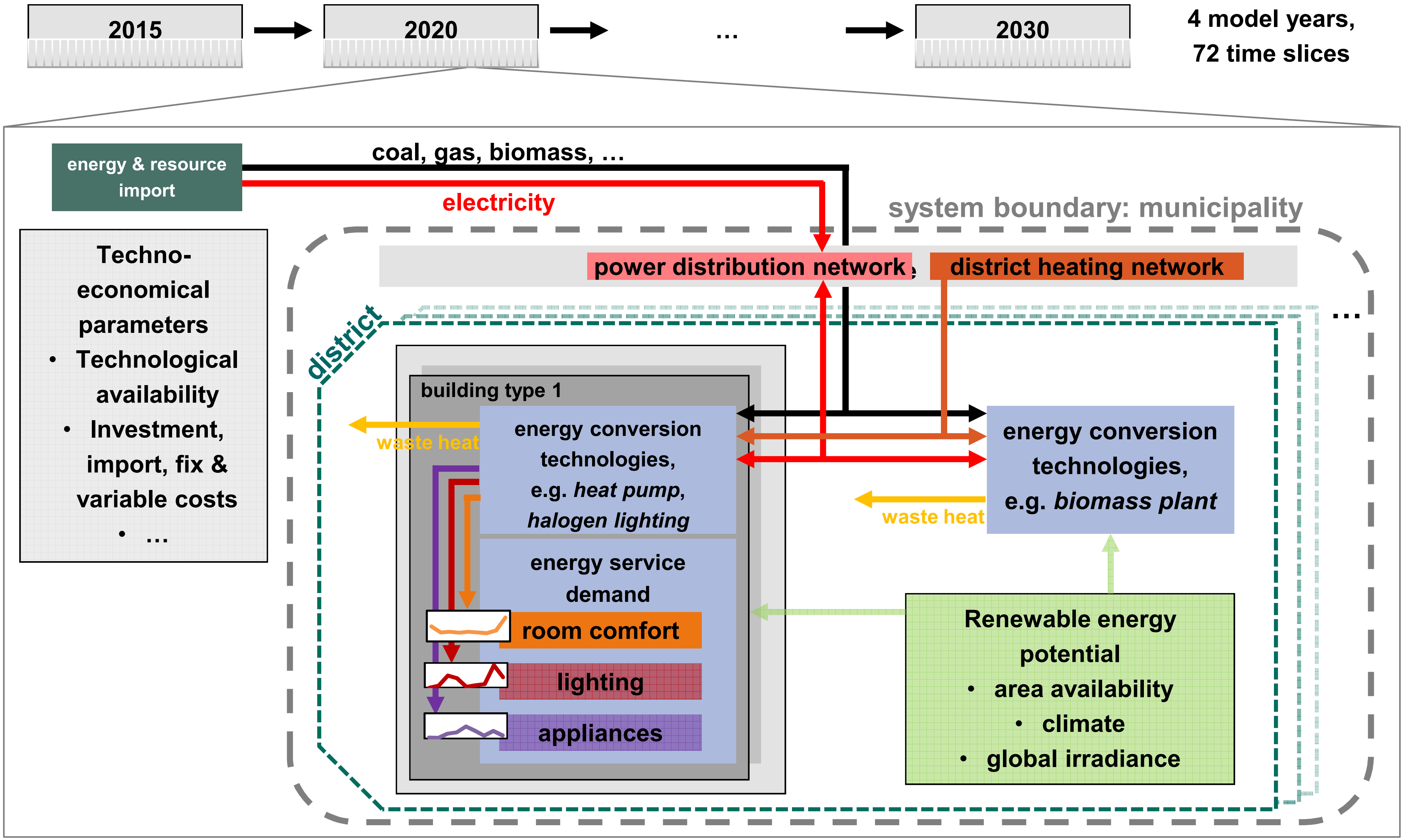
2.2. First workshop results and scenario definition

- First workshop with 20 local stakeholders, including Local Council (7), Administration (4), Energy Team (4), Farmers (2), interested Citizens (3)
- Results from the first workshop:
  - Objective of the study should be to derive realisitic goals and possible courses of action
  - Additional bioenergy development not desired, except wood fuel e.g. pellets
  - The priority for the municipality and the citizens is economics: perhaps a threshold of 10% above minimum
  - Building-sharp PV cataster would have a lot of value
  - Small-scale hydropower

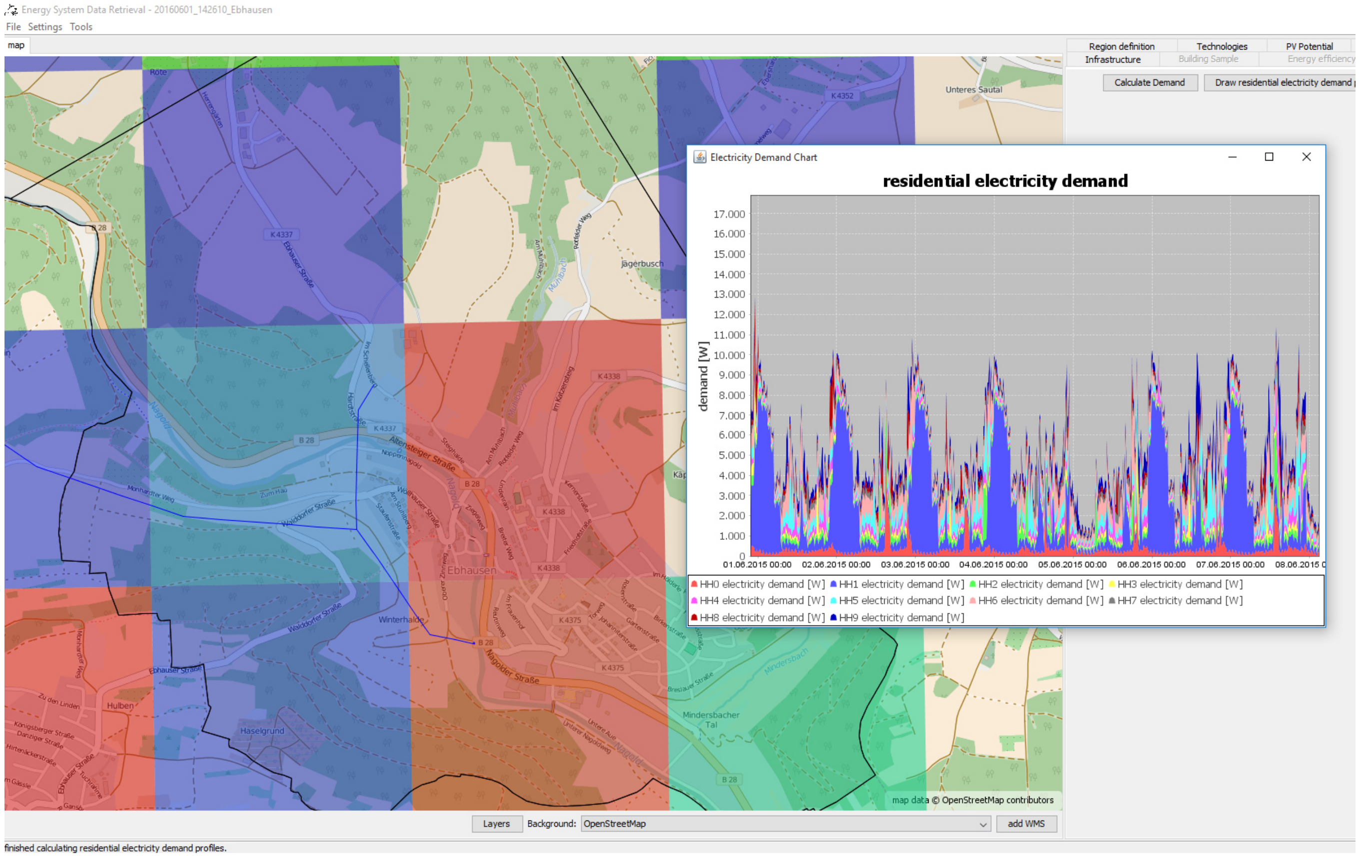


- Scenarios:
  - minimised system costs, total net energy (electricity) imports and CO2 emissions
  - In addition, intermediate scenarios, e.g. at 110% and 120% of the minimum costs

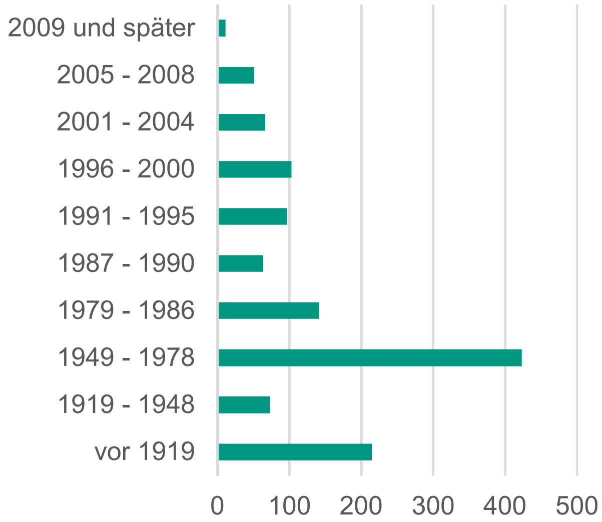
2.2 Methodological approach: optimizing energy and material flow model



2.2 Energy demand, existing building stock and scenario assumptions



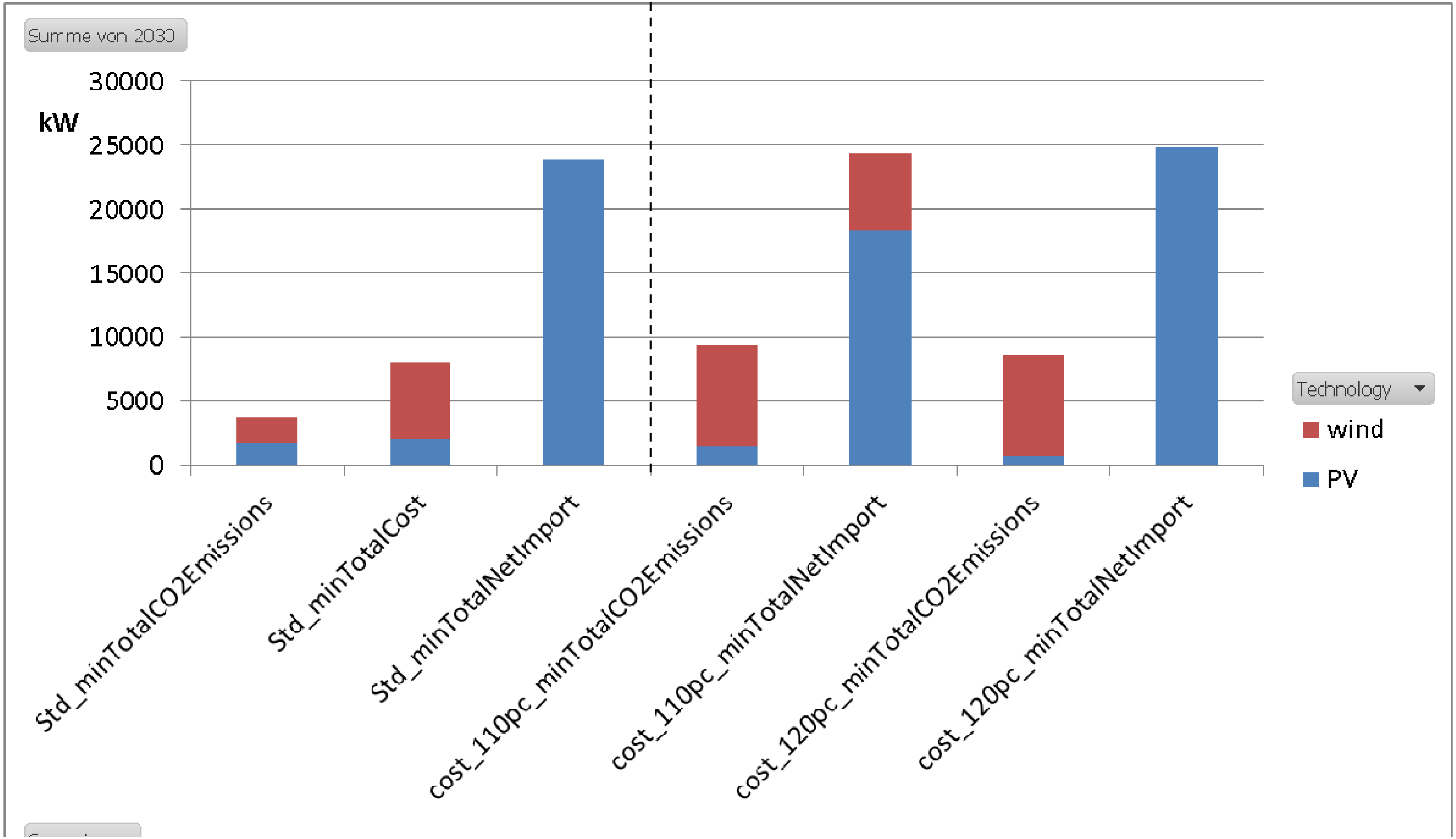
No. of residential builldings



Key scenario assumptions:

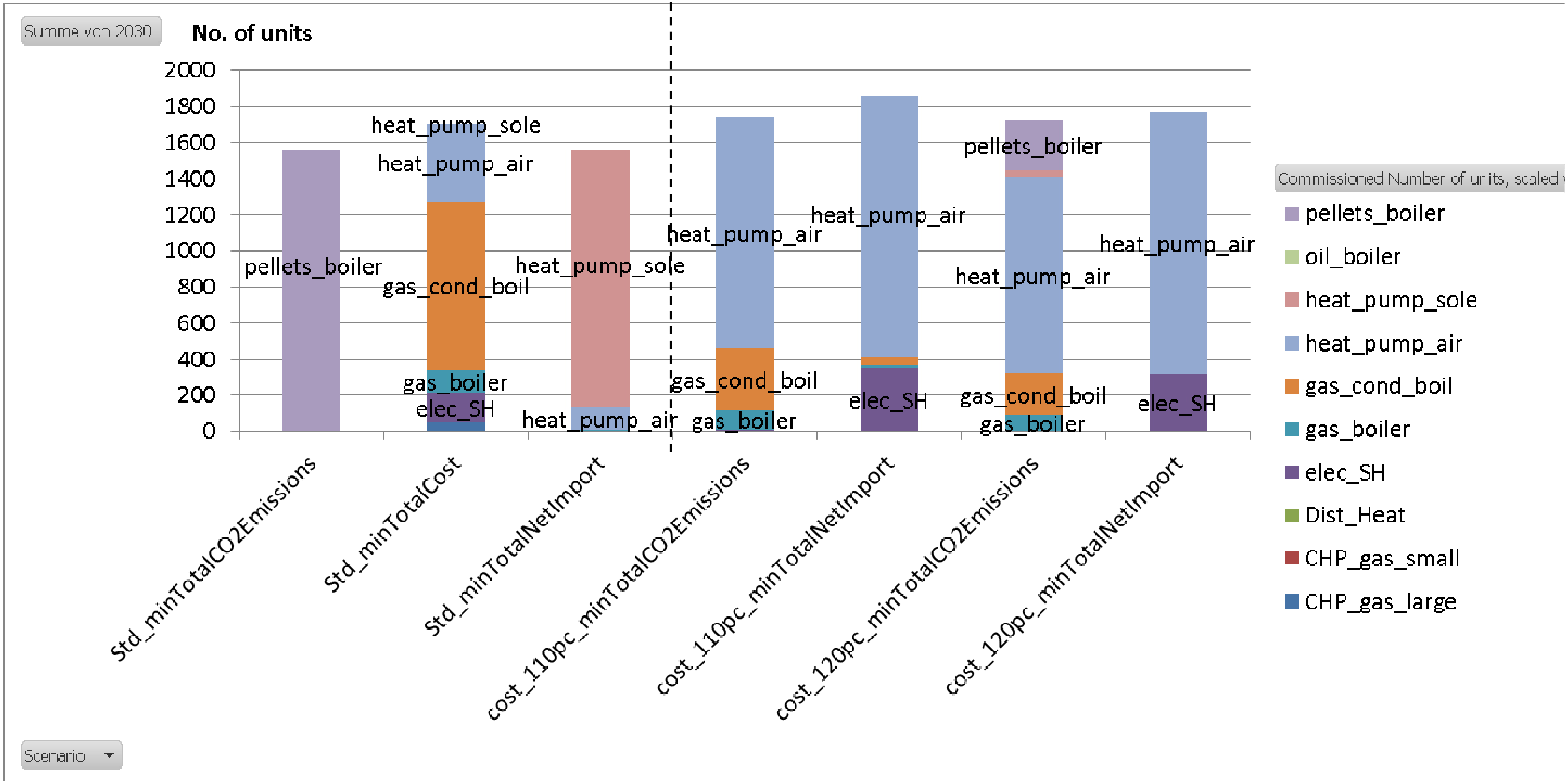
- 5% discount rate
- Constant demand
- Fuel and electricity price rise of 2.5% per year

2.2. Results of optimization in 2030: renewable capacities



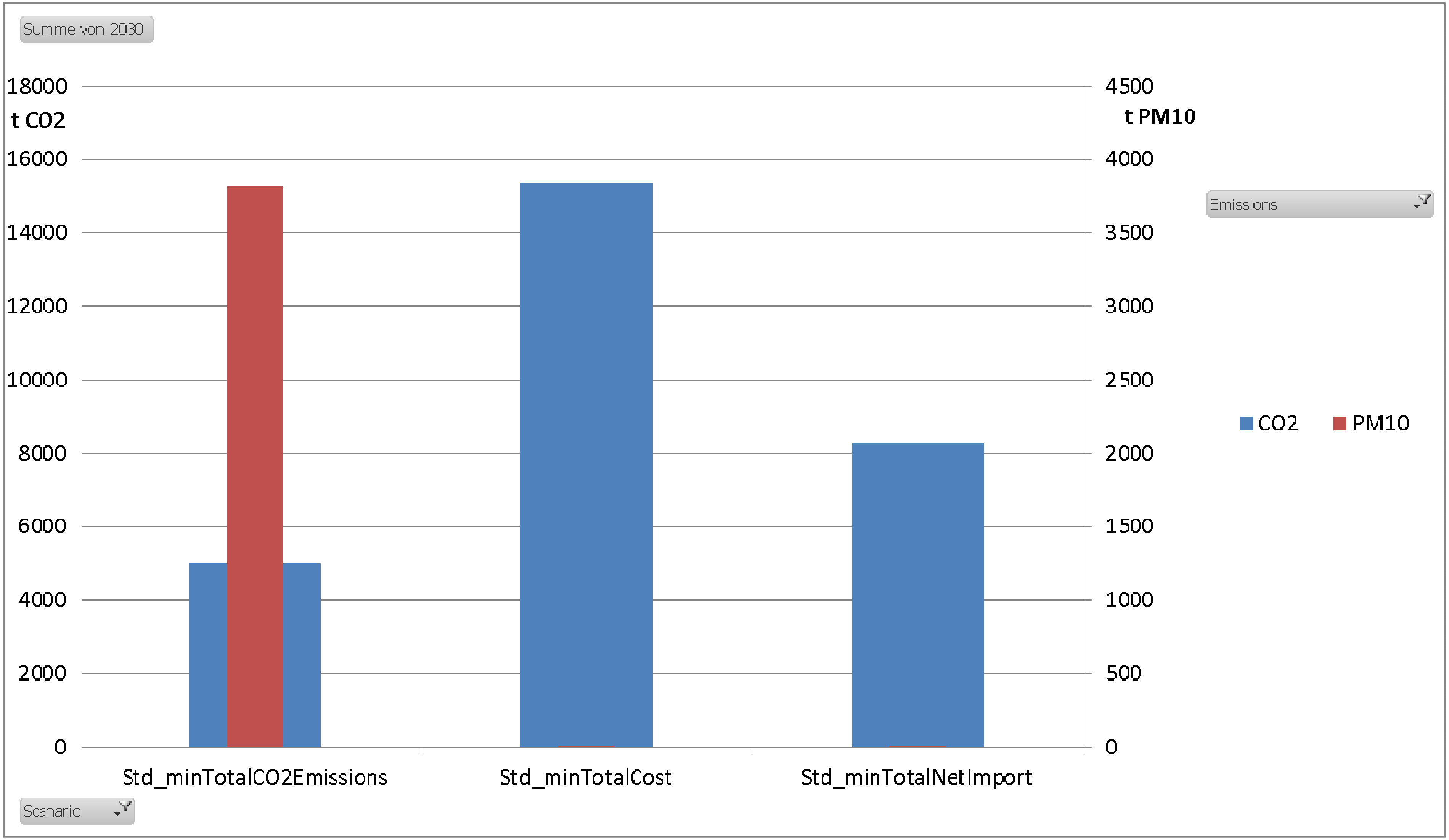
- ➢ Large differences between scenarios; small changes in total costs have significant impacts

2.2. Results of optimization in 2030: heating technologies



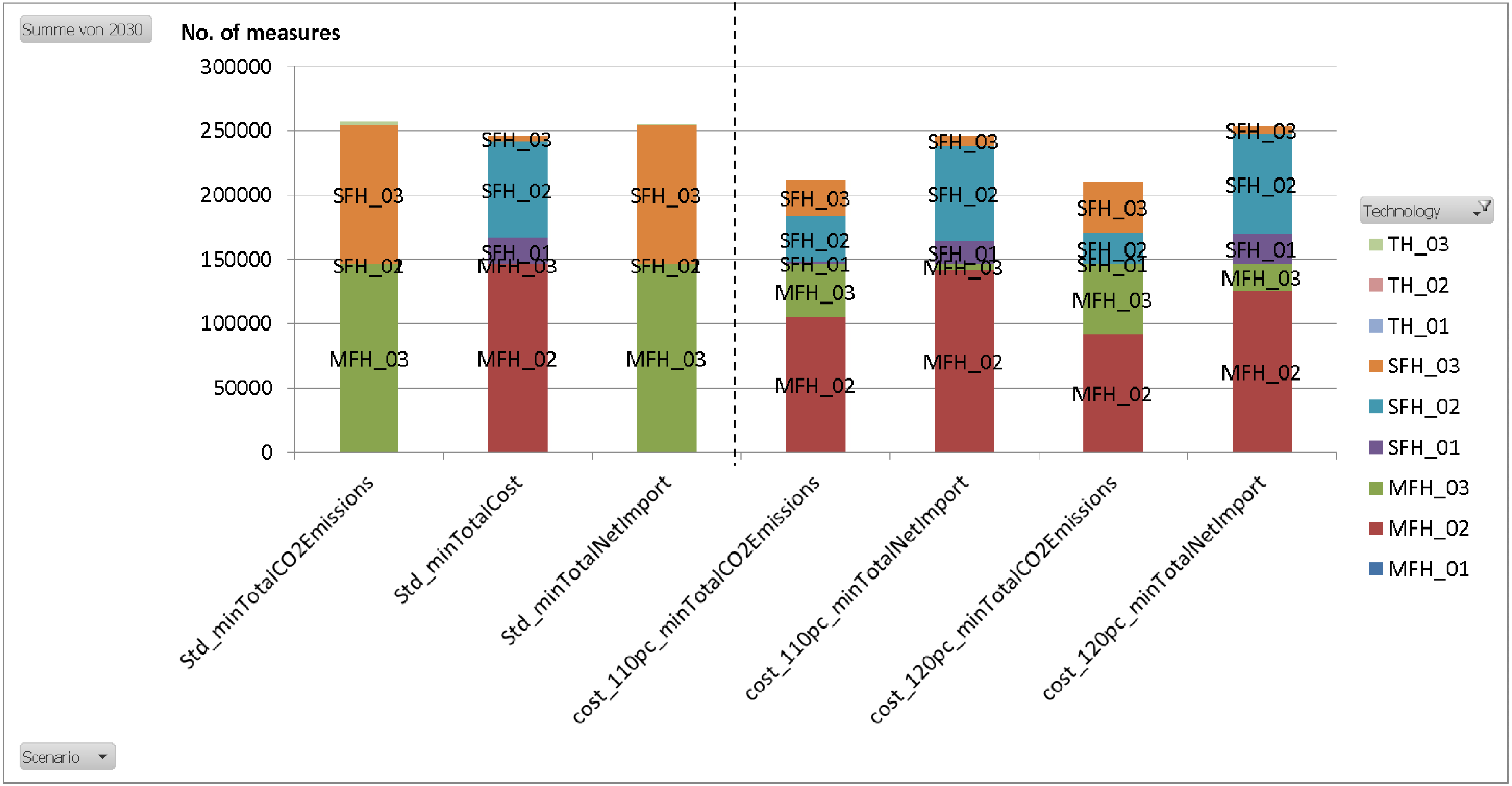
- ➢ The "extreme" heating technology portfolios are greatly relaxed at marginally higher costs

2.2. Results of optimization in 2030: total emissions



➢ Strong trade-off between CO2 and PM10 emissions due to pellet heating systems

2.2. Results of optimization in 2030: building insulation



- Moderately robust results for insulation: cost minimization results in shallower renovations

2.2 Exemplary results from a household perspective

Economics

Costs			
Panel Investment (/kW)	€ 1,300		
Panel Investment (kW)	€ 1,300		
Installation	€ 1,000		
Total Capital Cost	€ 2,300	% of Investment	
O&M Costs (at 1.5%)	€ 20	1.5%	

PV System	
Maximum Power (kW)	1
Area Occupied (m^2)[1]	7
Efficiency	15%
Electricity Generation from Selected Orientation (kWh/Year)	1509
Lifetime (Years)	20
Panel Decay	-1%

Average Area Occupied by PV Panel	
7	m^2/kW

Enter Tilt	35
Enter Azimuth	180

Modifiable Values	
Input Values	

Monetary Gains	
Total Financial Offset	€ 365
Gains After Annual Costs	€ 345

Consumption	
Annual Household Energy Consumption (kWh)	5000
Self Consumption (% of PV Generated)	72%
Self Sufficiency (%)	22%
Average Price of Electricity (c/kWh)[2]	28.69
Feed-in Tarriff (c/kWh)[3]	12.31

Financial Metrics	
Discount Rate	5%
Simple Payback Period	7
IRR (Constant Annuity)	14%
Combined IRR	16%
Net Present Value (Combined)*	€ 2,539
Net Present Value (Constant Annuity)	€ 2,000

Rise in Energy Cost	2%
Rise in Feed in Tarriff	0%

* Combined: Panel Decay + Rise in Energy Cost + Rise in Feed in Tarriff

Heating Technologies	Capital Cost	Annual Cost	Annual Emissions	Lifecycle Cost	LCOH	Lifecycle Emissions
Gas Boiler	Relative to Currently Used Gas Heating			Relative to Currently Used Gas Heating		
Oil Boiler	27%	123%	79%	48%	98%	34%
Electric Storage Heater	-27%	226%	178%	168%	168%	178%
Gas Condensing Boiler	8%	-4%	-7%	-2%	-2%	-7%
Pellets Boiler	98%	-28%	-88%	-17%	11%	-91%
Heat Pump Air	211%	42%	-21%	78%	78%	-21%
Heat Pump Sole	317%	55%	-27%	112%	112%	-27%
CHP Gas Small	556%	291%	38%	279%	405%	4%
CHP Gas Large	417%	200%	38%	174%	266%	4%

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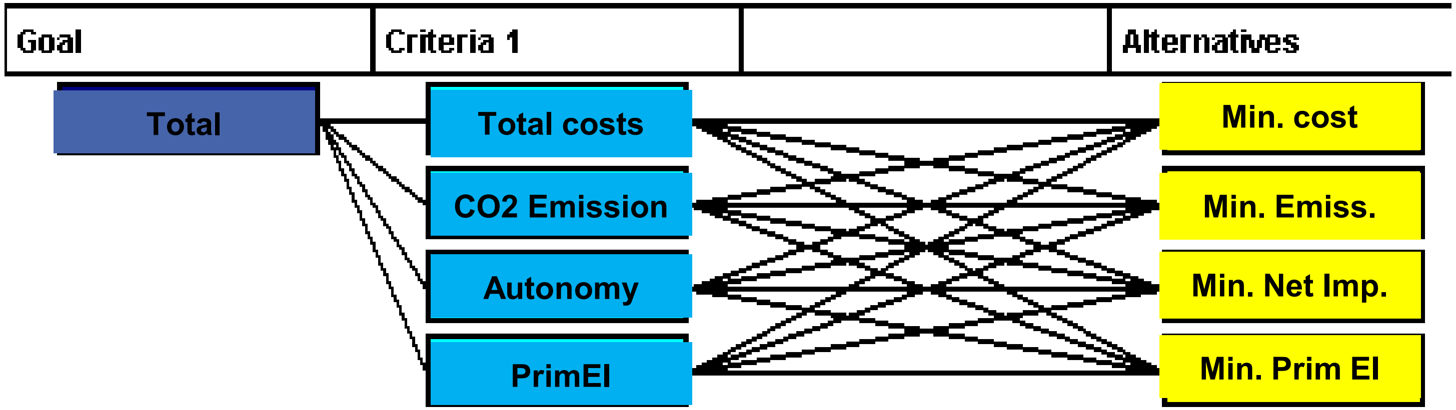
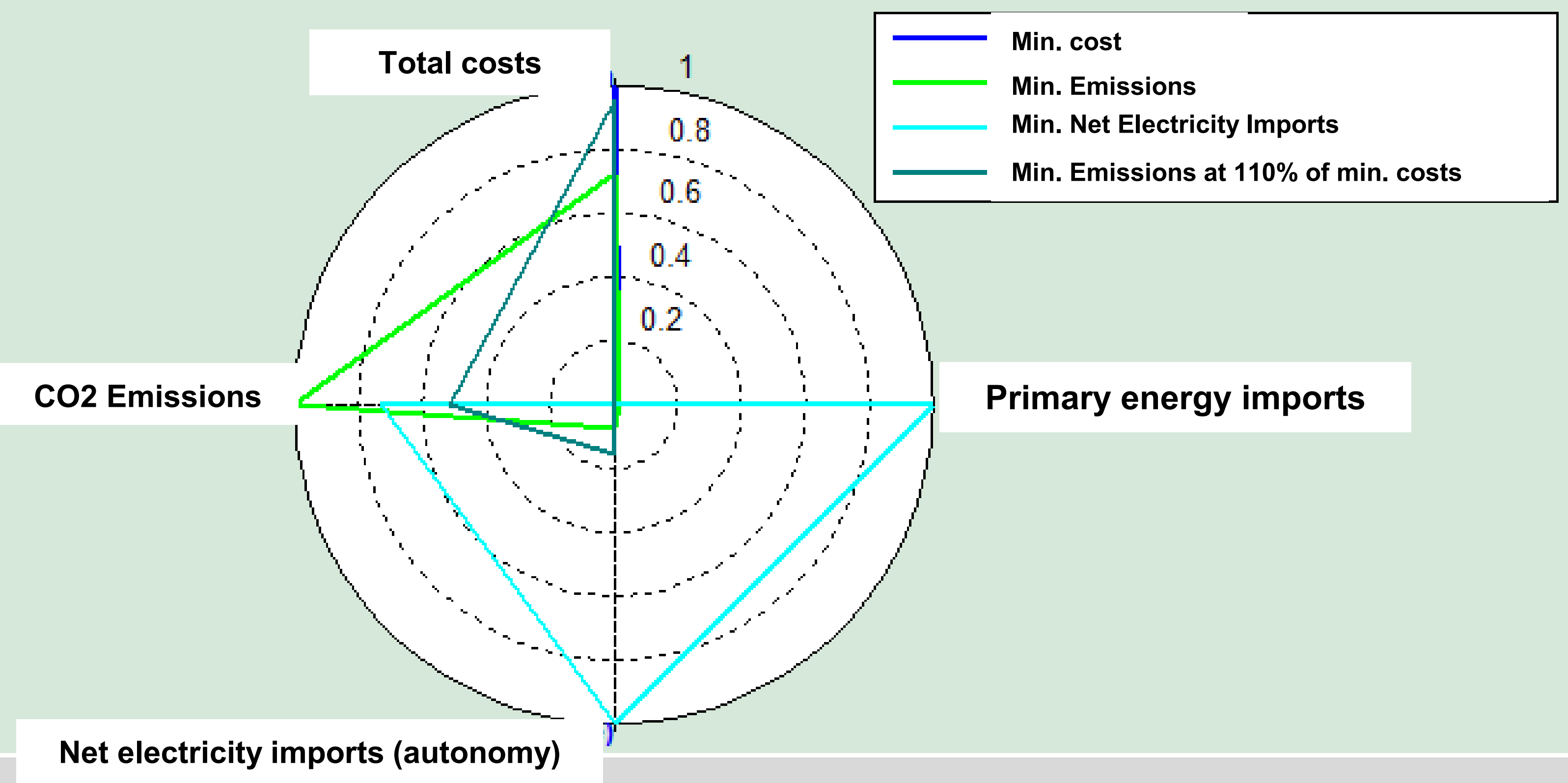
2.3 MCDA: Criteria heirarchy and spider diagram of alternatives





2.3 MCDA: weight elicitation in 2nd workshop

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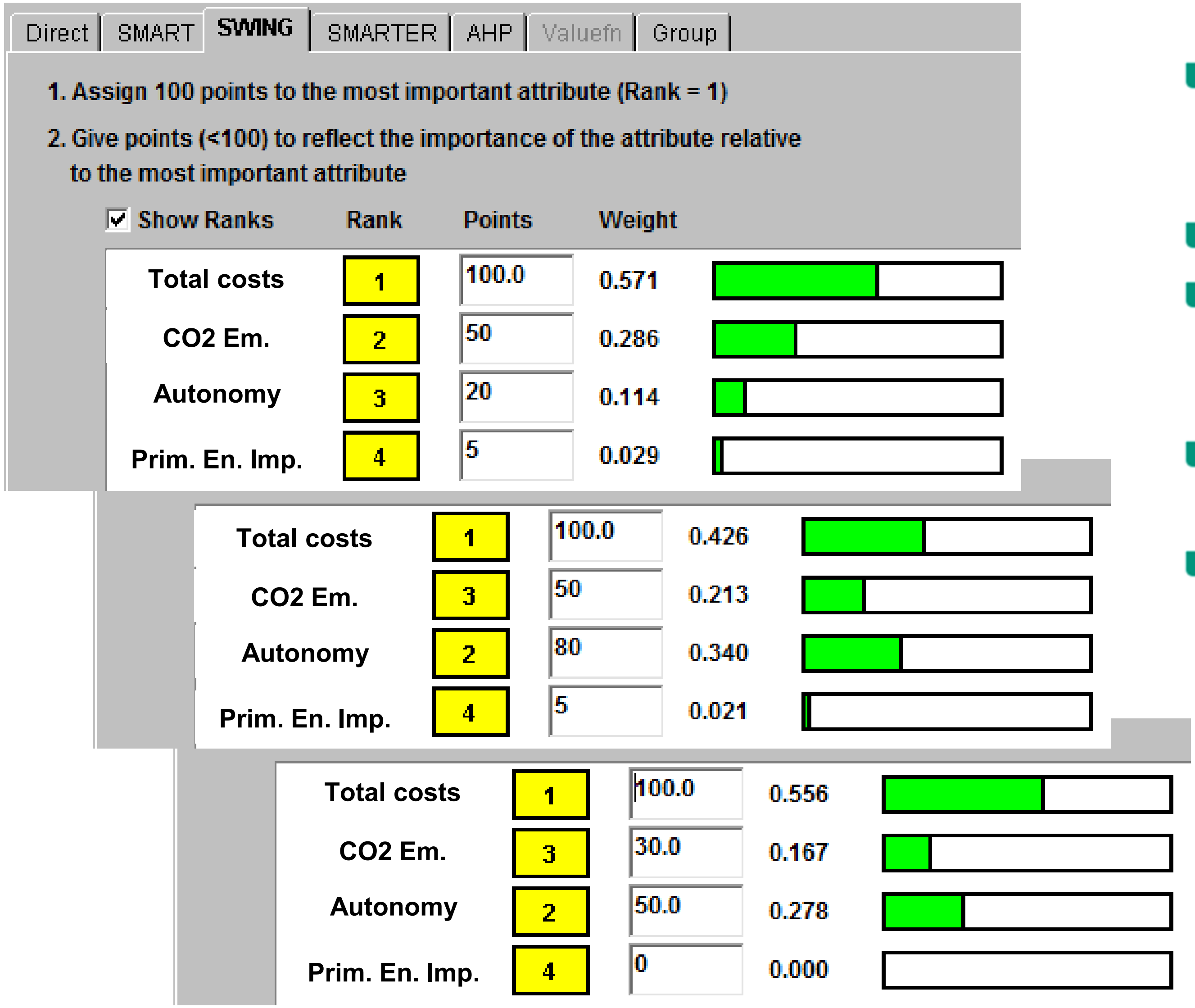
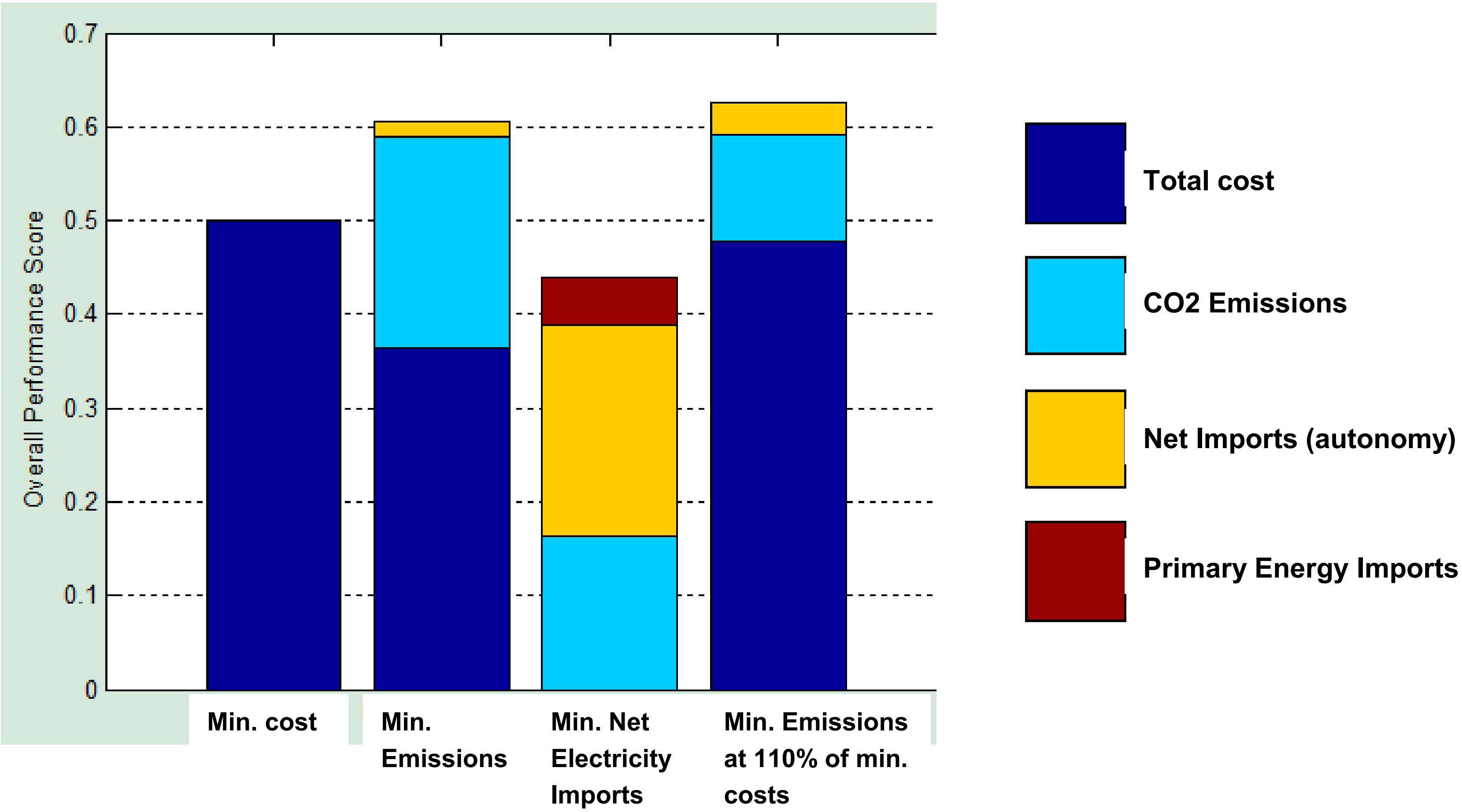


- The SWING weighting method was used for eliciting the weights within the workshop
- Linear value functions assumed
- Controversial discussion concerning the relative importance of the four criteria
- Highest uncertainty concerning the weight of “energy autonomy”
- Calculation of intervals including the three sets of weights

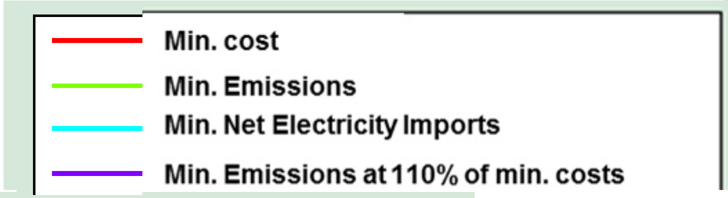
Criterion	Weight Interval
Costs	0.40-0.60
CO2	0.15-0.30
Autonomy	0.10-0.35
Primary	0.00-0.05

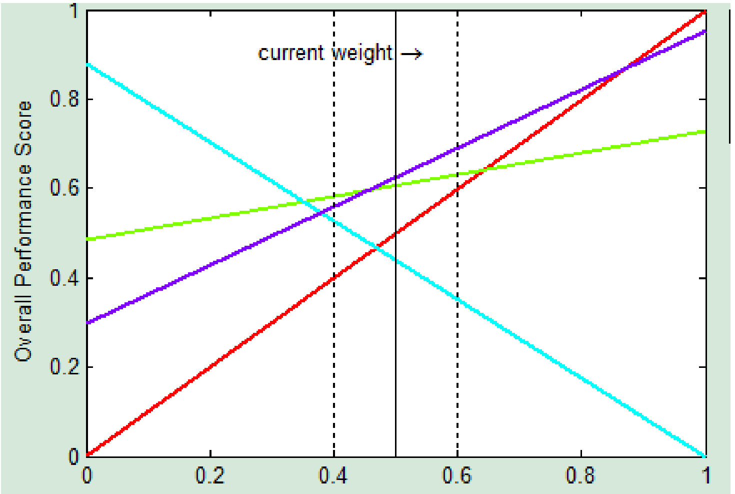
2.3 Ranking of the considered alternatives for the assumed deterministic weights



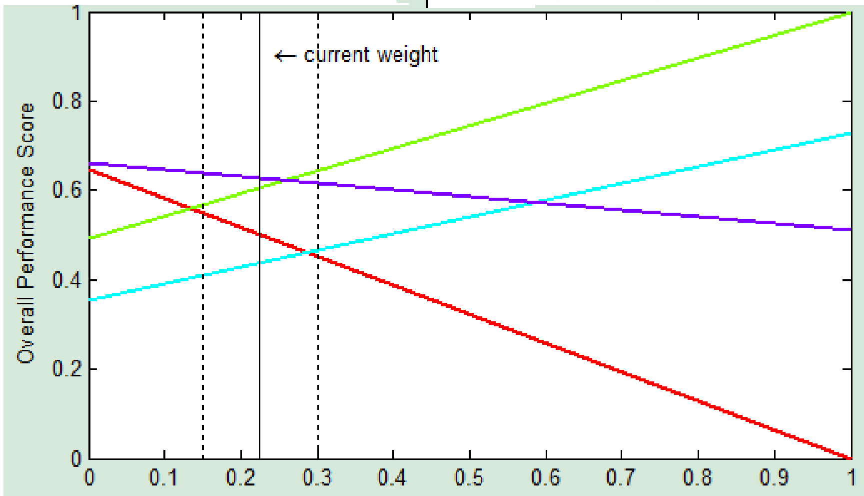
- Two scenarios perform significantly better based on OPS, but Min. Import most balanced

2.3 1-D sensitivity analysis for the weights

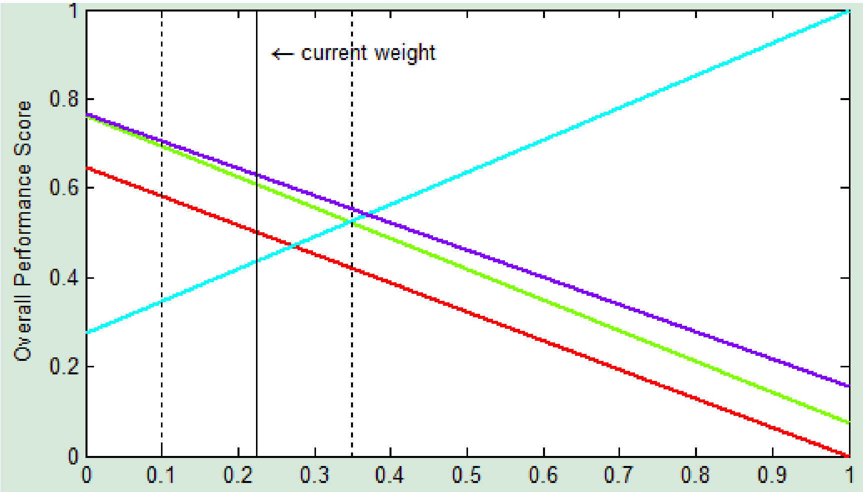




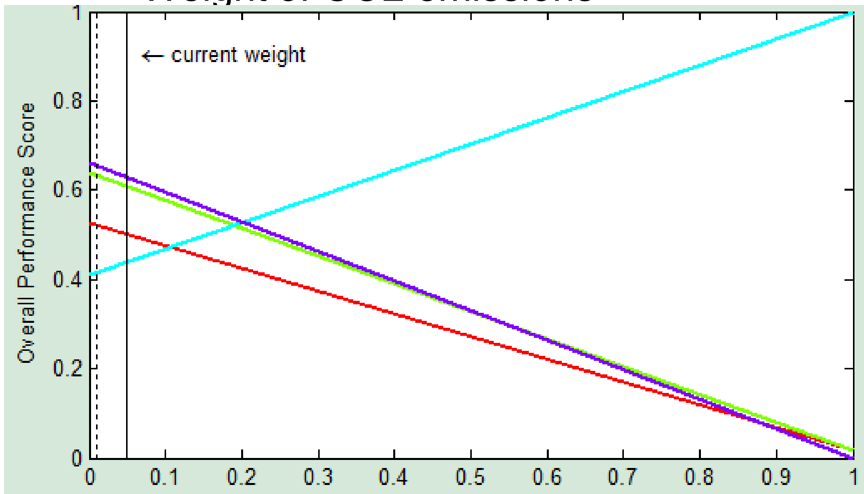
Weight of total costs



Weight of CO2 emissions



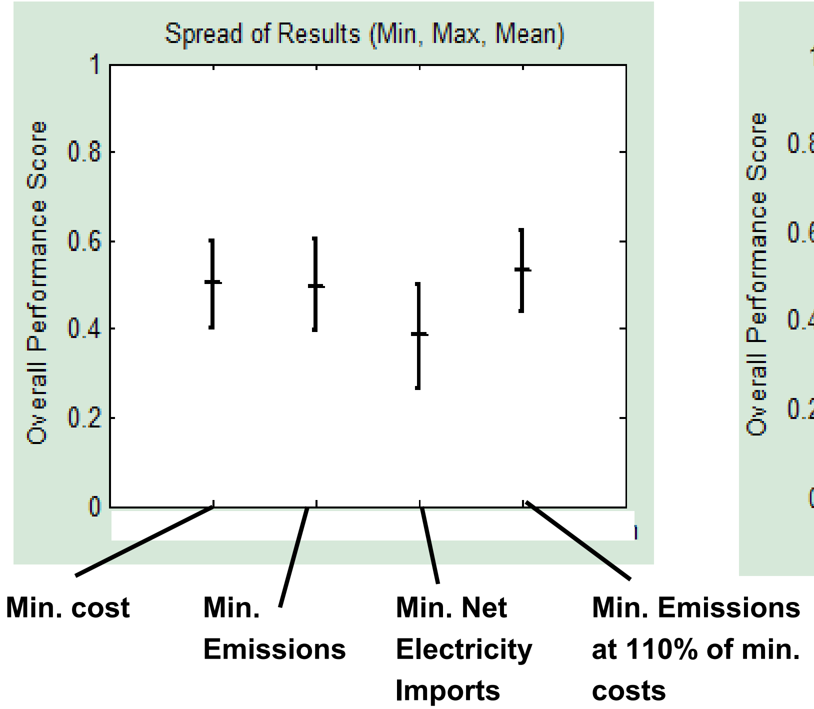
Weight of net el. imports

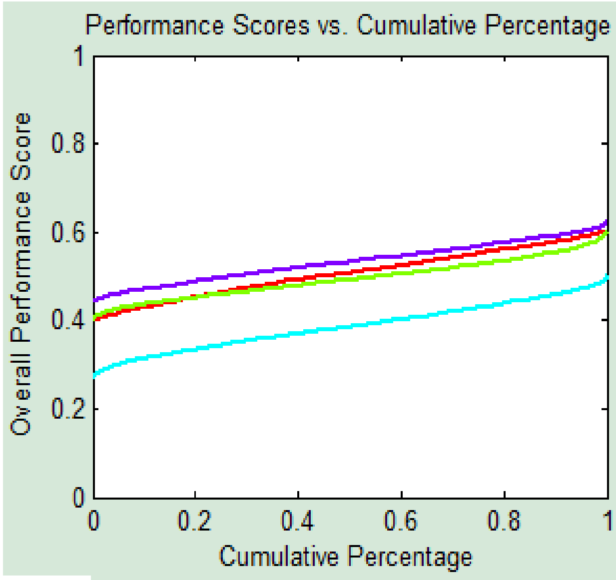


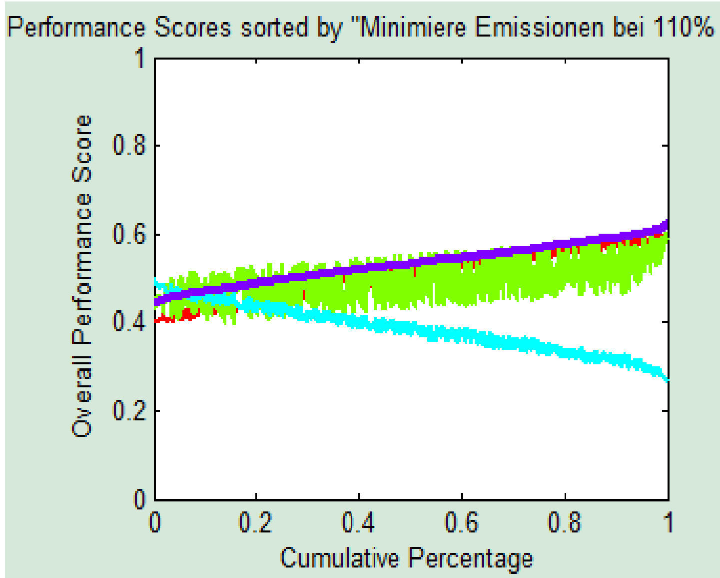
Weight of prim. En. imports

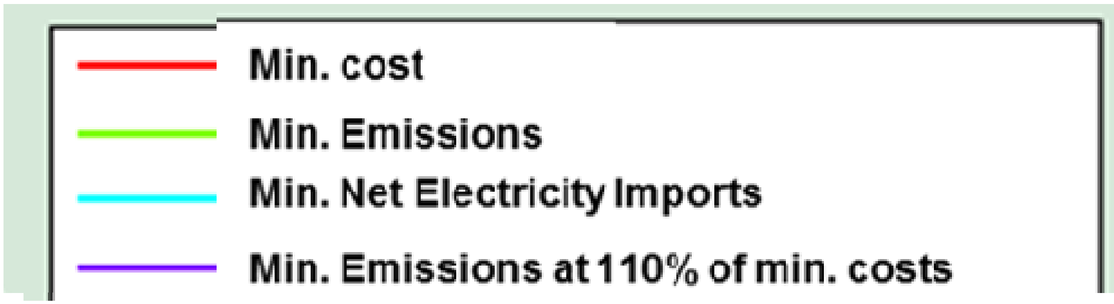
- ➢ Within the defined weight ranges, strong trade-offs between “emissions” and “emissions at 110% cost” scenarios

2.3 Multidimensional sensitivity analysis









- Alternative “minimise emissions at 110% min. costs” yields highest overall performance score for 74% of 1000 randomly sampled weights (within the assumed weight intervals)

3. Critical reflection on approach

- **Uncertainties**, e.g. relating to:
  - The reference energy system in the year 2015
  - Input parameters >> sensitivities
  - Depiction of technologies quite coarse >> comparison
- **Normative perspective**:
  - Abstracts from individual behaviour and barriers
  - Ex post consideration of preferences
  - 10-20% savings through non-investive measures possible?
- **Choice of municipality**: “already done a lot” has pros and cons…
- **Transport**: electric and/or hydrogen vehicles >> network
- **Sustainability** not (yet) assessed, e.g. lifecycle impact of measures

3. Conclusions and outlook

- Conclusions:
  - Despite the strong weighting, the minimum cost scenario is rarely the “best”
  - Depending on the weight allocated to emissions reduction, the emission minimization either with either “free costs” or “10% above minimum” is best
  - The “energy autonomy” alternative is quite balanced (in terms of contributions of attributes) but worse in terms of the costs
  - It remains to be determined whether there is an “optimal” %-value for the additional costs allowable for a particular weighting combination
- Outlook:
  - Completion by November, by that time:
    - Derivation of cost-potential curves for measure “bundles”
    - Assessment of results on a district level
    - Analysis of sensitivities with further scenarios (e.g. with battery storage)
    - Assessment of sustainability
  - And after that time attempt to obtain funding for follow on project:
    - Implementation, e.g. insulation campaigns, info-event about heating technologies
    - assess more “novel” technologies such as waste water heat recovery

Thank you for your attention!

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