Impuls-urbs

An Energy System Optimization Model with Life-Cycle Assessment Perspective

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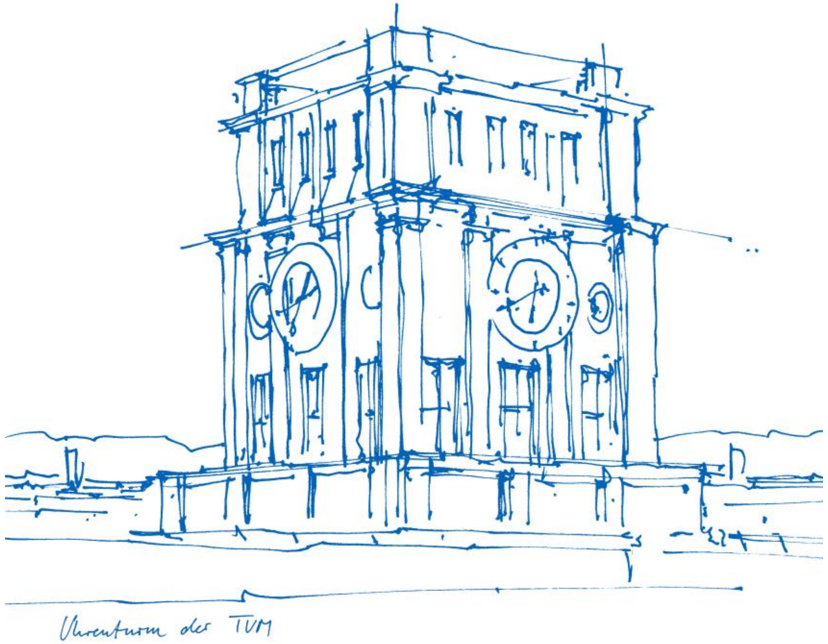

Agenda

1. Problem setting
2. Intertemporal *urbs*
3. Methodology of *Impuls-urbs*
4. Key challenges
5. Case study
6. Results / Observations
7. Questions & discussion

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Impuls-urbs: Integration of life cycle assessment into energy system models

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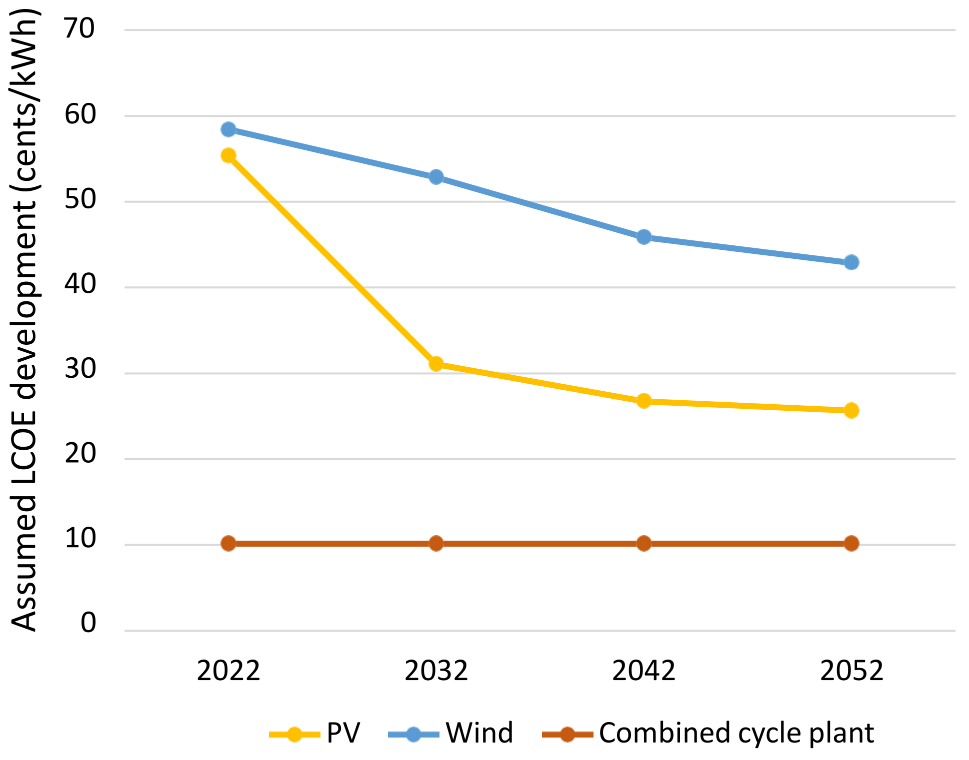
Emission-free Energy Technologies

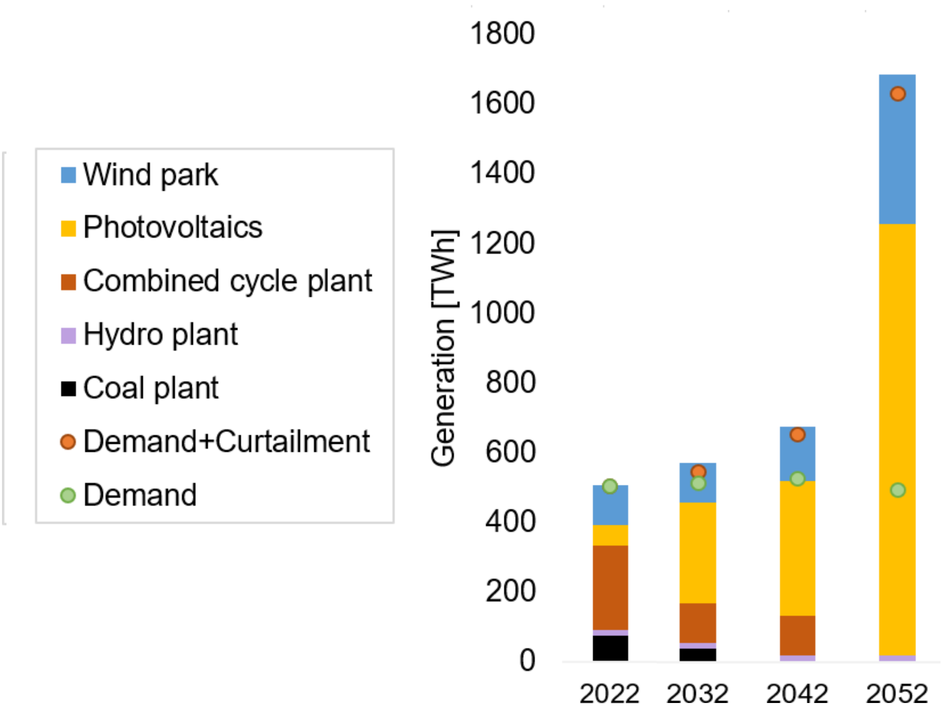
Cheap cost projections



Based on Pietzcker et al. 2018

An exemplary case study

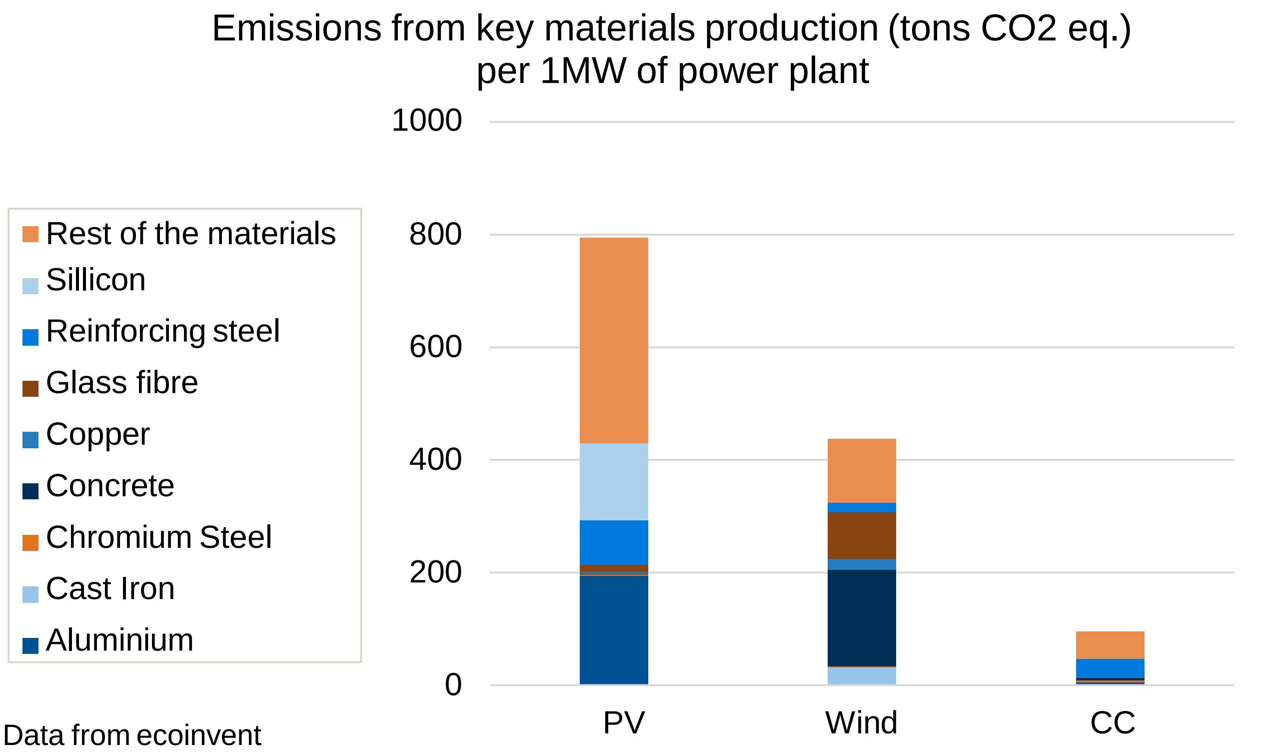
- Energy System Modeling (ESM) - *urbs*
- Goals: Least cost system with zero-carbon by 2052



Are renewable technologies truly Green?

Life Cycle Analysis – perspective
compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle

Production of materials:
- Energy intensive
- Emission intensive



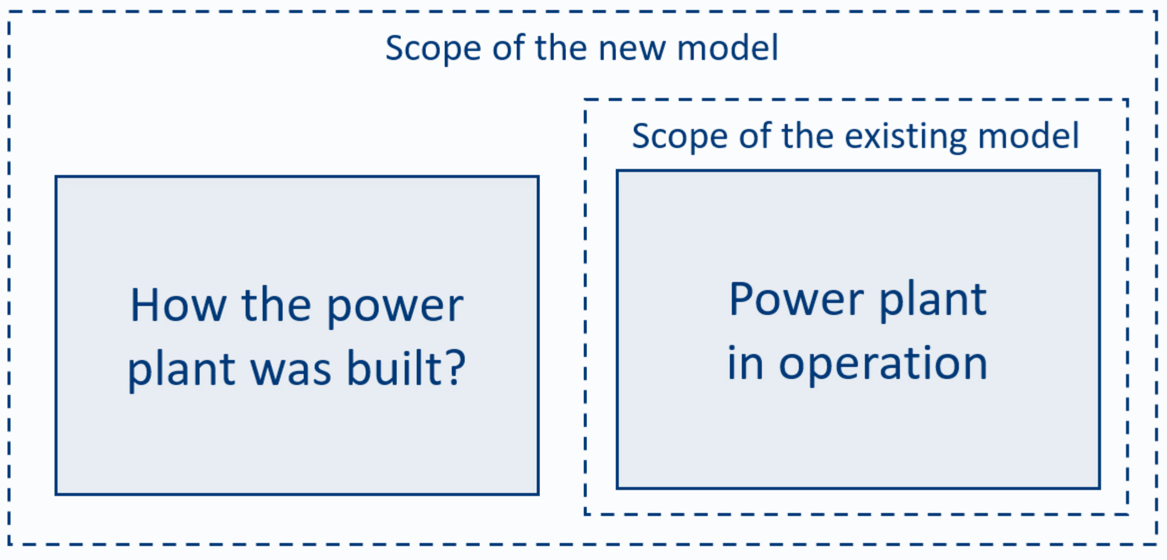
Data from ecoinvent

Existing integration strategies with ESM
- Usually done as a post analysis to ESM result
- Carbon tax introduction into objective function
- Introduction of LCA indicators
- Multi-objective optimization model

Integration LCA+ESM

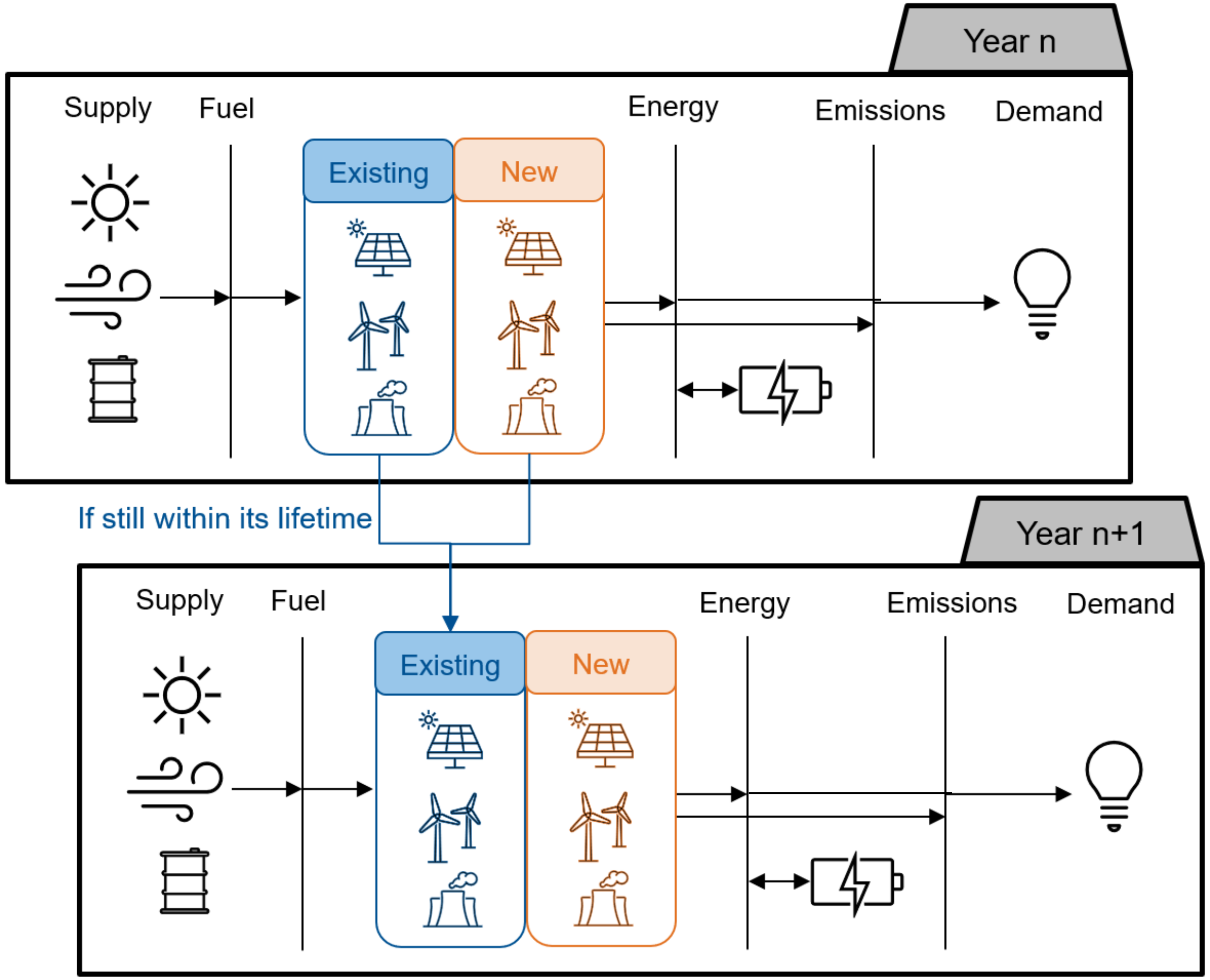
Prognosis

- Hard-coupling is possible
- The optimal solution itself would change



Intertemporal optimization in *urbs*

- Longer time horizon with multiple years
- Single optimization problem with perfect foresight
- Optimizes the evolution of the system
- End goals along with intermediate goals
- Lifetime of the power plants reflects the capacity



Intertemporal optimization in *urbs*

An exemplary case study

- Energy System Modeling (ESM) - *urbs*
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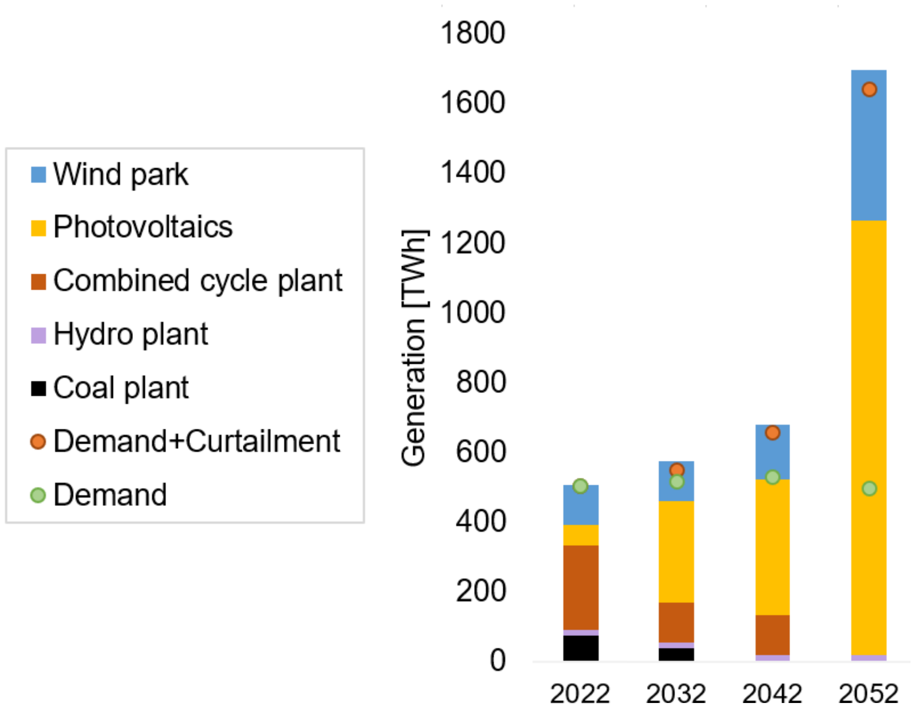


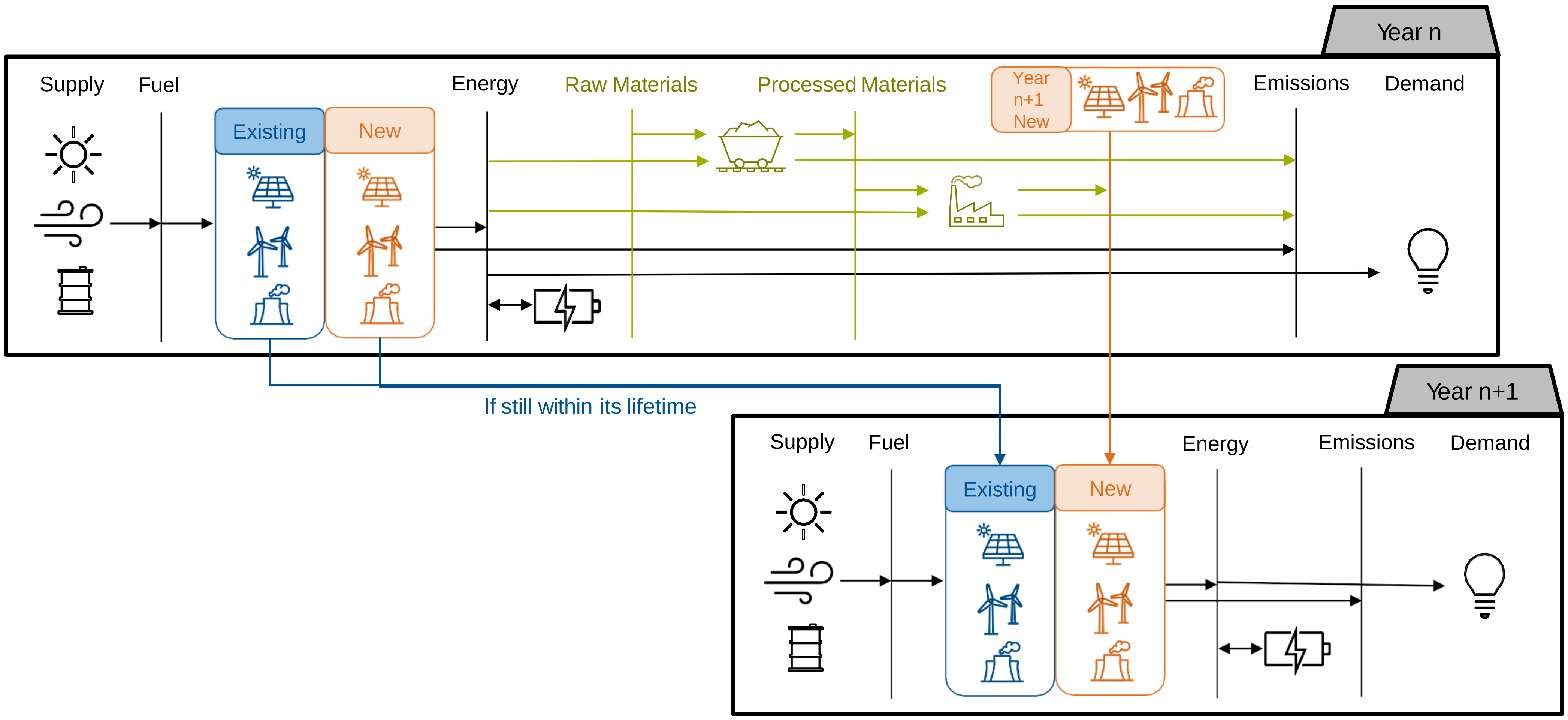
Problem

- Assumes that the new capacities are readily available to start the operation

Solution

- Have to manufacture them before they can be operated

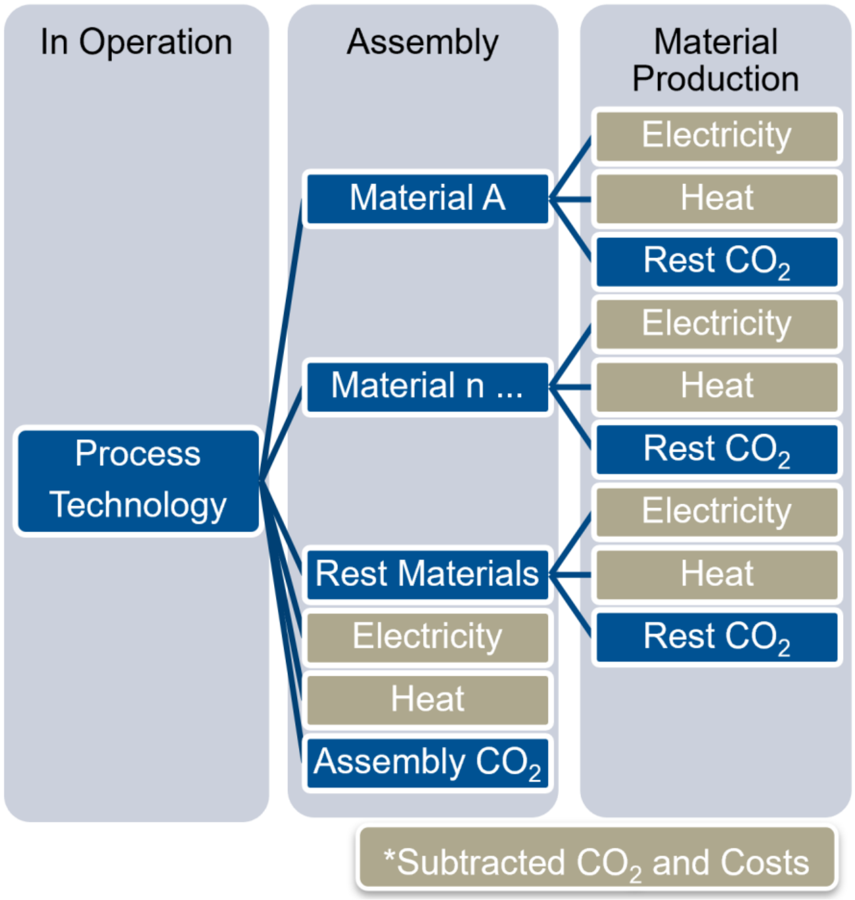
ESM with Material Production phase (*Impuls-urbs*)



Key challenges for *Impuls-urbs*

Challenge	Assumption/Solution
Double counting for emissions	Pre-processed input
Double counting for costs	Pre-defined electricity price
Upstream process operation	Constant demand
Upstream process time period	Only one modelled year ahead
Upstream process supply chain	Same site

Addressing Double counting problem:

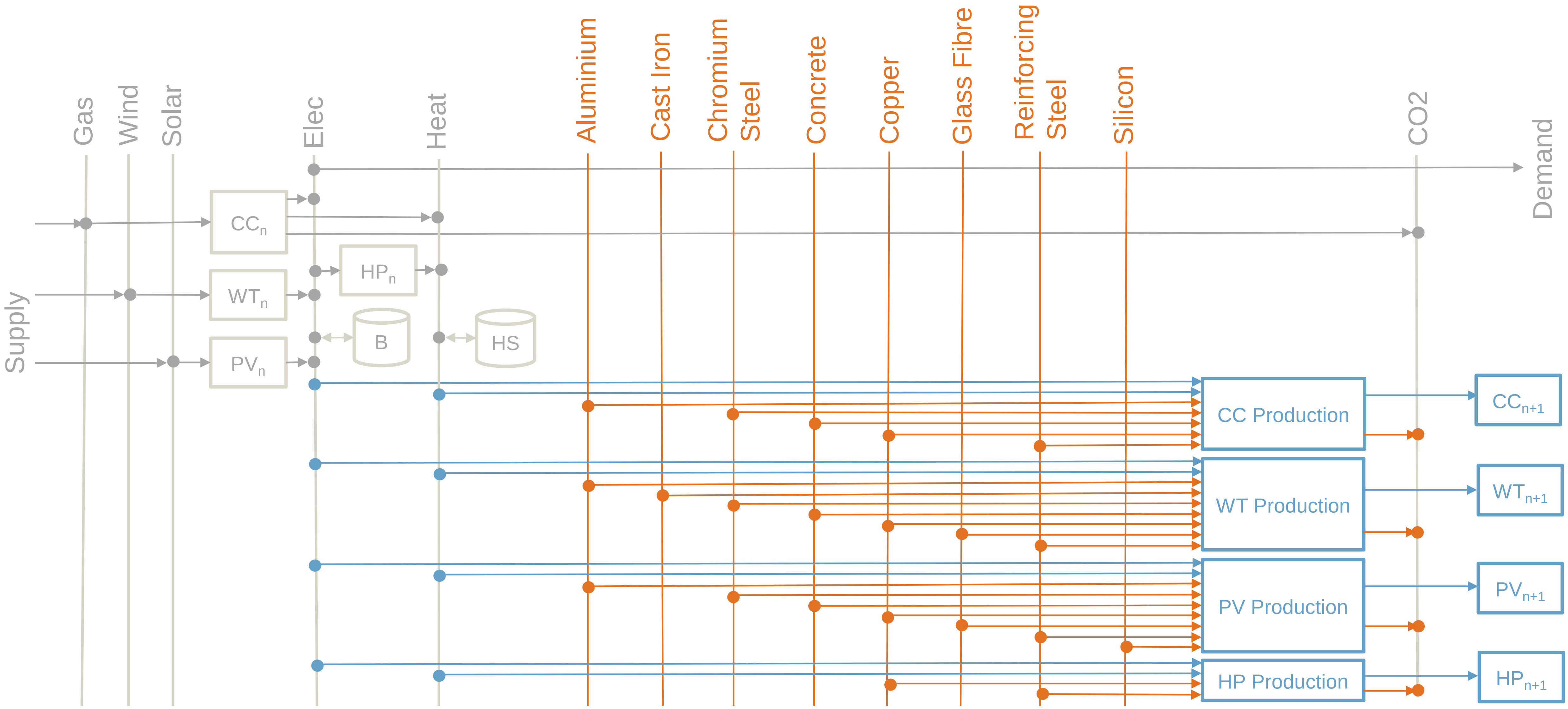


Case Study - Setup

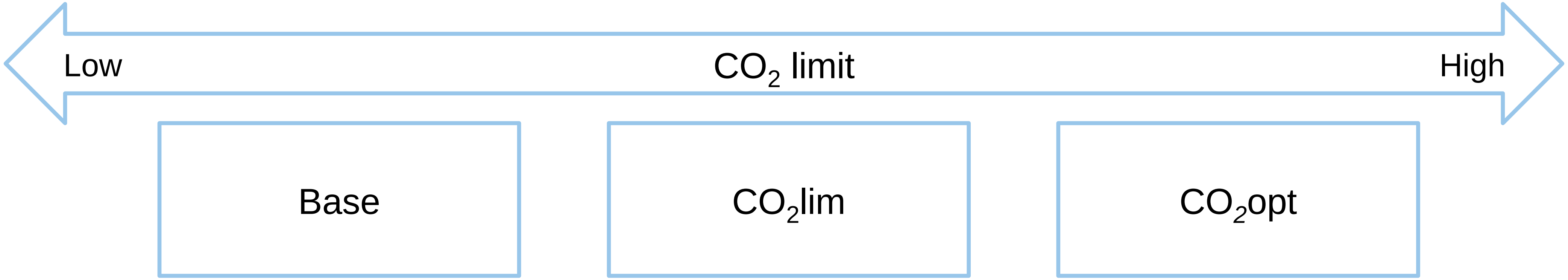
- Loosely based on Germany
- Only electricity demand
- 4 years – 2022,2032,2042,2052
- 5 power plants – Coal plant (phase out), Hydro plant (no expansion), Combined cycle plant, PV, Wind
- Battery storage
- CO_2 price increases from year to year
- 2 options for heat – Gas boiler, Heat pump
- 9 most relevant Materials with additional demand for electricity and heat
- Material data: Ecoinvent

Materials & Energy	Unit	Wind	CC	PV	Heat pump	Gas boiler
Aluminium	ton	0.22	1.10	50.14	-	0.03
Cast iron	ton	22.28	-	-	-	4.20
Chromium Steel	ton	1.42	4.50	1.87	-	0.23
Concrete	m3	685.85	15.00	4.06	-	-
Copper	ton	9.83	1.10	2.17	2.20	-
Glass fibre	ton	10.17	-	1.45	-	-
Reinforcing steel	ton	11.44	22.00	54.36	7.50	-
Silicon	ton	-	-	8.70	-	-
Assembly Electricity	MWh	98.94	48.69	316.76	14.00	2.78
Assembly Heat	MWh	-	97.72	28.89	36.97	6.24
Assembly CO_2eq.	ton	-	-	-	106.95	-

Case Study - Reference Energy System



Scenario Definition

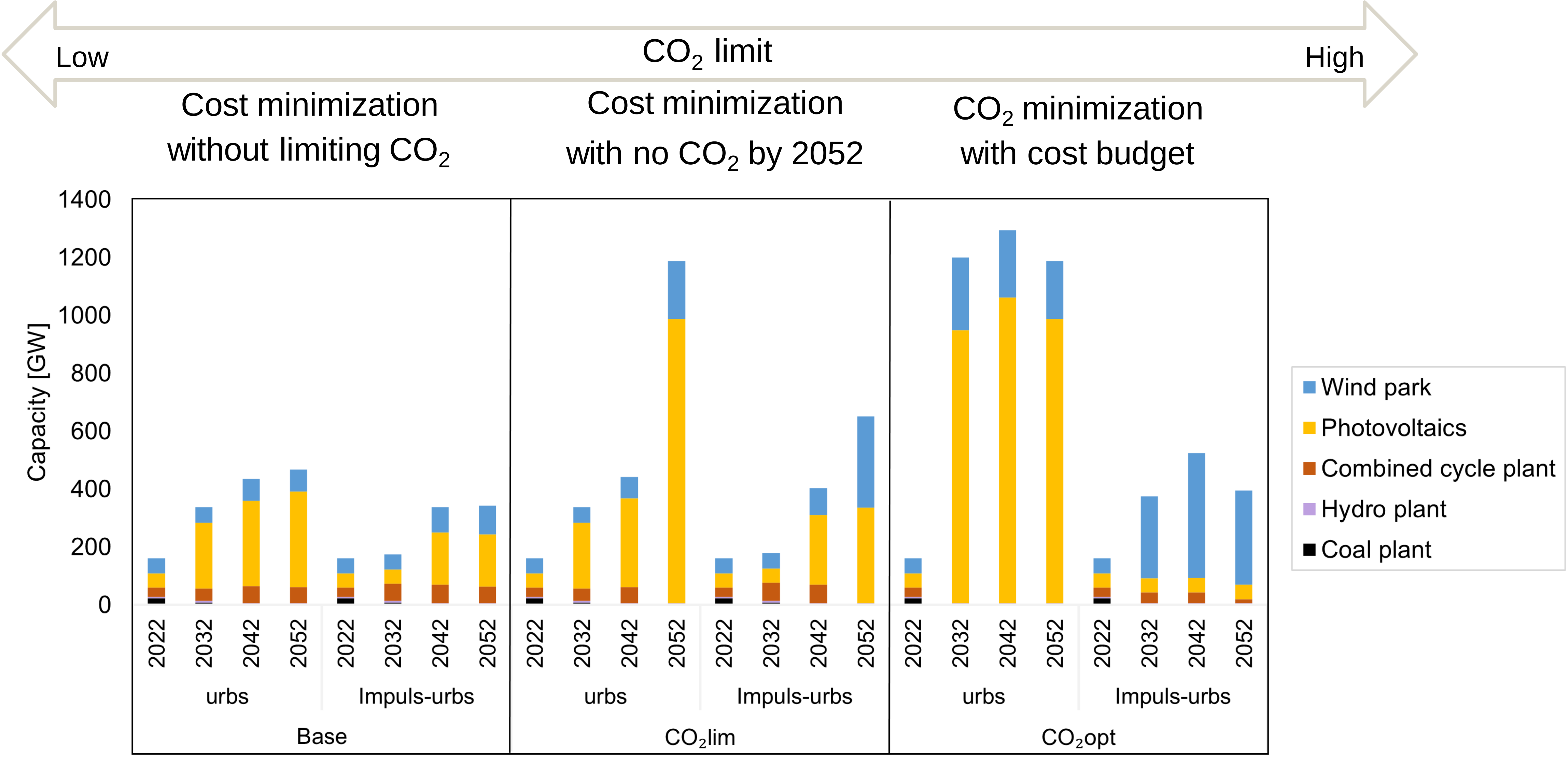


Cost minimization without limiting CO_2

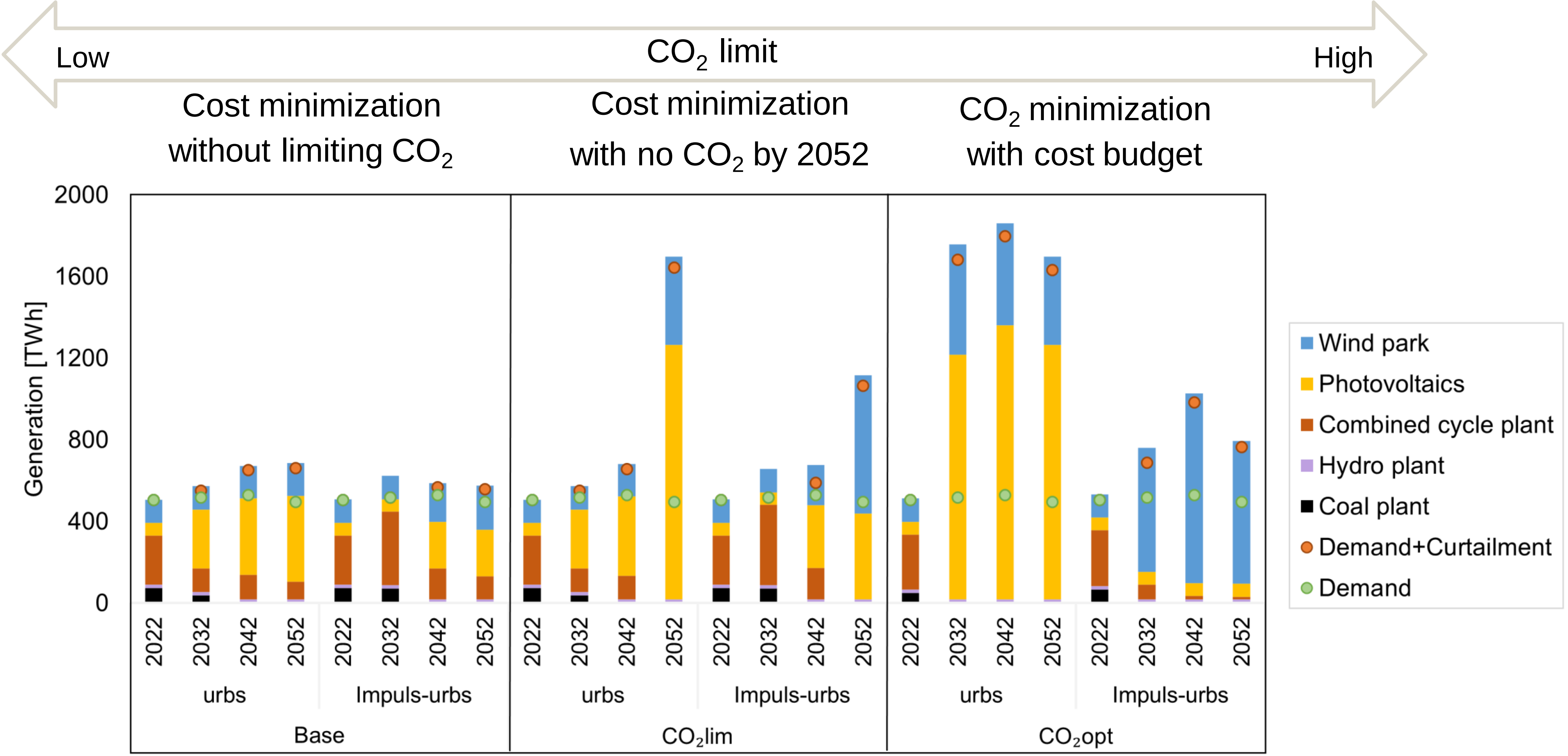
Cost minimization with no CO_2 by 2052

CO_2 minimization with cost budget

Impact of *Impuls-urbs*



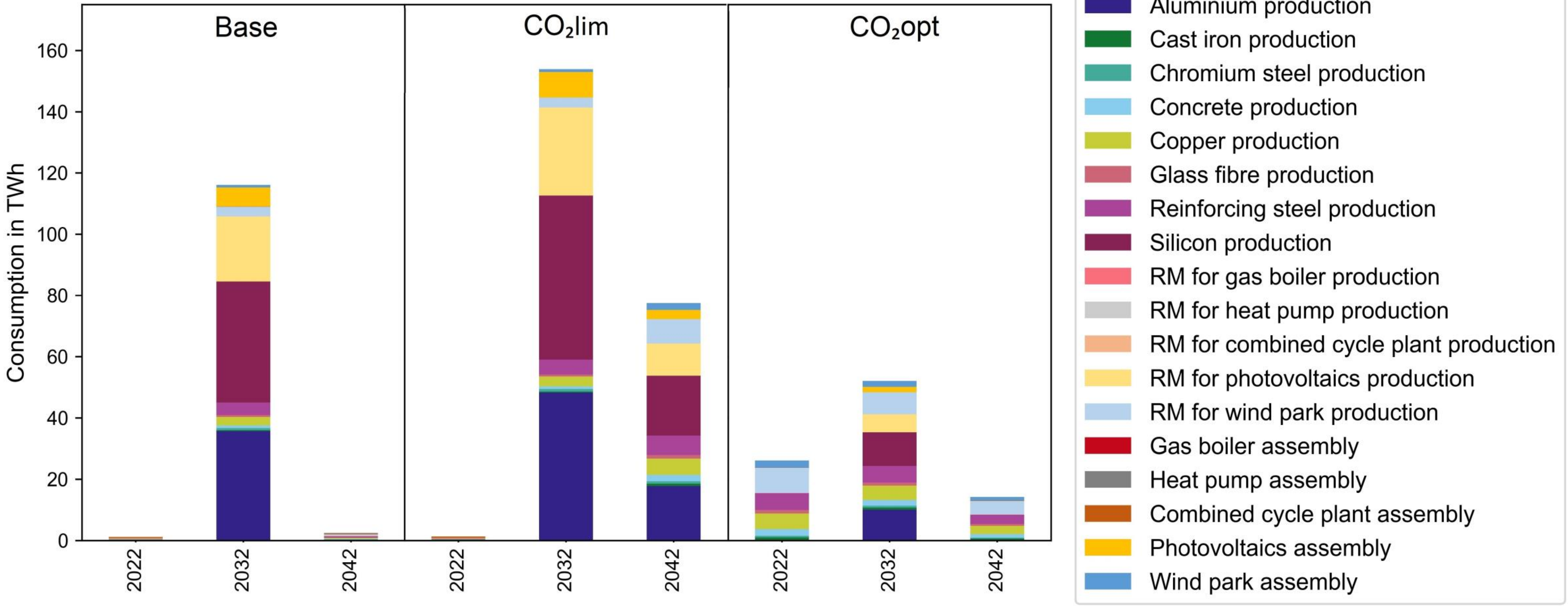
Impact of *Impuls-urbs*



Impact of *Impuls-urbs*

Low CO_2 limit High

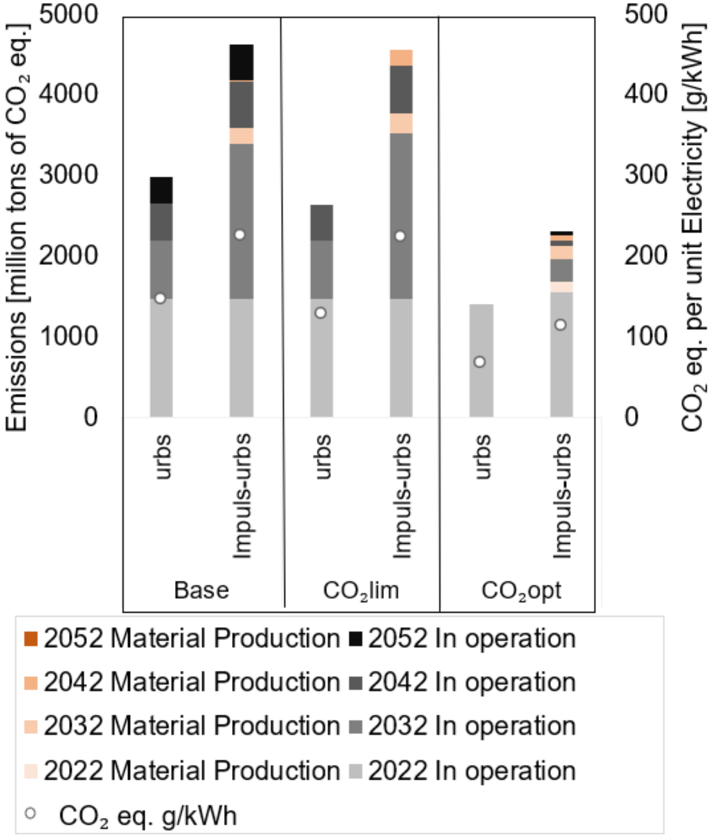
Cost minimization without limiting CO_2	Cost minimization with no CO_2 by 2052	CO_2 minimization with cost budget



Impact of *Impuls-urbs*

Key observations

- In the near future (2032), CC plant is preferred instead of earlier PV expansion.
- In the far future, Wind is more favored than PV.
- Silicon production is emission and energy intensive.
- Overall higher costs & higher emissions due to expanded scope.
- Higher demand for energy in the system
- The impact of upstream processes is significant with higher CO_2 limits.



Outlook

Summary

- First approach towards hard-coupling learnings from LCA into energy models
- High impact of material production on optimization output
- PV might not be the only solution when indirect emissions are considered
- Type of research questions: Which sector needs to be decarbonized first?

Scope for future work

- Material production for storage systems
- Material production at another site
- Other impacts in addition to GHG emissions
- Material efficiency & circular economy of materials
- End-of-life phase emissions
- Real case simulation

Technology inputs

Technology	Units	2022	2032 CAPEX	2042	2052	OPEX %	Life years
CC plant	€/kW	890	890	890	890	3.0	35
Wind	€/kW	1,257	1,137	987	923	3.0	25
PV	€/kW	703	395	340	326	1.0	25
Heat Pump	€/kW	700	560	490	420	1.0	20
Gas boiler	€/kW	250	250	250	250	1.6	25
Hydro plant	€/kW	2,718	2,718	2,718	2,718	2.0	50
Coal plant	€/kW	1,660	1,660	1,660	1,660	3.0	45
Battery	€/kWh	244	129	109	90	1.5	20
	€/kW	226	173	166	159		
Commodity			**Price**				
Gas	€/MWh	27	34	42	53	-	-
CO_2	€/ton	25	50	75	100	-	-

Energy input and emissions for the production of materials [41]

Material	Unit	Electricity MWh	Heat MWh	Remaining CO_2eq. ton
Aluminium	ton	33.450	6.210	3.880
Cast iron	ton	1.400	0.130	1.370
Chromium Steel	ton	7.990	6.860	1.100
Concrete	m^3	0.118	0.019	0.251
Copper	ton	19.180	3.180	1.970
Glass fibre	ton	3.492	1.440	8.120
Reinforcing steel	ton	1.450	0.620	1.450
Silicon	ton	200.690	53.380	15.690

Energy input and rest emissions for the production of the other remaining materials (RM) [41]

Material	Unit	Electricity MWh	Heat MWh	Remaining CO_2eq. ton
RM Wind	MW	291.79	65.40	113.72
RM CC	MW	50.80	8.40	48.34
RM PV	MW	1018.30	168.57	365.59
RM Heat pump	MW	31.78	6.12	11.59
RM Gas boiler	MW	3.48	0.33	0.31