Decarbonization of ceramic kilns through innovative solar-powered energy supply concepts

SolarPACES 2026, Bad Neuenahr-Ahrweiler

Martin Bolten[1], Stefano Giuliano[1], Tobias Hirsch[1], Giuseppe Noto[2]

[1] DLR Institute of Solar Research, [2] Villeroy & Boch

Supported by:

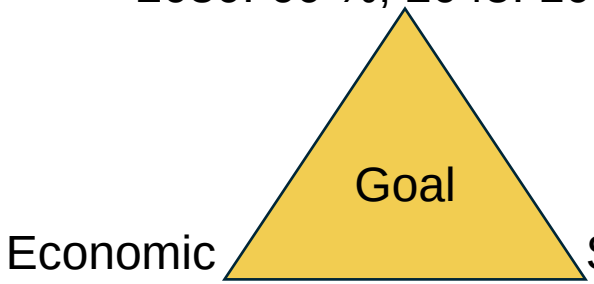
Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

DLR

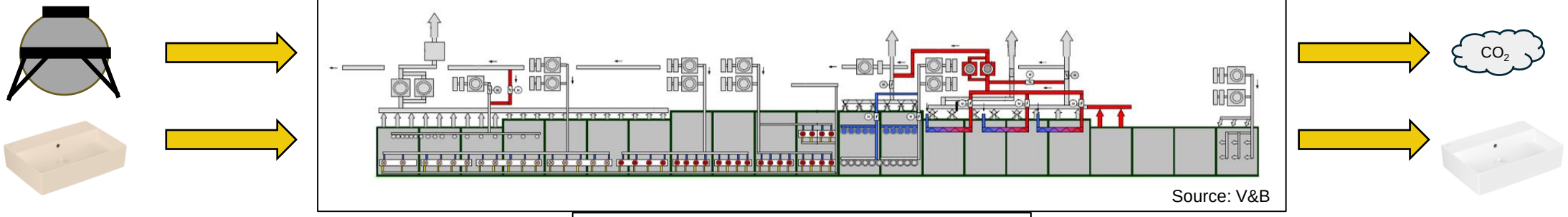
Alternatives to natural gas are needed to reduce CO_2-Emissons, but 1250°C must be reached

CO_2-Reduction:
2030: 60 %, 2045: 100 %



Economic feasibility

Security of supply

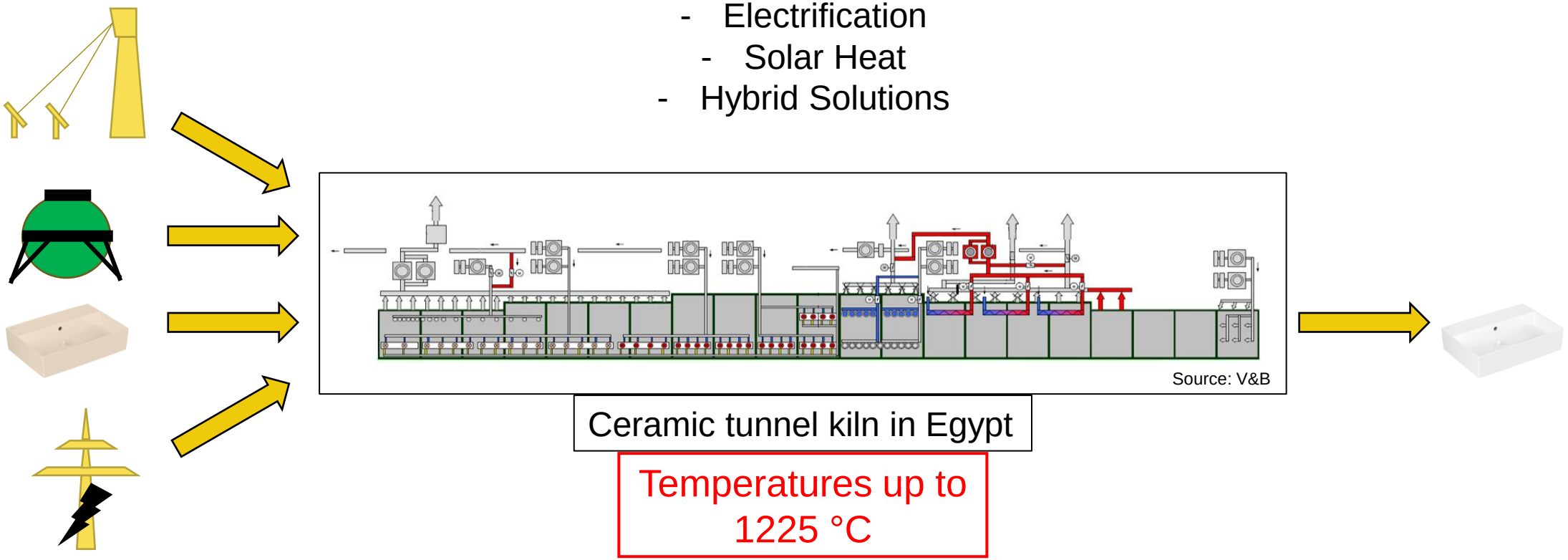


Ceramic tunnel kiln in Egypt

Temperatures up to 1225 °C

A multitude of alternative concepts are possible, a clear methodology is needed

Options for decarbonisation:
- Green Fuels
- Electrification
- Solar Heat
- Hybrid Solutions



Ceramic tunnel kiln in Egypt

Temperatures up to 1225 °C

Methodology: Techno-economic Analysis by optimizing design and operation of a multitude of concepts

Boundary Conditions

Concepts

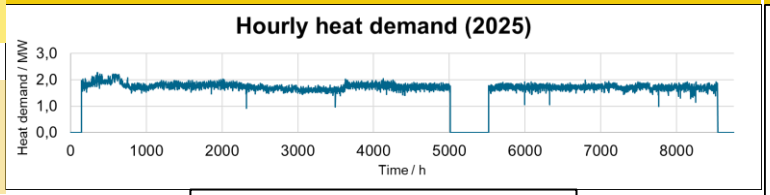
Model

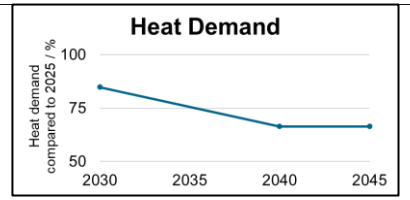
Optimization

Techno-economic assessment

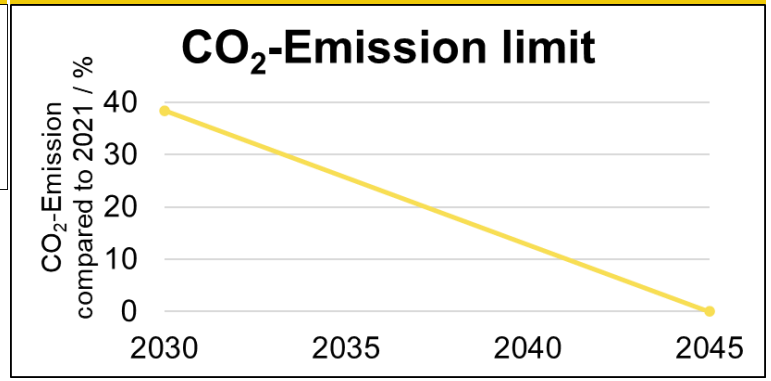
Final assessment

Energy demand

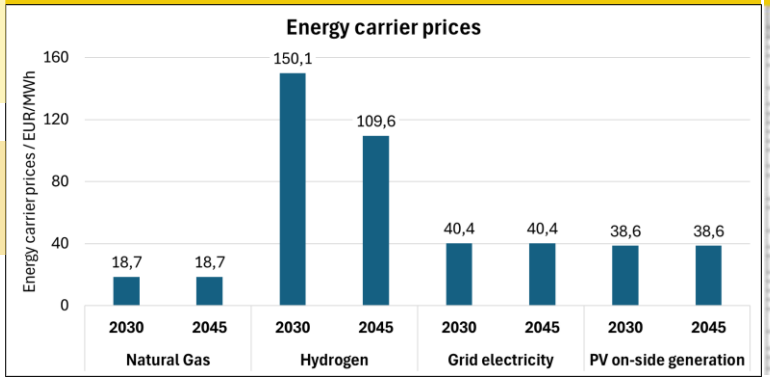




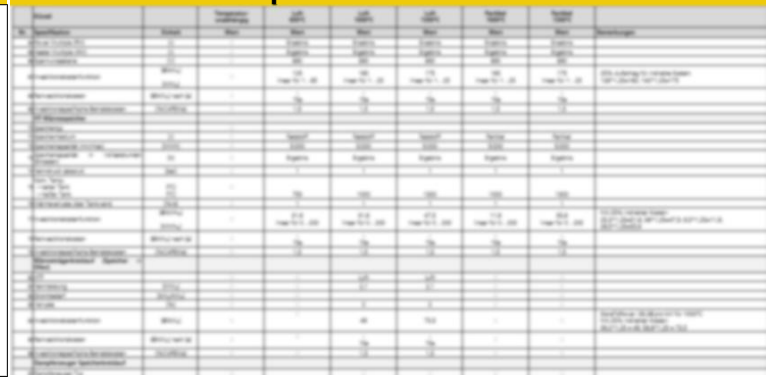
CO_2-Limit



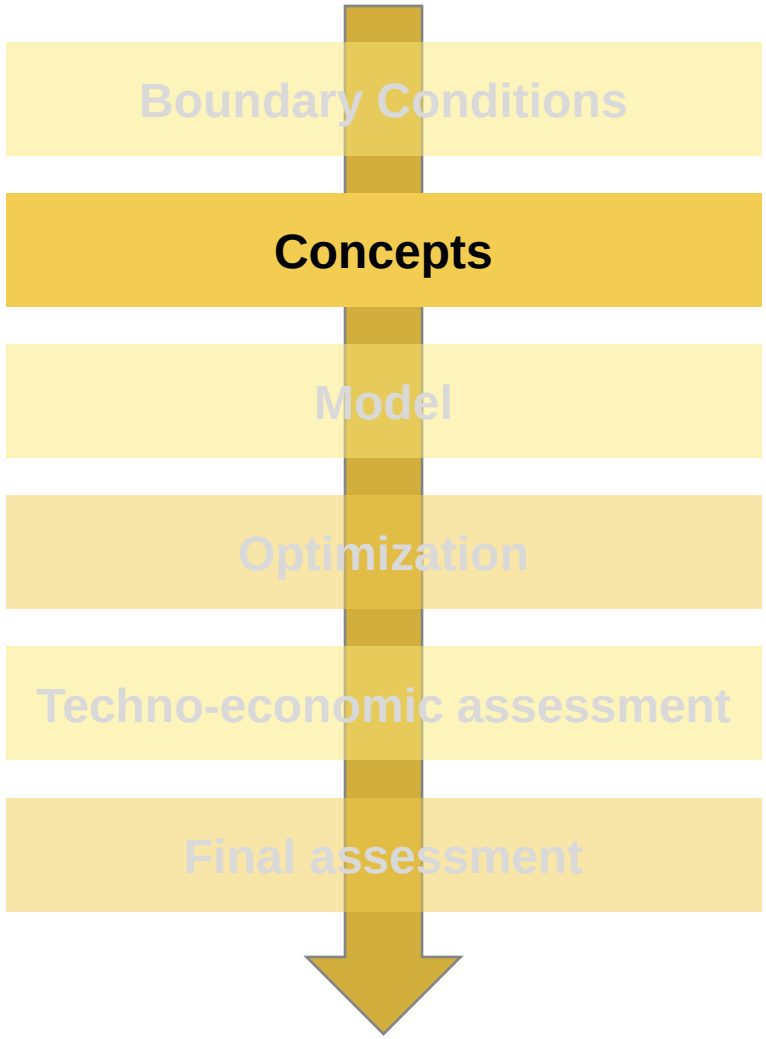
Energy prices



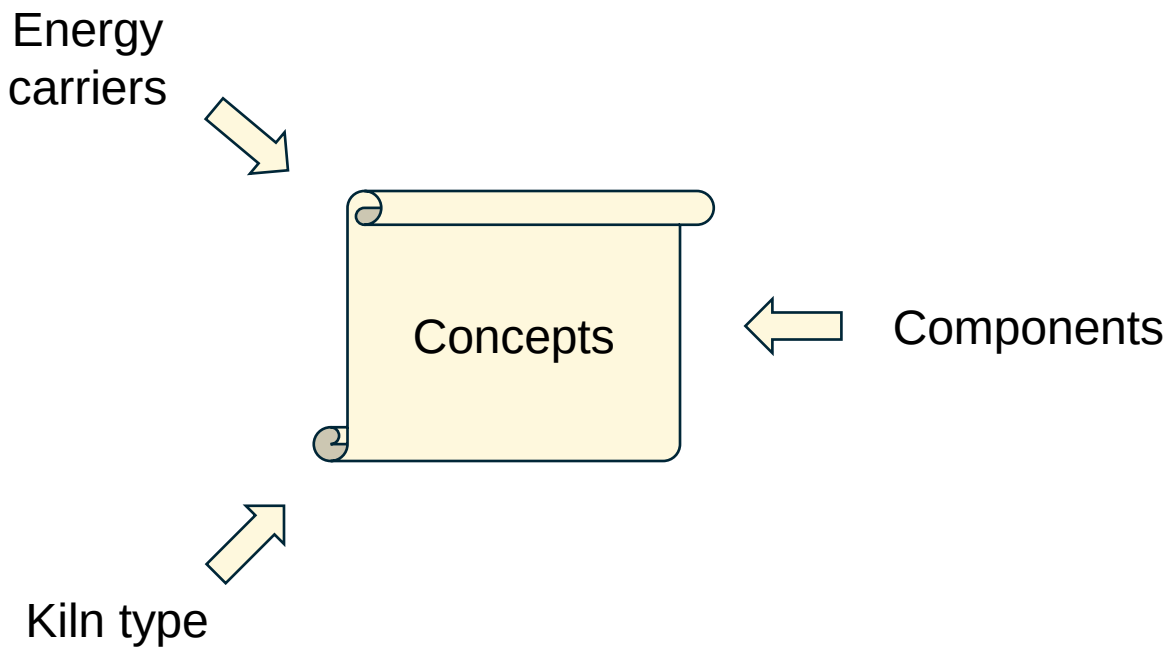
Technical and economical specifications



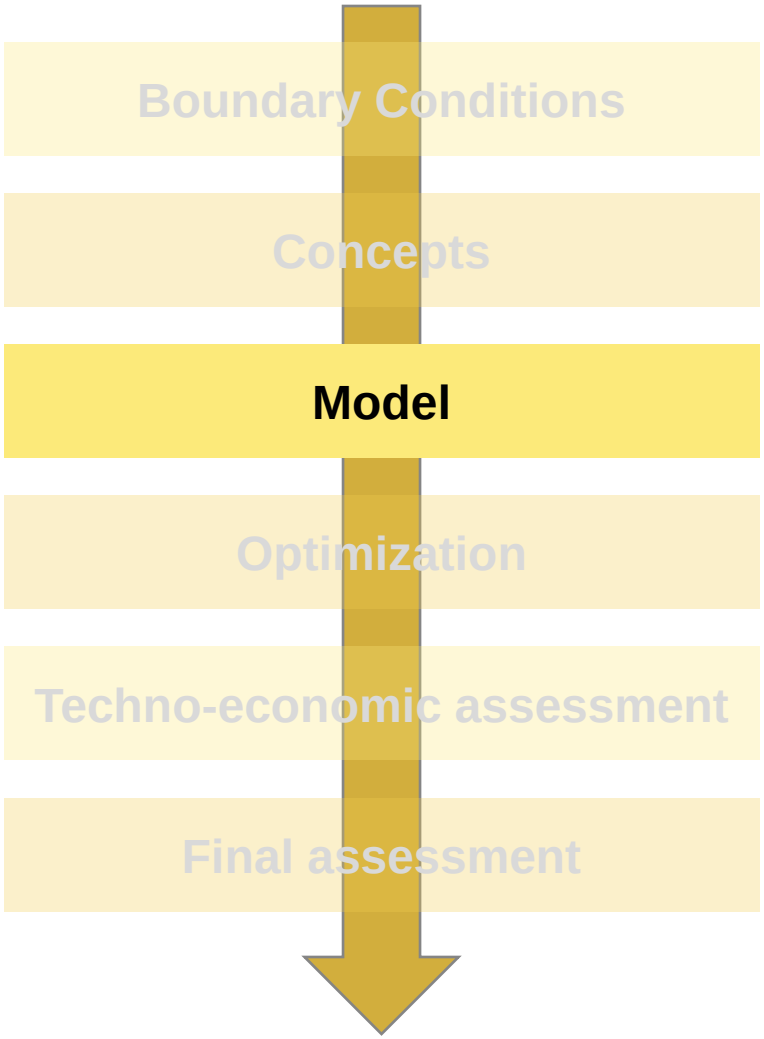
Methodology: Techno-economic Analysis by optimizing design and operation of a multitude of concepts



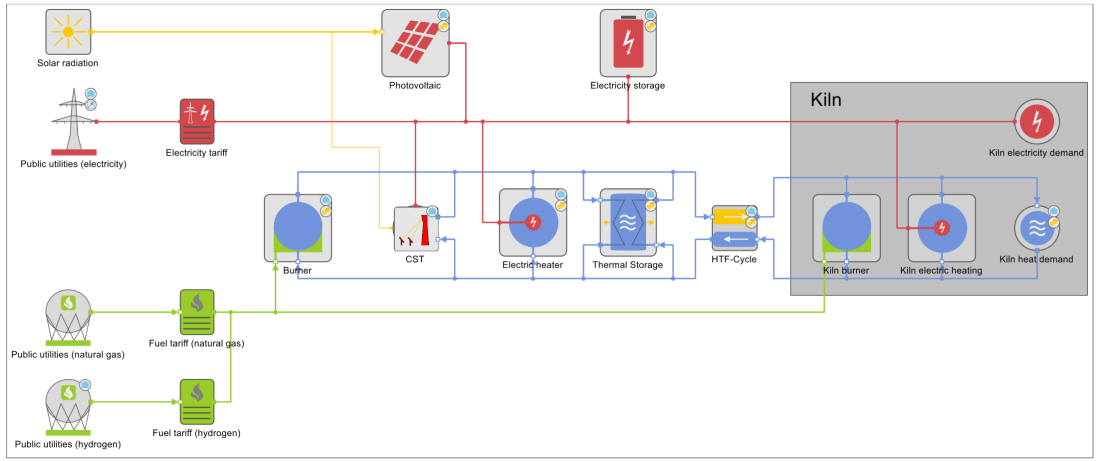
Definition and selection of concepts



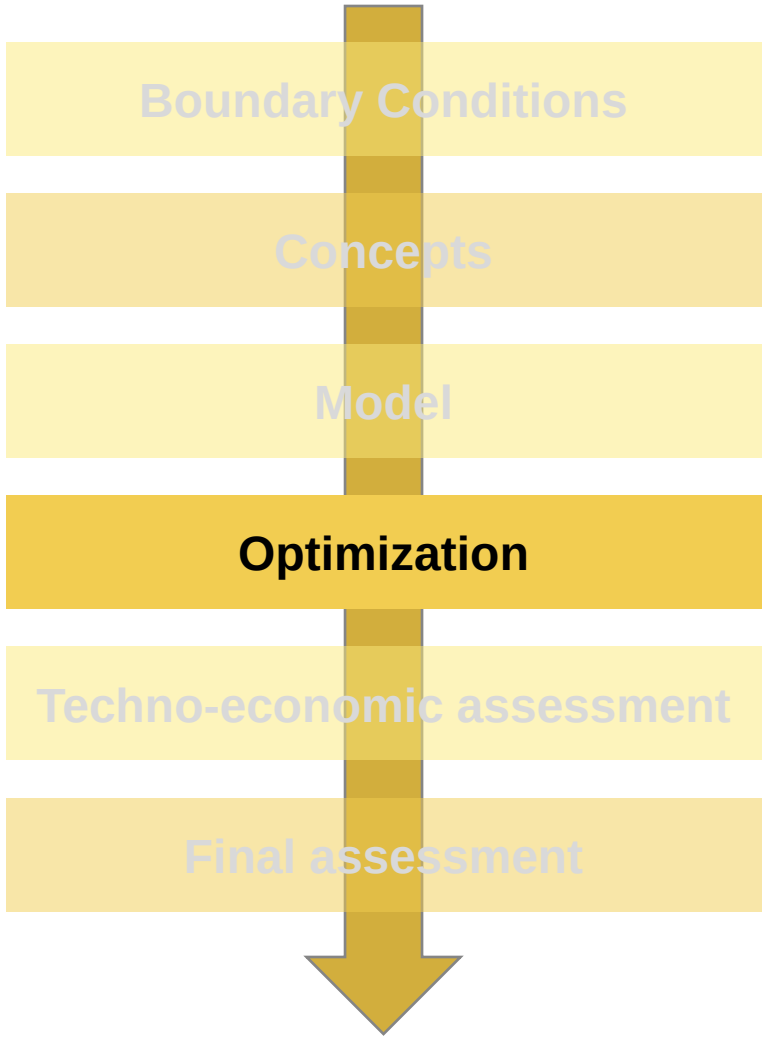
Methodology: Techno-economic Analysis by optimizing design and operation of a multitude of concepts



- Modelling with TOPENERGY®:
  - Mixed integer linear models
  - Only energy balances



Methodology: Techno-economic Analysis by optimizing design and operation of a multitude of concepts



Optimization I
Design and operation
2030, 2045
All concepts

Choosing promising concepts and designs

Optimization II
Operation
All Years (2030 → 2045)
Chosen concepts and designs

Methodology: Techno-economic Analysis by optimizing design and operation of a multitude of concepts

Boundary Conditions

Concepts

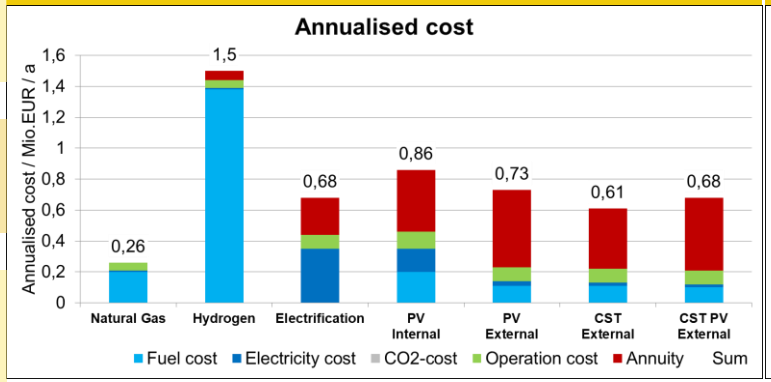
Model

Optimization

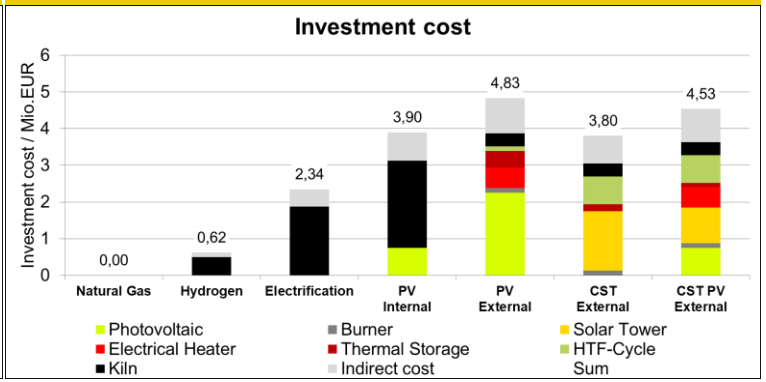
Techno-economic assessment

Final assessment

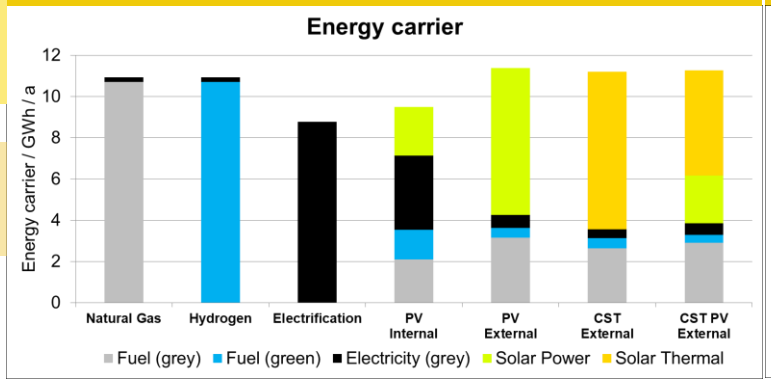
Annualized Cost



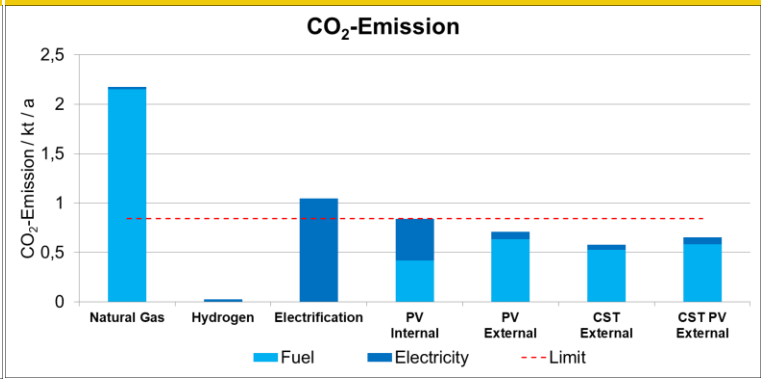
Investment Cost



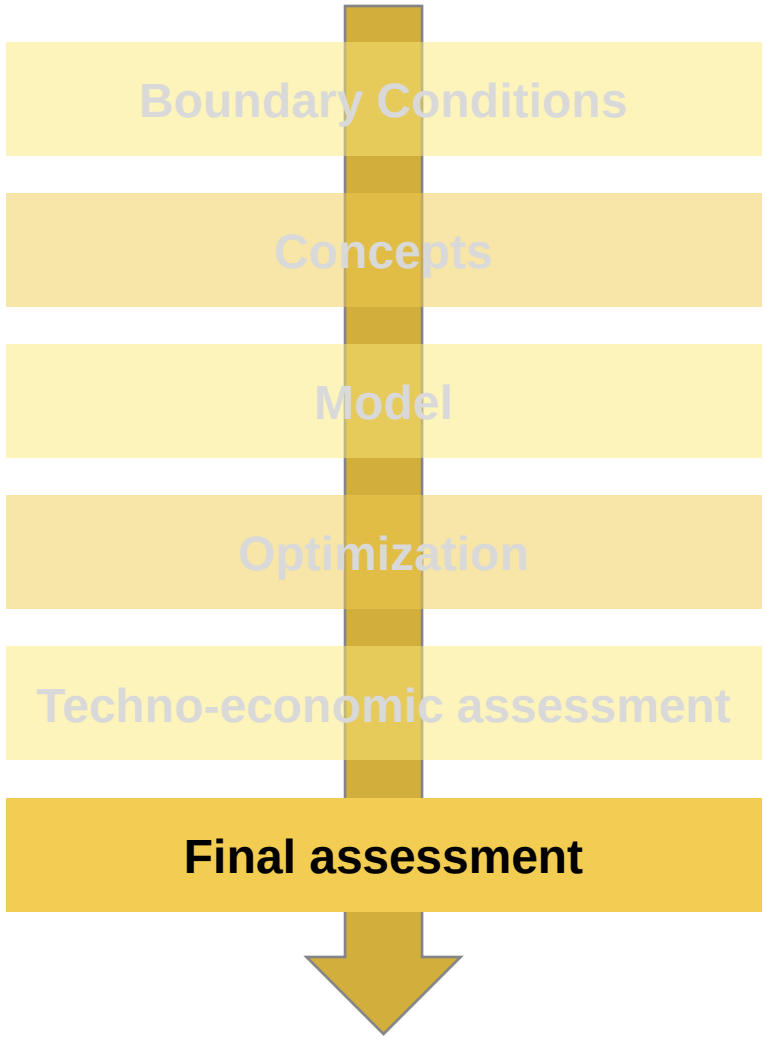
Energy Carrier



CO_2-Emission

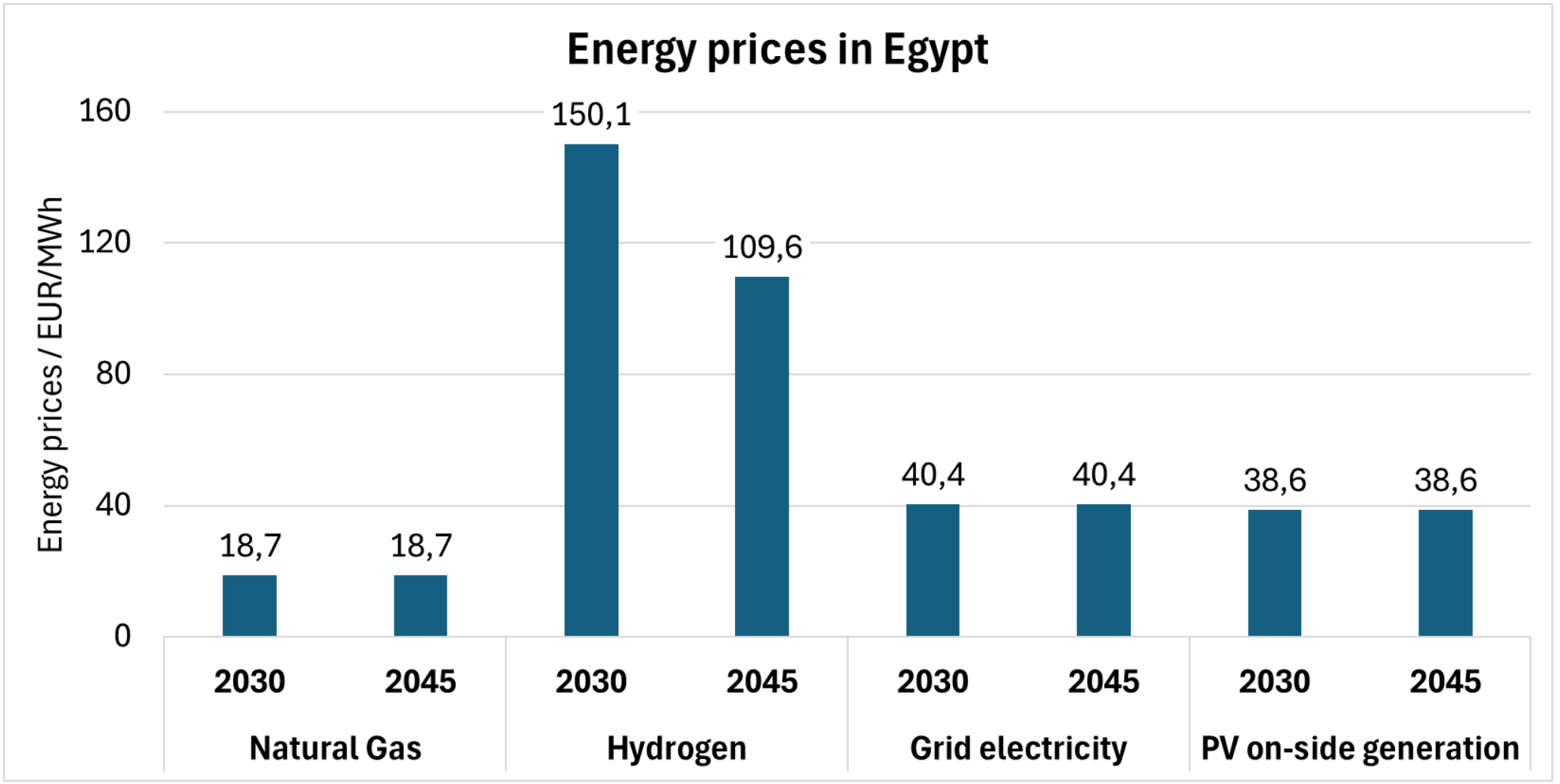


Methodology: Techno-economic Analysis by optimizing design and operation of a multitude of concepts



- Annualized Cost
- Investment Cost
- Sensitivity to energy prices
- Resilience
- Market readiness
- Plant complexity
- Degree of innovation (funding)

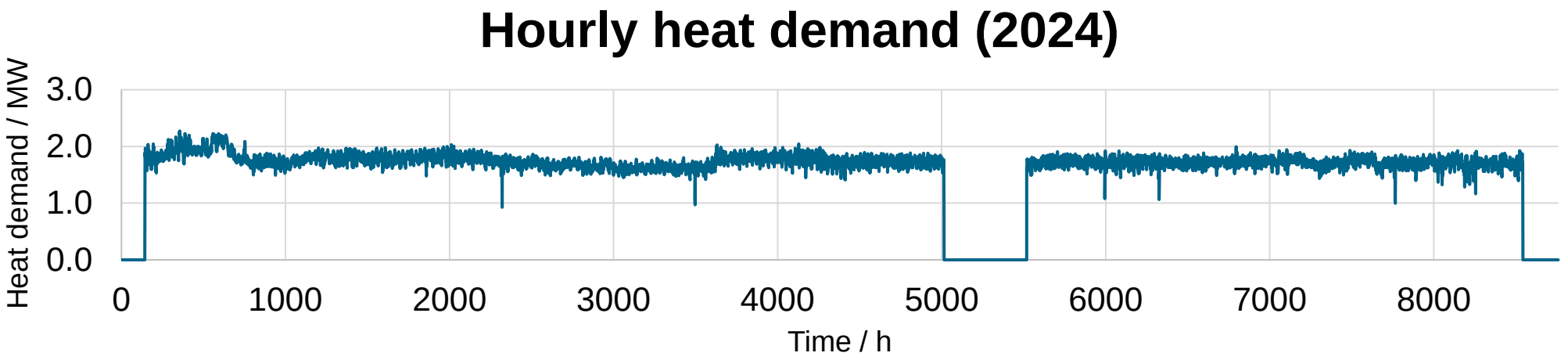
Natrual gas and grid electricity are cheap but not green, hydrogen green but expensive

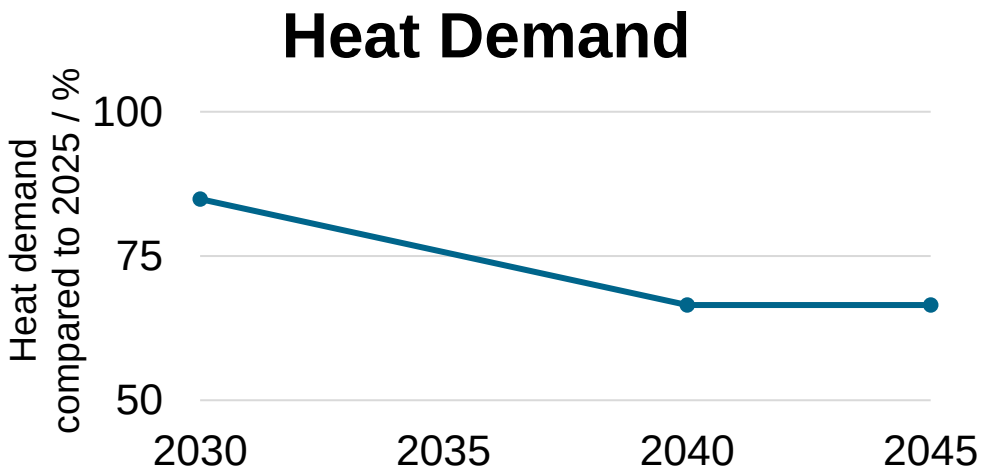


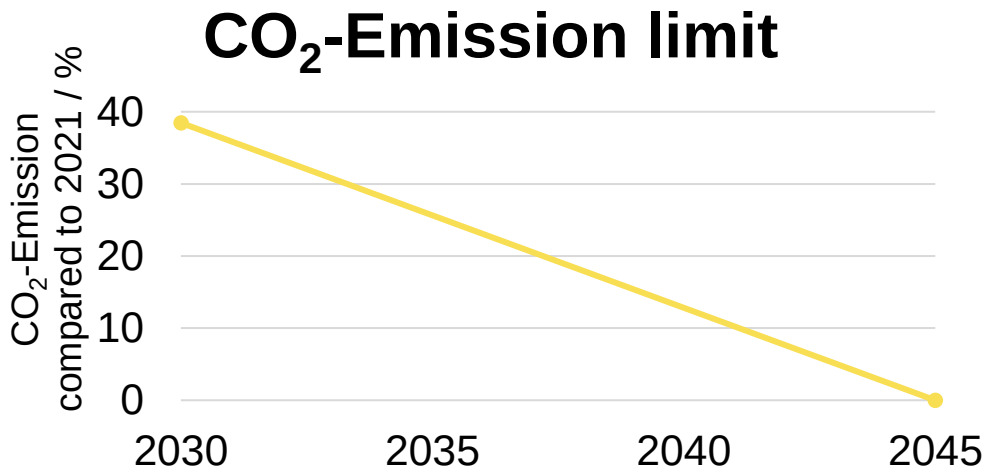
Boundary Conditions

- Concepts
- Model
- Optimization
- Techno-economic assessment
- Final assessment

Hourly demand curves from real operation. Energy demand and CO_2-Emission are declining.



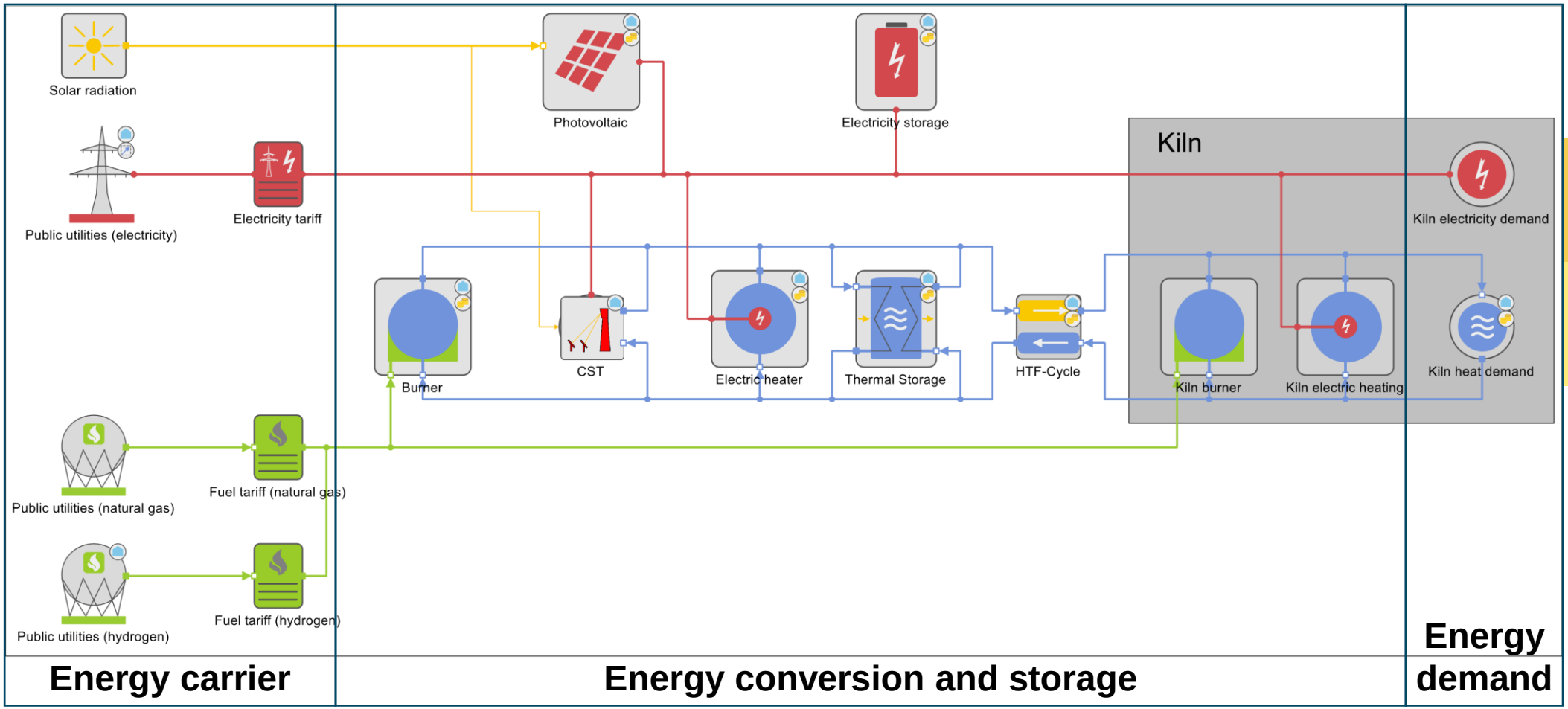




Boundary Conditions

- Concepts
- Model
- Optimization
- Techno-economic assessment
- Final assessment

One master level model to optimize a multitude of concepts.



Boundary Conditions

Concepts

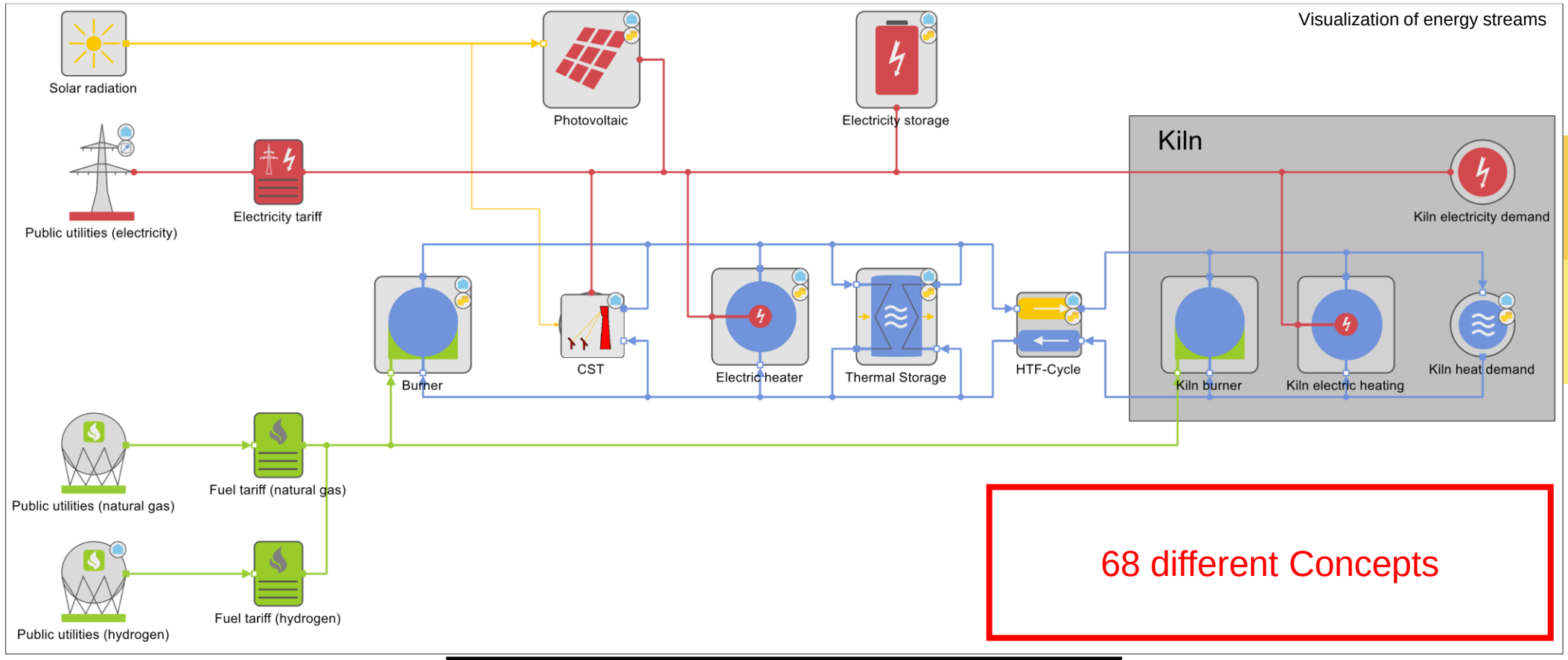
Model

Optimization

Techno-economic assessment

Final assessment

One master level model to optimize a multitude of concepts.



Master Model

Boundary Conditions

Concepts

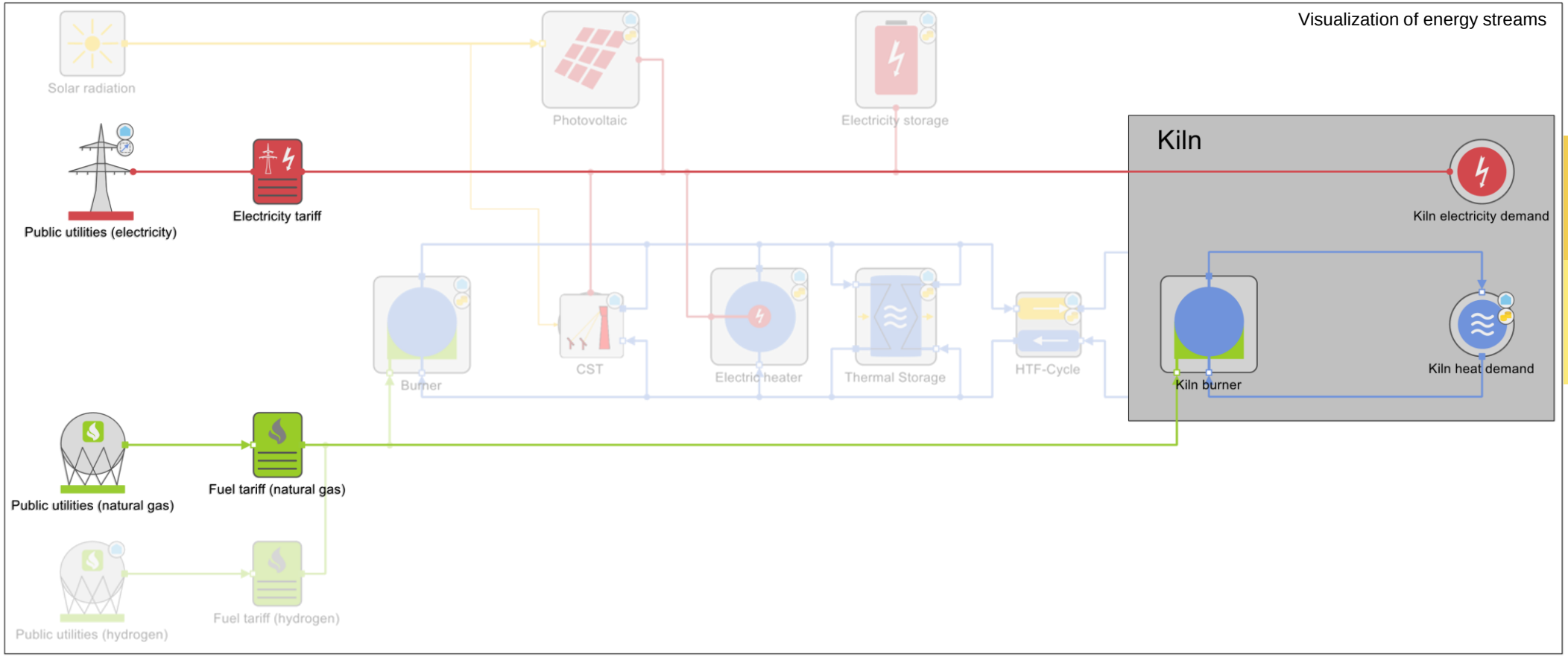
Model

Optimization

Techno-economic assessment

Final assessment

One master level model to optimize a multitude of concepts.



Natural Gas | Hydrogen | Electrification | PV Internal | PV External | CST External | CST PV External

Boundary Conditions

Concepts

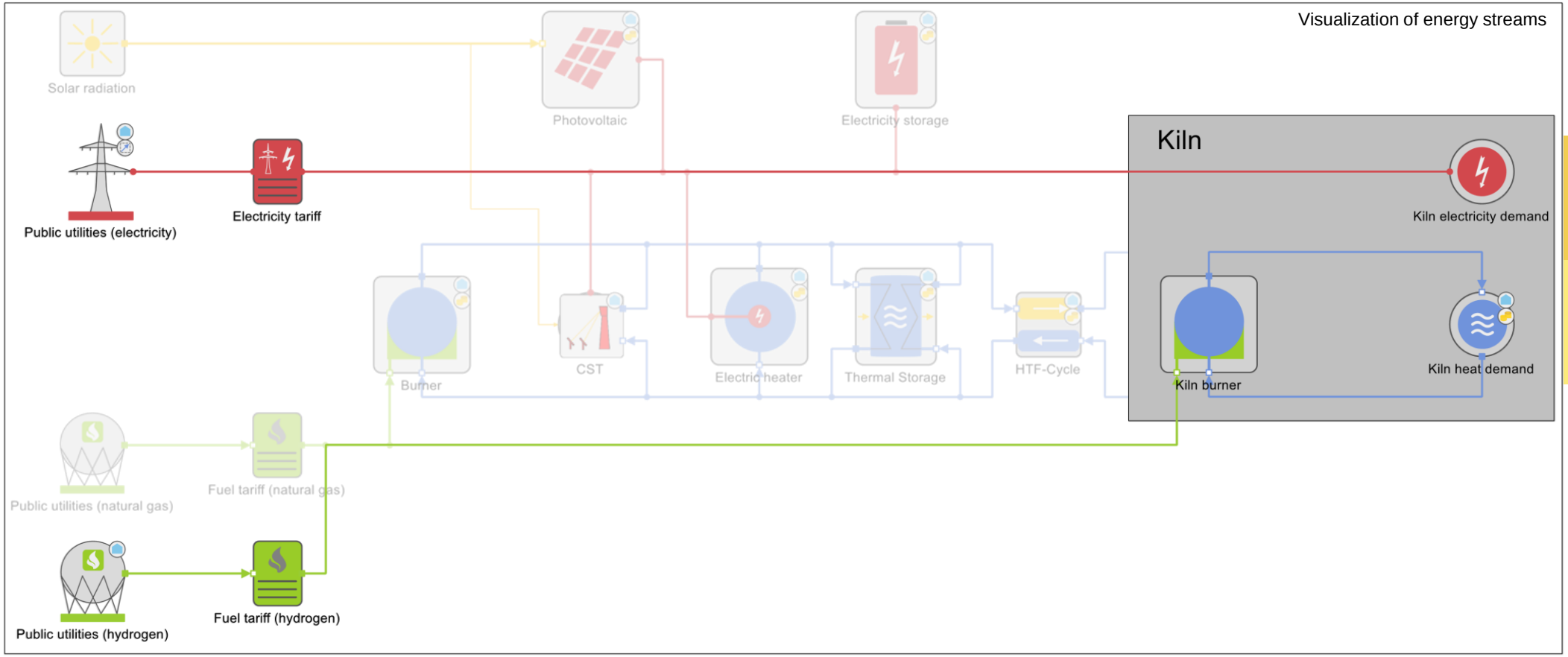
Model

Optimization

Techno-economic assessment

Final assessment

One master level model to optimize a multitude of concepts.



Natural Gas	**Hydrogen**	Electrification	PV Internal	PV External	CST External	CST PV External

Boundary Conditions

Concepts

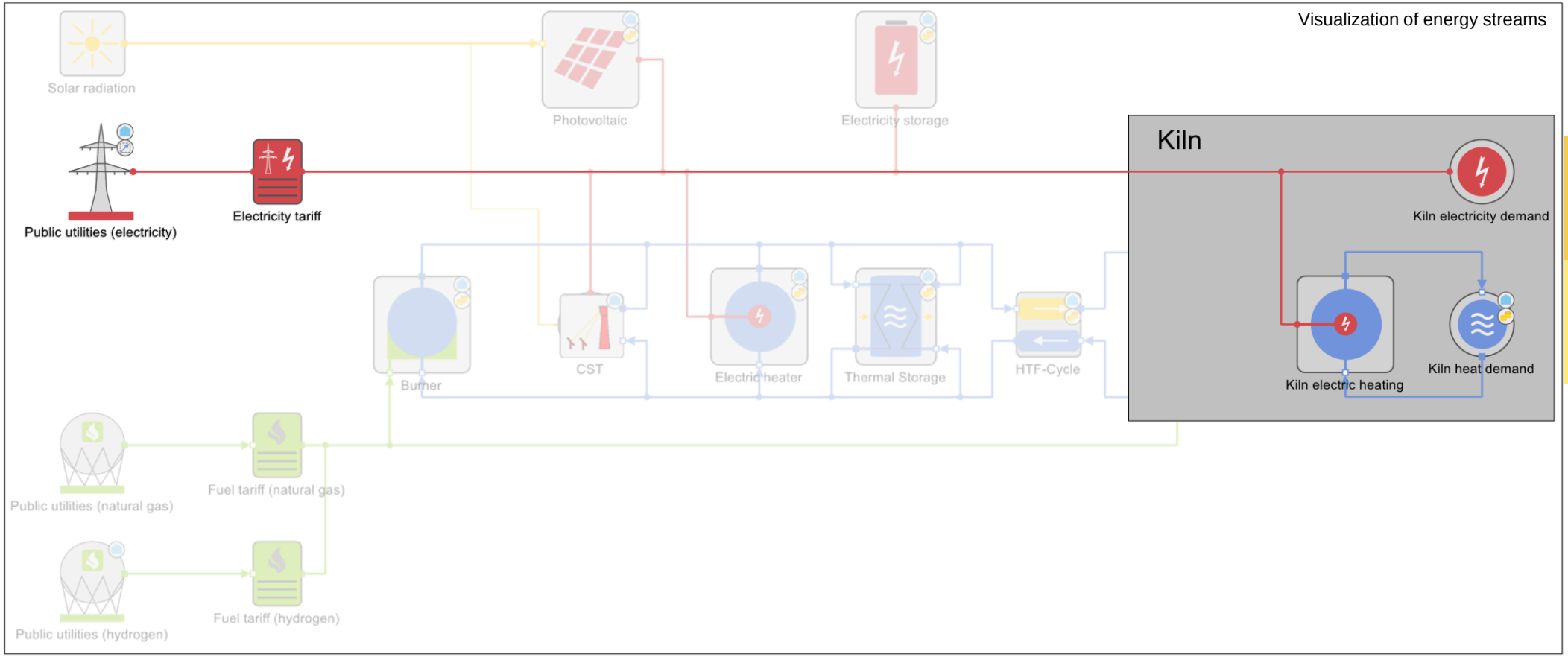
Model

Optimization

Techno-economic assessment

Final assessment

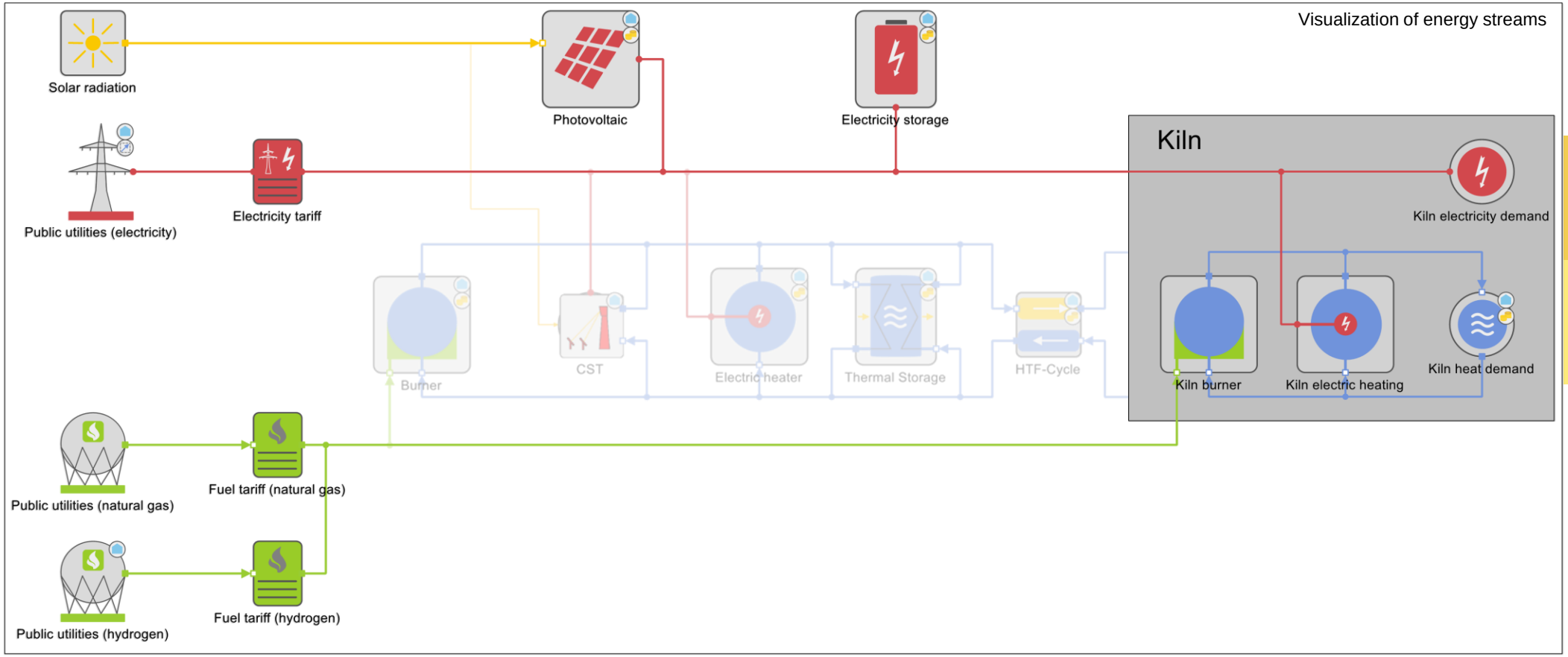
One master level model to optimize a multitude of concepts.



Natural Gas	Hydrogen	**Electrification**	PV Internal	PV External	CST External	CST PV External

- Boundary Conditions
- **Concepts**
- **Model**
- Optimization
- Techno-economic assessment
- Final assessment

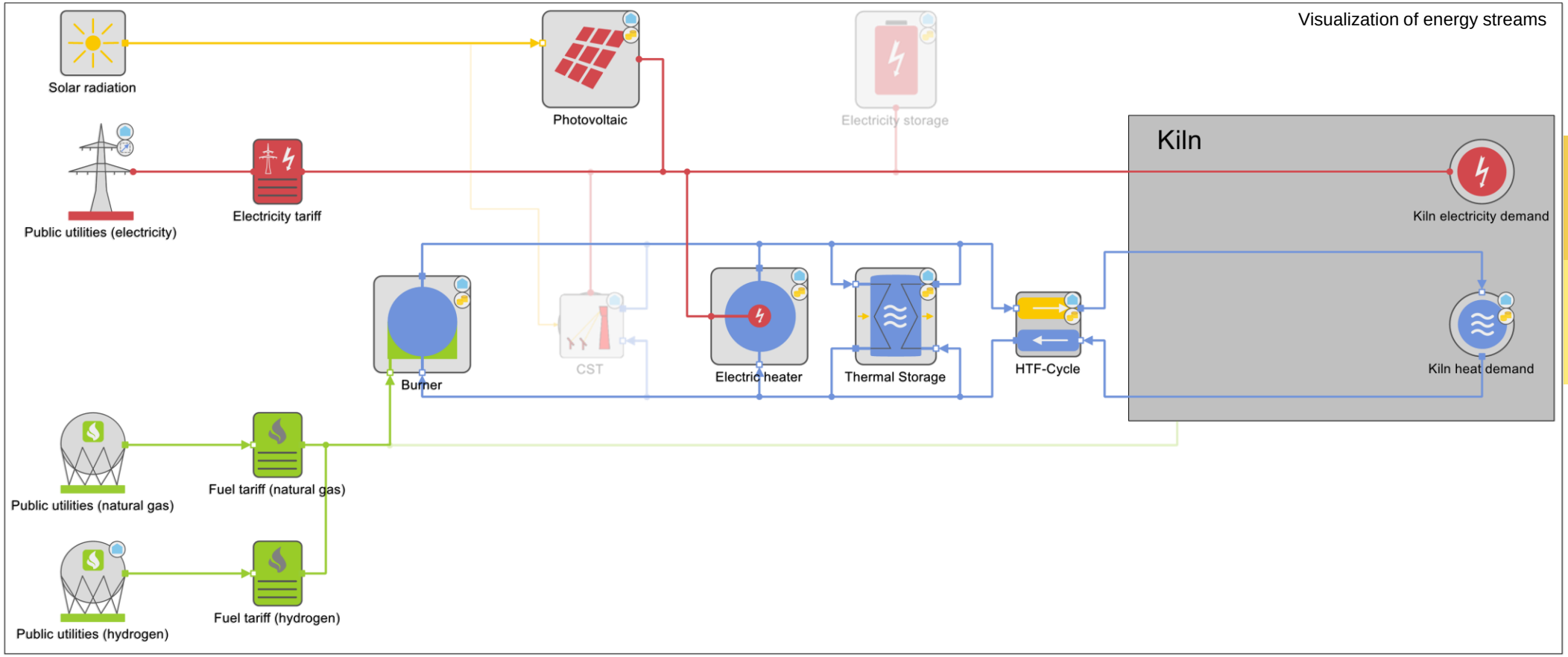
One master level model to optimize a multitude of concepts.



Natural Gas	Hydrogen	Electrification	**PV Internal**	PV External	CST External	CST PV External

- Boundary Conditions
- **Concepts**
- **Model**
- Optimization
- Techno-economic assessment
- Final assessment

One master level model to optimize a multitude of concepts.



Natural Gas	Hydrogen	Electrification	PV Internal	**PV External**	CST External	CST PV External

Boundary Conditions

Concepts

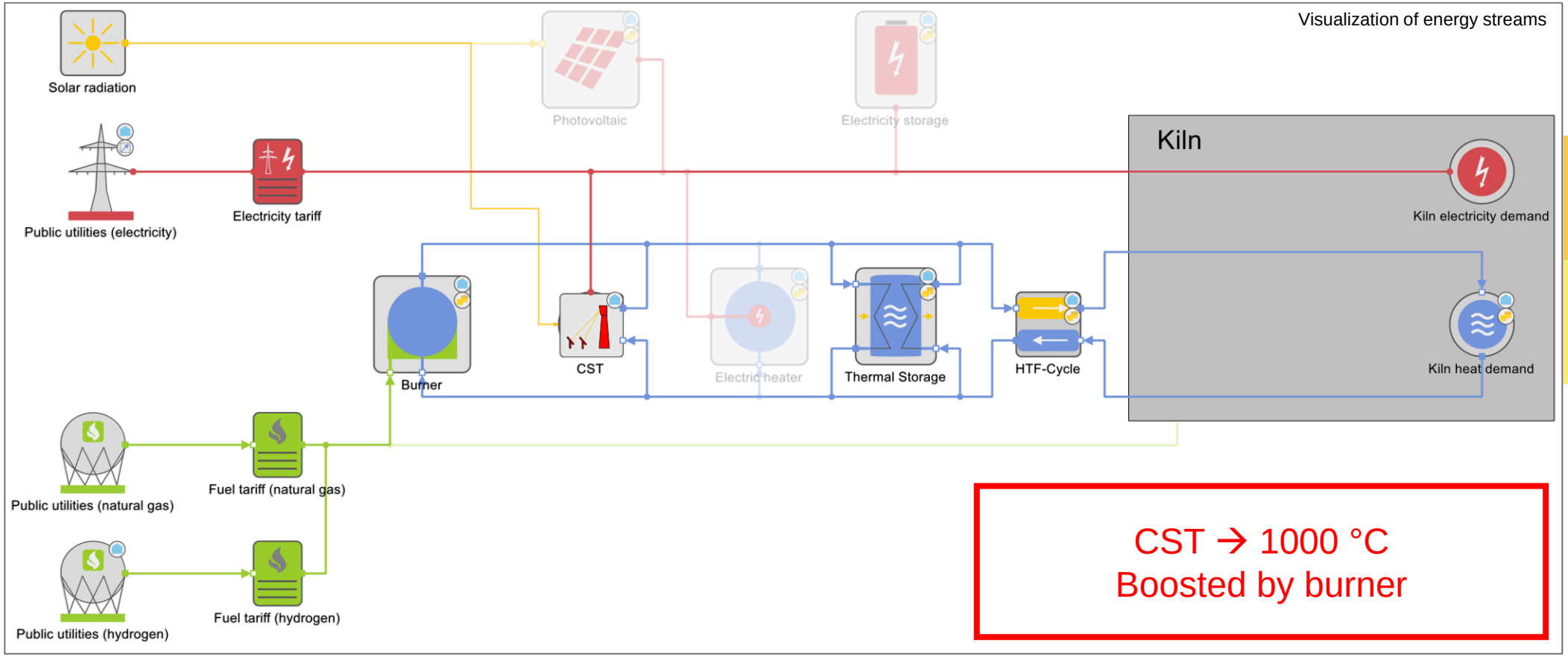
Model

Optimization

Techno-economic assessment

Final assessment

One master level model to optimize a multitude of concepts.



Natural Gas	Hydrogen	Electrification	PV Internal	PV External	**CST External**	CST PV External

Boundary Conditions

Concepts

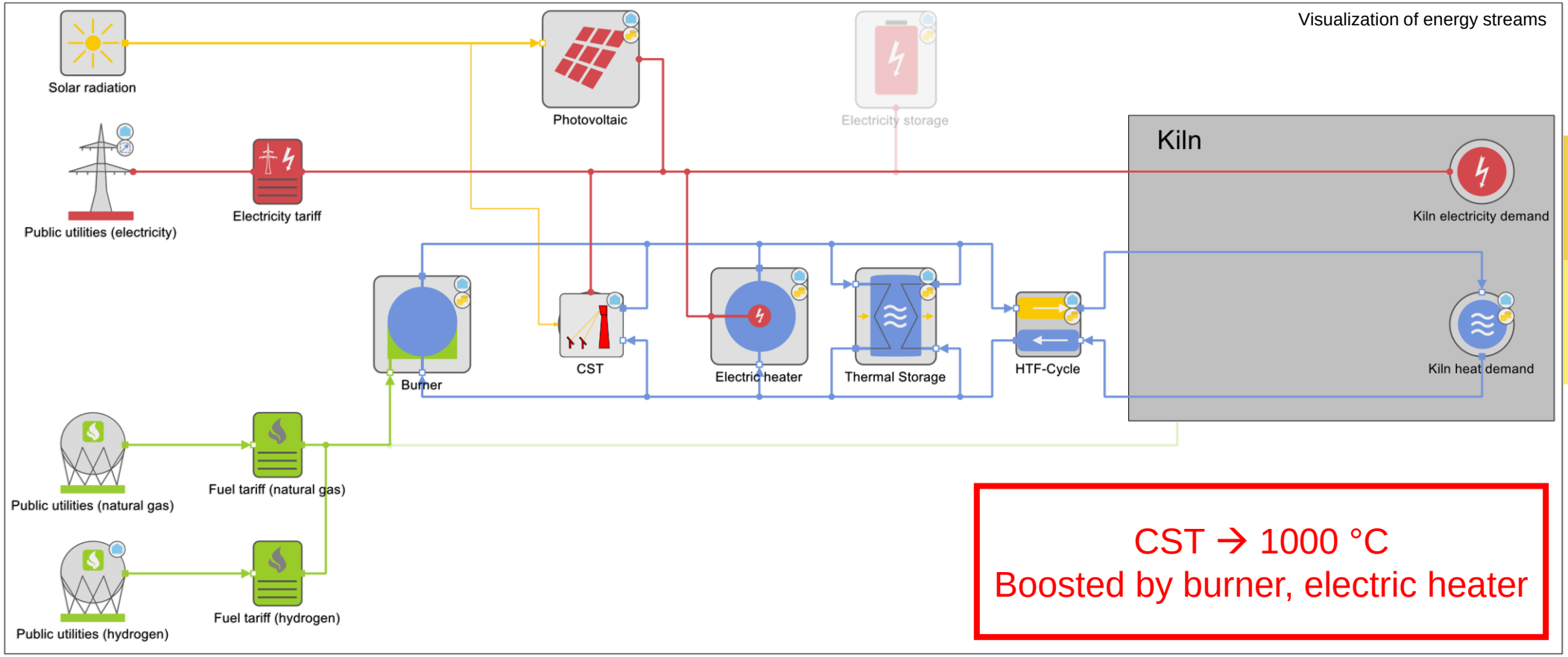
Model

Optimization

Techno-economic assessment

Final assessment

One master level model to optimize a multitude of concepts.



Natural Gas	Hydrogen	Electrification	PV Internal	PV External	CST External	**CST PV External**

Boundary Conditions

Concepts

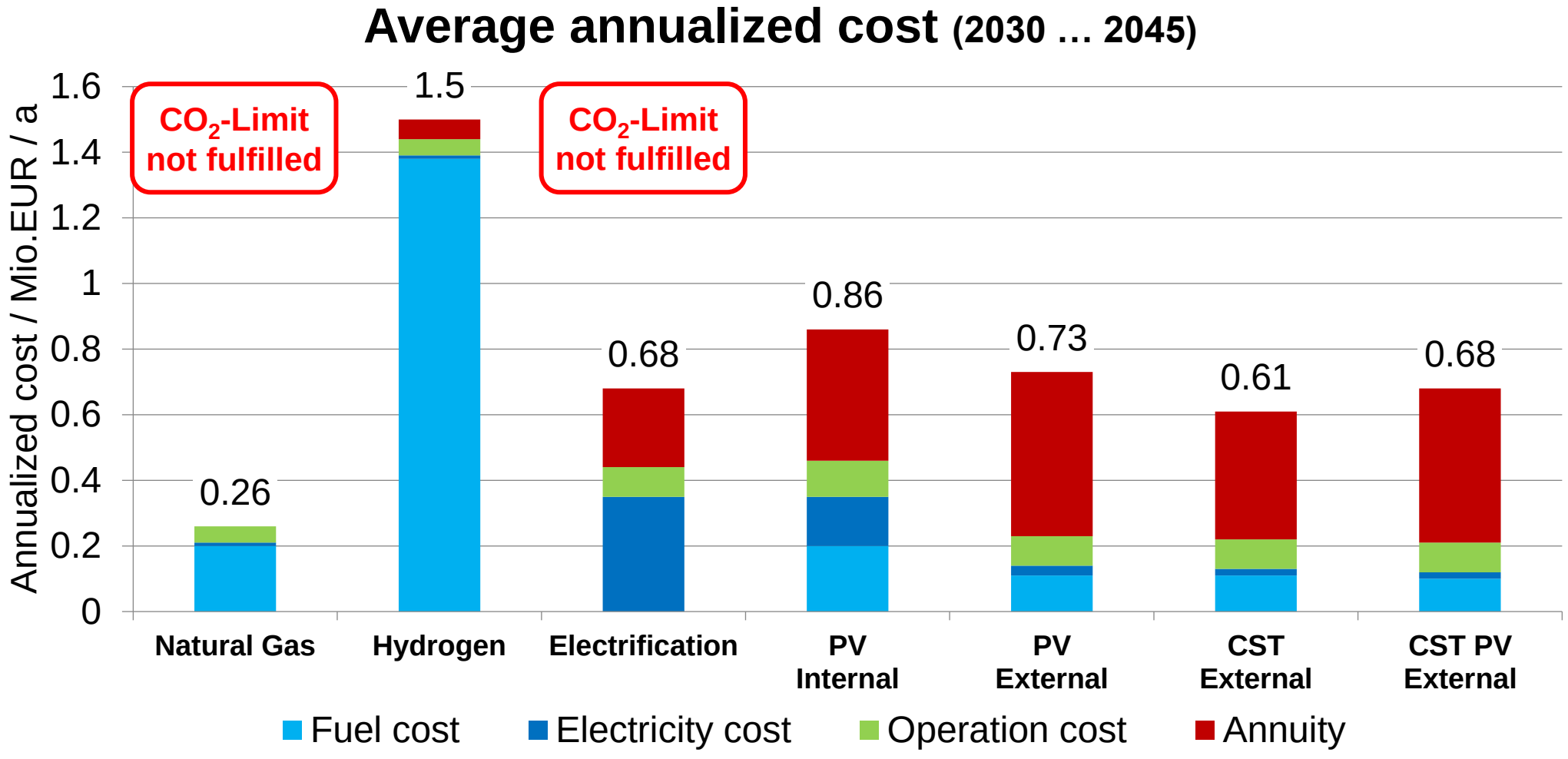
Model

Optimization

Techno-economic assessment

Final assessment

Decarbonization is expensive, but systems with solar generation and thermal storage are the most cost efficient alternative



Boundary Conditions

Concepts

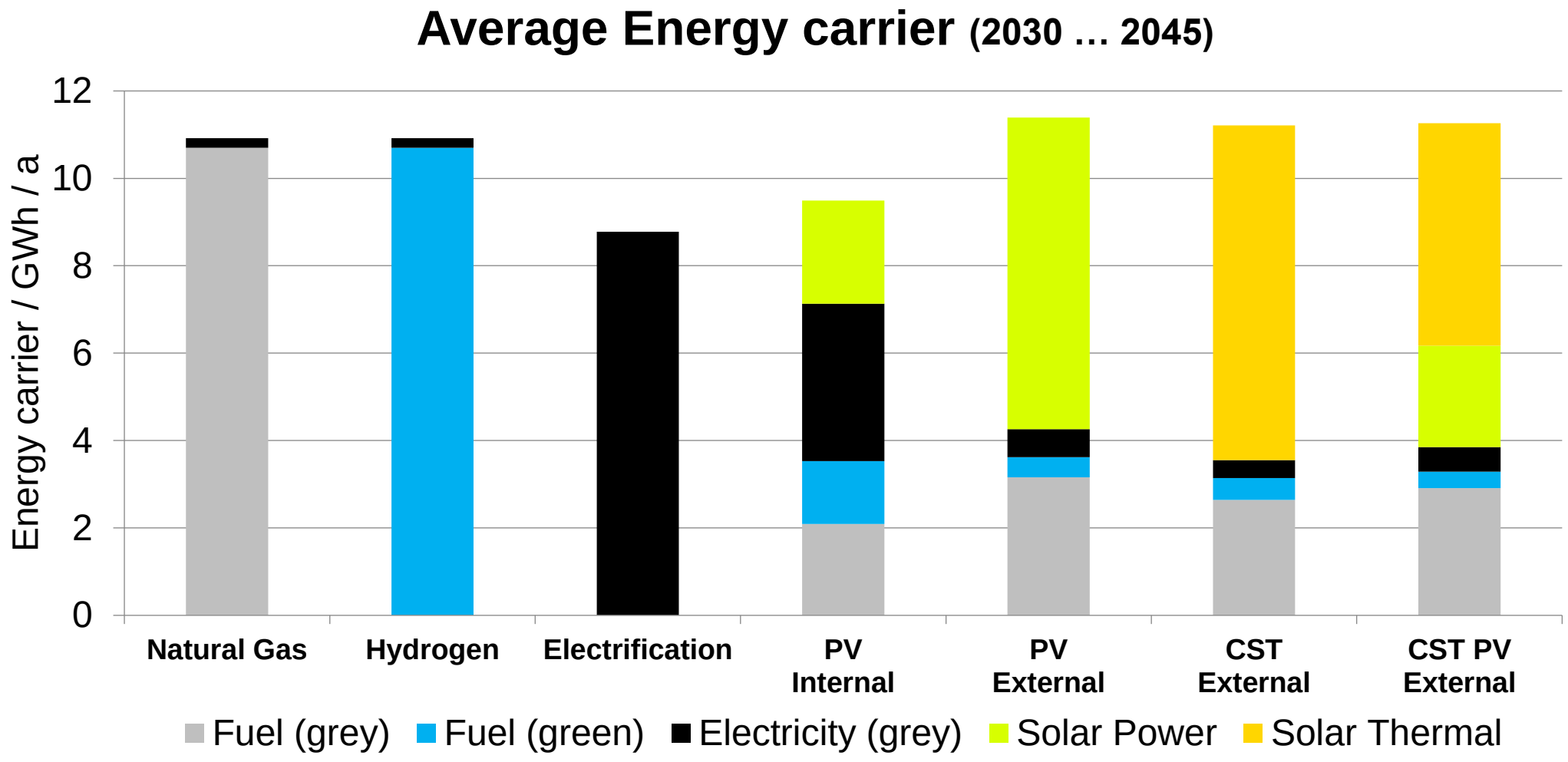
Model

Optimization

Techno-economic assessment

Final assessment

High share of on-site solar generation reduces dependencies to energy markets



Boundary Conditions

Concepts

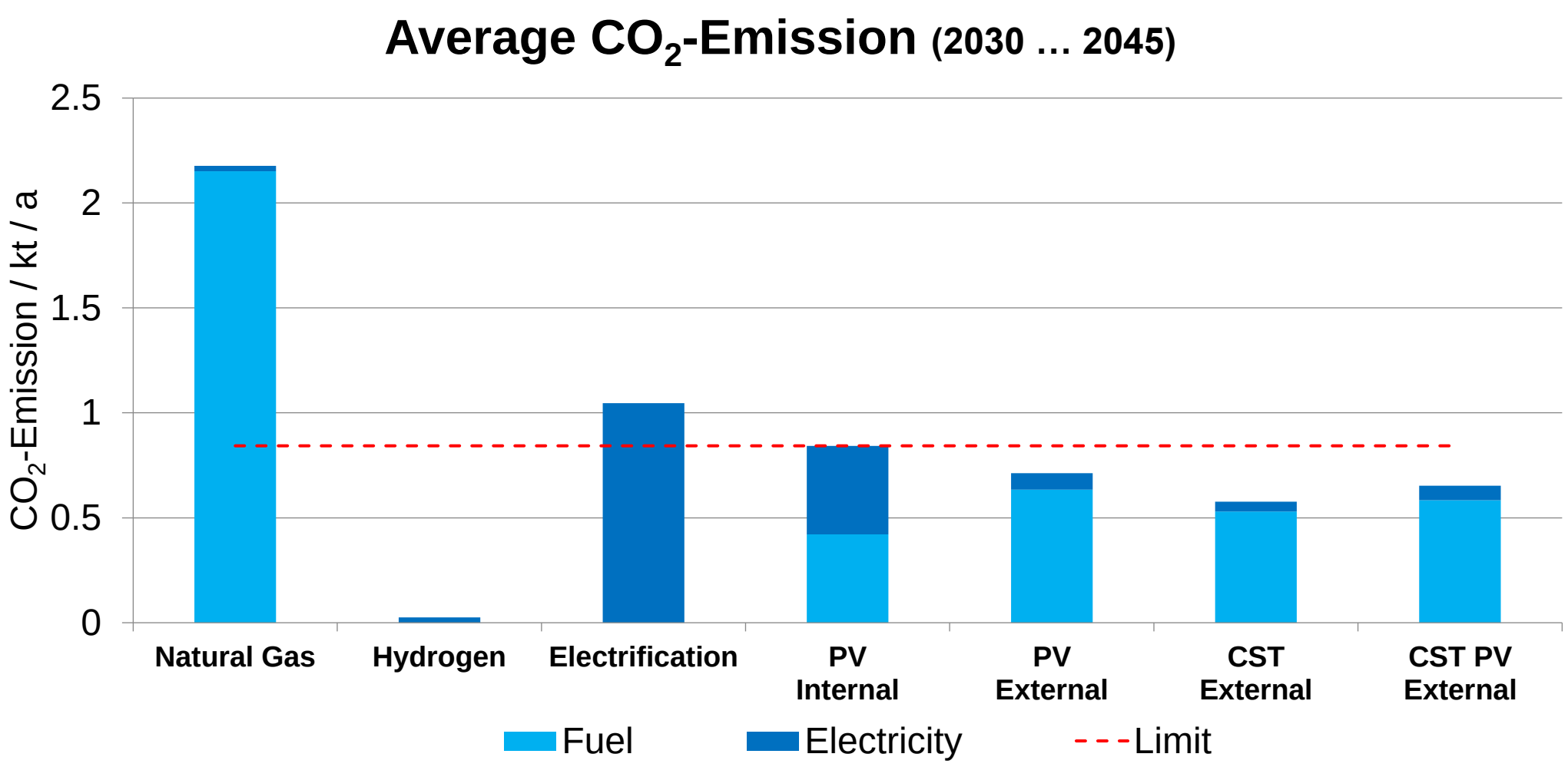
Model

Optimization

Techno-economic assessment

Final assessment

CST-based hybrid systems show the highest reduction of CO_2-emission



Boundary Conditions

Concepts

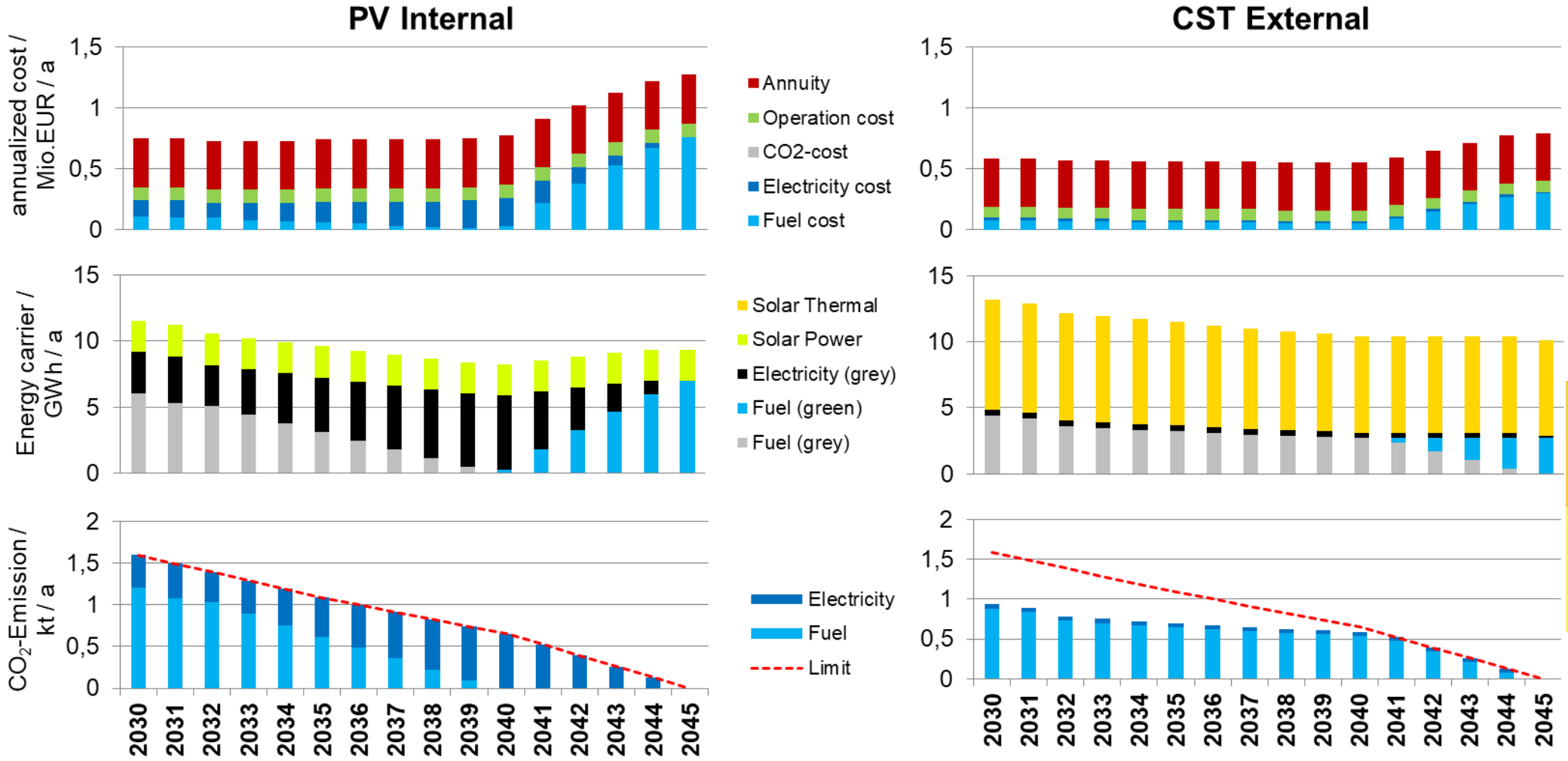
Model

Optimization

Techno-economic assessment

Final assessment

Hybrid systems enable a stepwise reduction of CO_2-emission



Boundary Conditions

Concepts

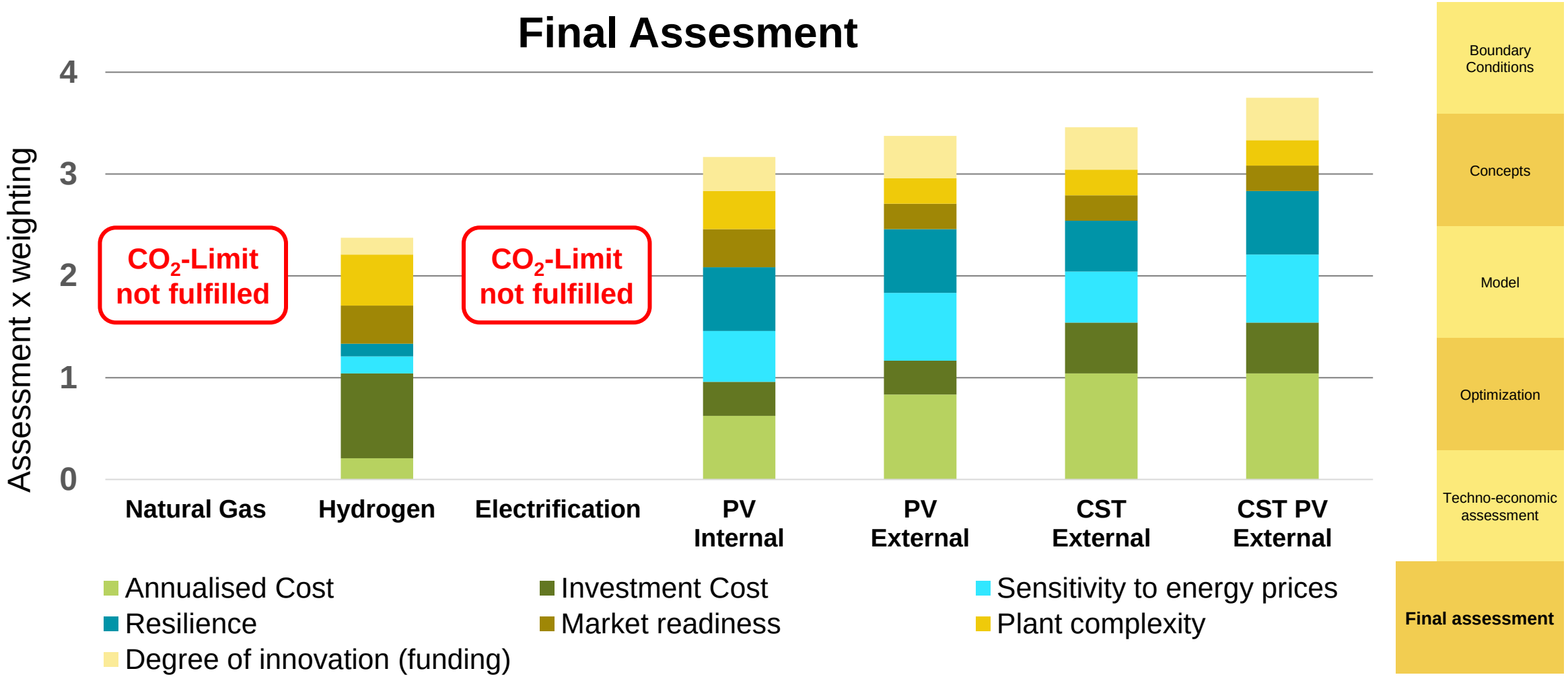
Model

Optimization

Techno-economic assessment

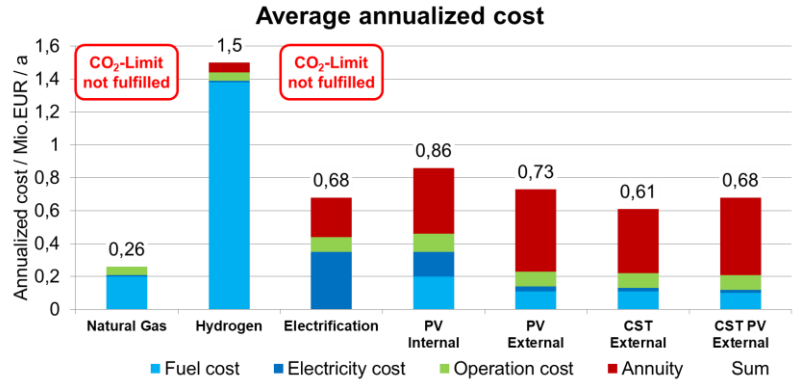
Final assessment

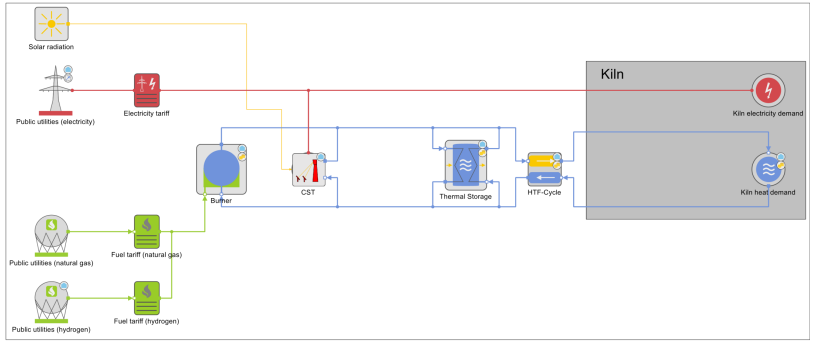
CST-based hybrid concepts combine low costs with reduced energy market dependency

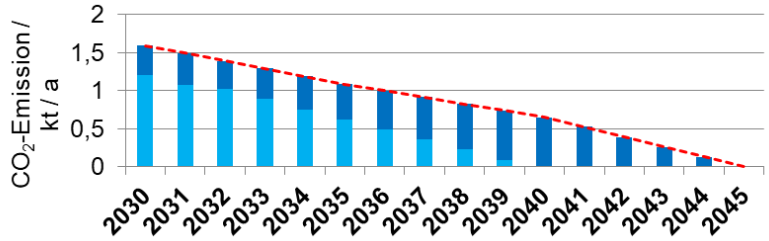


Conclusion

- Decarbonization is costly
  - Natural Gas most economic → CO_2-Limits not fulfilled
  - Hydrogen most expensive
- **Thermal storages** and **solar on-site generation** decrease costs and dependencies
- **CST External** more economic than **PV External**
- **CST PV External** with highest score in final assessment
- **Hybrid systems** enable stepwise reduction of CO_2-Emissions







THANK YOU FOR YOUR ATTENTION

Martin Bolten

martin.bolten@dlr.de

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

DLR