IPESE
Industrial Process and Energy Systems Engineering

Energyscope: A Tool for Energy System Modeling

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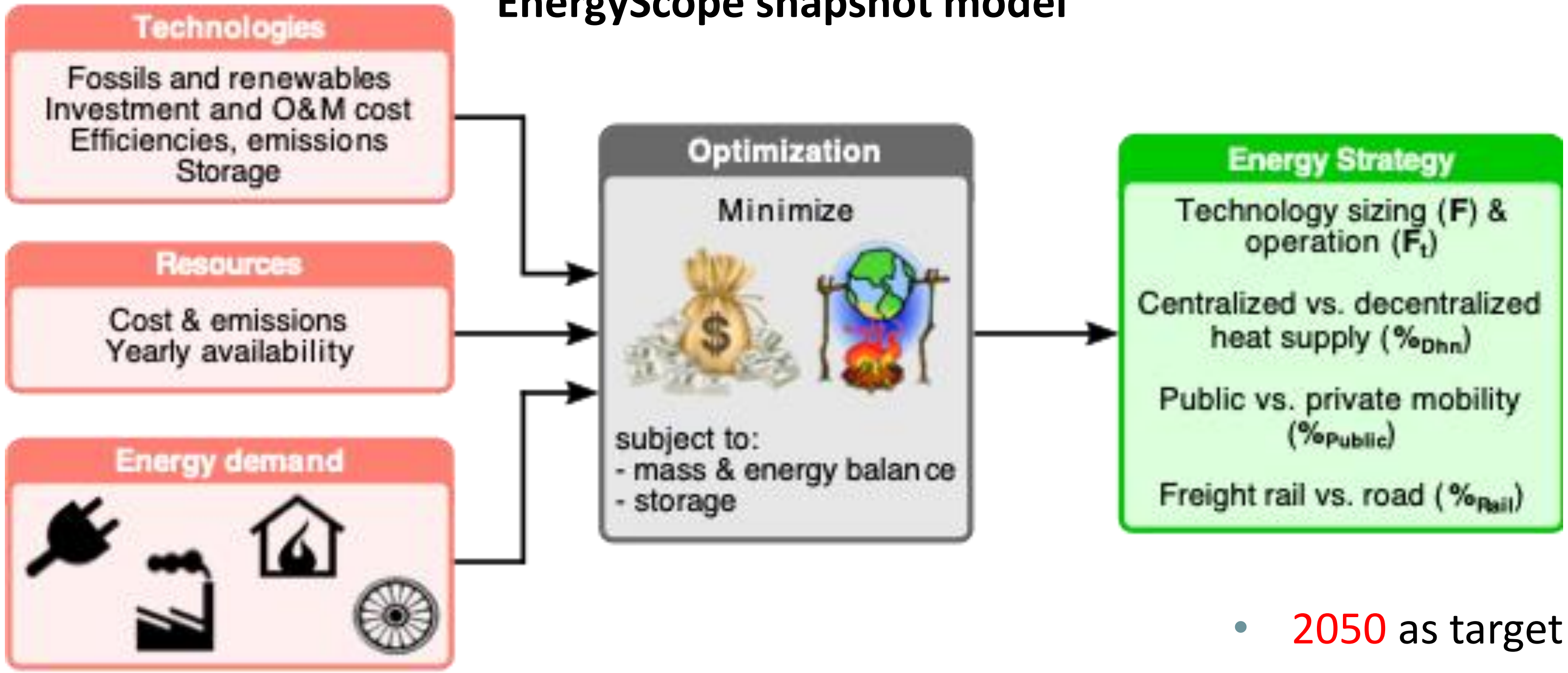
Doctoral School, 12 November 2020

The Swiss Energyscope Model

How to define the availability of the excess electricity?

EnergyScope snapshot model



- 2050 as target year
- Mean days approach (monthly resolution)
- Additional constraints for CH
- Model size:
  - 10646 decision variables
  - Solved in seconds (< 1s)

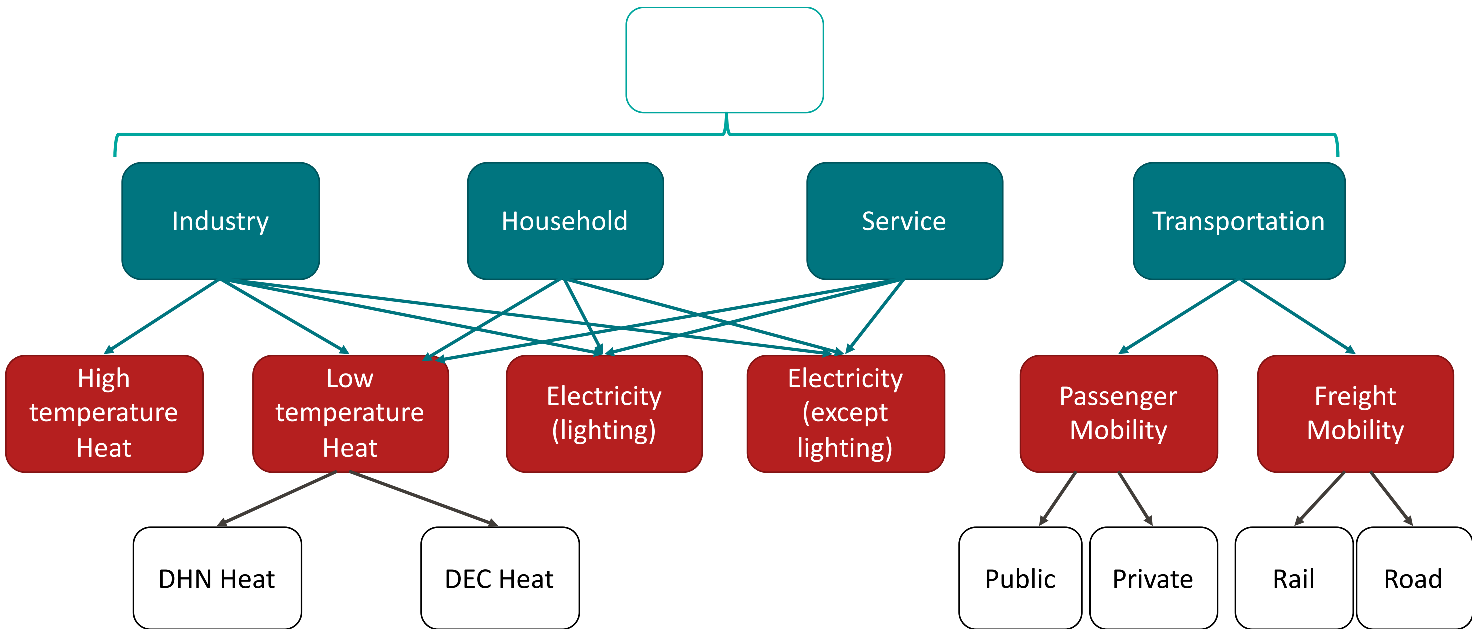
Gironès, Victor Codina, et al., *Energy* 90 (2015): 173-186.
Moret, Stefano, et al., *Applied energy* 202 (2017): 597-617.

Swiss Energyscope - Concept

- For what: Energy strategy design by creating specific energy scenarios and discover its implications for Switzerland.

- How:
  - MILP (Mixed Integer Linear Programming) Optimization
  - Programming language: AMPL (A Mathematical Programming Language)

- Features:
  - Snapshot of future scenarios
  - Good performance in the trade-off between modeling contents and convergence speed
  - Storage
  - Time resolution: monthly/hourly (typical days)
  - Space resolution: national/cantonal



[1] Swiss Energyscope: http://energyscope.ch/a-propos/les-enjeux/

Swiss Energyscope - Model

Objective: minimize the total cost of system

$$\min \mathbf{C_{tot}} = \min \left(\sum_{j \in \mathscr{E}} \mathbf{C_{inv}}(j) + \sum_{j \in \mathscr{E}} \mathbf{C_{maint}}(j) + \sum_{r \in \mathscr{R}} \sum_{t \in \mathscr{T}} \mathbf{C_{op}}(r,t) t_{op}(t) \right)$$

where $\mathscr{E}$, $\mathscr{R}$ and $\mathscr{T}$ represent the technology set, the resource set and time period set

the investment cost $\mathbf{C_{inv}}$ is annualized by:

$$\tau(j) = \frac{i_{rate}(i_{rate}+1)^{n(j)}}{(i_{rate}+1)^{n(j)} - 1}$$

Subject to:

- Supply-demand balance
- Mass/energy balance
- Availability of resources
- Potential of technologies
- Storage continuity
- Grid capacity
- Peak demand

Modeling equations

$$\mathbf{C_{inv}}(j) = c_{inv}(j)\mathbf{F}(j) \qquad \forall j \in TECH \quad (1.3)$$

$$\mathbf{C_{maint}}(j) = c_{maint}(j)\mathbf{F}(j) \qquad \forall j \in TECH \quad (1.4)$$

$$\mathbf{GWP_{constr}}(j) = gwp_{constr}(j)\mathbf{F}(j) \qquad \forall j \in TECH \quad (1.5)$$

$$f_{min}(j) \leq \mathbf{F}(j) \leq f_{max}(j) \qquad \forall j \in TECH \quad (1.6)$$

$$\mathbf{N}(j) f_{ref}(j) = \mathbf{F}(j) \qquad \forall j \in TECH \quad (1.7)$$

$$\mathbf{F_t}(j,t) \leq \mathbf{F}(j) c_{p,t}(j,t) \qquad \forall j \in TECH, \forall t \in T \quad (1.8)$$

$$\sum_{t \in T} \mathbf{F_t}(j,t) t_{op}(t) \leq \mathbf{F}(j) c_p(j) \sum_{t \in T} t_{op}(t) \qquad \forall j \in TECH \quad (1.9)$$

$$\mathbf{C_{op}}(i) = \sum_{t \in T} c_{op}(i,t) \mathbf{F_t}(i,t) t_{op}(t) \qquad \forall i \in RES \quad (1.10)$$

$$\mathbf{GWP_{op}}(i) = \sum_{t \in T} gwp_{op}(i,t) \mathbf{F_t}(i,t) t_{op}(t) \qquad \forall i \in RES \quad (1.11)$$

$$\sum_{t \in T} \mathbf{F_t}(i,t) t_{op}(t) \leq avail(i) \qquad \forall i \in RES \quad (1.12)$$

$$\sum_{i \in RES \cup TECH \setminus STO} f(i,l) \mathbf{F_t}(i,t) + \sum_{j \in STO} (\mathbf{Sto_{out}}(j,l,t) - \mathbf{Sto_{in}}(j,l,t)) - \mathbf{EndUses}(l,t) = 0 \qquad \forall l \in L, \forall t \in T \quad (1.13)$$

$$\mathbf{F_t}(j,t) = \mathbf{F_t}(j,t-1) + t_{op}(t) \cdot \left(\sum_{l \in L | \eta_{sto,in}(j,l)>0} \mathbf{Sto_{in}}(j,l,t) \eta_{sto,in}(j,l) - \sum_{l \in L | \eta_{sto,out}(j,l)>0} \mathbf{Sto_{out}}(j,l,t) / \eta_{sto,out}(j,l) \right) \qquad \forall j \in STO, \forall t \in T \quad (1.14)$$

$$\mathbf{Sto_{in}}(j,l,t)(\lceil \eta_{sto,in}(j,l) \rceil - 1) = 0 \qquad \forall j \in STO, \forall l \in L, \forall t \in T \quad (1.15)$$

$$\mathbf{Sto_{out}}(j,l,t)(\lceil \eta_{sto,out}(j,l) \rceil - 1) = 0 \qquad \forall j \in STO, \forall l \in L, \forall t \in T \quad (1.16)$$

$$\left\lceil \sum_{l \in L | \eta_{sto,in}(j,l)>0} \mathbf{Sto_{in}}(j,l,t) / m(j,l,t) \right\rceil + \left\lceil \sum_{l \in L | \eta_{sto,out}(j,l)>0} \mathbf{Sto_{out}}(j,l,t) / m(j,l,t) \right\rceil \qquad \forall j \in STO, \forall t \in T \quad (1.17)$$

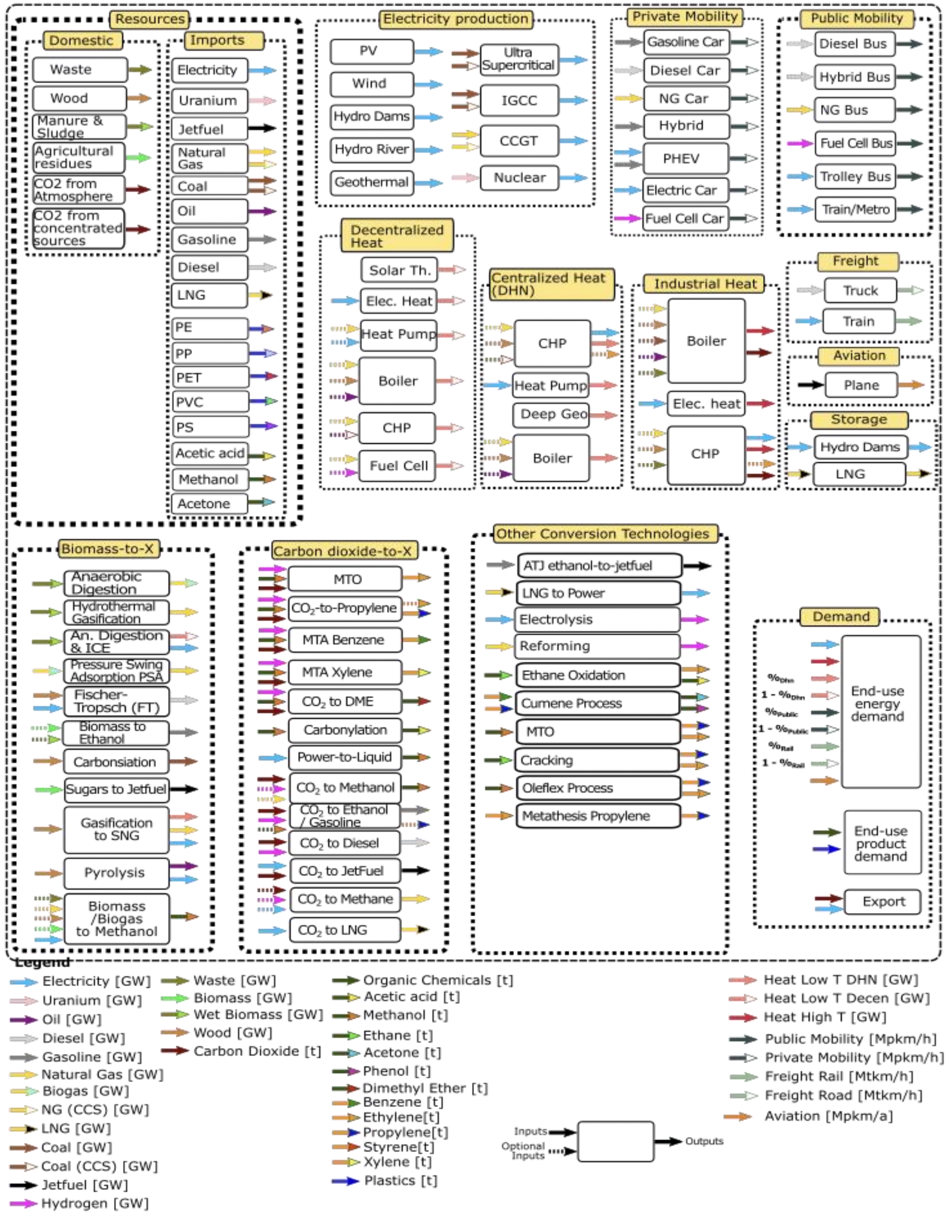
$$\mathbf{Loss}(eut,t) = \left(\sum_{i \in RES \cup TECH \setminus STO | f(i,eut)>0} f(i,eut) \mathbf{F_t}(i,t) \right) \%_{loss}(eut) \qquad \forall eut \in EUT, \forall t \in T \quad (1.18)$$

$$\mathbf{F_t}(j,t) + \mathbf{F_t}(k,t) \mathbf{Y_{Solar}}(j) \geq \frac{\mathbf{EndUses}(HeatLowTDHN,t) + \mathbf{EndUses}(HeatLowTDec,t)}{endUsesInput(HeatLowTSH) + endUsesInput(HeatLowTHW)} \sum_{t \in T} \mathbf{F_t}(j,t) t_{op}(t)$$
$$k = Dec_{Solar}, \forall j \in TECH\ OF\ EUT(HeatLowTDec) \setminus \{k\}, \forall t \in T \quad (1.19)$$

$$\sum_{j \in TECH} \mathbf{Y_{Solar}}(j) \leq 1 \qquad (1.20)$$

[2] S. Moret, Strategic energy planning under uncertainty, PhD Thesis.

Considered Technologies



Over 120 technologies grouped in:

- Power production
- Heat production (e.g. DHN, CHN, Industrial etc.)
- Mobility (e.g. private, public etc.)
- Biomass to X
- CO_2 to X
- Other (e.g. intermediate processes, bio-products, etc.)
- Demand (e.g. heat, power, export etc.)

Technologies appropriately connected to resource, heat, electricity, products, CO_2 and demand layers

Technology Implementation - Gasification

The partial (sub-stoichiometric) oxidation of lignin-rich biomass to mainly produce syngas, a mixture of CO and H_2.

Methane can be synthesized using a subsequent step comprised of :

a) concentration adjustment by water-gas shift (WGS) and

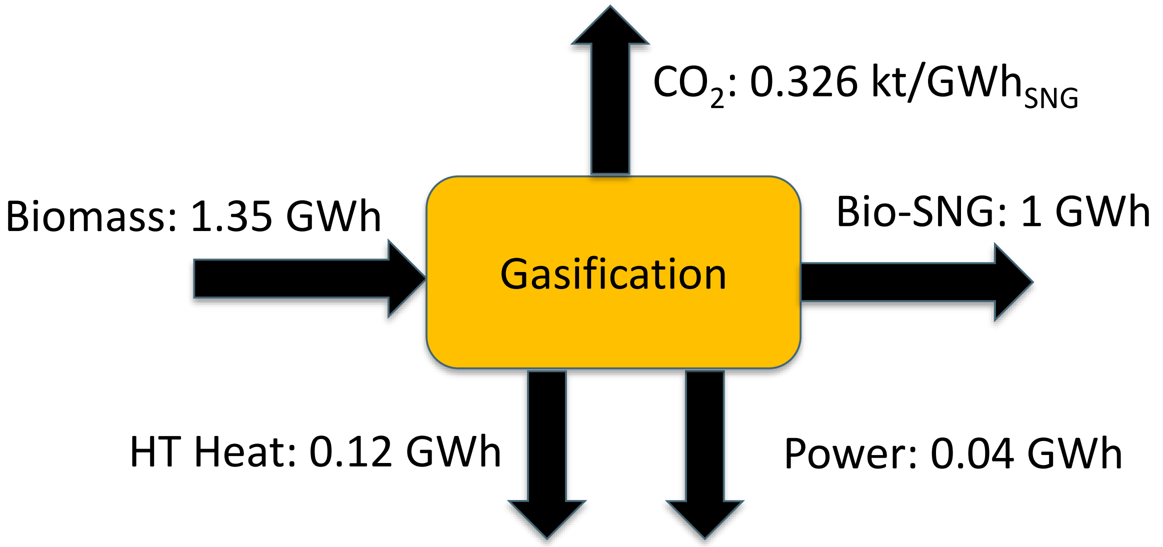
b) the Sabatier reactions:

$$CO + H_2O \rightleftharpoons CO_2 + H_2 \quad \textit{WGS reaction}$$

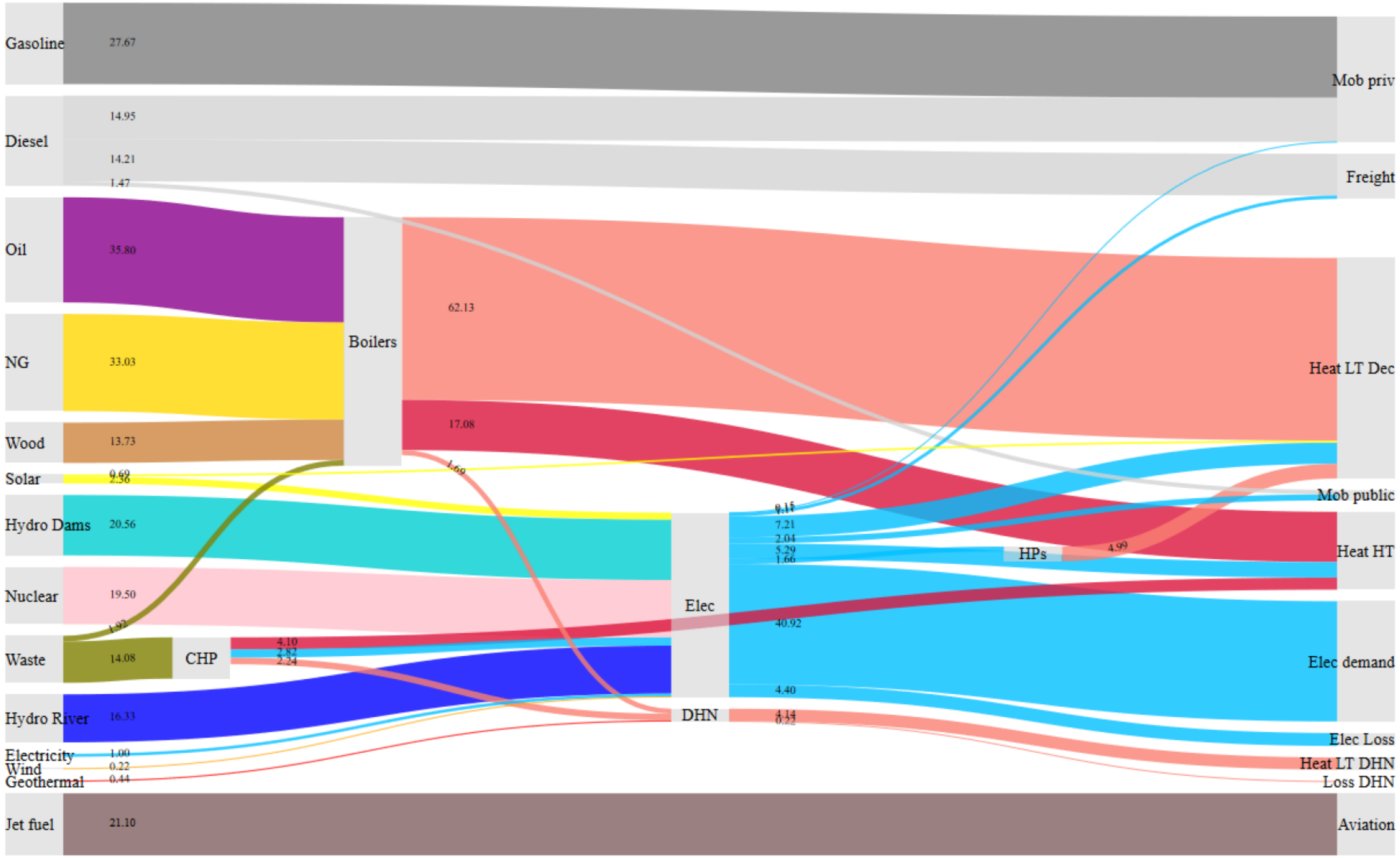
$$\left.\begin{array}{l} CO_2 + 4H_2 \rightleftharpoons CH_4 + 2H_2O \\ CO + 3H_2 \rightleftharpoons CH_4 + 2H_2O \end{array}\right\} \textit{Sabatier reactions}$$

Model input data:

E_{ch}:	*0.74*	
E_{el}:	*0.03*	
E_{th}:	*0.09*	
CO_2 flow:	*0.326*	*kt/GWh_{prod}*
C_{inv}:	*2930*	*MCHF/GW*
C_{maint}:	*149.44*	*MCHF/GW*
GWP:		*kt CO_2 eq/GWh*
TRL:	*8*	
Lifetime:	*25*	*y*
C_p:	*0.86*	
Ref_size:	*0.001*	*GW*



Swiss Energyscope Model - Validation



Model validation

		Values from Model (TWh/y)	*Values from Literature (TWh/y) (BFE, 2018)*	*% Deviation*
Electricity	Nuclear	19.50	19.50	0.00
	CHP	2.82	2.80	0.71
	PV	2.36	2.28	3.51
	Wind	0.22	0.22	0
	Hydro Dam	20.56	20.72	-0.77
	Hydro River	16.33	15.95	2.38
Fuels and heat sources	Gasoline	27.67	27.67	0
	Diesel	30.63	31.82	-3.74
	Jetfuel	21.10	21.10	0.00
	Electricity (Import)	1.00		
	Gas	33.03	33.03	0.00
	Oil	35.80	35.54	0.73
	Wood	13.73	13.73	0.00
	Heat from waste (DHN)	2.24		
	Heat from heat pump	4.99	4.64	7.54
	Solar (thermal)	0.69	0.69	0.00

Swiss Energyscope - Use

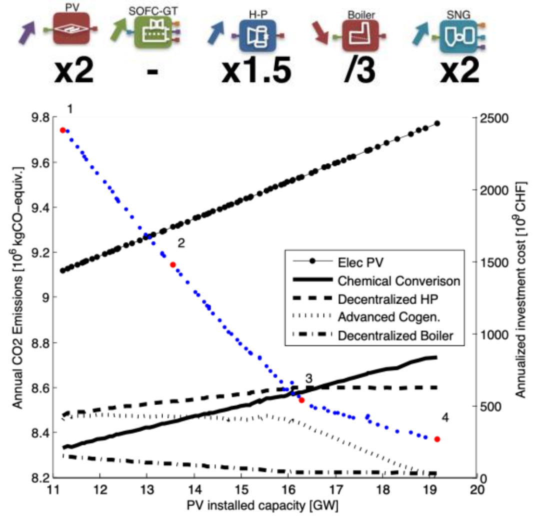
Scenarios generation

Objectives → Constraints → Indicators

Objectives	Constraints	Indicators
Cost	*Self-sufficiency* *CO_2*	*CO_2* *PV*

Codina Gironès, Víctor, et al. "On the assessment of the CO_2 mitigation potential of woody biomass." *Frontiers in Energy Research* 5 (2018): 37.

CO_2



Cost

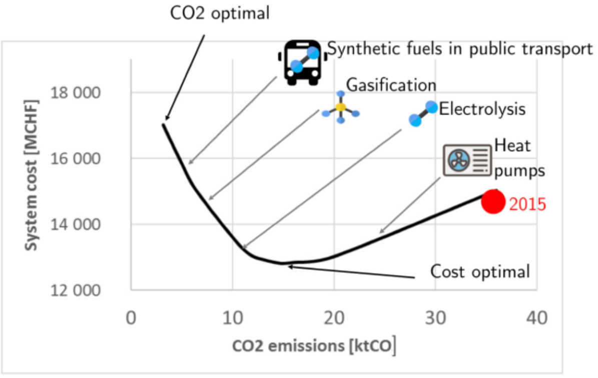
PV

CO_2 -40% vs NEP

Parametric constraints: RES penetration

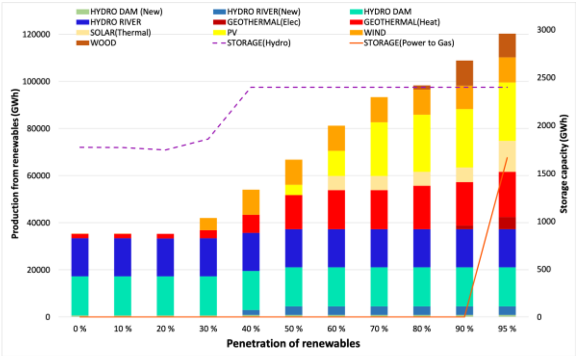
Total cost sensitivity

Cost



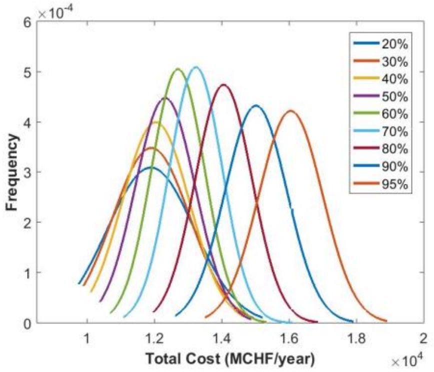
CO_2

Technology options

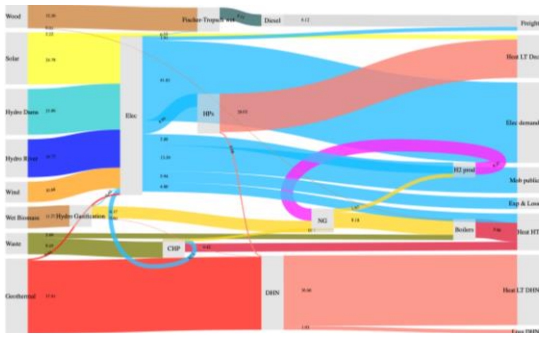


% of RES

Total Cost probability



Scenario assessment



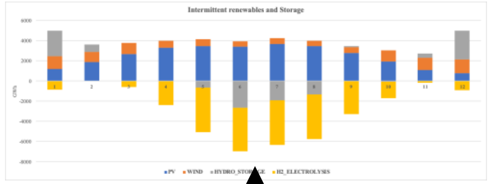
Flows in GWh/year

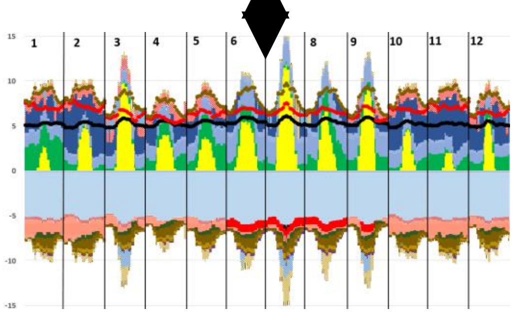
Swiss Energyscope: Perspectives

Regionalization

Energyscope/canton
Impact of cantonal/regionalized policy
Resources exchanges
Grid infrastructure
* LV-MV-HV electrical grids
* Gas network

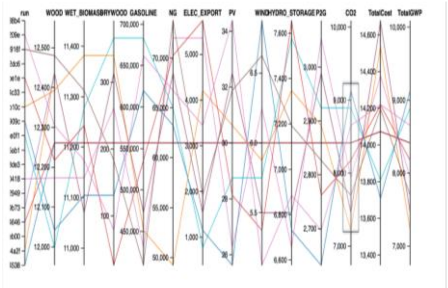
Energy management

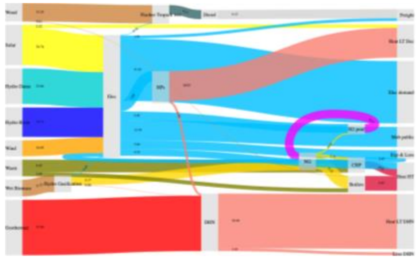


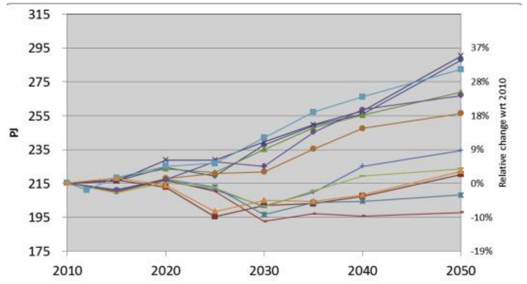


Transition

Explore targets → Select target → Generate transition







Energyscope → STEM

New Indicators

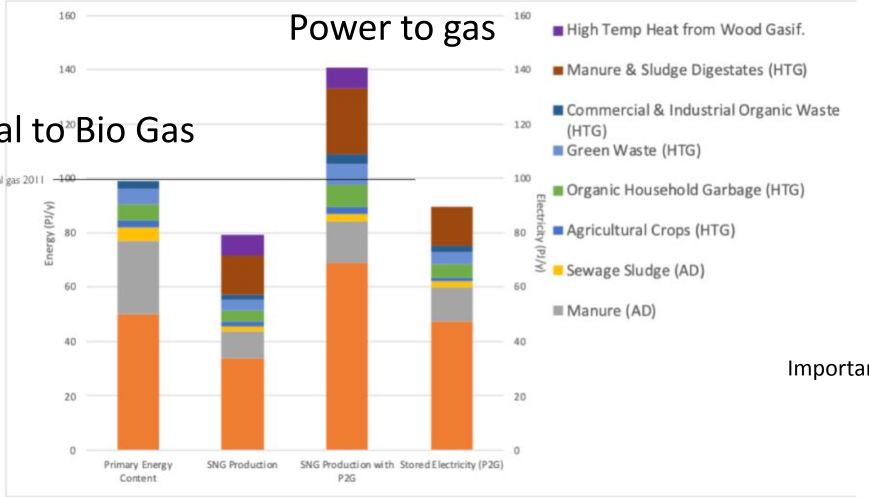
Employment
Air Quality : sherpa
LCA indicators

Energyscope : Applications

Biomass resources and conversion

Natural to Bio Gas

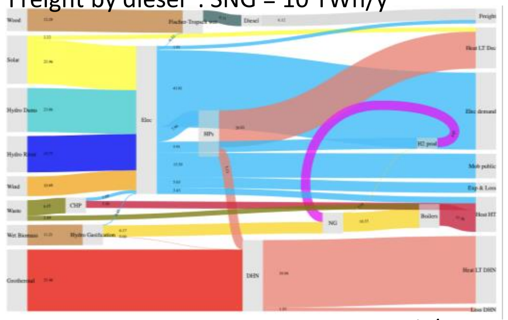
Power to gas



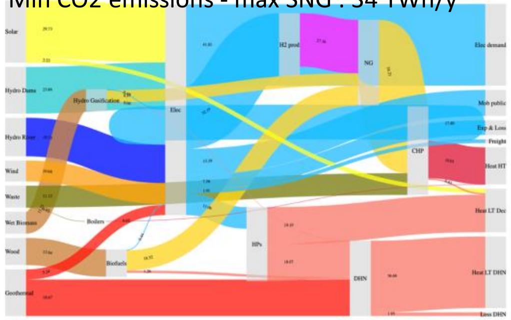
Importance of energy management

High deep geothermal

Freight by diesel : SNG = 10 TWh/y



Min CO2 emissions - max SNG : 34 TWh/y



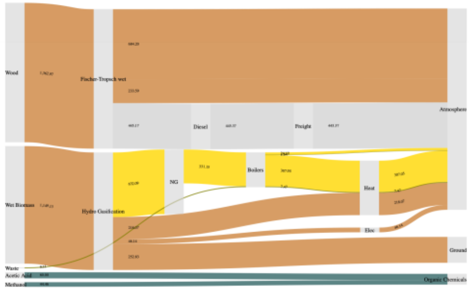
Carbon flows

CO_2 flows & emissions

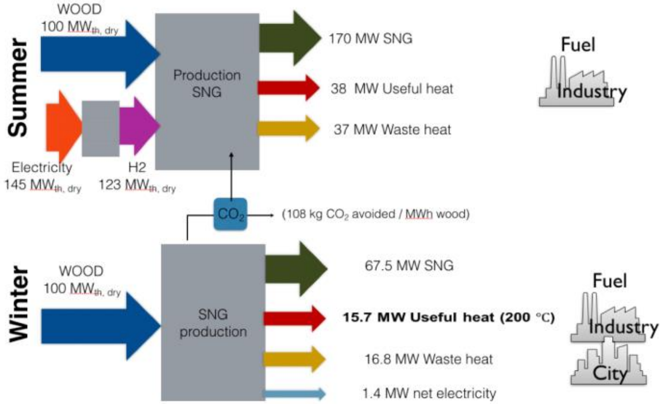
CO_2 sequestration

Chemical products

Where is Carbon going ?



Combined heat and fuel and CO_2 sequestration

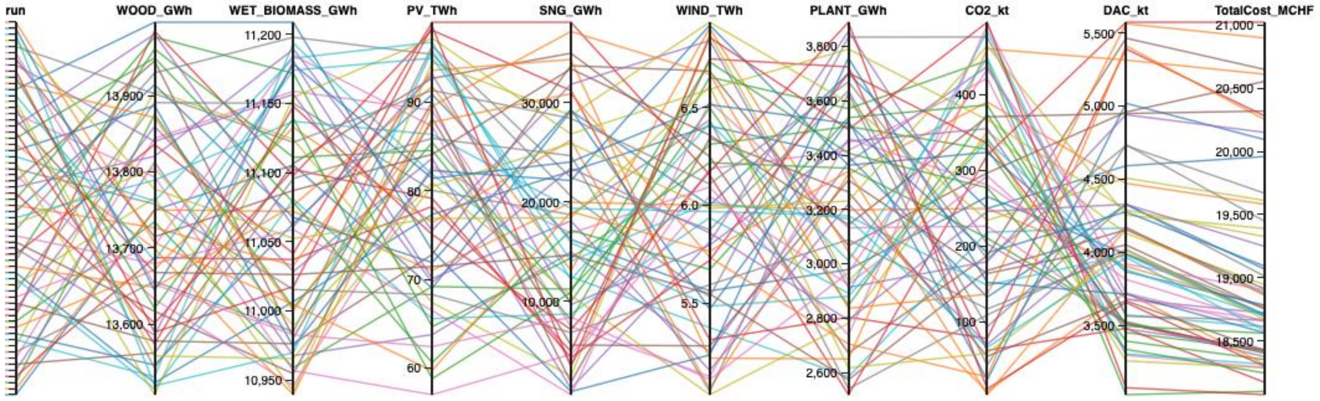


Celebi, Ayse Dilan, et al. "Next generation cogeneration system for industry-combined heat and fuel plant using biomass resources." *Chemical Engineering Science* (2019).

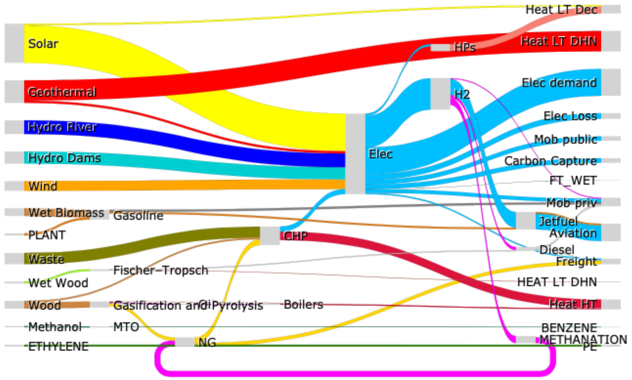
Application

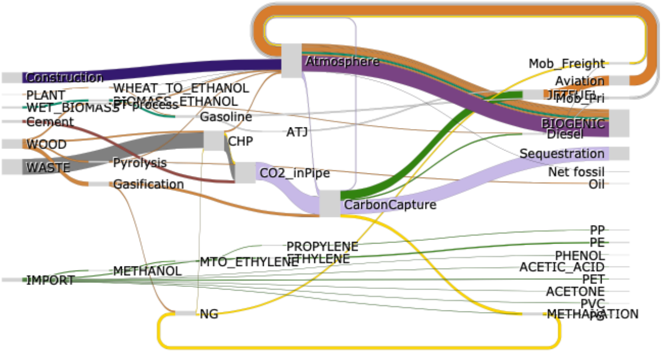
Add Constraints

Generate Multiple Solutions

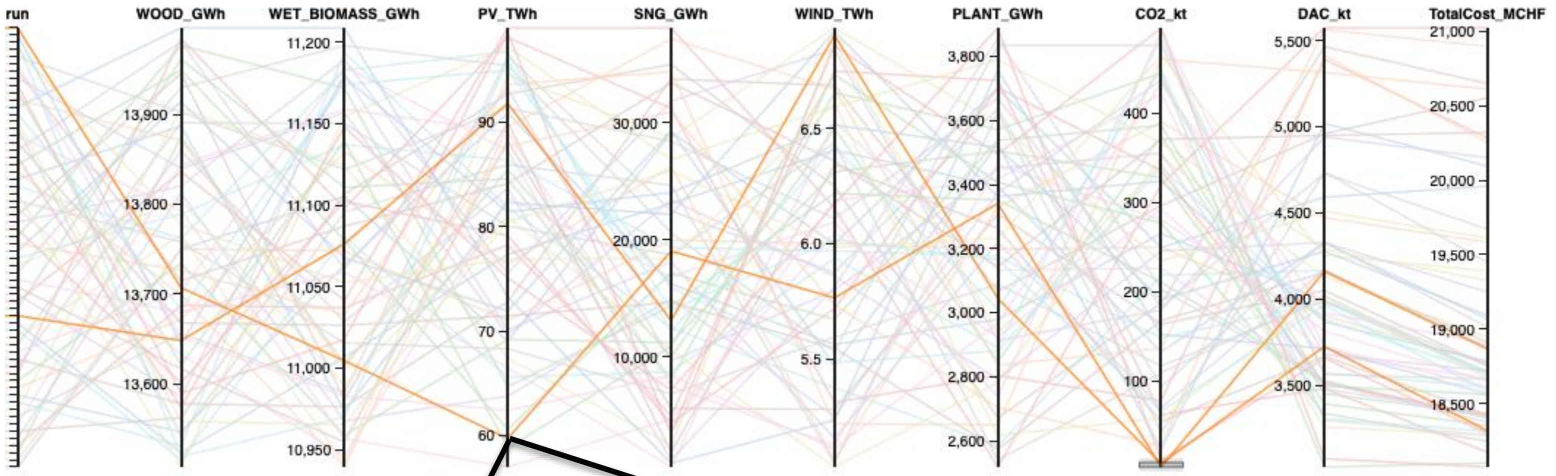


Evaluate Solutions

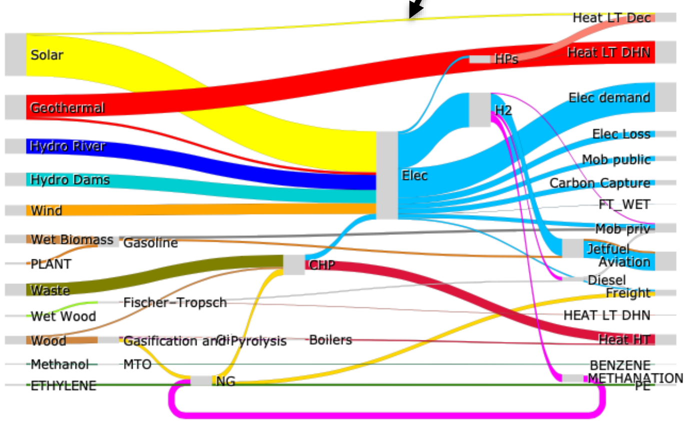




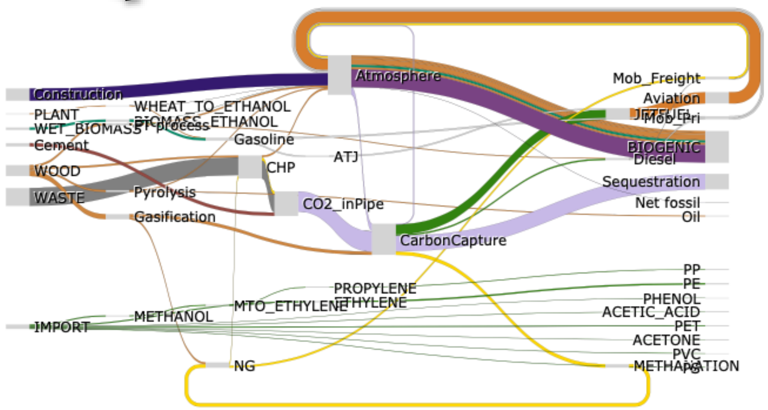
Application



Browsing of competing solutions for comparison



Energy Sankey



Carbon Sankey

Energy and carbon Sankey diagrams show the respective flows across each system

Website

https://calculator.energyscope.ch

Socio-economic

Population [million inhabitants]

8.89

7.50 10.00

Economic growth [%/year]

0.72

0.00 3.00

Energy efficiency

Building specific demand [kWh/m2]

57

41.00 57.00

Industry energy intensity [kWh/CHF]

0.25

0.20 0.25

Appliances average consumption [kWh/household]

2661

2400.00 2700.00

Lighting average consumption [kWh/m2]

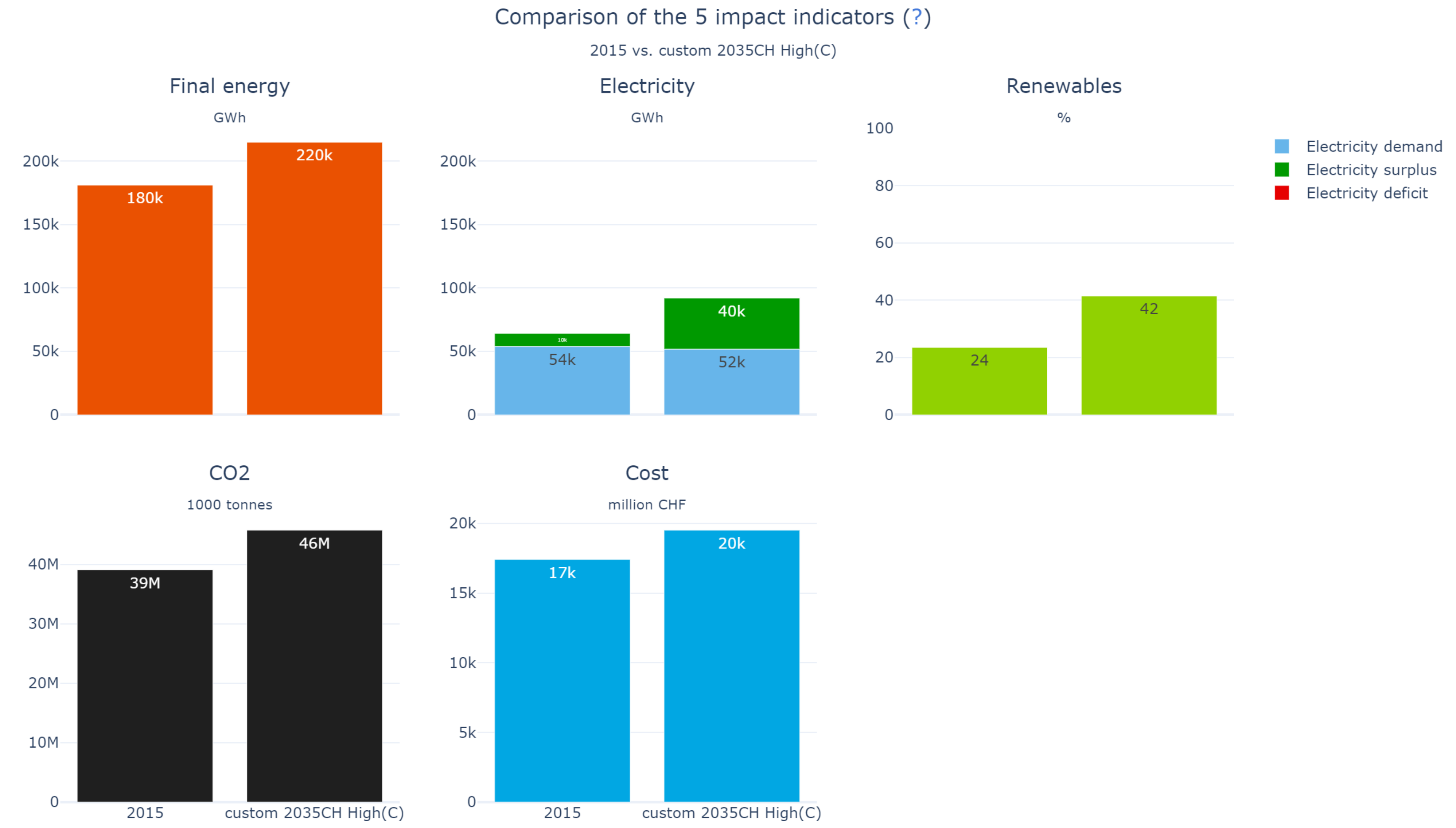
0.9

0.60 0.90

Transport

Vehicle types +

Public transport [%]



Take Home Messages

- Swiss energy system representation using the concept of Energyscope
- Solution(s): connection(s) of resources, technologies and demand by sector using MILP optimization.
- Technology implementation is easy provided meaningful data are retrieved.
- The energyscope platform can be used for completely assessing the energy system including perspectives on sectorial analysis, renewables penetration, regionalization among others.
- Assessment of different solutions to cover the entire solution space.
- Interactive and easy to use online platform (https://calculator.energyscope.ch)