Excess heat recovery potentials in Swiss industrial systems

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- Conclusions

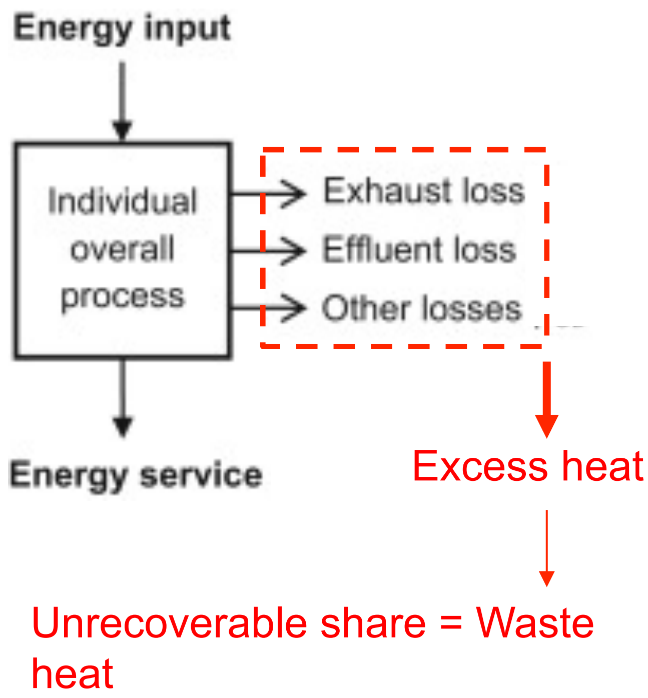
Introduction

- Thermal energy demand for process heat → ~70% of total final energy demand in industry.

- Two major components of process heating systems:
  1. Device that generates and supplies heat
  2. Device that transfers heat from the source to the product

- Excess heat → A significant amount of heat leaves the system through walls, stacks and effluents heat.

- Waste heat → heat energy that is unavoidably lost to the surroundings of a system and that cannot be recovered.



References:
US DOE, Quadrennial Technology Review 2015 - Chapter 6: Innovating Clean Energy Technologies in Advanced Manufacturing: Technology Assessments, 2015.
Iowa State University, Energy-related best practices: A sourcebook for the chemical industry, 2005.
C. Forman, I.K. Muritala, R. Pardemann, B. Meyer, Estimating the global waste heat potential, Renew. Sustain. Energy Rev. 57 (2016) 1568–1579. doi:10.1016/j.rser.2015.12.192.

Introduction

Gap in literature

Reasonable amount of studies on excess heat recovery potentials BUT:

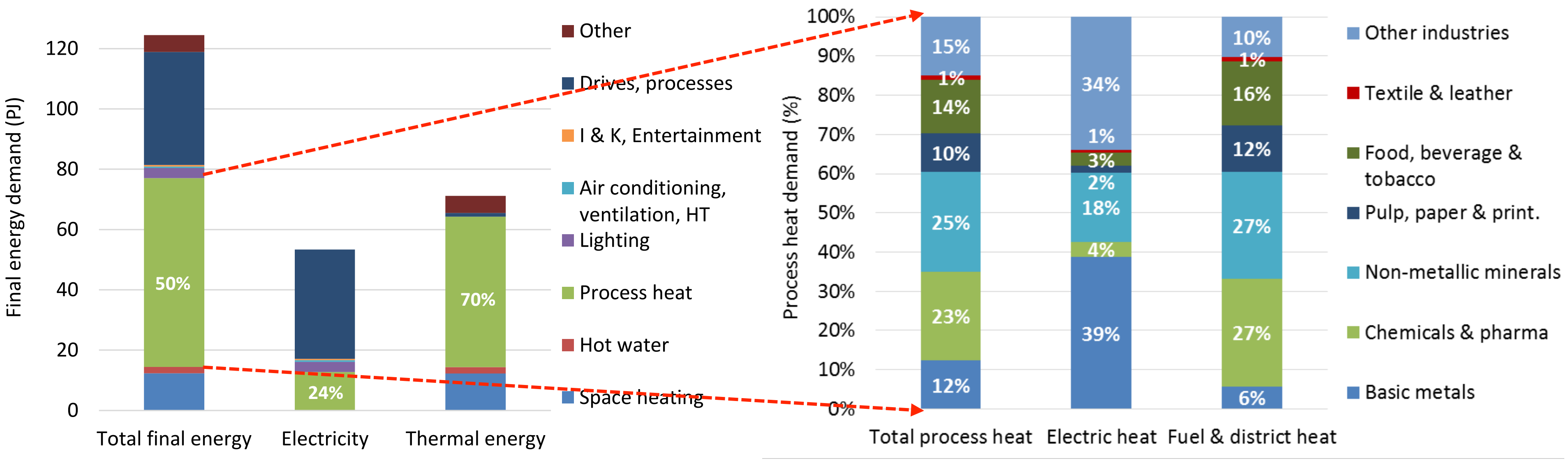
- *No clear methodology for estimating these potentials*
- *Lack of studies classifying excess heat by temperature levels*
- *Mapping of excess heat recovery potential is rarely done*

Aims & objective

- Energy and exergy analysis to estimate excess heat recovery potentials in Switzerland
- Spatial distribution of the process heat demand by energy carrier
- Spatial distribution of the excess heat recovery potential by temperature level

Input data and methods

<u>Process heat demand in Swiss industry</u>



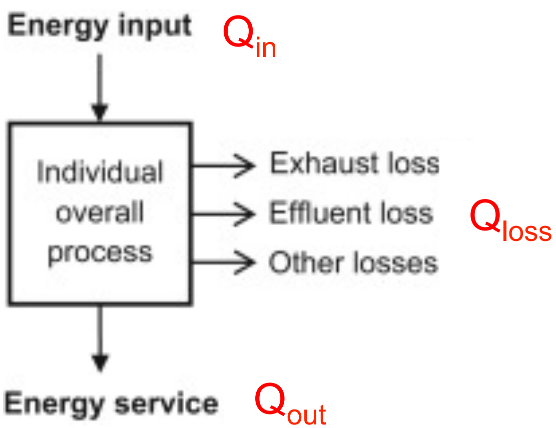
Final energy demand by application | Process heat demand by industry sector

References:
Prognos AG/BFE, Die Energieperspektiven für die Schweiz bis 2050., BFE, Basel, 2012.
BFE. Analyse des schweizerischen Energieverbrauchs 2000 - 2016 nach Verwendungszwecken. Bern: 2017.
US DOE, Manufacturing Energy and Carbon Footprints (2010 MECS).

Input data and methods

Energetic and exergetic assessment

Energy balance



$$Q_{in} = Q_{out} + Q_{loss}$$

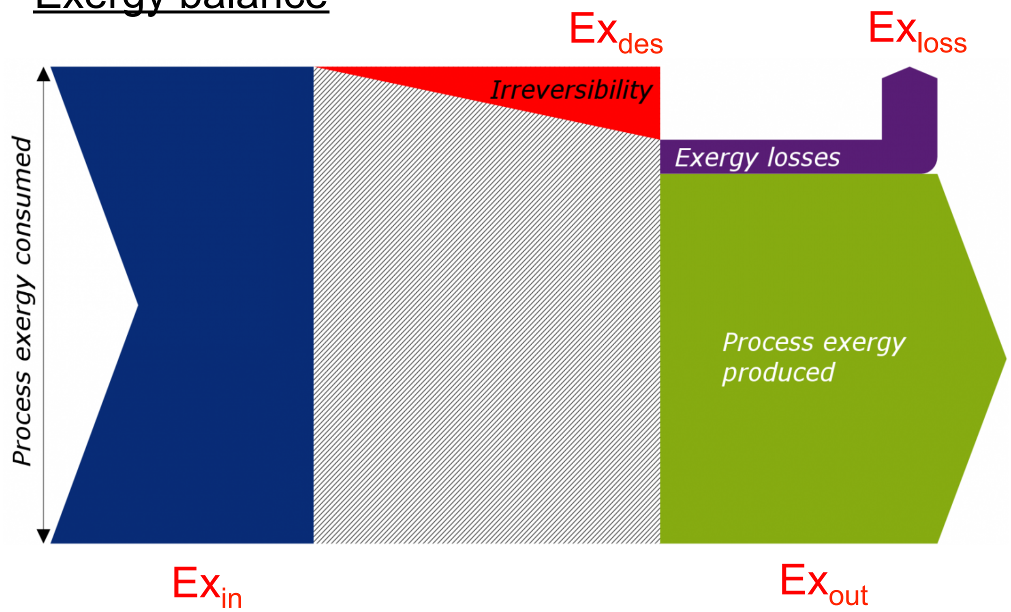
where:

Q_{in} = Thermal energy input

Q_{out} = Thermal energy output

Q_{loss} = Thermal energy loss (excess heat)

Exergy balance



$$Ex_{in} = Ex_{out} + Ex_{loss} + Ex_{des}$$

where:

Ex_{in} = Thermal exergy input

Ex_{out} = Thermal exergy output

Ex_{loss} = Thermal exergy loss

Ex_{des} = Thermal exergy destroyed

Input data and methods

<u>Energetic and exergetic assessment</u>

$$\epsilon = \left(1 - T_o / T_P\right)\eta$$

where:

ϵ = Mean exergy eff. T_o = Ref. state temp. (15°C)

η = Mean energy eff. T_p = Mean process temp.

Table Energy efficiency for industrial heating with fuels and electricity

Category	Temp. range °C	Heating energy efficiencies: Electricity %	Heating energy efficiencies: Fuel %
Low	≤120	100	65
Medium	120 - 380	90	60
High	≥380	70	50

Data sources: Sanaei et al. (2012), Al-Ghandoor et al. (2010), Dincer et al. (2004)

Table Estimated process heating data for Swiss industrial sectors

Industry sector	NOGA class.	T_p Range	T_p Mean temp. °C	Energy use breakdown: Electricity %	Energy use breakdown: Fuel %
Food, beverage & tobacco	10-12	Low	65	100	20
		Med.	215	0	66
		High	450	0	14
Textile & leather	13-15	Low	40	50	22
		Med.	180	50	78
		High	0	0	0
Pulp, paper & printing	17-18	Low	40	100	0
		Med.	0	0	0
		High	650	0	100
Chemicals & pharma.	20-21	Low	40	60	5
		Med.	190	25	48
		High	625	15	47
Non-metallic minerals	23	Low	40	69	0
		Med.	210	0	5
		High	1'050	31	95
Basic metals	24	Low	50	17	25
		Med.	140	1	8
		High	1'060	82	67
Other industries	16,22,25 -32	Low	40	51	16
		Med.	160	27	62
		High	600	22	22

Data sources: Naegler et al. (2015), Sanaei et al. (2012), Al-Ghandoor et al. (2010), Utlu and Hepbasli (2008), Oladiran et al. (2007), Dincer et al. (2004), Brown and Harry (1996).

Input data and methods

Energetic and exergetic assessment

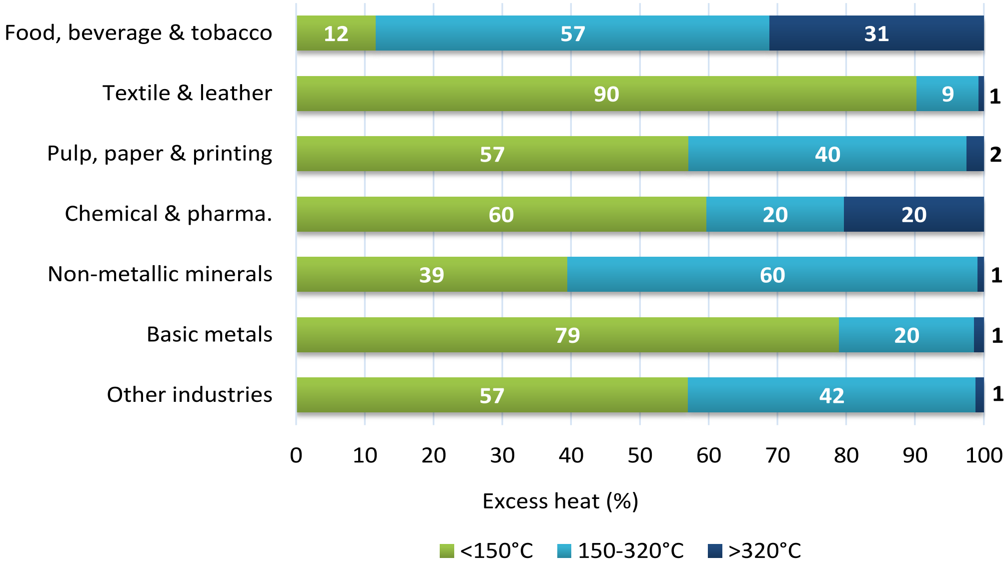


Figure Excess heat temperature ranges as assumed for Swiss industrial sectors

Based on the only *detailed* study on excess heat temp. in US.

Reference: Waste Heat to Power Market Assessment, ICF Intl., 2015

Energy loss:

$$Q_{loss} = (1-\eta) \times Q_{in}$$

Exergy loss:

$$Ex_{loss} = \left(1 - T_o / T_L\right) Q_{loss}$$

where:
Ex_{loss} = Exergy loss
Q_{loss} = Energy loss
T_o = Reference state temperature
T_L = Mean excess heat temperature

Reference state: 15°C, 1 atm

Mean excess heat temp. is determined from the figure while the thermal energy loss is estimated from the energy balance.

Input data and methods

Mapping excess heat recovery potential

- Site-specific data on physical production, annual final energy demand, process heat demand and excess heat volumes → not available in Switzerland.
- Alternative indicator → number of employees (full-time equivalent) to assess excess heat availabilities in Swiss industry.
- STATENT (Statistique structurelle des entreprises) database
  - *managed by Swiss Federal Office for Statistics (FSO)*
  - *number of employees by industrial sector at a spatial resolution of one hectare (>40,000 data points)*
- GIS Software: QGIS - version 2.18.11

$$Q_{loss,H} = (Q_{in,S} / NE_S) \times NE_H \times (1 - \eta_S)$$

where

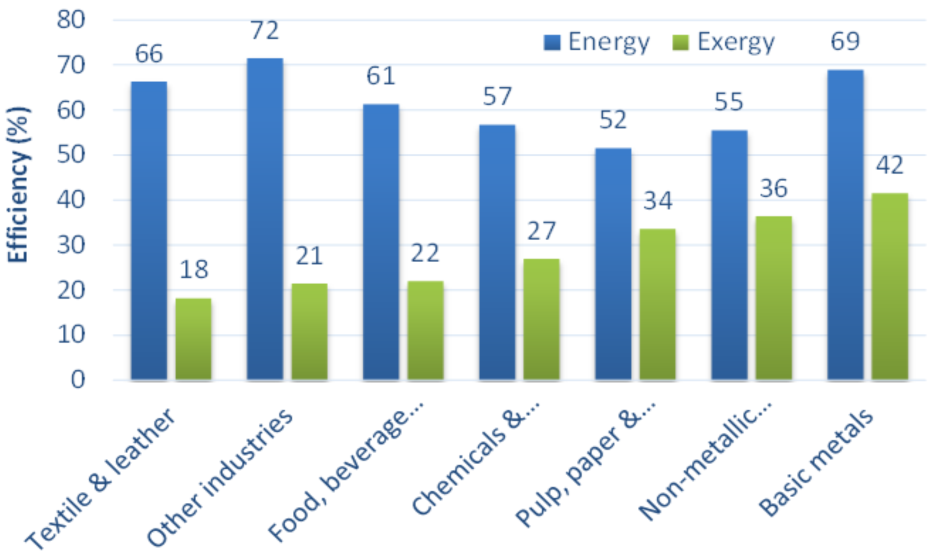
$Q_{in,S}/NE_S$ = Average process heat demand per employee in an industrial sector

NE_H = Number of employees per hectare

η_S = Energy efficiency of the industrial sector

Results

<u>Energy and exergy efficiency improvement potential</u>



Energy and exergy efficiencies of heating processes in Swiss industrial sectors

Table Energy efficiency for industrial heating with fuels and electricity

Category	Temp. range °C	Heating energy efficiencies Electricity %	Fuel %
Low	≤120	100	65
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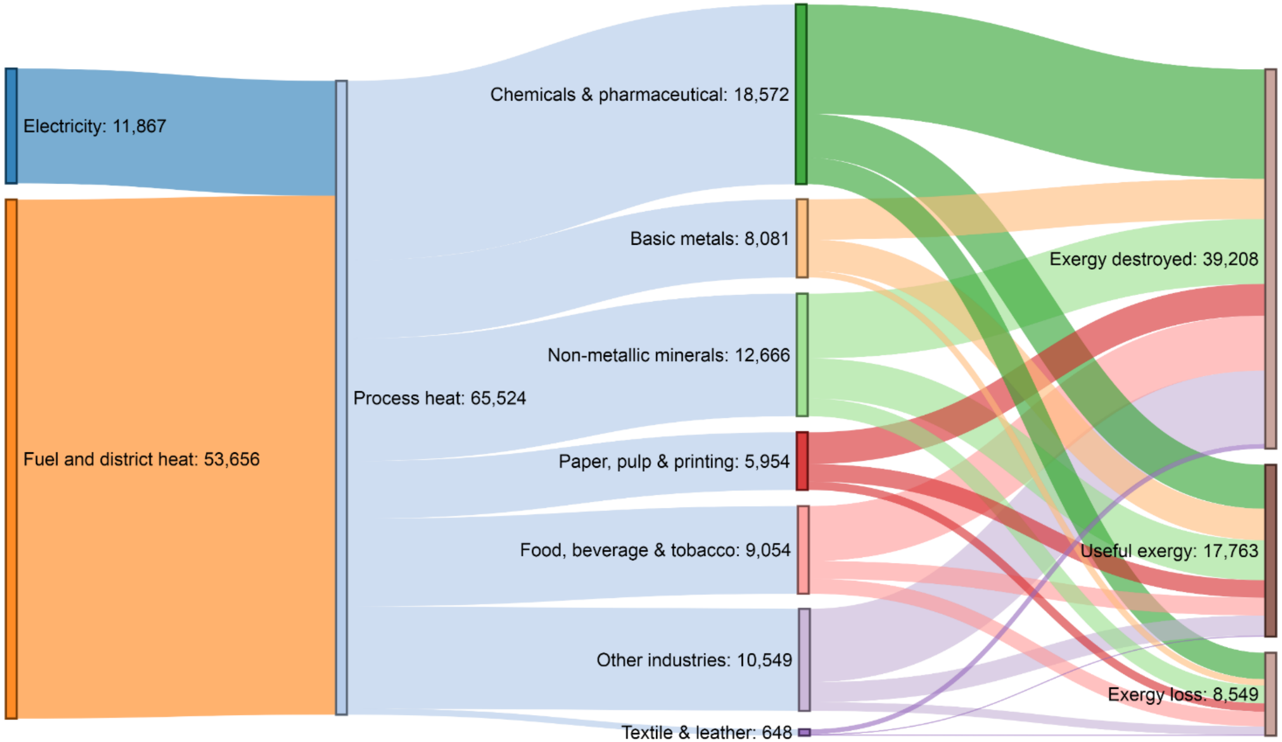
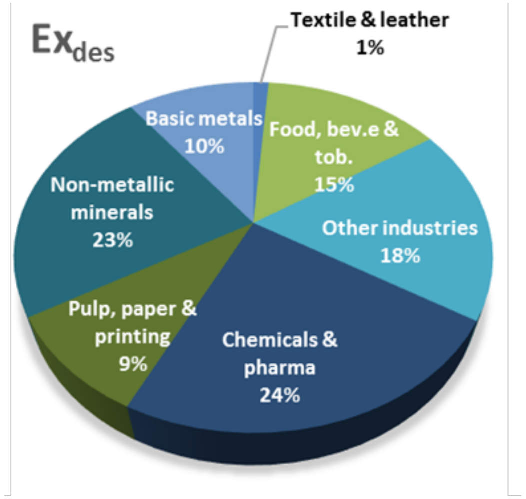
Data sources: Sanaei et al. (2012), Al-Ghandoor et al. (2010), Dincer et al. (2004)

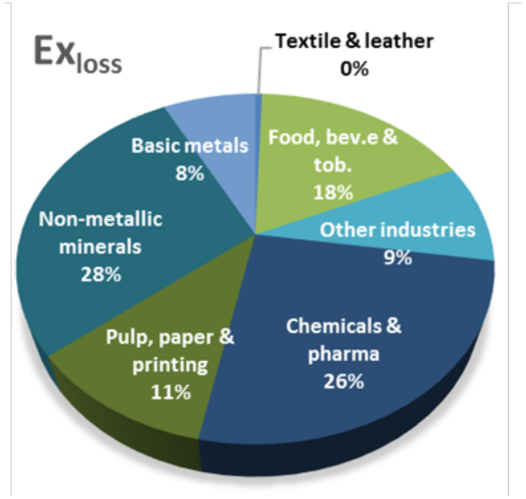
$$\epsilon = \left(1 - T_o / T_P\right)\eta$$

Results

Energy and exergy efficiency improvement potential



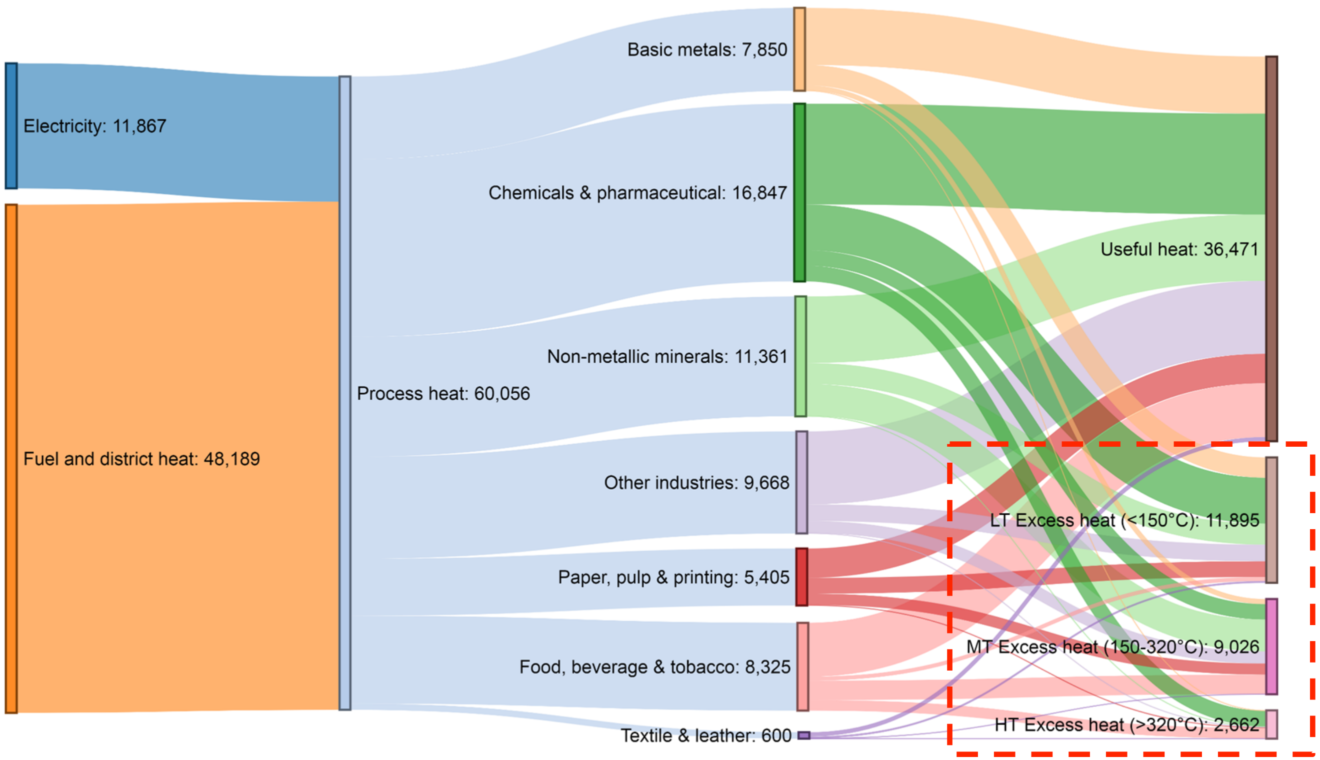




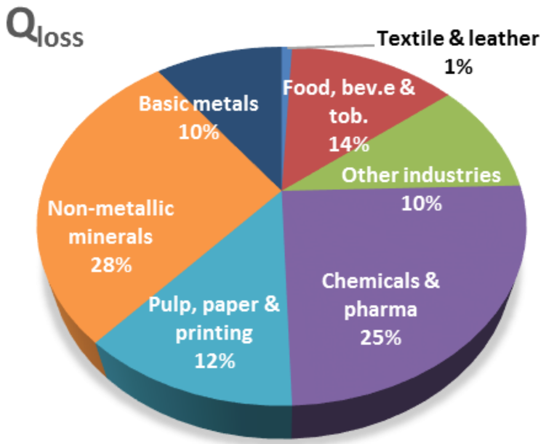
The flow of exergy for process heat through ind. sectors (all values in TJ)

Results

Energy and exergy efficiency improvement potential



The flow of energy for process heat through ind. sectors (all values in TJ)

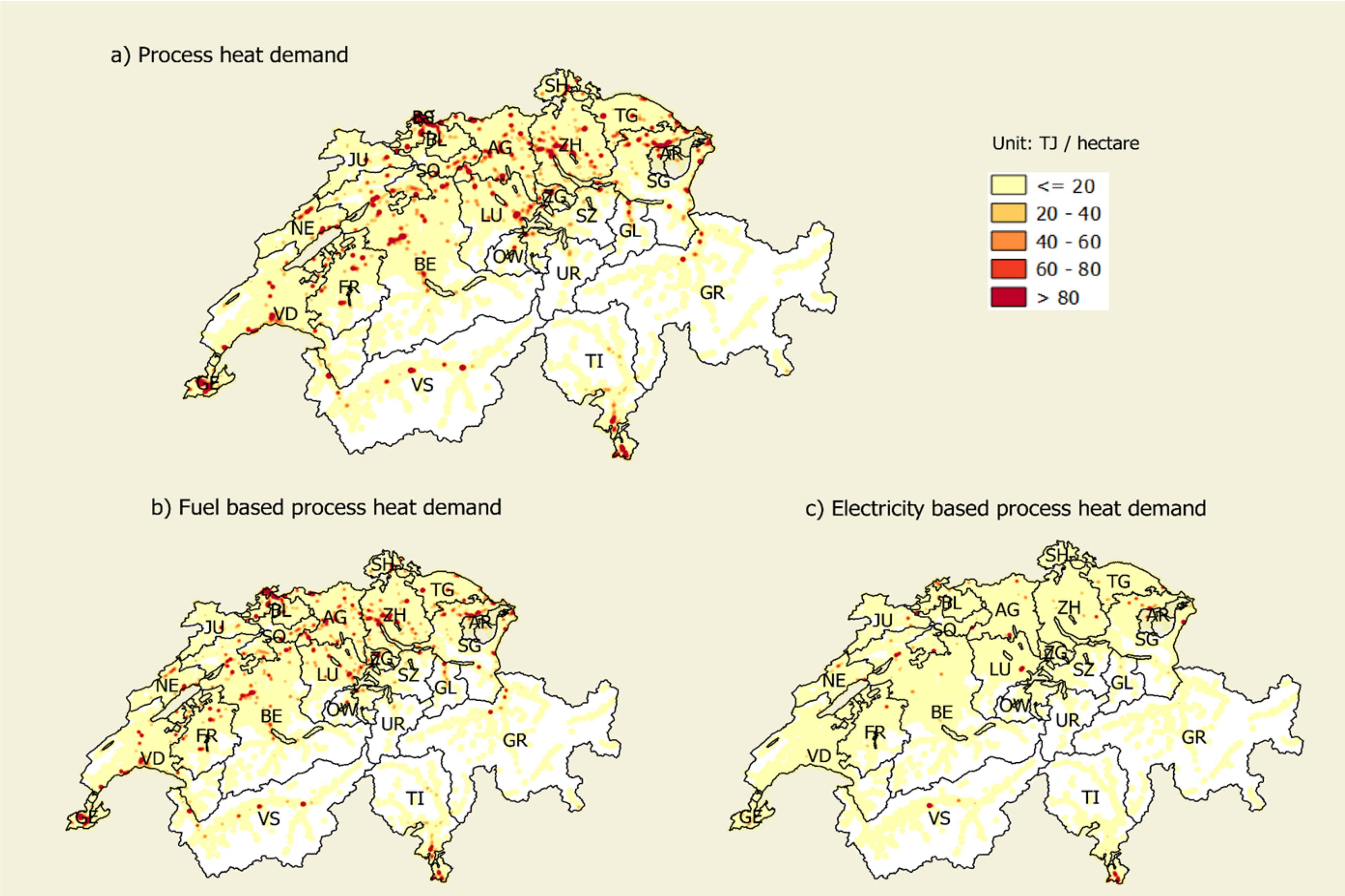


60% in the form of exhausts and effluents → ~14 PJ

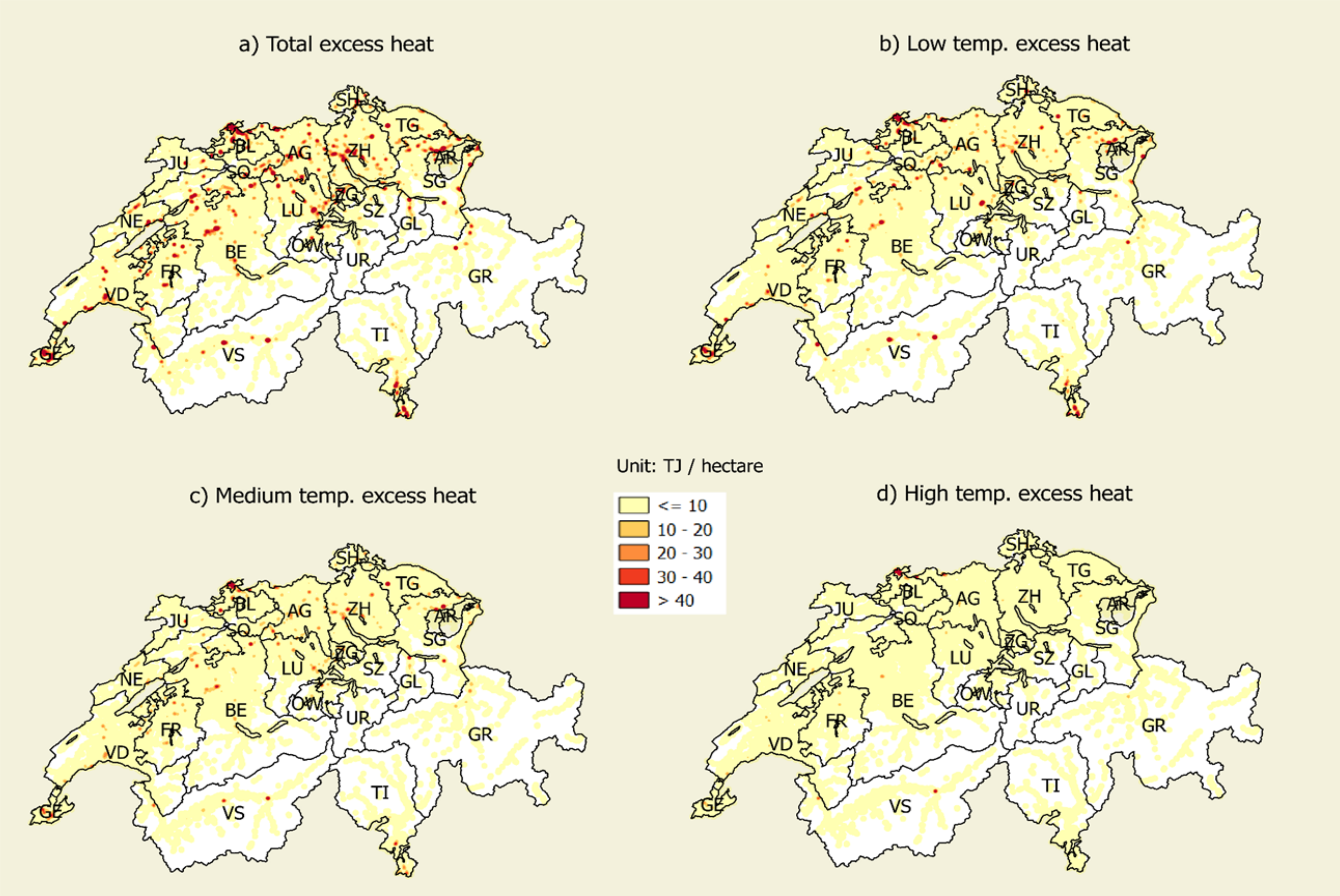
References:

C. Forman, I.K. Muritala, R. Pardemann, B. Meyer, Estimating the global waste heat potential, Renew. Sustain. Energy Rev. 57 (2016) 1568–1579. doi:10.1016/j.rser.2015.12.192.

Results – Process heatmaps of Swiss industry



Results – Excess heatmaps of Swiss industry



Conclusions

- Overall mean energy efficiency of the Swiss industrial sector =61%
- Overall mean exergy efficiency of the Swiss industrial sector =27%

- Exergy destruction → most in textile, food and beverage and *other* industries.
- One of the most energy and exergy efficient sectors → Basic metal industry

- Excess heat recovery potential → 14 PJ (12% or 24% of total final energy or process heat demand respectively).
- Comparable to the estimate given by Eicher+Pauli AG (2014) for Swiss industry i.e. ~13 PJ.

- The clusters with the amounts of excess heat beyond 30 TJ/hectare → densely located in Basel-Stadt (BS), Geneva (GE), Aargau (AG) and Zurich (ZH) regions.

- Large potential for district heating networks and heat cascading among different industries can be realized in these regions.

THANK YOU!!!

BACKUP SLIDES

Input data and methods

Energetic and exergetic assessment

$$Ex_{out} = (1 - T_o / T_P) Q_{out}$$

where:

T_o = Reference state temperature

T_P = Mean process temperature

$$Ex_{loss} = (1 - T_o / T_L) Q_{loss}$$

where:

T_L = Mean heat loss temperature

Reference state:

15°C, 1 atm

Input data and methods

Energetic and exergetic assessment

$$\text{Energy eff.} = \text{Usef. en. from the proc.} / \text{Total energy input}$$

$$\eta_e = Q_{out} / W$$ *(electric heating)*

$$\eta_f = Q_{out} / \sum m_f H_f$$ *(thermal heating)*

where:

W = Workdone on the system

m_f = Amount of fuel ‘f’

H_f = Calorific value of fuel ‘f’

$$\text{Exergy eff.} = \text{Usef. ex. from the proc.} / \text{Total exergy input}$$

$$\epsilon_e = (1 - T_o / T_P) Q_{out} / W$$ *(electric heating)*

$$\epsilon_f = (1 - T_o / T_P) Q_{out} / \sum m_f H_f \boldsymbol{\gamma_f}$$ *(thermal heating)*

$$\boldsymbol{\epsilon = (1 - T_o / T_P) \eta}$$

where:

$\boldsymbol{\gamma}_f$ = Exergy grade function of fuel ‘f’ (taken as 1 in this analysis)

Input data and methods

Sample calculations

$$\epsilon=(1-T_o/T_P)\eta$$

For Basic Metal Industry

Electric process heat calculations

Low, T_p = 47 + 273 = 320 K

$$\epsilon=(1-288/320)\times1=10\%$$

Medium, T_p = 141 + 273 = 414 K

$$\epsilon=(1-288/414)\times0.9=27\%$$

High, T_p = 1060 + 273 = 723 K

$$\epsilon=(1-288/1333)\times0.7=55\%$$

Fuel process heat calculations

Low, T_p = 47 + 273 = 320 K

$$\epsilon=(1-288/320)\times0.65=6\%$$

Medium, T_p = 141 + 273 = 414 K

$$\epsilon=(1-288/414)\times0.6=18\%$$

High, T_p = 1060 + 273 = 723 K

$$\epsilon=(1-288/1333)\times0.5=39\%$$

Input data and methods

Sample calculations

For Basic Metal Industry

Mean electric process heat efficiencies

Energy:

$$\eta e = Elec.\ used\ breakdown \times Energy\ eff.$$

$$\eta e = (0.17 \times 1) + (0.01 \times 0.9) + (0.82 \times 0.7)$$

$$\eta e = 75\%$$

Exergy:

$$\epsilon e = Elec.\ used\ breakdown \times Exergy.\ eff.$$

Mean fuel process heat efficiencies

Energy:

$$\eta f = Fuel\ used\ breakdown \times Energy\ eff.$$

$$\eta f = (0.25 \times 0.65) + (0.08 \times 0.6) + (0.67 \times 0.5)$$

$$\eta f = 55\%$$

Exergy:

$$\epsilon f = Fuel\ used\ breakdown \times Exergy.\ eff.$$

Input data and methods

Sample calculations

For Basic Metal Industry

Mean process heat efficiency of the basic metal sector

Energy:

$$\eta = (els \times \eta e) + (fls \times \eta f)$$

$$\eta = (0.63 \times 75) + (0.37 \times 55)$$

$$\boldsymbol{\eta = 68\%}$$

Exergy:

$$\epsilon = (els \times \epsilon e) + (fls \times \epsilon f)$$

$$\epsilon = (0.63 \times 47) + (0.37 \times 29)$$

$$\boldsymbol{\epsilon = 40\%}$$

where:

els = share of electric heating in total process heat demand

fls = share of electric heating in total process heat demand

Both els and fls are determined based on the information provided by Swiss Federal Office of Energy (SFOE)

Results – Swiss excess heat activity map