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Excess heat recovery: An invisible energy resource for the Swiss industry sector

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HIGHLIGHTS

- The mean exergy efficiency of the Swiss industry sector is estimated to be 27%.
- The mean energy efficiency of the Swiss industry sector is estimated to be 61%.
- Energy efficiency cost curves are developed for excess heat recovery in industry.
- The annual economic thermal energy saving potential is estimated at 14 PJ.
- New steam gen. technologies could provide 30–40% of the Swiss ind.'s steam demand.

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ABSTRACT

Typically, 70% of the total final energy demand in the industry sector is used for process heat. A substantial share of this energy could be provided by excess heat recovery. This study evaluates the techno-economic excess heat recovery potential in the Swiss industry through exergy and energy analysis and provides an overview of the spatial distribution of the potential by temperature level. The specific costs and payback periods of excess heat recovery are analyzed by conventional and new measures, as well as the overall costs of sector-wide excess heat recovery. The overall mean energy and exergy efficiencies of the Swiss industry sector are estimated to be 61% and 27%, respectively. The total amount of potentially recoverable excess heat is estimated at 14 PJ per year, i.e. 12% of the total final energy and 24% of the total process heat demand of Swiss industry in 2016. However, the economic potential amounts to only 5% and 10% if a payback period of 3 and 4 years is assumed, respectively. Long payback times of heat recovery measures and a high percentage of low-quality and small heat streams were the most important barriers to energy efficiency improvement in Swiss industry. Furthermore, 30–40% of the steam demand in Swiss industry could be provided from excess heat in an economically viable manner, if all excess heat available at temperatures below 80 °C was utilized for steam generation using low pressure evaporation, vapor compression, and high temperature heat pump techniques. The results and the data provided in this study can be adapted to other regions of the world and can serve as a base for conducting more comprehensive analyses and formulating more effective policies.

1. Introduction

1.1. Background

The demand for process heat typically accounts for 70% of the total final energy demand in industry [1]. A significant amount of heat leaves the system through the walls of heat generation and transfer devices and via stacks, exhausts, and effluents. These heat streams are considered to be excess heat. A part of this heat can be recovered and utilized for a number of applications in order to increase process efficiency [2]. In this study, waste heat is defined as the part of excess heat that is lost to the surroundings of a system and cannot be recovered.

Depending on various factors including industry characteristics, fuel inputs, and operational practices, industrial excess heat accounts for 10 to 50% of the total thermal energy demand in industry across different countries. This can be a valuable energy resource if it is managed well

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Nomenclature

ANF	annuity factor
B_y	annual benefits of the measure (CHF)
$C_{spec,y}$	specific costs of measure y (CHF/GJ)
$C_{spec,CO2,y}$	CO_2 abatement costs of measure y (CHF/tCO_2)
CA_y	annual potential CO_2 savings by measure y (tCO_2)
CF_t	annual cash flow for the year t
COP	coefficient of performance
El_c	electricity demand by compressor (J)
El_{HP}	electricity demand by heat pump (J)
El_p	electricity demand by pump (J)
El_t	total electricity consumption (TJ)
Ex_{acc}	exergy accumulation (TJ)
Ex_{des}	exergy destruction (TJ)
Ex_{in}	exergy input (TJ)
Ex_k	exergy of heat (TJ)
Ex_{loss}	exergy loss (TJ)
Ex_{out}	exergy output (TJ)
EF_f	emission factor of fuel f (tCO_2/TJ)
ES_y	annual potential final energy savings by measure y (TJ/yr)
ex	specific exergy (J/kg)
ex_{CH}	specific chemical exergy (J/kg)
ex_f	specific chemical exergy of fuel (J/kg)
FlS_y	annual potential thermal energy savings by measure y (TJ/yr)
H_f	calorific value of fuel f (TJ/kt)
h	specific enthalpy (J/kg)
h_{cd}	specific enthalpy of steam at compressor discharge (J/kg)
h_{ci}	specific enthalpy of steam at compressor inlet (J/kg)
h_o	specific enthalpy at reference state (J/kg)
h_s	specific enthalpy of steam at final state (J/kg)
h_w	specific enthalpy of water at initial state (J/kg)
I_y	initial investment (CHF)
L_y	lifetime of measure y (years)
m_f	amount of fuel f (kt)
m_s	mass of steam (kg)
m_w	amount of water (kg)
$\dot{m}$	mass flowrate of steam (kg/h)
N	number of compressor stages
N_h	number of hours of steam production
NPV_y	net present value of measure y (CHF)
NE_H	number of employees per hectare
NE_S	total number of employees in a sector
$O\&M_y$	annual operations and maintenance costs of measure y (CHF)
P_{CO2}	CO_2 price in year t (CHF/tCO_2)
P_d	pressure of water at pump discharge (Pa)
P_E	weighted average thermal energy price in year t (CHF/GJ)
P_i	pressure of water at pump inlet (Pa)
PBT_y	payback time of measure y (years)
Q_{acc}	energy accumulation (TJ)
Q_h	theoretical thermal energy demand to produce a unit of steam (TJ/kg)
Q_{in}	energy/process heat input (TJ)
$Q_{in,S}$	process heat demand of a sector S (TJ)
Q_k	energy of thermal stream k (TJ)
Q_{loss}	energy loss/excess heat (TJ)
$Q_{loss,H}$	excess heat per hectare (TJ)
Q_{out}	energy output (TJ)
r	real discount rate
s	specific entropy (J/kg K)
s_o	specific entropy at reference state (J/kg K)
T_k	temperature of thermal stream k (K)
T_L	temperature of lost stream (K)
T_o	reference temperature (K)
T_P	mean process temperature (K)
t	year
W	work done on the system (TJ)
W_f	share of fuel f in the total fuel demand (%)

Greek letters

ϵ	exergy efficiency (%)
ϵ_e	electrical exergy efficiency (%)
ϵ_f	fuel exergy efficiency (%)
η	energy efficiency (%)
η_c	compressor isentropic efficiency (%)
η_e	electrical energy efficiency (%)
η_f	fuel energy efficiency (%)
η_p	pump efficiency (%)
η_S	energy efficiency of a sector S (%)
γ_f	exergy grade function
ρ_w	density of water (kg/m^3)

[3]. Excess heat recovery can be used to produce process steam, other types of process heat, district heat, and electricity. However, challenges associated with harnessing excess heat are its occurrence in different forms, non-continuous availability, insufficient temperature levels, the need for heat transfer (i.e. conduction, convection or radiation), and the distance between excess heat source and sink [4]. These technical aspects, among others, influence the economic viability and the investment risks [5].

Industrial excess heat is considered an invisible source [3] and is often neglected by companies due to the aforementioned challenges. However, interest in excess heat recovery has grown in recent years, necessitating more accurate estimates of the resource potential [6]. Excess heat recovery can help Switzerland to achieve its policy targets related to energy and climate. According to the Swiss Energy Strategy 2050, Switzerland aims to reduce its final energy demand by 35% and 46% in 2035 and 2050, respectively, compared to the base year 2010 under its new energy policy (NEP) [7]. Swiss industry, which is responsible for approximately 20% of the country's total final energy demand [8], can contribute significantly to the achievement of these goals by employing best practices including excess heat recovery and utilization within the sector's most energy intensive processes.

1.2. Applied methods for industrial excess heat estimation

There is very large potential for industrial excess heat recovery worldwide [4,9] that can at least partly be used to substitute the process heat demand in industrial sectors. Stakeholders and policymakers require accurate estimates of excess heat recovery potential as an input for their environmental strategies. Several methods are available to estimate the recovery potential at sectoral level [10]. These methods include:

1. Bottom-up surveys: collecting excess heat information from individual industrial plants via surveys and/or mandatory reports. For example, a study by Norwegian state company 'Enova' in 2009 [11] invited 72 companies representing 63% of the industrial final energy demand in Norway to fill out a questionnaire with detailed information about their excess heat resources. They estimated a 25% thermal energy savings potential in Norwegian industry. Similarly, Lopez et al. [12] used the data of 290 companies provided by the Basque government's energy agency to estimate the industrial excess heat potential at approx. 40% of the final energy demand in the Basque country (Spain).