Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Federal Department of the Environment, Transport, Energy and Communications DETEC

Swiss Federal Office of Energy SFOE
Energy Research and Cleantech

SWEET Call 1-2020: DeCarbCH

Deliverable report

Deliverable n°	D4.3.2
Deliverable name	Aggregated sectorial energy profiles for studied industrial sectors
Authors The authors bear the entire responsibility for the content of this report and for the conclusions drawn therefrom.	Benjamin H. Y., Ong, HSLU-TEVT, **benjamin.ong@hslu.ch** Navdeep Bhadbhade, UNIGE-EE, HSLU-TEVT, **navdeep.bhadbhade@hslu.ch** Donald G. Olsen, HSLU-TEVT, **donald.olsen@hslu.ch** Beat, Wellig, HSLU-TEVT, **beat.wellig@hslu.ch**
Delivery date	December 2023

Table of contents

sweet swiss energy research for the energy transition

Summary

Process heat electrification, energy efficiency improvement, and renewable technology integration are the most effective ways of achieving industrial decarbonization. However, precise knowledge of thermal energy demands and excess heat sources along with the corresponding temperature levels is imperative for the most optimum integration of aforementioned process. This report presents a methodology for constructing sector-wide composite curves to rigorously characterize the thermal energy demands and the available excess heat sources for the Swiss industry subsectors. The sector-wide energy demand profiles derived from this methodology offer valuable insights into the quantity of heat demand and the quality of the available excess heat. Thus, enabling the implementation of energy efficiency and decarbonization technologies such as heat pumps, and renewable heating and cooling technologies. The sector-wide energy demand profiles are built using Pinch Analyses and top-down statistical approach, thus ensuring complete sectoral coverage. The application of this approach is demonstrated using Swiss meat and chocolate industry subsectors as case studies. Based on the sector-wide energy demand profiles developed for meat and chocolate production, heat pump integration and solar thermal integration can potentially reduce about 80% of process heat demand, for both sectors.

1 Introduction

Meeting Switzerland's net zero carbon objective by 2050 requires a substantial transformation, with targets set to reduce 29% of total final energy use and 46% of fossil energy use within the next three decades [1]. Among the three sectors (household, industry, and service), the industrial sector has very specific, widely varying requirements regarding their thermal energy demand profiles, particularly in terms of demand quality or the temperature levels. The industrial sector is responsible for 18.1% of total energy consumption in Switzerland, with process heat alone accounts for 56% of the consumption [2]. To achieve the goals of the Swiss energy strategy 2050, CO_2 emissions of the industry sector must be reduced while enhancing economic competitiveness. Given that energy consumption is the primary source of CO_2 emissions, prioritizing energy efficiency is crucial, as it is the most cost-effective and environmentally friendly "energy resource" available. This approach enables meeting growing energy demands, enhancing competitiveness, and facilitating the integration of limited renewable energy sources that are available in Switzerland. However, one of the market failures and implementation barriers preventing the realization of energy efficiency measures is the lack of data on energy use and systematic evaluations [3].

The aim of Work Package (WP) 4 is to enhance the understanding of the energy demands from industry to facilitate successful integration of energy efficiency measures, and renewables within the process energy supply. The WP adopts Process Integration (PI) methodology to characterize process energy demands, aiming at both company and sectorial levels. Determining industrial energy demand profiles (quantity, quality, temporal), based on real data analysed using state-of-the-art PI techniques, is a crucial precursor to supporting integration of renewable heating and cooling (henceforth termed “renewables integration”), and excess heat use (e.g. in thermal grids), as they form the basis for accurate characterization and eventual matching of demands with suitable renewables technologies emerging and currently on the market.

In Task 4.3, the aim is to construct exemplary energy profiles (GCCs) that represent the energetic demands and excess heat at company level for various production classes in Switzerland, using statistical analysis and to aggregate profiles into sector-wide energy profiles. The latter is to aid understanding the energetic demands of the various industry sectors. This task builds on work carried out in Task 4.1 where a database for Pinch Analysis (PA) was built.

To develop effective strategies for CO_2 emissions reduction through the implementation of energy-efficient technologies and renewable technologies, it is crucial to understand and identify the actual process heat demands of different industrial sectors at required temperature levels. This is particularly important since most renewable energy sources, (geothermal and environmental heat, non-concentrating solar thermal) have limitation on the maximum temperature they can provide, with exceptions to biomass, power-to-X technologies. However, Switzerland has limited potential for sustainable biomass.

The existing literature related to the quantification of process heat from the industrial sectors can be categorized as either bottom-up or top-down [4] based on the data used for estimation.. At the system level, Zuberi et al. [5] analysed the potentials for energy efficiency improvements and CO_2 emission reductions for the cement sector in Switzerland. In this study, the specific energy consumption (SEC) of the sector is derived with a bottom-up model that is process-specific, and cost-effective energy efficiency improvement are estimated based on process-specific technology replacement. Similar methodology was used to study other sectors in Switzerland, e.g. electric motor systems, chemicals/pharmaceuticals sector [6], and metals sector [7], and food and beverage sector [8]. While these studies present the energy efficiency improvement potentials of the sectors at the process level, the understanding of process energy demand by temperature levels, the energy efficiency at a system level can be further improved.

To date, there is a limited detailed and comprehensive industrial process heat data, by sector, and not available in Switzerland [9], necessary to estimate the potential integration of energy efficiency measures and renewable energy sources in the industrial sector. Enova [10] in Norway conducted a bottom-up survey by collecting excess heat data from individual industrial plants through detailed questionnaire or mandatory reports. The data for excess heat are categorized into different temperature levels (25 – 40 °C, 40 – 60 °C, 60 – 140 °C, and > 140 °C). However, the Enova study is limited in their assessment for temperature above 140 °C. Persson et al. [11] estimated the industrial excess heat for the EU through a top-down estimation from the carbon dioxide emission data. The excess heat was back calculated with emission factors and efficiency based on the fuel used. McKenna and Norman [12] estimated the spatial industrial heat loads in the UK using a top-down approach based on the EU Emissions Trading Scheme, supplemented by the SEC and the capacities of the sectors. The work categorised the industrial heat to five temperature bands, where the range of the bands is up to 500 °C. The heat recovery and waste heat potentials in their work are critique to underestimate the heat recovery potential for boilers and steam systems and in several sectors due to the broad range of temperature bands. Hammon and Norman [13] built on the work carried out by Mckenna and Norman [12] to assess identified heat recovery opportunities using different energy efficiency measures (EEMs) based on the temperature bands. The temperature bands were broken down to a smaller range but, were kept to the range of temperature bands from McKenna and Norman due to the uncertainties in estimating the heat surplus. Papapetrou et al. [14] adopted the methodology for EU and for the year 2015, where some of their estimations differ from other studies due to differences in methodologies and assumptions. Bühler et al. [15] modeled the sectoral profiles for excess heat availability in the Danish industry using the distribution of fuels and temperature levels for different process of 22 sectors, using exergy and energy analysis. In Switzerland, efforts to estimate industrial excess heat has been conducted for the different sectors. Zuberi et al. [9] analysed the Swiss sectors using exergy analysis in the design and analysis of energy systems. The temperature levels are grouped into three temperature levels based on Elson et al. [16].

Cornelis and Van Bael [17] applied the different methods categorized by Brückner et al. [4] to validate the estimation of industrial waste heat in Europe: 1) top-down estimation, 2) bottom-up estimation, and 3) combined bottom-up and top-down estimation. According to their result, top-down estimation has difference of a factor of 10 with the industrial data. Methods 2 and 3 are different in a factor of 2 to 3. The two main reasons of the high level inaccuracy are because waste heat flows and temperatures are estimated as they are not monitored and the key figures are derived for a specific sample of companies in a particular country and are not representative of the studied countries. Dénarié et al. [18] applied a multi-criteria analysis to five different methodologies (3 top-down and 2 bottom-up) and identified that the different methods led to different results based on the method and the input data. In the study conducted by Miró et al. (2015) to collect data from different literature on industrial waste heat in the EU, they concluded that due to the lack of specifications on methodologies and boundary conditions on the data collection for the industrial waste heat, further research is needed to analyse the data reliability. In addition, some data are unreliable and inconsistent because of the inconsistency in reporting or economic status [19].

The aim of this report is to address these limitations. This paper utilises the concept of Process Integration, a holistic approach to design operation which emphasises the unity of the process [20]. PI tools and methods have been used to analyse the energy use and other resources in the industrial sector and to identify ways to increase productivity, decrease costs and address environmental issues. Within PI, Pinch Analysis, is a method for reducing energy use and emissions in industrial plants and has been successfully applied across many industries. PA leverages graphical representations such as composite curves (CCs), shifted CCs, and the Grand Composite Curves to analyse heat integration problems, providing insights into the heat supply and demand of a process in terms of temperature and enthalpy. By using PA methodology, the collected data are usually within a specified boundary conditions and reporting standard. The present work thus leverages the insights provided by the PAs by developing a database to record available PAs that were conducted in Switzerland [21] and utilising the Site Composite Curves [22] to estimate heat demands and surplus heat availability at the sector-wide level (excess heat). Unlike previous studies relying on published Best Available Technology Reference documents [23] or literature data, this approach utilises Swiss data to provide a more precise representation of the industrial sector. By generating sector-wide profiles, this methodology enhances the accuracy and quality of thermal energy demand estimations, facilitating the assessment of energy efficiency measures, energy conversion units, and potential renewable energy replacements within the industry.

2 Method

Figure 1 shows the key steps of generating the sector-wide energy demand profile. The methodology utilizes a Pinch Analysis database specifically built for Switzerland, and the data are subsequently scaled to generate the sector-wide energy demand profiles.

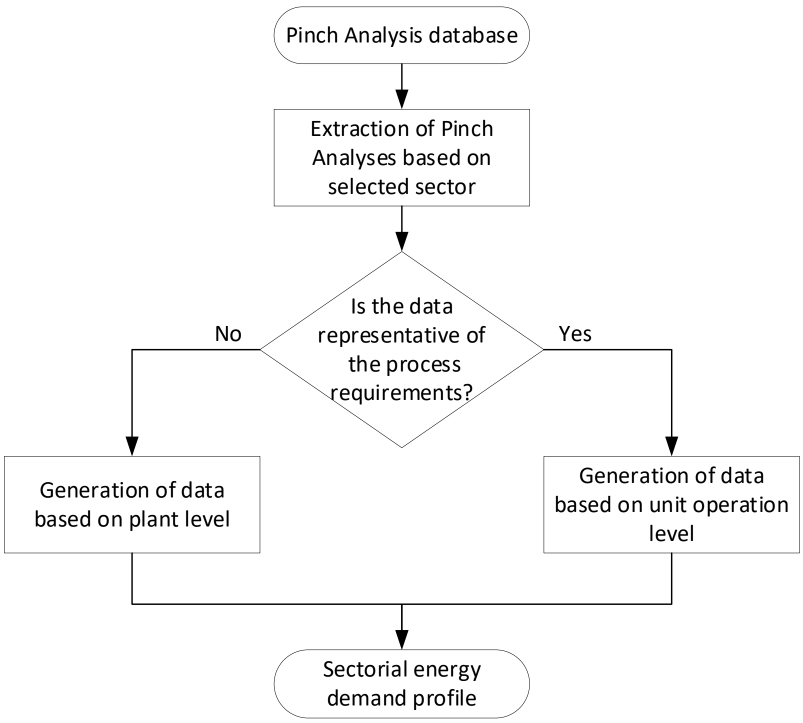


Figure 1: Overall methodology for sector profile generation

The methodology employs two methods for generating the sector-wide energy demand profiles, depending on the level of detail in the PA modeling. PA encompasses three levels of modeling depth: "black-box," "grey-box," and "white-box," which represent different levels of detail in the data extraction process [24]. For white- and grey-box modelling, the data are usually representative of the process requirements.

White-box modeling involves a complete understanding of thermal process requirements, with the process requirements defined as accurately as possible. Grey-box modeling considers heat transfer involving utilities and is often used as a replacement for white-box modeling. It focuses on processes with limited process-to-process heat exchange but significant utility usage. In these cases, the process streams that are heated or cooled by utility are considered; however, the process–process heat exchange matches are not considered. In this way, the process/utility interface can be optimized in a site-wide area instead of internal optimization within the process. Modelling according to the grey box has the advantage, that critical parts of the process remain unchanged and the energy optimisation (if measures are found at all) can be implemented with a high degree of probability. At the same time, this reduces the optimisation potential. Black-box PA refers to cases where the process is unknown, energetically irrelevant, economically unchangeable, or where data anonymization is necessary due to process confidentiality.

Process Integration is a holistic approach to design operation which emphasises the unity of the process [1]. PI tools and methods have been used to analyse the use of energy and other resources in the multiple industries and to identify ways to increase productivity, decrease costs and address environmental issues. PI, which includes PA, is a method to reduce energy use and emissions in industrial plants and has been successfully applied across many industries. It achieves this by providing a framework for systematic and rigorous systems analysis to understand the intrinsic thermodynamic requirements of industrial production systems with a special emphasis on the efficient use of energy and water, and the minimisation of environmental impacts.

2.1 Database

PA provides important insights into the absolute energy saving potential of an overall system and with which measures this can be correctly exploited, e.g. heat recovery, optimisation of the energy supply, use of energy conversion systems (e.g. heat pumps), and thermal energy storage. This section introduces the structure of the database built to record the PA information collected. The Swiss Federal of Energy (SFOE) has been promoting the performance of Pinch Analyses in the Swiss industry for years. The PA database serves as a repository for recording the collected PA information. Microsoft Access, an information management tool, is used to build the database. The database was built in four steps: (1) the classification of the processes (2) the energy demands of the processes and their information (process requirements categorised in unit operations, scheduling information), (3) the current status of the processes focusing on utilities, and (4) the suggested and implemented EEMs. Further information of the database is available in D4.1.1.

To calculate energy consumption in the industry, final energy consumption is modeled as precisely as possible for individual sub-sector groups using the NOGA code. The NOGA code, a six-digit code derived from the Statistical Classification of Economic Activities in the European Community, was developed by the Federal Statistical Office [25]. Table 1 provides an overview of the sectors in the Swiss industry and their associated NOGA codes.

However, some sectors have a high variability of products and the associated production processes. For example, in a subdivision of the Food & Beverage sector into subsectors such as dairy, meat, beverage, etc., the major products within the sector will be further defined into subsectors. The particularities and/or important activities of the have been incorporated in the last two positions of the six-digit code.

Table 1: Sectors in the Swiss industry and the associated NOGA codes.

Sectors	NOGA 2008
Food and Beverage	10-12
Textiles	13-15
Paper	17-18
Chemicals	20-21
Minerals	23
Metals	24
Metal products	25
Electrical engineering	26-27
Machinery	28-30
Water/Waste	36-39
Construction	41-43
Other sectors	05-09/16/22/31-33

2.2 Sector-wide energy profile

The Site Composite Curves concept [26] is used to provide the annual temperature-enthalpy picture of the whole sector. In this work, the generation of the sector-wide profiles is carried out based on two different types of data and process.

2.2.1 Generation of sector-wide profile at plant level

When the black-box data is available, the construction of the sector-wide profile is conducted at plant level. On the other hand, the sector-wide energy profile is also generated using this method when the processes within the sector are standardised or are similar, e.g. the food industry due to regulatory aspects, without different options of technologies for the processes. The steps for generating the profiles at plant level are presented in Figure 2.

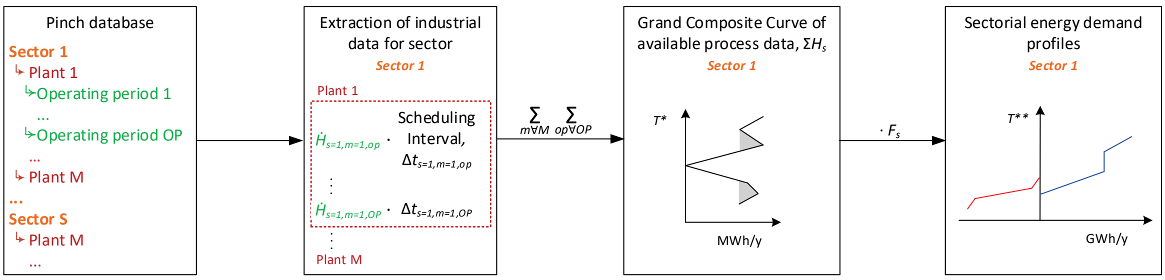


Figure 2: Method to create a sector-wide profile using plant data.

Extraction of industrial data: Based on the NOGA classification, the available energy targets for individual processes within the desired sector are extracted from the database. In the Swiss PAs, the data are divided into multiple periods, *op*, (e.g. winter and summer or day and night, or even multiple products). Based on the standardised data basis (a GCC per period), the net heating and cooling of the GCC, $\dot{H}$, are multiplied by the corresponding scheduling interval, Δt, and a GCC with the annual energy quantities/enthalpies are obtained for that period, as shown in Eq.(1).

$$H_{s,m,op} = \dot{H}_{s,m,op} \cdot \Delta t_{s,m,op} \qquad (1)$$

where s is the sector, *m* is the plant, and *op* is for operating periods. This procedure is applied for each period. Subsequently, the GCCs of the individual periods are summed into a plant profile, Eq(2).

$$H_{s,m} = \sum_{op \forall OP} H_{s,m,op} \qquad OP = \{1, \dots, op, \dots NOP\} \qquad (2)$$

The construction simply involves the generation of CCs from the heat source and the heat sink elements of the GCCs [11]. Starting from the Pinch point, all energy quantities/enthalpies per temperature level are added. This results in a plant profile that represents the annual energy quantities per temperature level. This procedure is carried out for all existing and available industrial plants in the studied sector or subsector and one profile per industrial plant is obtained.

Energy profiles of the available data: These analysed industrial plant profiles are merged again in the next step by applying the same procedure for the creation of the plant profiles. The result of this (intermediate) step is aggregated profiles of the analysed plant profile from the existing (available data) plants which serves as a basis for scaling to the sector profile, Eq(3).

$$H_{s_{Analysed}} = \sum_{m \forall M} H_{s,m} \qquad M = \{1, \dots, m, \dots NM\} \tag{3}$$

Scaling up for sectorial profiles: The scaling for this work can be done in one of two ways, either through energy consumption or through annual production. Eq(4) shows the scaling factor calculation according to the ratio of energy consumption, F_{S_E}, (fuel or total consumption) of the actual energy consumption of the sector, E_{Sector} to the analysed plants, $E_{Analysed}$.

$$F_{S_E} = \frac{E_{Sector}}{E_{Analysed}} \tag{4}$$

$E_{Analysed}$ can be identified from the GCC, or the data can also be found in the utility database, as mentioned in Deliverable D4.1.1. The E_{Sector} can be found in the EnAW (Energy Agency of the Swiss Private Sector) database or the energy consumption report (Sauvin et al., 2018).

Depending on data availability, scaling can also be based on production volumes, $F_{S_{AP}}$. Similar to the scaling by energy consumption, the scaling is based on the ratio of the production volume of the sector, AP_{Sector}, to the analysed plants, $AP_{Analysed}$, as shown in Eq(5).

$$F_{S_{AP}} = \frac{AP_{Sector}}{AP_{Analysed}} \tag{5}$$

The production quantities of the individual companies can be found in the database. The production volumes of the entire sector can also be found on the websites of the sector representatives or in statistical data. Eq(6) scales the data to the sector-wide energy demand profile:

$$H_{S_{overall}} = H_{S_{Analysed}} \cdot F_S \tag{6}$$

2.2.2 Generation of sector-wide profile based on unit operations

Based on the white- or grey-box modelling, this section aggregates the data from individual process steps, unit operations. Figure 3 represents the method to create the sector-wide profile using unit operation data.

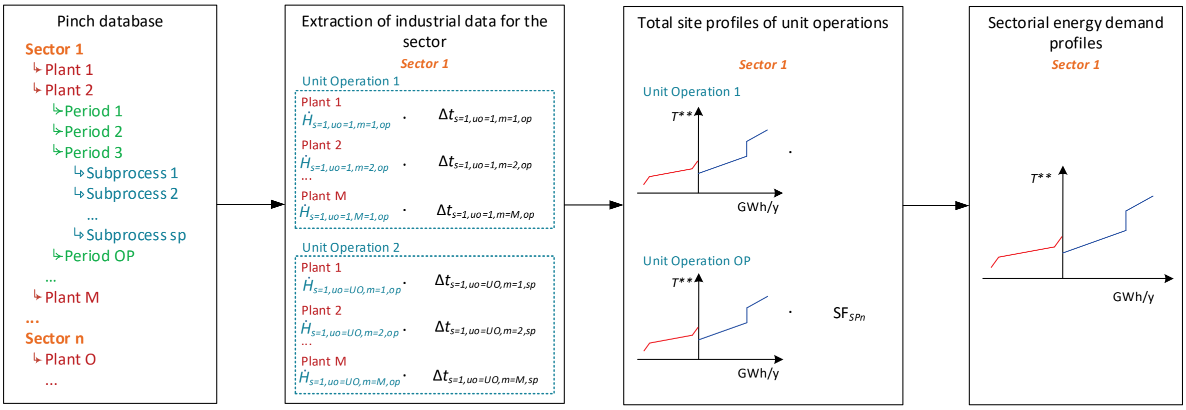


Figure 3: Method to create sector-wide profile using at unit operation level.

Extraction of industrial data: Based on the sub-sector selected, the data for each unit operations, *sp*, within the industrial plants are extracted from the Pinch database. Based on the standardised data basis (a GCC per unit operation), $\dot{H}_{s,m,op,sp}$, the enthalpy rates of the GCC are multiplied by the corresponding scheduling interval, and a GCC with the annual energy quantities/enthalpies is obtained for that unit operation, Eq(7). This procedure is applied for each unit operation.

$$H_{s,uo,m,op} = \dot{H}_{s,uo,m,op} \cdot \Delta t_{s,uo,m,op} \qquad (7)$$

Total site profiles of unit operations: These analysed unit operations profiles are then used to construct a TSP of the unit operations, eq(8).

$$H_{s,uo} = \sum_{m \forall M} \sum_{op \forall OP} H_{s,uo,m,op} \qquad OP = \{1, \dots, op, \dots NOP\} \quad M = \{1, \dots, op, \dots NM\} \qquad (8)$$

The result of this intermediate step serves as a basis for scaling to the sector profile. Eq(9) shows the scaling factor calculation according to the ratio of the energy consumption of the subprocess, E_{SP} to the analysed energy consumption of the unit operation (fuel or total consumption) of the unit operation, $E_{AnalysedP}$. The TSP for the different unit operations within the sector is then added up to generate the sector-wide energy profile Eq(10).

$$F_{S_{UO}} = \frac{E_{UO}}{E_{Analysed}UO} \qquad (9)$$

$$H_{S_{Analysed}} = \sum_{uo \forall UO} H_{s,uo} \cdot F_{S_{UO}} \qquad UO = \{1, \dots, UO, \dots NUO\} \qquad (10)$$

2.3 Sector-wide profile

The result of the scaling is the sector profile. For the interpretation of the results, it is essential to note that the sectorial profile is derived from the GCCs under the assumption that all heat recovery potentials were (directly) exploited, as mentioned by Smith [11]. This means that the results show the minimum energy quantities for the heat source and heat sink. For batch processes, the indirect heat recovery between the individual periods is not taken into account. Figure 2 summarises the procedure for the generation of sector profiles.

3 Results and discussion

Following the method outlined in section 2, the current section presents the results in the form of case studies for two product groups from the Swiss food and beverage industry. The database created in this work is based on collected and compiled PAs in the Swiss industry performed in the past 15 years. In this effort, respective companies were contacted, and existing final reports and data related to PA were collected. Of the PAs conducted, documents from 104 PAs were collected or made available. While the process of building sector-wide heat demand profiles for the Swiss industry sectors is continuously evolving with the inclusion of various product groups and subsectors, product groups of meat processing and chocolate production are chosen to demonstrate the application of methodology developed in this work. The food and beverage (F&B) sector has the highest number of PAs collected so far in the Swiss industry. The Swiss F&B sector is responsible for 14% (22 PJ) total final energy demand of the Swiss industrial sector [27]. However, it should be noted that the sectorial profile is derived with the assumption that all heat recovery (direct) potentials were exploited, as mentioned by Smith [22]. This means that the results show the minimum energy quantities for the heat source and heat sink.

3.1 Meat processing and production subsector

The Swiss meat processing and production (13%) is the second largest energy-consuming product group in the F&B sector, with values estimated based on the Swiss Energy Agency [8]. In Switzerland, pork meat is the preferred meat product with 21.6 kg per capita, equivalent to 95.5% of the total pork processing and production [28]. The demand for white meats (poultry) has increased in the last few years poultry being the second highest consumed meat at 14.2 kg per capita and 11.4 kg per capita for beef.

This case study will be used to illustrate the scaling up based on the data from at plant level and estimation of sector-wide potentials for the integration of HPs and solar thermal (Section 2.2.1). Based on the database mentioned in Section 2.1, there are four meat processing and production industrial plants. Due to the confidentiality of the process data, only the energy data for one plant, industrial plant A is shared in Table 2. Industrial plant A has a total of 9 multi-periods. These periods are divided into summer, winter, transitional periods, productions, cleaning, and off-peak periods. Although the sector-wide profile presented in this work provides total annual heat sinks and sources, the methodology presented in section 2 also enables seasonal estimation of available heat sinks and sources.

Table 2: Energy targets of industrial plant A.

Period	Operating hours (h/y)	Hot utility (MWh/y)	Cold utility (MWh/y)
Production - Winter	442	792	1,011
Production - Transitional	1,214	1,662	2,776
Production – Summer	1,094	1,205	2,501
Cleaning – Winter	281	462	602
Cleaning – Transitional	773	944	1,656
Cleaning – Summer	696	664	1,491
Off-peak – Winter	685	543	747
Off-peak – Transitional	1,881	693	2,052
Off-peak – Summer	1,694	225	1,902

Based on the aggregated energy consumption of the four industrial plants, the scaling, based on the total energy consumption, is used. Using Eq. (1) and with the total energy consumption by the meat sector [23], the scaling ratio calculated is 1.35. The total energy consumption for the meat industry, in turn, is estimated based on the share of meat industry in the total final energy consumption of the food and beverage industry subsector provided EnAW database [29] and the total final energy consumption data for the food and beverage industry published by SFOE [30]. This means that the energy consumption data from the four plants included in the database covers approximately 74% of the meat processing and production subsector. Figure 4 presents the sector-wide meat processing and production sub-sector. A ΔT_{cont} of 5 °C for each stream, which has a $\Delta T_{min(global)}$ of 10 °C, where ΔT_{cont} is stream-specific contribution minimum temperature contribution [31] and $\Delta T_{min(global)}$ is the global process minimum temperature difference [26].

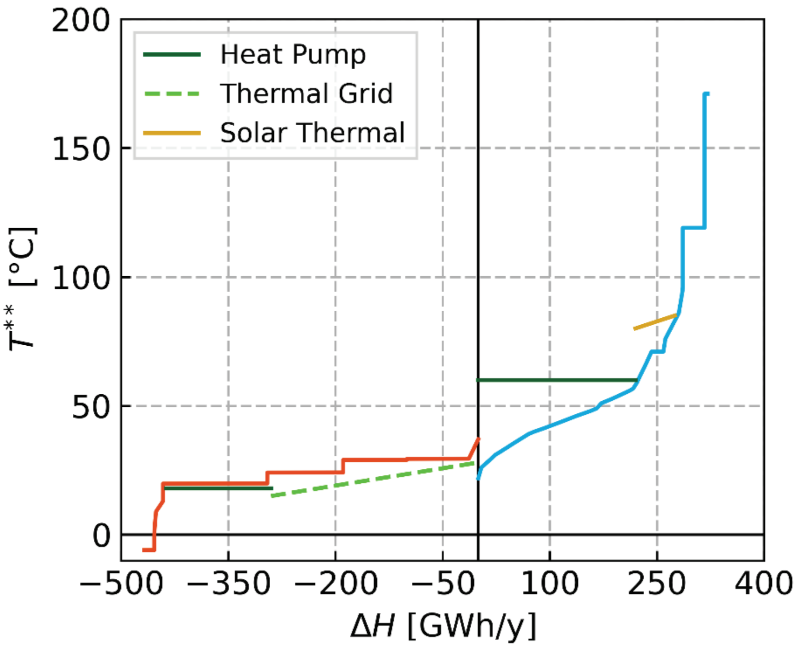


Figure 4: Sector-wide energy profile for the meat processing and production subsector.

In the study, the direct heat recovery potential in the meat sector is approximately 187 GWh/y. Figure 4 shows that the cold and hot utilities used in the meat sector are approximately 497 GWh/y and 187 GWh/y, respectively. The sector-wide profile thus provides an indicative assessment of the potential for different technologies, as shown in Table 3. The two plateaus in the heat sources are from two different technologies used for refrigeration.

Table 3: Integration potentials for various energy-efficient technologies in Swiss meat sector.

	Temperature level of	Target processes/unit operations	Technology	Potentials	
				Energy reduction (GWh/year)	Fuel related CO_2 abatement (kt/year)[1]
Heat sink	60 °C	Hot water preheat	Standard heat pump	147.0	66.2
	60 °C	Hot water preheat	Solar thermal	55	24.8
Heat source	30 °C to 50 °C	District heating network	Thermal grids for 5th generation DH	290	130.5[2]

[1]CO_2 abatement potentials are estimated using the typical emissions factor for food industry, with 75% natural gas.

[2]Although CO_2 abatement potential is estimated here based on the assumption that the excess heat is used to replace the natural gas, it should be noted that in reality this potential will vary.

Based on the sector-wide heat demand profile generated for the meat industry, heat pump can potentially supply almost 46% of the heating for the meat sector. This is assuming the heat pump is operating in a steady state. This potential is an estimate and can vary depending on temperature, application, and also scheduling. In terms of solar thermal, the temperature estimated for Switzerland is from 80 – 85 °C [32]. The estimated potential for solar thermal is at 18% of the hot utility. Lastly, the heat could be supplied to district heating. Based on the temperature level, it is possible to supply the heat to a fifth-generation district heating network, which has a supply temperature of 30 °C and returns at 15 °C [33]. As shown in the figure, this can replace 62% of the cold utility. However, these options are a quick possible snapshot of possible energy conversion units or renewable heating and cooling that can be applied to the sector.

3.2 Cocoa and chocolate production subsector

Switzerland processes 1% of the total global cocoa beans [34]. Switzerland is home to 16 chocolate manufacturers, where the major two manufacturers are Barry Callebaut and Lindt & Sprungli. Approximately 70% of Swiss chocolate sales are from export [35], where it accounts for 1.8% of the global chocolate processing. The cocoa and chocolate production energy consumption is estimated at 7% of the total F&B industrial sector.

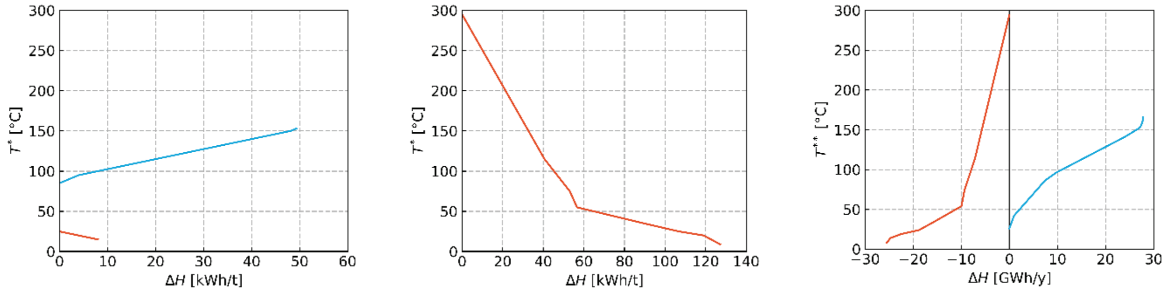
Based on the data analysed from the available Pinch reports of the chocolate production plants in Switzerland, thermal process energy demand amounts to 44% of the subsector's annual TFE demand. The breakdown of the thermal process energy demand for the subsector is presented in Table 4. Similar to the meat industry, the chocolate sector is also modelled with a grey-box modelling approach, where the critical parts of the process are unchanged. Therefore, only the process streams that are heated or cooled by utilities are considered. The share of the waste heat is in addition to the process heat.

[1] HP is assumed to have a COP of 3 and is operated with a temperature lift of 40K.

Table 4: Total process energy demand based on unit operations.

Unit operation	Share	Modeling
Process Heat		
Cleaning-in-Place	2%	White
Roasting	30%	Grey
Conching	23%	White/Grey
Drying	15%	Grey
Blending	0.5%	Grey
Tempering	8%	Grey
Moulding	2%	Grey
Debacterization	1.5%	Grey
Waste heat from		
Refrigeration	27%	Grey
Compressed air	6%	Grey

The chocolate production in Switzerland takes place via two main production routes namely, Whole beans roasting and 2) infrared-dried cocoa nibs roasting. The other unit operations remain the same. Figure 5 shows the specific GCC of two production routes for the roasting process used. These GCCs are the building blocks of the sectorial profile for the cocoa and chocolate industry. However, as there is limited information on the breakdown of each of the technology used in the Swiss chocolate industry, both technologies are assumed to contribute 50% to the energy demand of the roasting unit operation.



(a) (b) (c)

Figure 5: (a) GCC of specific whole cocoa bean roaster, (b) cocoa-nibs roaster, and (c) sector-wide roasting energy demand in the cocoa and chocolate subsector.

Figure 6 shows the sector-wide energy demand profile for the cocoa and chocolate production sub-sector developed based on the methodology explained in section 2 with ΔT_{cont} of 5 °C for each stream, which has a $\Delta T_{min(global)}$ of 10 °C. The available Pinch Analyses and the subsequent sectorial profile indicate overall sector-wide heat recovery of 26 MWh/y and heat sinks and sources of 118 and 172 MWh/y, respectively. The sectorial profile thus helps identify the potential for heat pump integration, solar thermal integration, thermal grids, and corresponding temperature levels. Table 5 presents the overall sector-wide potentials identified for Swiss cocoa and chocolate production. The sectorial profile indicates that heat pumps can be used to supply heat at 65 °C, which represents about 52% of total sector-wide heat sinks. Similarly, solar thermal integration can be used to supply about 27% of total sector-wide heat at the temperature of 80°C. Thus, HP integration along with the integration of solar thermal represents about 80% decarbonization[2] potential for the Swiss chocolate and cocoa production. It should however be noted that the HP integration potential estimated in this study refers only to currently commercially available standard technology options such as standard heat pumps and solar thermal (TRL>7).

[2] Decarbonization potential is estimated based on the current (2022) fuel mix and considering only scope 1 CO2 emissions.

Based on the sectorial profile, heat sources from the cocoa and chocolate industry are available in the temperature range of 30 °C to 50 °C. Some part of the available heat source (approx. 10% of the available sector-wide heat source) is valorized via HP[3] and used for process heating and the remaining heat (approx. 23% of the total available heat source) can be potentially utilized for 5th-generation district heating networks.

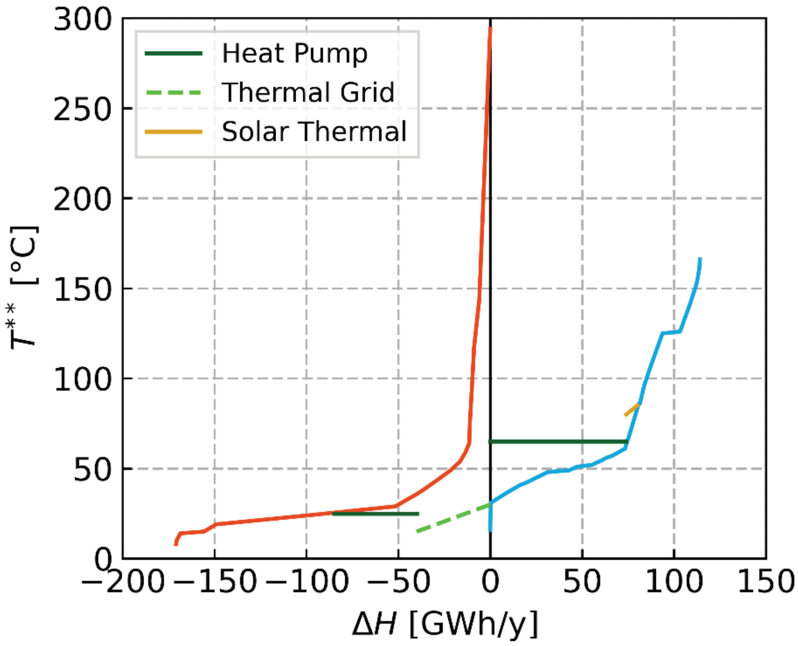


Figure 6: Sector-wide energy profile for the cocoa and chocolate production subsector.

Table 5: Integration potentials for various energy-efficient technologies in Swiss cocoa and chocolate production

	Temperature level of	Target processes/unit operations	Technology	Potentials	
				Energy reduction (GWh/year)	Fuel-related CO_2 abatement (kt/year)[1]
Heat sink	55 °C	Tracing circuits	Standard heat pump	74	32.7
	80°C	CIP	Solar thermal	6	2.6
Heat source	30 °C to 50 °C	District heating network	Thermal grids for 5th generation DH	40	17.6[2]

[1]CO_2 abatement potentials are estimated using the typical emissions factor for natural gas since 98% of thermal demand in Swiss chocolate industry is fulfilled with natural gas.

[2]Although CO_2 abatement potential is estimated here based on the assumption that the excess heat is used to replace the natural gas, it should be noted that in reality this potential will vary.

[3] COP of 3 and continuous operation is assumed for the HP.

One of the assumptions in the work is that all heat recovery is assumed. For the tornado roaster (5(b)), to achieve the heat all heat recovery of the process, the maximal energy recovery heat exchanger network assumes that multiple heat exchangers are placed in the flue gas pipes of the Tornado roasters and are transferred to various heat sinks. According to the report, the proposed ideal heat exchanger network is not feasible in practice. There is no sufficient space in the smoke tube of the roaster for at most one heat exchanger. Based on further investigations, it is only feasible to have one heat exchanger in the flue gas pipe of the roaster. Therefore, further work considers this as not heat recovery is achievable in practice.

3.3 Other sectors

Due to the limited time to the work, in the last DeCarbCH Networking conference, it was decided that sectorial profiles created in SCCER [23] could be used to supplement in addition to what has been completed.

4 Conclusions

In conclusion, this study developed a methodology to quantify sector-wide thermal energy requirements of subsectors based on a database of conducted Pinch Analyses in Switzerland. The methodology allows for the aggregation and scaling of real industrial energy profiles to provide initial insights and directions for improving energy efficiency beyond conventional heat recovery methods. Heat pumps are considered one of the most important technology levers for process heat electrification and energy efficiency improvement. Moreover, the excess heat available from industrial plants can potentially be used to fulfil the heat demand from the other industrial subsectors or end-use sectors through district heating networks. While each integration case requires site-specific considerations, the methodology provides a starting point for sector-wide energy optimization. It is important to acknowledge that achieving complete consistency in modeling between different data sources and statistics is challenging due to variations in definitions, collection methods, and extrapolations. However, by using energy consumption statistics to scale up energy demand profiles using final energy consumption data, the sector-wide model can closely replicate individual energy consumption levels and trends.

The methodology was applied to the meat processing and production, as well as cocoa and chocolate production subsectors. The results showed significant potentials for the integration of heat pumps, solar thermal as well as the integration of excess heat into the district heating network. The integration heat pumps and solar thermal can potentially supply at least 200 GWh (63%) of the annual hot utility requirement of the meat production and 80 GWh (79%) of the annual hot utility requirement of the chocolate production in Switzerland. Based on the integration potentials for the three identified energy efficient technologies, the identified potential for CO_2 abatement for the meat production and chocolate subsectors are 91.0 kt/year and 52.9 kt/year, respectively. An additional CO_2 abatement potential of about 130.5 kt from the meat production and 17.6 kt/year from chocolate can be identified from the sector-wide energy profiles in the form of excess heat availability for the use outside the plant boundaries. It is important to note that the assumption of fully exploiting the heat recovery potential means that the results represent the minimum energy requirements for the subsectors. In summary, the developed methodology provides a valuable tool for assessing energy consumption and identifying opportunities for energy optimization in specific subsectors. By utilizing the sector-wide energy profiles, potential technologies and strategies can be evaluated to improve energy efficiency beyond conventional heat recovery methods. This methodology has the potential for broader application beyond the Swiss context, serving as a valuable tool for energy planning and optimization in industrial sectors worldwide.

This paper has been published in Energy [36].

5 References

1. Bundesamt für Energie, Schweizerische Gesamtenergiestatistik 2022. 2023, BFE: Bern, Switzerland.
2. Kemmler, A. and T. Trachsel, Analyse des schweizerischen Energieverbrauchs 2000 - 2021 nach Verwendungszwecken. 2022, Bundesamt für Energie BFE: Bern, Switzerland.
3. Singh, J., Why Energy Efficiency Matters and How to Scale It UP. 2016, World Bank Group.
4. Brueckner, S., et al., Methods to estimate the industrial waste heat potential of regions – A categorization and literature review. Renewable and Sustainable Energy Reviews, 2014. 38: p. 164-171.
5. Zuberi, M.J.S. and M.K. Patel, Bottom-up analysis of energy efficiency improvement and CO2 emission reduction potentials in the Swiss cement industry. Journal of Cleaner Production, 2017. 142: p. 4294-4309.
6. Zuberi, M.J.S. and M.K. Patel, Cost-effectiveness analysis of energy efficiency measures in the Swiss chemical and pharmaceutical industry. International Journal of Energy Research, 2019. 43: p. 313-336.
7. Bhadbhade, N., M.J.S. Zuberi, and M.K. Patel, A bottom-up analysis of energy efficiency improvement and CO2 emission reduction potentials for the swiss metals sector. Energy, 2019. 181: p. 173-186.
8. Bhadbhade, N. and M. Patel, Analysis of energy efficiency improvement and carbon dioxide abatement potentials for Swiss Food and Beverage sector Analysis of energy e ffi ciency improvement and carbon dioxide abatement potentials for Swiss Food and Beverage sector. 2020. 161.
9. Zuberi, M.J.S., et al., Excess heat recovery: An invisible energy resource for the Swiss industry sector. Applied Energy, 2018. 228: p. 390-408.
10. Enova, Utnyttelse av spillvarme fra norsk industry - En Potensialstudie. 2009, Enova: Trondheim, Norway.
11. Persson, J., B. Möller, and S. Werner, Heat Roadmap Europe: Identifying strategic heat synery regions. Energy Policy, 2014. 74: p. 663-681.
12. McKenna, R.C. and J.B. Norman, Spatial modelling of industrial heat loads and recovery potentials in the UK. Energy Policy, 2010. 38: p. 5878-5891.
13. Hammond, G.P. and J.B. Norman, Heat recovery opportunities in UK industry. Applied Energy, 2014. 116: p. 387-397.
14. Papapetrou, M., et al., Industrial waste heat: Estimation of the technically available resource in the EU per industrial sector, temperature level and country. Applied Thermal Engineering, 2018. 138: p. 207-216.
15. Bühler, F., et al., Industrial excess heat for district heating. Applied Energy, 2017. 205: p. 991-1001.
16. Elson, A., R. Tidball, and A. Hampson, Market Heat to Power Market Assessment 2015, ICF International: Virginia, USA.
17. Cornelis, E. and J. Van Bael. How well can the potential of industrial excess heat be estimated? in ECEE Industrial Summer Study Proceedings. 2016. Berlin, Germany.
18. Dénarié, A., et al., Industrial excess heat recovery in district heating: Data assessment methodology and application to a real case study in Milano, Italy. Energy, 2019. 166: p. 170-182.
19. Ramírez, C.A., M. Patel, and K. Blok, How much energy to process one pound of meat? A comparison of energy use and specific energy consumption in the meat industry of four European countries. Energy, 2006. 31: p. 2047-2063.
20. El-Halwagi, M.M., Pollution prevention through process integration: Systematic design tools. 1997, California, USA: Academic Press.
21. Schubaschitz, M. Evaluation of pinch analysis projects in swiss industry. Hochschule Luzern, Master of Science in Engineering 2021 Acces Date NA]; Available from: https://sites.hslu.ch/ta-bachelorarbeiten/wp-content/uploads/sites/6/2021/06/MSE_2021_Schubaschitz_Michael.pdf.

22. Smith, R., Chemical process: Design and integration. Second edi ed. 2016, Chichester, West Sussex, United Kingdom: Wiley.
23. Kantor, I. and F. Marechal, Potential Impact of SCCER-EIP Work Package 4 Toward Switzerland's ES2050. 2017: Lausanne, Switzerland. p. 1-50.
24. Ong, B.H.Y., et al., A user workflow for combining process simulation and pinch analysis considering ecological factors. Chemical Product and Process Modeling, 2021.
25. Federal Statistical Office. NOGA - Coding Tool for classifications. 2021 02.02.2023]; Available from: https://www.kubb-tool.bfs.admin.ch/en.
26. Dhole, V.R. and B. Linnhoff, Total site targets for fuel, co-generation, emissions, and cooling. Computers and Chemical Engineering, 1993. 17: p. S101-S109.
27. Sauvin, L., et al., Energieverbrauch in der Industrie und im Dienstleistungssektor - Resultate 2017. 2018. p. 79.
28. Federal Office of Agriculture, The Swiss pig market. 2019, Federal Office for Agriculture: Bern, Switzerland.
29. Energie-Agentur der Wirtschaft EnAW, Database of energy efficiency measures. 2016.
30. Christian Del Taglia, S.S., Athanassia Chalimourda, Erica Madonna, Silvia Doytchinov, Maxime Seydoux, Energieverbrauch in der Industrie und im Dienstleistungssektor, B.f. Energie, Editor. 2022: Bern, Switzerland.
31. Fodor, Z., et al., Total Site Targeting with Stream Specific Minimum Temperature Difference. Chemical Engineering Transactions, 2012. 29: p. 409-414.
32. Rittmann-Frank, M.H., et al., Konzernrelevante Verringerung von CO2- Emissionen durch die Integration von skalierbaren und kostengünstigen Solarwärme Einheiten (BillySolar). 2020: Bern, Switzerland.
33. Joubert, J., et al. Developing 4th and 5th Generation District Heating within the UK. in Interreg North-West Europe HeatNet HWE. 2020. Online.
34. CBI Ministry of Foreign Affairs. The Swiss market potential for cocoa. 2022 02.02.2023]; Available from: https://www.cbi.eu/market-information/cocoa-cocoa-products/switzerland/market-potential/.
35. Chocosuisse. Facts & figures. 2021 02.02.2023]; Available from: https://www.chocosuisse.ch/en/services/facts-figures.
36. Ong, B.H.Y., et al., Characterizing sector-wide thermal energy profiles for industrial sectors. Energy, 282: p. 129028.