Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

Annex 58

High-Temperature Heat Pumps

Task 3 – Applications and Transition

Task Report

Operating Agent:
Benjamin Zühlsdorf, PhD
Danish Technological Institute

March 2024
Report no. HPT-AN58-4

Published by

Heat Pump Centre
c/o RISE – Research Institutes of Sweden
Box 857, SE-501 15 Borås
Sweden
Phone +46 10 16 53 42

Website

https://heatpumpingtechnologies.org

Legal Notice

Neither the Heat Pump Centre nor any person acting on its behalf:
(a) makes any warranty or representation, express or implied, with respect to the information contained in this report; or
(b) assumes liabilities with respect to the use of, or damages, resulting from, the use of this information.
Any reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favouring.
The views and opinions of the authors expressed herein do not necessarily state or reflect those of the Heat Pump Centre or any of its employees. The information herein is presented in the authors' own words.
Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement recommendation or favouring.
The views and opinions of authors expressed herein do not necessarily state or reflect those of the Heat Pump Centre, or any of its employees. The information herein is presented in the authors' own words.

Production

Heat Pump Centre, Borås, Sweden

ISBN 978-91-89896-80-2
Report No. HPT-AN58-4
DOI: 10.23697/dn21-0b02

Preface

This project was carried out within the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP), which is a Technology Collaboration Programme within the International Energy Agency, IEA.

The IEA

The IEA was established in 1974 within the framework of the Organization for Economic Cooperation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster cooperation among the IEA participating countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology and research and development (R&D). This is achieved, in part, through a programme of energy technology and R&D collaboration, currently within the framework of nearly 40 Technology Collaboration Programmes.

The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) forms the legal basis for the implementing agreement for a programme of research, development, demonstration, and promotion of heat pumping technologies. Signatories of the TCP are either governments or organizations designated by their respective governments to conduct programmes in the field of energy conservation.

Under the TCP, collaborative tasks, or "Annexes", in the field of heat pumps are undertaken. These tasks are conducted on a cost-sharing and/or task-sharing basis by the participating countries. An Annex is in general coordinated by one country which acts as the Operating Agent (manager). Annexes have specific topics and work plans and operate for a specified period, usually several years. The objectives vary from information exchange to the development and implementation of technology. This report presents the results of one Annex.

The Programme is governed by an Executive Committee, which monitors existing projects and identifies new areas where collaborative effort may be beneficial.

Disclaimer

The HPT TCP is part of a network of autonomous collaborative partnerships focused on a wide range of energy technologies known as Technology Collaboration Programmes or TCPs. The TCPs are organised under the auspices of the International Energy Agency (IEA), but the TCPs are functionally and legally autonomous. Views, findings and publications of the HPT TCP do not necessarily represent the views or policies of the IEA Secretariat or its individual member countries.
This report has been produced within HPT Annex 58. Views and findings in this report do not necessarily represent the views or policies of the HPT TCP and its individual member countries.

The Heat Pump Centre

A central role within the HPT TCP is played by the Heat Pump Centre (HPC).
Consistent with the overall objective of the HPT TCP, the HPC seeks to accelerate the implementation of heat pump technologies and thereby optimise the use of energy resources for the benefit of the environment. This is achieved by offering a worldwide information service to support all those who can play a part in the implementation of heat pumping technology including researchers, engineers, manufacturers, installers, equipment users, and energy policy makers in utilities, government offices and other organisations. Activities of the HPC include the production of a Magazine with an additional newsletter 3 times per year, the HPT TCP webpage, the organization of workshops, an inquiry service and a promotion programme. The HPC also publishes selected results from other Annexes, and this publication is one result of this activity.

For further information about the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) and for inquiries on heat pump issues in general contact the Heat Pump Centre at the following address:
Heat Pump Centre
c/o RISE - Research Institutes of Sweden
Box 857, SE-501 15 BORÅS, Sweden
Phone: +46 10 516 53 42
Website: https://heatpumpingtechnologies.org

Operating Agent

Annex 58 about High-Temperature Heat Pumps is coordinated by the Operating Agent:

Benjamin Zühlsdorf, PhD, bez@dti.dk
Danish Technological Institute, Energy and Climate

The Annex is being operated from 01/2020 to 12/2023. The main information can be found at the Annex 58 homepage: https://heatpumpingtechnologies.org/annex58/

Participating countries of Annex 58

A high number of countries are participating in Annex 58, while each country is represented by a national team consisting of several organizations. The following countries are formally participating in the Annex 58:

- Austria
- Belgium
- Canada
- China
- Denmark
- Finland
- France
- Germany
- Japan
- Netherlands
- Norway
- South Korea
- Switzerland
- USA

A presentation of all national teams can be found on the Annex 58 homepage.

Authors of the report and contributors to Task 3

The report has been prepared as a collaborative effort with contributions from various authors and coordinated by the main author, Sabrina Dusek. The contributors are shown in Table 0-1.

Table 0-1: Overview of contributors to Task 3.

Name	Role/Title	Organization & Country	Contact information (E-mail)
Benjamin Zühlsdorf	Centre Project Manager, PhD	DTI, Denmark	bez@teknologisk.dk
Jonas Lundsted Poulsen	Senior Specialist	DTI, Denmark	jlp@teknologisk.dk
Virginia Amato	Consultant	DTI, Denmark	vgm@teknologisk.dk
Hans Madsbøll	Senior Specialist	DTI, Denmark	hm@teknologisk.dk
Sabrina Dusek	Research Engineer	AIT, Austria	sabrina.dusek@ait.ac.at
Gerwin Drexler-Schmid	Senior Research Engineer	AIT, Austria	gerwin.drexler-schmid@ait.ac.at
Bastian Fibi	Junior Research Engineer	AIT, Austria	bastian.fibi@ait.ac.at
Sophie Knöttner	Research Engineer	AIT, Austria	sophie.knoettner@ait.ac.at
Johannes Riedl	Research Engineer	AIT, Austria	johannes.riedl@ait.ac.at
Veronika Wilk	Senior Research Engineer	AIT, Austria	veronika.wilk@ait.ac.at
René Rieberer	Professor	TU Graz, Austria	rene.rieberer@tugraz.at
Manuel Verdnik	PhD student	TU Graz, Austria	manuel.verdnik@tugraz.at
Chantal Leroy	Manager	Natural Resources Canada, Canada	chantal.leroy@nrcan-rncan.gc.ca
Luwei Yang	Professor	TIPC-CAS, China	lwyang2002@mail.ipc.ac.cn
Shupeng Fang	Manager	ZHANGGU, China	spfang@blower.cn
Qinbo Wang	Manager	HYTM, China	wangqinbo@powerbeijinghytm.com
Martin Pihl Andersen	PhD Student	DTU, Denmark	mapian@dtu.dk
Brian Elmegaard	Professor	DTU, Denmark	brel@dtu.dk
Fridolin Müller Holm	Head of Industry	Viegand & Maagøe, DK	fmh@viegandmaagoe.dk
Teemu Turunen-Saaresti	Professor	Finland	teemu.turunen-saaresti@lut.fi
Panagiotis Stathopoulos	Group leader	DLR, Germany	Panagiotis.Stathopoulos@dlr.de
Sebastian Benkert	PhD Student	Fraunhofer ISE, Germany	Sebastian.Benkert@ise.fraunhofer.de
Ursula Wittstadt	Research Engineer	Fraunhofer ISE, Germany	Ursula.wittstadt@ise.fraunhofer.de
Florian Schlosser	Senior Research Engineer	Paderborn University, Germany	florian.schlosser@uni-paderborn.de
Cordin Arpagaus	Senior Research Engineer, Dr. sc. techn.	OST, Switzerland	cordin.arpagaus@ost.ch
Kashif Nawaz	Section Head	ORNL, USA	nawazk@ornl.gov
Pengtao Wang	R&D Associate Staff Member	ORNL, USA	wangp@ornl.gov

Foreword

This report has been compiled as part of the IEA HPT Annex 58 about High-Temperature Heat Pumps (HTHP). The Annex is structured into the following 5 tasks:

- Task 1: Technologies – State of the art and ongoing developments for systems and components
- Task 2: Integration Concepts – Development of best practice integration concepts for promising application cases
- Task 3: Applications and Transition – Strategies for the conversion to HTHP-based process heat supply
- Task 4: Definition and testing of HP specifications – Recommendations for defining and testing specifications for high-temperature heat pumps in commercial projects
- Task 5: Dissemination

The overall objective of the Annex is to provide an overview of the technological possibilities and applications as well as to develop best practice recommendations and strategies for the transition towards HP-based process heat supply. The intention is to improve the understanding of the technology's potential among various stakeholders, such as manufacturers, potential end-users, consultants, energy planners, and policy makers. In addition, the Annex aims to provide supporting material to facilitate and enhance the transition to an HP-based process heat supply for industrial applications.

This will be achieved by the following sub-objectives:

- Provide an overview of the technology, including the most relevant systems and components that are commercially available and under development (Task 1).
- Identify technological bottlenecks and clarify the need for technical developments regarding components, working fluids, and system design (Task 1).
- Present best practice system solutions for a range of applications to underline the potential of HTHPs (Task 2).
- Develop strategies for the transition to heat-pump-based process heat supply (Task 3).
- Enhance the information basis about industrial HPs, potential applications, and potential contributions to the decarbonization of the industry (Task 1, 2 & 3).
- Develop guidelines for handling industrial HP projects with a focus on the HP specifications and the testing of these specifications (Task 4).
- Disseminate the findings to various stakeholders and add to the knowledge base for energy planners and policy makers (Task 5).

Annex 58 focuses on HTHPs, which are HPs that supply a relevant share of their heating capacity at temperatures above 100 °C. In this context, the focus is on developing, summarizing, and communicating information about the most relevant technologies and applications rather than covering all technologies. The relevance was mainly determined by the various participants and indirectly given by the technologies' application potential and market perspectives. Therefore, the Annex primarily focuses on applications for industrial heat supply but will not specifically be limited to these applications. This report documents the work of Task 3 – Applications and Transition. Chapter 1 introduces the topic of decarbonization strategy development and its importance. Chapter 2 deals with the topic of target setting. Different drivers for achieving a goal are presented as well as how important it is to identify the ambition level. To illustrate this, common methods of formulating and defining goals and targets are presented here as example. Chapter 3 deals with the topic of describing the current status of the site to be decarbonized. It covers what information is needed to develop a strategy, specifically for heat recovery measures such as heat exchangers and HPs. This chapter addresses where this information can usually be found. The development and evaluation of concept solutions are discussed in Chapter 4. Technologies for decarbonizing the process heat supply are presented, and methods for developing concepts are explained in more detail. Furthermore, the different possible integration levels of HPs are discussed, highlighting the importance of utility and process parameter optimization. Important aspects that should be considered when developing a roadmap and an example of a roadmap are discussed in Chapter 5. Chapter 6 contains a conclusion.

Executive Summary

Decarbonization has already become a high priority for industrial companies, making company- and site-specific decarbonization strategies necessary. Easy-to-implement, low-cost, and low-risk measures that have a rapid impact on decarbonization are typically implemented quickly. However, these measures are hardly sufficient for complete decarbonization, so further measures must be implemented. Nonetheless, without a structured strategy, previously implemented measures may hinder further measures, such as efficiency. By developing a strategy that takes a holistic view of an entire site, such effects can be prevented or at least minimized. Developing such a detailed strategy is often complex as it requires a lot of knowledge about available technologies and the company's production processes. Furthermore, the definition of strategy needs to consider external conditions and the company's objectives.

A long-term decarbonization strategy should include technologies that are available today and those that will become available soon. This puts special emphasis on HTHPs, which are a key technology for decarbonized process heating but are not yet fully commercially available. HPs increase the efficiency of processes and electrically driven heat pumps are also an electrification measure. Instructions for creating decarbonization strategies were developed in Task 3 of IEA HPT Annex 58 to improve technology integration. These instructions have been summarized in a guideline with illustrations. This guideline aims to support companies in developing their decarbonization strategy for the process heat supply, which can also be summarized as complete or partial reduction of the so called "Scope 1 emissions". The content of the guideline is explained in more detail in this report. The following four main questions are addressed and answered in the guideline:

- How to define a decarbonization goal?
- How to describe the current status/reference scenario?
- How to develop and evaluate concept solutions for decarbonized systems?
- How to derive the decarbonization path?

First, it is addressed that the development of a decarbonization strategy starts with setting an overarching goal, the timeline in which the goal has to be achieved, and the fact that the development process is not linear but often requires several iterations. Interim targets can be derived from the overarching goal, which should be continuously evaluated regarding their feasibility during the strategy development. The goal, interim targets and timeline can be influenced by various factors. Some examples of such influencing factors are mentioned. The importance of the level of ambition for goal achievement and the importance of communicating goals clearly and well is also addressed.
The second question deals with the collection of data on the current status of the site under consideration, which is essential for the development of concept solutions for implementing the decarbonization strategy and the definition of the reference scenario for evaluating the solutions. The required information is described. The information needed to identify the feasibility of efficiency-enhancing measures such as HPs and heat exchangers is highlighted explicitly. It is also emphasized that information on boundary conditions, such as site-specific conditions, the connection between individual processes, and information on future developments is also required. The importance of an up-to-date, detailed overall picture of the site under consideration is highlighted.

The next question focuses on developing and evaluating concept solutions for decarbonizing an industrial site's heating demand. An overview of the possible technologies is provided, divided into different categories. In the further course of the report, the focus is on HP technology. The possible integration levels for HP technology are explained in more detail, and methods such as *Pinch analyses*, physical modelling, and mathematical optimization for concept development are presented. It is also emphasized that the efficiency of a measure can be significantly increased if the process temperature or the supply temperature level is reduced. The HP integration concepts and HP concepts for various applications developed in IEA HPT Annex 58 Task 2[1] can also support for concept development. The evaluation of the developed concepts is also discussed in more detail. The selection and weighting of the evaluation criteria necessary for a company is important here. These evaluation criteria can be economic (e.g. investment or operating costs) and non-economic (e.g., space requirements and feasibility). When evaluating concept solutions for decarbonization, the reduction of CO_2 emissions is an essential evaluation criterion.

[1] IEA HPT Annex 58, Task 2 – Integration Concepts https://heatpumpingtechnologies.org/annex58/task-2-integration-concepts/

The last question deals with the development of an implementation roadmap. Various influencing factors, such as the technology readiness level, are presented, and tips for minimizing risk are given. The factors affect the concepts and the division into sub-projects considered in the roadmap, and the timeline. Determining the team and whether only internal or external know-how is required is essential. The definition of milestones is also part of the roadmap preparation. A theoretical example of a roadmap is given at the end. Here, it is emphasized that the influence of the implemented measures should be evaluated during implementation, and the strategy and roadmap should be adapted accordingly.

Nomenclature

CC	Composite Curve
CDP	Carbon Disclosure Project
COP	Coefficient of Performance
GCC	Grand Composite Curve
HP	Heat Pump
HTHP	High-Temperature Heat Pump
HU	Hot Utility
HR	Heat Recovery
KPI	Key Performance Indicator
SBTi	Science-based target initiative
TRL	Technology Readiness Level
WRI	World Resources Institute
WWF	World Wide Fund for Nature

Table of content

Preface 4
Operating Agent 5
Participating countries of Annex 58 5
Authors of the report and contributors to Task 3 6
Foreword 7
Executive Summary 8
Nomenclature 10
Table of content 11
1. Introduction 12
2. How to define a decarbonization goal? 14
  2.1. What is important for you? 14
  2.2. How are goals and targets be defined? 15
  2.3. Further information 16
3. How to describe the current status / reference scenario? 17
  3.1. Which information is needed? 17
  3.2. What do I need in the future? 19
  3.3. How to collect and evaluate the information? 20
  3.4. What needs to be known to assess the feasibility of heat recovery measures? 21
4. How to develop and evaluate concept solutions for decarbonization? 22
  4.1. What technologies are available for decarbonization of process heat supply? 22
  4.2. What is the level of integration? 22
  4.3. Can we do better? 23
  4.4. How to get a concept solution? 24
  4.5. Will it pay off? 27
5. How to derive the decarbonization path? 29
  5.1. How to define an implementation roadmap? 29
  5.2. How can a roadmap look like? 30
6. Conclusion 32
7. References 33

1. Introduction

The HP and especially the HTHP is a technology that will play a significant role in the decarbonization strategies of industrial companies, as it is not only a measure for electrification, but even more importantly makes a significant contribution to increasing the efficiency and thus reducing the energy demand of an industrial company. Due to the wide range of applications of this technology, it can be used to supply different temperature levels.

In general, complete decarbonization can only be achieved by implementing several measures that influence each other to a greater or lesser extent. Moreover, there are often several alternative measures that can be applied. It is important to consider the overall picture before implementing individual measures, as the implementation of one or more measures may lead to dead ends and make further decarbonization more difficult or even prevent it. This is schematically shown in Figure 1-1. It is also necessary to decide when to implement which measure, as it is often not possible or feasible to implement all measures at the same time. A well-thought-out strategy and roadmap are necessary to achieve complete decarbonization as soon as possible. The aim is to identify the most suitable and efficient set of measures for the site under consideration, the implementation order, and the time frame for realization. It is important to note that for decarbonization not only the replacement of fossil fuels, but also the increase of efficiency of processes and equipment, and thus the reduction of energy consumption is essential.

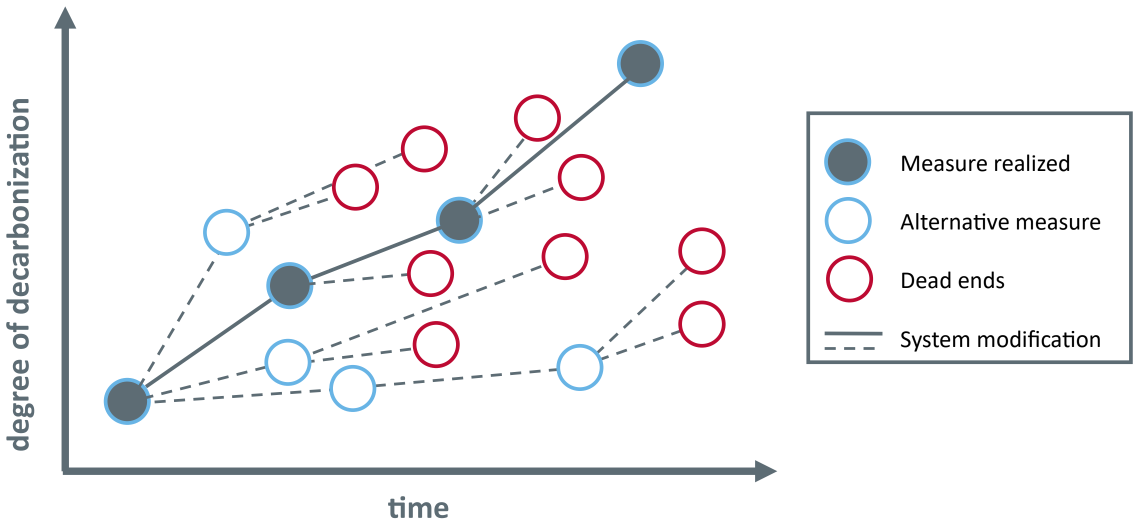

Figure 1-1: Schematic representation of decarbonization pathways (Source: AIT Austrian Institute of Technology GmbH)

When analysing emissions, a distinction can be made between Scope 1, Scope 2 and Scope 3. A detailed explanation of the categories can be found in [1]. Scope 1 emissions are those that are caused by activities on site, such as emissions from the combustion of fuels. Indirect emissions from the external production of energy such as electricity are defined as Scope 2 emissions. Scope 3 emissions include the remaining indirect emissions that can be caused through its activities, such as emissions caused by business travel or purchased goods. In the guideline and in this document, the focus is on the decarbonization of on-site heat supply contributing to Scope 1 emissions.

The development of a strategy for the decarbonization of the process heat supply was discussed in IEA HPT Annex 58 Task 3. A guideline was created based on these discussions[2]. The aim of this guideline is to support industrial companies in developing a decarbonization strategy in which HPs play a role, not exclusively but primarily. From the working group's point of view, the guideline contains important points to consider when developing a strategy. This report provides additional information and explanations in addition to the content of the guidelines.

[2] IEA HPT Annex 58, Task 3 – Applications and Transition, https://heatpumpingtechnologies.org/annex58/task-3/

The path to a decarbonization strategy is presented based on the four main steps:

- goal setting (see Chapter 2)
- analysing the current status and defining the reference scenario (see Chapter 3)
- develop and evaluate concept solutions (see Chapter 4)
- driving the strategy (see Chapter 5)

Figure 1-2 provides an overview of the process of developing a decarbonization strategy and the information required for this. The required information and development steps are discussed in more detail in this report. The development of a decarbonization strategy is often an iterative process, as further information may need to be obtained during concept development, for example.

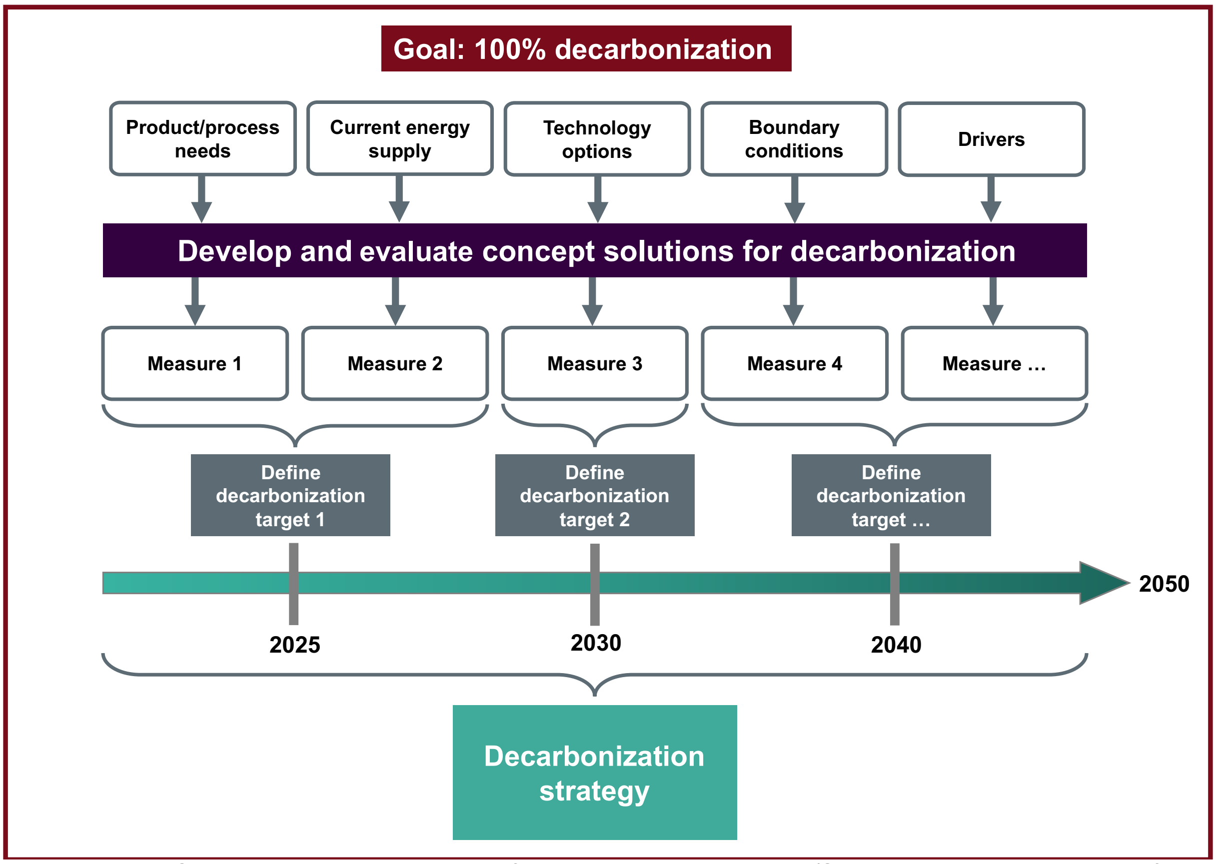

Figure 1-2 Overview on the development of a decarbonization strategy (Source: AIT Austrian Institute of Technology GmbH)

In general, several contributions are available on the topic of decarbonization strategies and their development. Hechelmann et al. [2], for example, describe the development and analysis of decarbonization strategies for eight manufacturing companies in Germany. The contribution from Dupond Holdt et al. [3] deals with the development of decarbonization strategies for industrial process heat supply. The topic of roadmap development is also addressed in IEA [4]. In Task 3 of IEA HPT Annex 58, the focus was on preparing a simple and compact guideline based on the experience of the Annex' participants.

2. How to define a decarbonization goal?

The decarbonization strategy development process starts with the overarching goal that must be defined. This includes the time limit for achieving full decarbonization. Based on this, interim targets are defined and should be continuously evaluated in terms of feasibility as the strategy is developed.
In this document, the term *goal* is used in the context of a long-term and higher-level result to be achieved. The term *target* is used in the context of a specific and comparatively short-term achievable result.

It is essential to define strategic goals at management level and then to roll them out within the company and emphasize the importance of the goal. Once the goal is defined, intermediate targets can be set during the strategy development process. Clear and well-communicated goals and targets are essential for effectively selecting and evaluating measures to be implemented.

2.1. What is important for you?

In general, drivers play a significant role in goal and target setting. Figure 2-1 shows different, potential drivers that positively influence the decision to achieve a decarbonization goal. Available alternative technologies that make it possible to reduce emissions from thermal energy supply and the existence of legal requirements act as drivers for achieving decarbonization. Financial benefits and the positive image resulting from the marketing of emission savings at the location also act as a driver. Satisfying customer expectations in the manufacturing of the product can be a driver, as can reducing the impact on the environment.

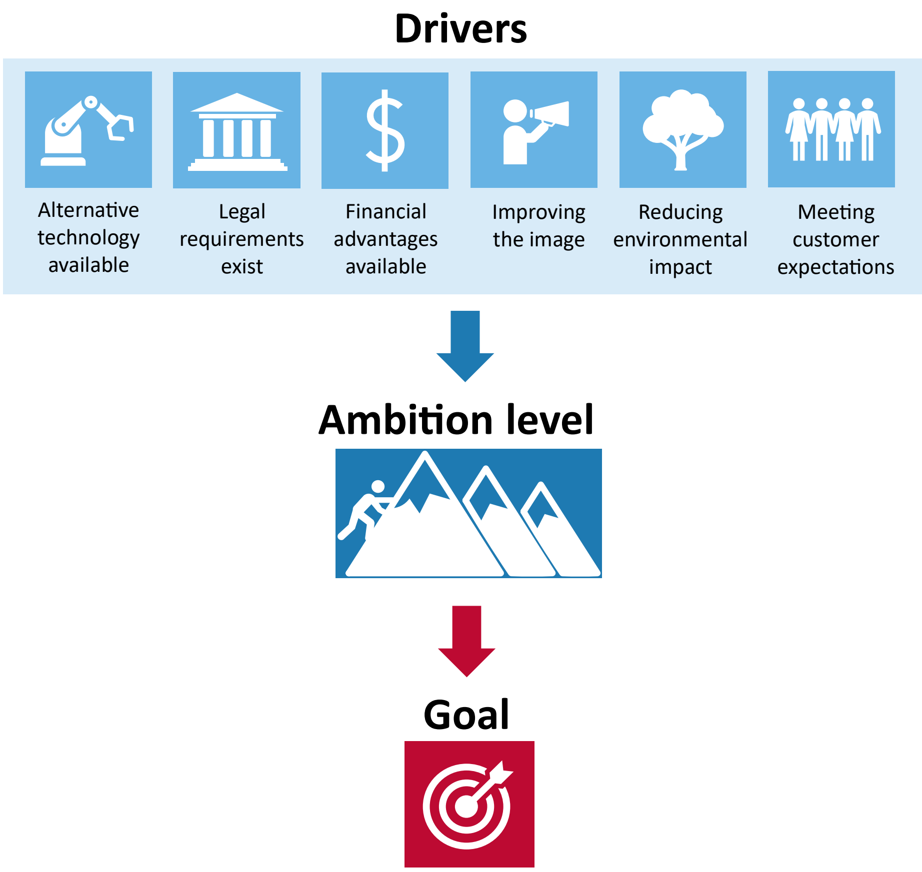

Figure 2-1: Drives for goal setting (Source: AIT Austrian Institute of Technology GmbH)

In addition to the decarbonization goal, there are often other company goals or boundary conditions that make it more difficult or delay the decarbonization goal's achievement and reduce the drivers' influence. One example of such a boundary condition is low payback periods for technology investments. This can prevent the implementation of technologies (such as HP) that are needed for efficient decarbonization. Therefore, it must be elaborated how important these drivers are and, thus, the corresponding goal is. This also means that the ambition level must be clear. Whether the goal is seen as *mandatory* (high ambition level) or as *nice to have add-on* (low ambition level). Once the importance of the goal and the drivers, as well as the level of ambition, have been identified, it is indispensable to communicate this clearly.

2.2. How are goals and targets be defined?

A precise definition is also essential when setting goals or interim targets. There are different methods available for defining goals and targets, one of them is the *SMART* method. This method implies that a goal or target should be specific, measurable, achievable, relevant, and timed, as shown in Figure 2-2.

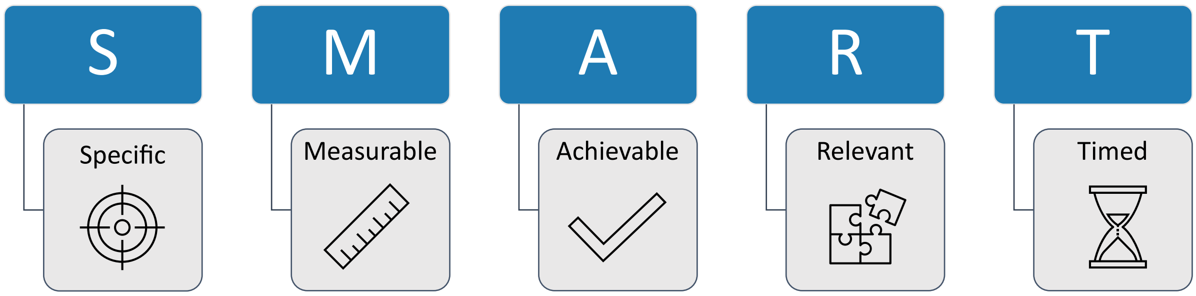

Figure 2-2: SMART method (Source: AIT Austrian Institute of Technology GmbH)

An example of a target defined according to the *SMART* method is given below. The starting point in this example is the intention to implement an HP for hot water production.

- **Specific:** The hot water requirement of production process A is to be covered by HP with a heating capacity of 2 MW.
- **Measurable:** CO_2 emissions from the production process A are to be reduced by 100%.
- **Achievable:** Sufficient waste heat is available. Technology is available. Sufficient connection power is available. Space for the HP is available. Sufficient personnel is available to implement the measure. The investment budget is reserved.
- **Relevant:** The measure is important to reach the company's decarbonization goal.
- **Timed:** The implementation of the measure, including test operation, should be completed by the end of 2025 (delivery times considered).

To support the definition of a goal or target according to the *SMART* method, the following questions are listed for each property. Answering these questions can assist in defining a goal precisely.

Specific:
- What is the geographical scope? Which site, which production line, or which process should be the target concern?
- Which parties of the company/industrial site are responsible?
- Which rules/targets can be derived from political measures?

Measurable:
- What is the target value? (e.g., emissions reduction)
- Is there a reference value? (e.g., current emissions)
- Should the target figure be related to another figure? (e.g., production quantity)

Achievable:
- Is the target value set realistically?
- Does the goal or target fit to the regulations?
- What effect does it have on the core business?
- What are the constraints that must be respected, and do they allow to achieve the goal or target?
- Is the achievement of the goal or target supported at all personnel levels (management level, co-workers, ...)?

- Is the goal or target achieved already somewhere else? (best practice example)
- Is it financially possible to achieve the target?
- Is the required technology available, or will the technology be available in time?

Relevant:
- How does the goal or target comply with the company strategy?
- What does the goal or target contribute to the company strategy?

Timed:
- What is the Technology Readiness Level (TRL) level of the technology or measure?
- What kind of delivery times can be expected?
- Is there any previous experience with the implementation of this measure or technology?
- How much time is available besides the daily business to reach the goal or target?
- Is sufficient information already available for the conceptual design, or do measurements still need to be carried out?

2.3. Further information

One initiative that supports companies in setting greenhouse gas emission reduction goals based on the Paris Agreement is the *Science-based target initiative* (SBTi) [5]. The SBTi is a cooperation between *Carbon Disclosure Project* (CDP), the *United Nations Global Compact*, the *World Resources Institute* (WRI), and the *World Wide Fund for Nature* (WWF). Science-based targets are those that are necessary, based on the latest climate research, to achieve the goals of the Paris Agreement. The SBTi defines and encourages practices for setting science-based targets. It also provides resources and guidelines to reduce barriers to adoption. In addition, the SBTi evaluates and approves corporate goals. Faria et al. [6] present a model framework for science-based methods and compare four different methods for setting science-based targets. The Net-Zero initiative [7] is another initiative that presents a framework for describing and categorizing companies' contributions to global climate neutrality.

3. How to describe the current status / reference scenario?

A description of the current status is essential to develop concept solutions for decarbonization, including the current heat supply system and identifying what the process really requires. This is important as heat supply systems often provide energy with process parameters that deviate from the actual requirements of the process. Examples are a steam boiler that supplies a significantly higher pressure and thus higher temperature than the process requires or the use of steam boilers where (pressurized) hot water would be sufficient for process heat supply. The description of the current status is often a very time-consuming task because not all information is readily available or even available at all. This chapter describes what information is required and gives examples on where this information can be found.

3.1. Which information is needed?

To develop efficient concepts, it is important to quantify the demand of the individual processes and the available waste heat flows or cooling demands over a characteristic period with a sufficiently small timestep length. A characteristic period is a period that includes all the changes that usually occur in the processes. It is also important to have information about how different processes are connected (flow diagram) and other boundary conditions necessary for the process to run optimally. The better the information base, the better the concept solutions can be developed.

The starting point of a valuable information base is an overview and understanding of the processes contained on the site under consideration and their interfaces. An example of a flow diagram is shown in Figure 3-1.

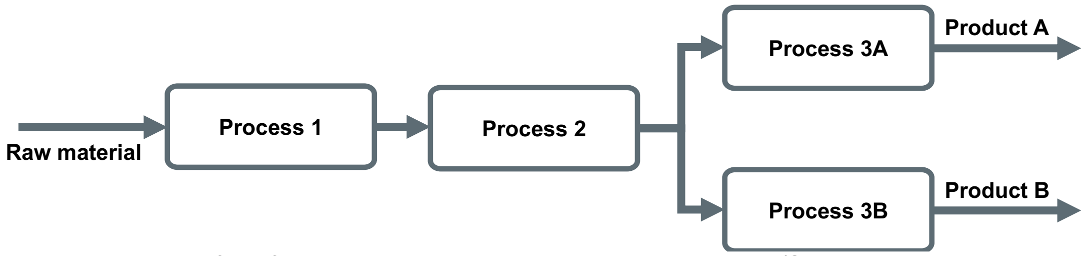

Figure 3-1: Example for a flow diagram to represent process relationships (Source: AIT Austrian Institute of Technology GmbH)

Figure 3-1 shows the flow chart from the product perspective. To have sufficient information for the decarbonization of the energy supply, especially for the thermal energy supply, it makes sense to also enter the required energy flows or energy carrier flows. This is shown in Figure 3-2. It is also helpful to include available waste heat flows. If heat recovery measures have already been implemented in the system, it is advantageous to take these into account as well.

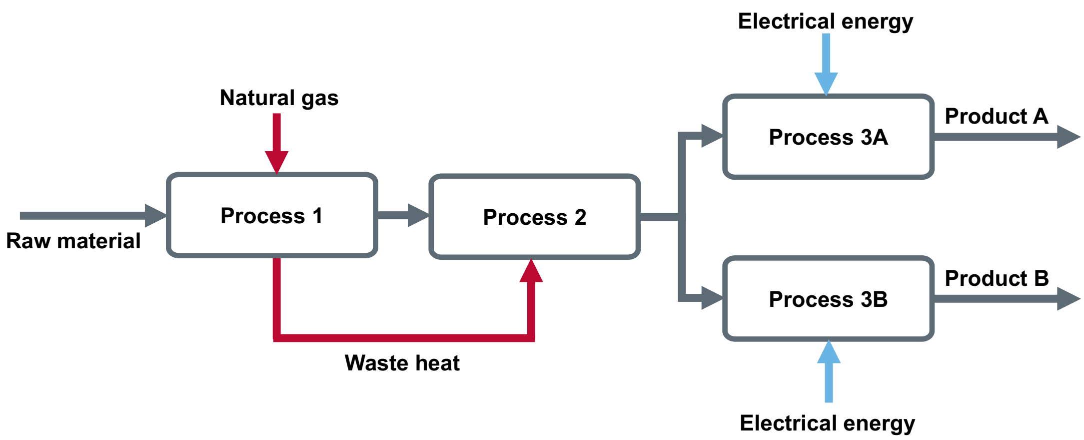

Figure 3-2: Exemplary representation of a process block diagram including energy supply (Source: AIT Austrian Institute of Technology GmbH)

A Sankey diagram can be used to gain an overview of the current supply of on-site energy demands. Figure 3-3 shows such an exemplary diagram for energy consumption in the paper industry sector. Sankey diagrams can support, for example, identifying large energy consumers of a specific energy carrier or generally provide an overview of the amount of energy consumption per energy source and process.

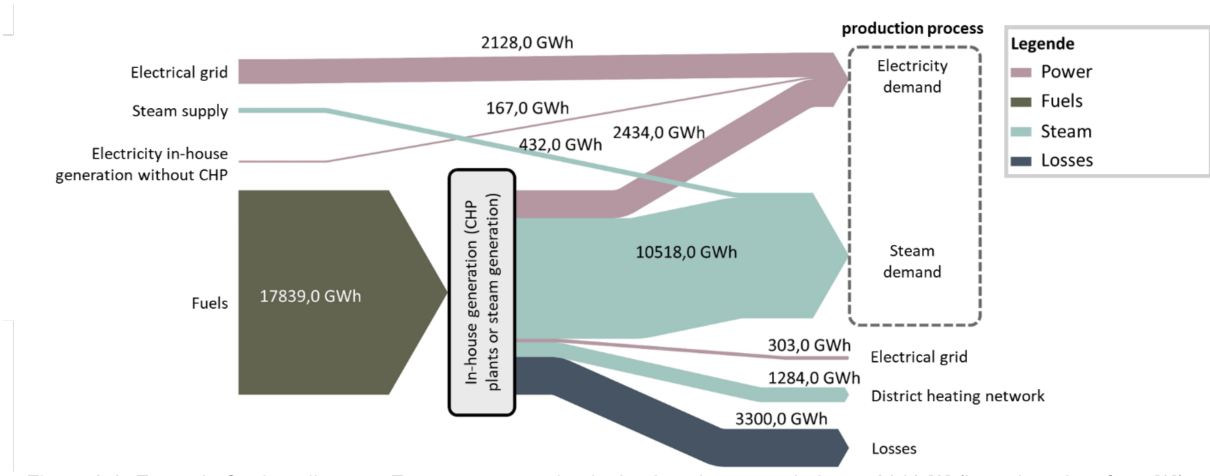

Figure 3-3: Example Sankey diagram: Energy consumption in the Austrian paper industry 2016 [8] (based on data from [9])

If a good overview of the processes and their demands is available, it is also necessary to describe the heating and cooling requirements as well as the available waste heat and the boundary conditions in detail. Figure 3-4 summarizes the basic information that is required. In this step of collecting information checklists can be helpful as show in Chapter 3.4 of this report.

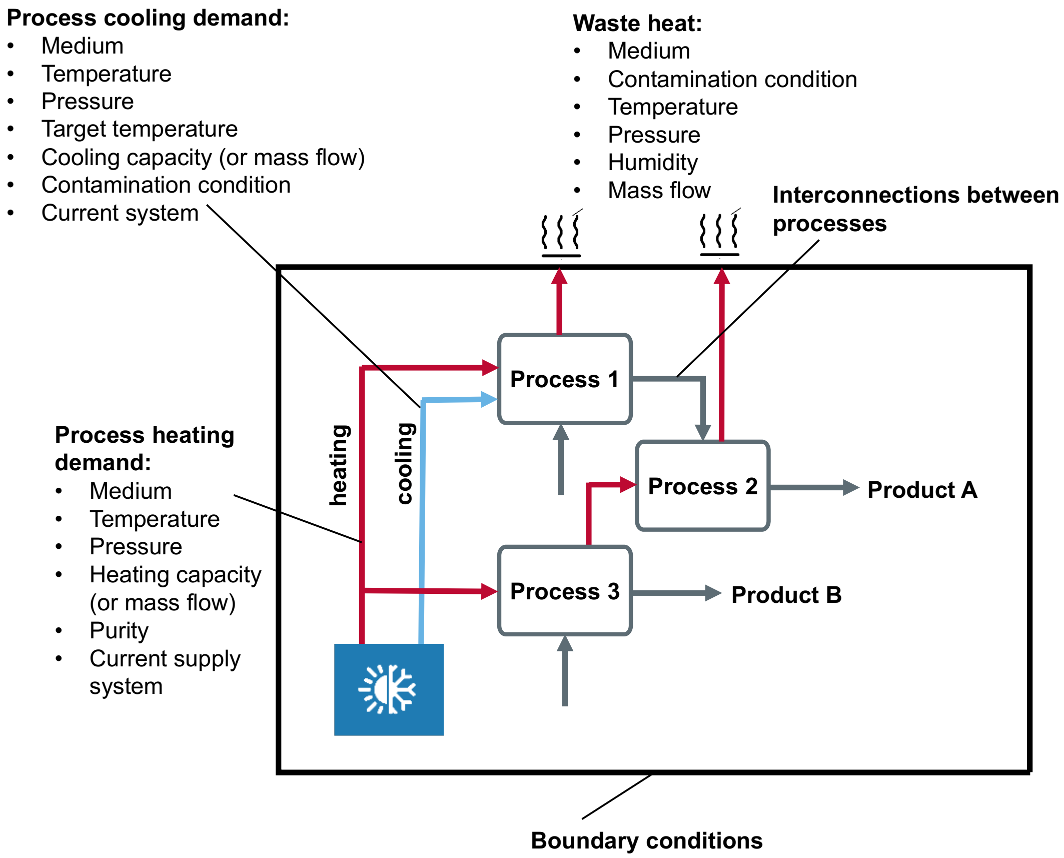

Figure 3-4: General presentation of the required information (Source: AIT Austrian Institute of Technology GmbH and Fraunhofer Institute for Solar Energy Systems ISE)

In Figure 3-4, it can also be seen that it is important to know how the processes depend on each other and what the boundary conditions are. Examples of some site-specific boundary conditions that should be gathered during data collection are listed below:

- Remaining depreciation period and lifetime of existing technology
- Distance between waste heat source and consumer
- Permitted sound emissions
- Space availability
- Other usable heat sources such as ambient air, geothermal energy
- Ownership of energy infrastructure
- Maximum available connection power now and in the future

As already mentioned, it is also important to know the parameters describing the process demand and waste heat over a characteristic period. Is the process continuous, or is it a batch process? Another relevant characteristic of timeseries (e.g., load profile and waste heat availability) is their periodicity. Is the process fluctuating on, for example, daily, hourly, minutely, or seasonal basis? What influences the temporal behaviour (e.g. product or tool changes, rinsing and cleaning cycles)? An example of such a load profile and waste heat ability is given in Figure 3-5. Even if some timeseries or parameters are constant when the corresponding process or plant is in operation, the temporal behaviour of the individual processes to each other should be known and understood.

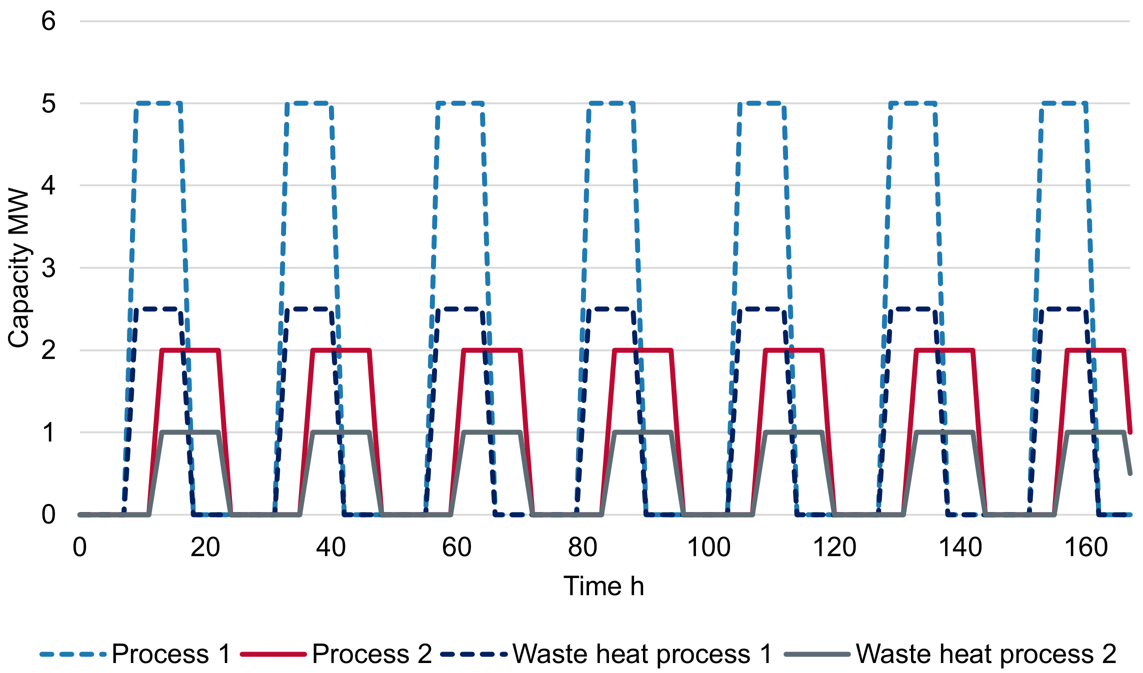

Figure 3-5: Example of a load profile with heat demand and waste heat output (Source: AIT Austrian Institute of Technology GmbH)

3.2. What do I need in the future?

Future developments such as expansion or reduction of production capacity, changes to processes or even equipment that needs to be renewed must also be considered in this task. The current heat supply system can be used as a reference system for evaluating individual measures and concepts.

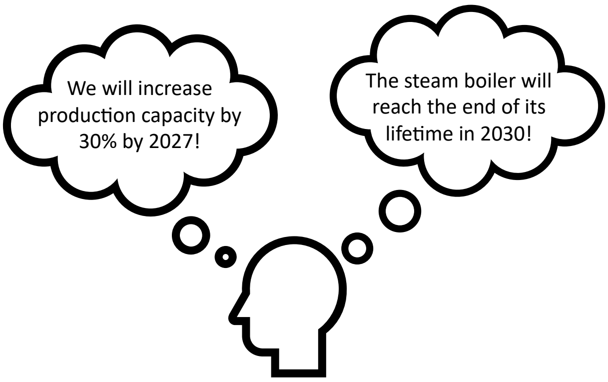

Figure 3-6: Consideration of future developments (Source: AIT Austrian Institute of Technology GmbH)

3.3. How to collect and evaluate the information?

It is important to collect valid and up-to-date information. Information on the processes can be obtained from a wide range of sources. Figure 3-7 gives examples of data sources. It is useful to check whether this information is reasonable (for example, by means of mass and energy balance). It is not always easy to collect the necessary information or is often unavailable. Since this information does not necessarily have an impact on the product quality and quantity or the trouble-free operation of the process, it is often not measured or collected. If the database is incomplete, it must be completed with additional measurements, calculations, or reasonable assumptions (for example through correlation between production and energy data). In addition, when checking or calculating missing information, it must be considered that losses such as heat loss occur in the system. It is also advantageous to estimate these losses.

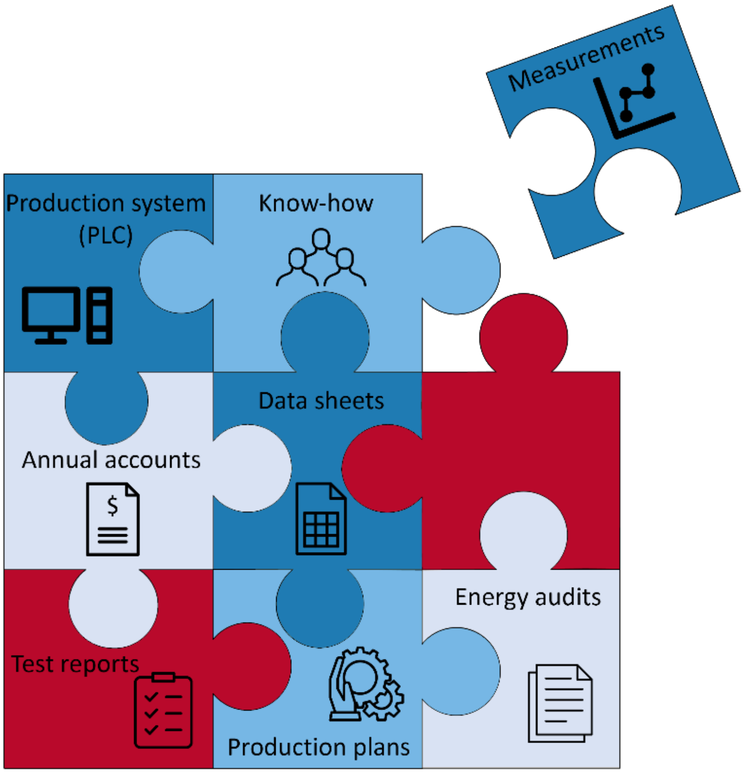

Figure 3-7: Sources of information (Source: AIT Austrian Institute of Technology GmbH)

3.4. What needs to be known to assess the feasibility of heat recovery measures?

Increasing energy efficiency is a crucial contribution for the transition to decarbonized industrial energy systems. The questions that need to be answered to create a basis for evaluating the applicability of efficiency improvement measures such as heat exchangers and HPs are listed in Table 3-1.

Table 3-1: Checklist for creating the information basis for assessing the applicability of efficiency improvement measures

Checklist
Is there a need for cooling? What needs to be cooled? What is the temperature of the medium to be cooled? What is the target temperature? What is the cooling capacity or the mass flow of the medium to be cooled? How does the cooling requirement change over time? How is cooling currently provided?
Is there unused waste heat? What kind of medium is it? Is it polluted? What is the temperature of the waste heat? What is the temperature to which the waste heat flow can be cooled? Humid air: What is the humidity (dew point …)? What is the mass flow? How does the waste heat flow (temperature, capacity) change over time?
Is there a heating demand? Which medium should be heated? What is the target temperature? What is the required mass flow? How does the demand (temperature, capacity) change over time?

4. How to develop and evaluate concept solutions for decarbonization?

Once a good database has been created, the development of concept solutions for decarbonization of the site under consideration or its subsystems and their evaluation can begin. The optimal concept is case-specific and can vary significantly depending on the application. Various aspects need to be evaluated to develop a concept solution. The development of concept solutions is often iterative rather than straightforward. In addition, external expertise often must be consulted.

4.1. What technologies are available for decarbonization of process heat supply?

Several technologies and energy carriers can be used to decarbonize process heat supply. Figure 4-1 shows four categories of such technologies and energy carriers. The *Efficiency increase* category includes heat exchangers, HPs and storages. HPs cannot only increase the efficiency of the heat supply, but they also contribute to its electrification. Therefore, HPs are also included in the second category *Electrification*, which includes electric boilers and electric heating elements. an important key performance indicator (KPI) in evaluating HPs. This is the coefficient of performance (COP). It describes the ratio between the provided heat capacity and the electrical energy consumed by the HP and is, therefore, an indicator of the efficiency of the HP measure. The HP requires significant less electrical energy for the same heating capacity than an electric boiler or electrical heating elements (e.g. one third of a COP of 3 can be reached). The *Renewable gases* category includes biogas, synthetic methane, and hydrogen. The energy carriers wood, energy crops, and waste materials are included in the *Biomass* category. Which of the technologies are suitable must be assessed, for example, based on the application range of the individual technologies, availability, or other boundary conditions. For both the energy carriers in the “Renewable gases” category and the “Biomass” category, it should be ensured during concept development that these are sufficiently available for the long term. This document and the guideline focus on the HP technology.

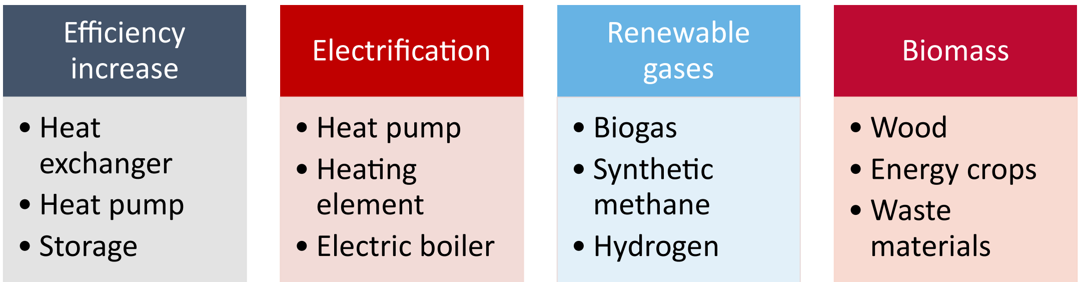

Figure 4-1: Technological components and energy carriers for the decarbonization of process heat supply (Source: AIT Austrian Institute of Technology GmbH)

Regarding HP technology, it should also be mentioned that there are clear advantages when there is a cooling demand. The HP can then cover the cooling demand and simultaneously generate process heat. This means that cooling requirements can be reduced and equipment such as cooling towers can be removed. In addition, the technology can also be used as a flexibility measure, for example, in combination with storage tanks, whereby the aim should be to operate the HP as continuously as possible to reduce start-up and shut-down processes.

4.2. What is the level of integration?

When integrating HPs, a distinction can be made between different levels of integration, as shown in Figure 4-2. In the case of integration at the *process level*, the process medium is reused and “upgraded” after the process before it is fed back into the process as a supply. An example of this is mechanical vapor recompression (MVR). At the *unit level*, integration takes place, as the name suggests, for a consumption unit while using its waste heat. For example, the energy supply for heating the drying air in a dryer with an HP by utilizing the energy from its exhaust air. A central steam-generating HP supplying several processes, for example instead of a steam boiler, is referred to as integration at the *utility level* (HP-based boiler). For example, waste heat from one or more processes can be utilized. In the case of integration at the *sector level*, the HP is used to supply one or more processes, utilizing a heat source from another sector. An example of this is the supply of process heat when using district heating as a heat source for the HP.

When integrating HPs, the measure's efficiency increases if the HP is integrated closer to the process. The reason for this is that the closer to the process, the lower the required temperature level, as lower thermal losses are expected due to the lower distance to the supply unit. The same applies for waste heat, which has the highest temperature level directly at the process where it occurs. Integration at the process level is the most complex, and the dependency on process requirements increases the closer the integration is to the process. Integration at the sector level offers the greatest flexibility, economies of scale, and planning horizon.

The optimal integration level generally depends on the actual site layout and characteristics, the heat sources available, and the temporal planning horizon.

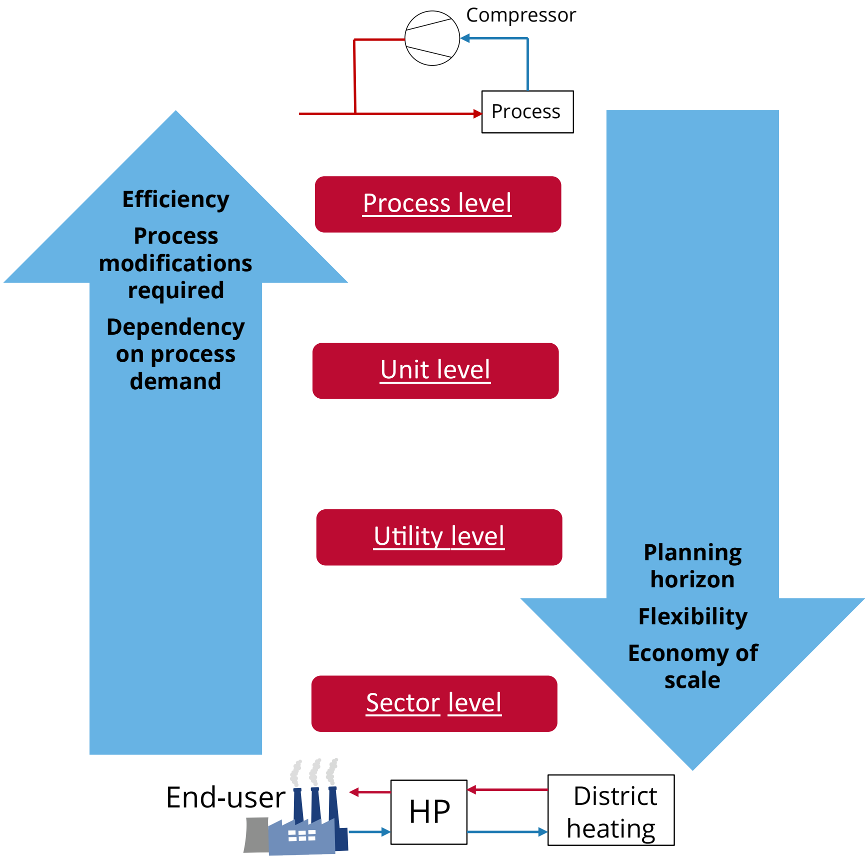

Figure 4-2: Presentation of the different levels of integration and their effects (Source: Danish Technological Institute)

4.3. Can we do better?

Integration as close as possible to the process increases the COP of the HP. The COP of a HP depends on the temperature lift (temperature difference between sink and source outlet) it must overcome. The higher the temperature lift, the more electrical energy is required and the lower the COP. Therefore, the adaptation of process or utility parameters, i.e., reducing the sink outlet temperature, typically leads to an increased COP

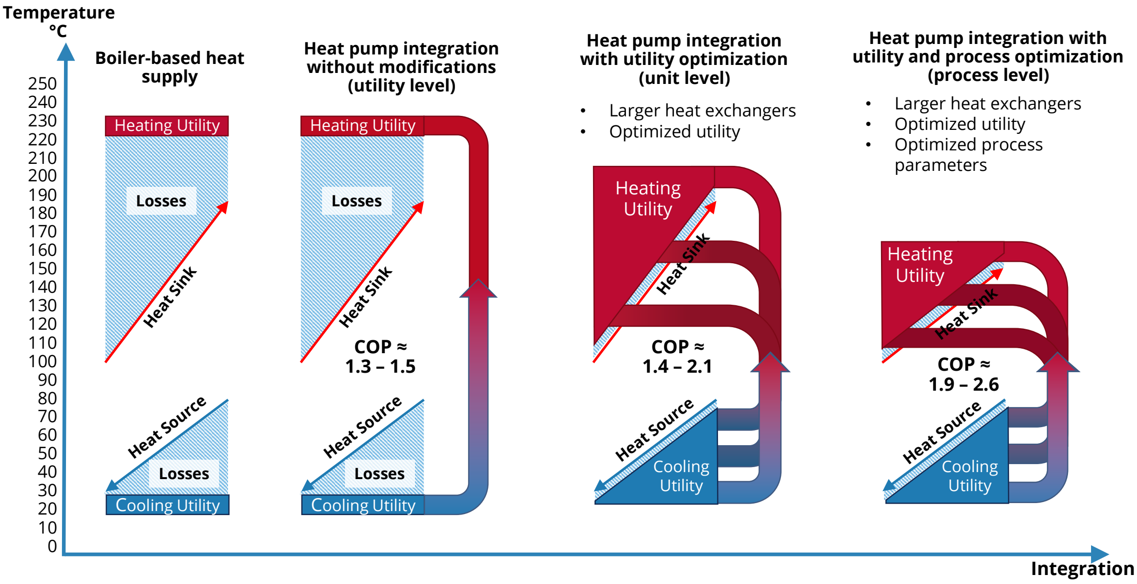

Figure 4-3: Example of optimized integration of HPs with exemplary COP improvement (Source: Danish Technological Institute)

Not only does the efficiency of the HP increase by reducing heat losses through these and subsequent efficiency measures on process level, but the total energy demand also decreases. The kilowatt hour that is not required does not have to be provided and does not incur any costs. In order to save energy costs and not oversize heat recovery systems or HPs, this step is particularly relevant.

Therefore, it is important to be clear about the supply medium parameters the product or the process really needs. If it is possible to reduce the temperature to be supplied, the impact on the available waste heat should be analysed and quantified. Figure 4-3 shows, as already mentioned, that the COP increases with integration from the utility level to the process level. Furthermore, it is shown that utility adaption to the actual demand (i.e. when the supply medium is not only provided at the highest temperature level) can lead to an increase in efficiency (third figure from the left). If the process parameters are also adjusted, a further increase in COP can be achieved (last figure).

4.4. How to get a concept solution?

The path to an optimal concept solution is shown in Figure 4-4. The optimal concept is highly dependent on the application. The data collected forms the basis for developing the optimal concept. Also, site-specific boundary conditions such as available connection power and space availability are important for the identification of the optimal concept. These site-specific criteria can limit the extent to which the technology can be implemented, such as the capacity of the technology, and can also strongly influence the costs for integrating the technology. Different methods to develop the optimal concept are available: *Pinch analyses*, *physical modelling*, and *mathematical optimization*.

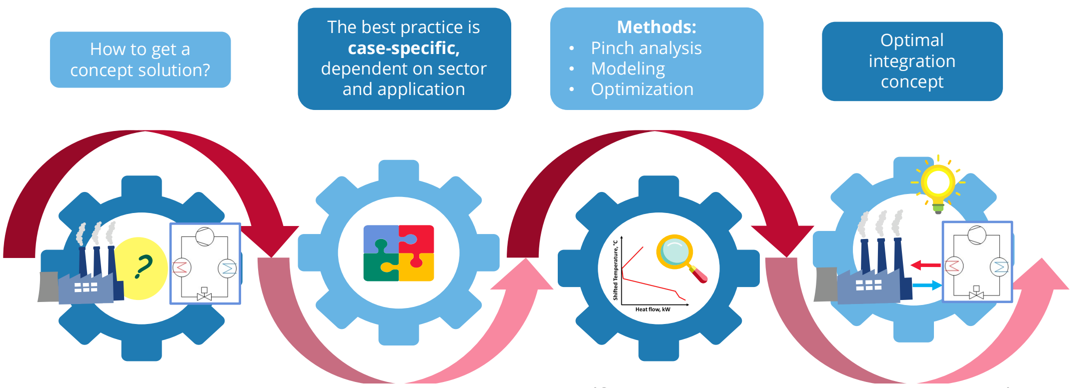

Figure 4-4: The path to an optimal integration concept (Source: Danish Technological Institute)

The *Pinch analysis* is a graphical approach holistically describing the thermal streams by their demand and temperature level and thereby supporting the identification of heat recovery potentials. It can help to determine which share should be recovered by means of heat exchangers and and how heat pumps can be integrated in the overall process in an optimal way. Further introductory information on the methods can be found in Kemp [10].The first step of a *Pinch analysis* is collecting all process flows with a cooling, heating demand or excess heat potential (flows without an obligatory cooling requirement that can be used for heat recovery, i.E. flue gas or exhaust streams). A curve is then entered in a $\dot{H}$- T-diagram for all flows with a heating demand. The curve indicates the heating capacity needed per temperature difference for all flows and is called the cold composite curve (cold CC). The hot CC is created similarly for all flows with cooling demand. The hot CC includes not only flows that need to be cooled but also waste heat flows that are released into the environment without cooling. The resulting CCs are shown for the example process in Figure 4-5(a) based on data from [11].

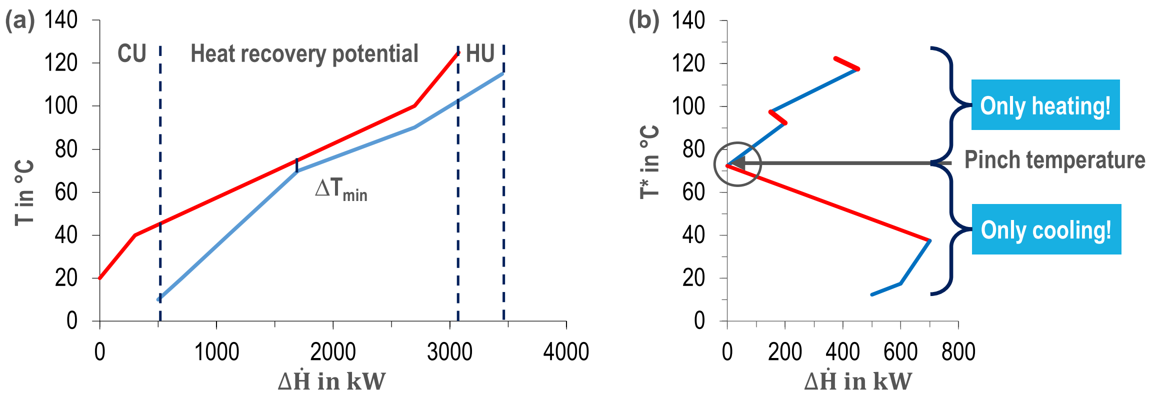

Figure 4-5: (a) Targeting of heat recovery potential using CCs and (b) remaining heat and cooling demand by the GCC [12]

The overlap of the two curves on the horizonal axis, presents the direct heat recovery potential (HR). The point at which the hot and cold CC come closest to each other (minimum temperature difference) is called the pinch point. This minimum temperature difference can be changed by moving the curves horizontally. In general, the smaller the temperature difference at the pinch point, the larger the heat exchanger surface. The non-overlapping part of the hot CC represents external cooling demand (cold utility, CU) and excess heat potentials. Similarly, the overlap of the cold CC represents the need for external hot utility (HU).

Three rules for *Pinch analysis* can be summarized:

(i) No external heat supply below the pinch point
(ii) No external cooling above the pinch point
(iii) No heat transfer across the pinch point

The grand composite curve (GCC) can be derived from the two CCs. This is shown in Figure 4-5 (b). The GCC provides information about how much (remaining) heating or cooling is required at which temperature level. To obtain the GCC, the hot and cold CC must first be shifted vertically in equal proportions until they meet at the pinch point. In the GCC, the pinch point lies on the y-axis, and the GCC is constructed by plotting the thermal load difference between shifted cold and hot CC at the corresponding temperature.

Based on the three rules mentioned above, an HP should be integrated so that it cools below the pinch point and heats above the pinch point. Exclusive HP integration above or below the pinch point leads to efficiency losses or even higher energy demand as it can be seen in Figure 4-6. The worst-case scenario is shown in the first illustration, because the HP in this example even increases the cooling demand (CU) by the electrical compressor load (P_{el}) because both heating and cooling is done where only cooling is allowed. Integration above the pinch temperature only covers the heating demand (HU) by the compressor load. Only the integration of the HP around the pinch temperature can unlock the efficiency potential of a HP as it cools where cooling is needed and upgrade the waste heat to a useful temperature level for heating above the pinch temperature.

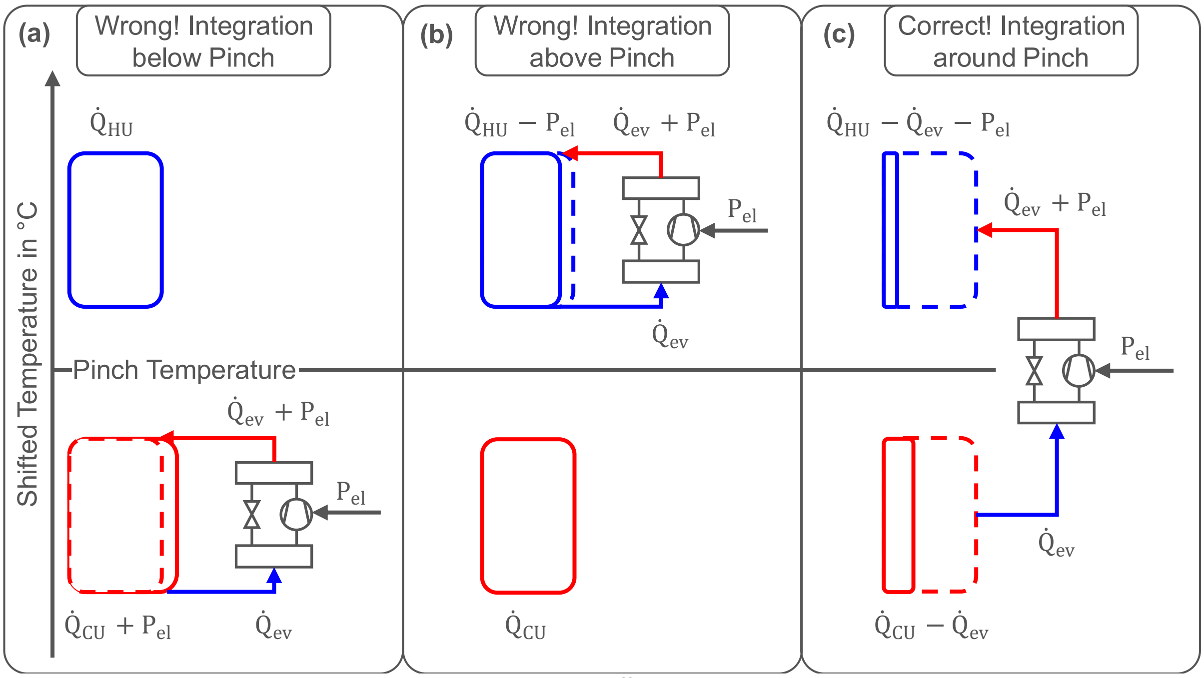

Figure 4-6: Integration possibilities and corresponding effect on remaining heating and cooling demand [13]

HP integration exclusively above or below the pinch point can only be useful in rare cases in so-called pockets of the GCC. This is not discussed in detail here. A detailed explanation and presentation of the method and the procedure can be found, for example, in Arpagaus [14]. Moreover, the left diagram in Figure 4-7 shows a real example of a *Pinch analysis* with targeting of the heat recovery potential by the CCs. In the middle of Figure 4-7 a corresponding HP integration is shown and the diagram on the right shows the CC resulting after successful HP integration.

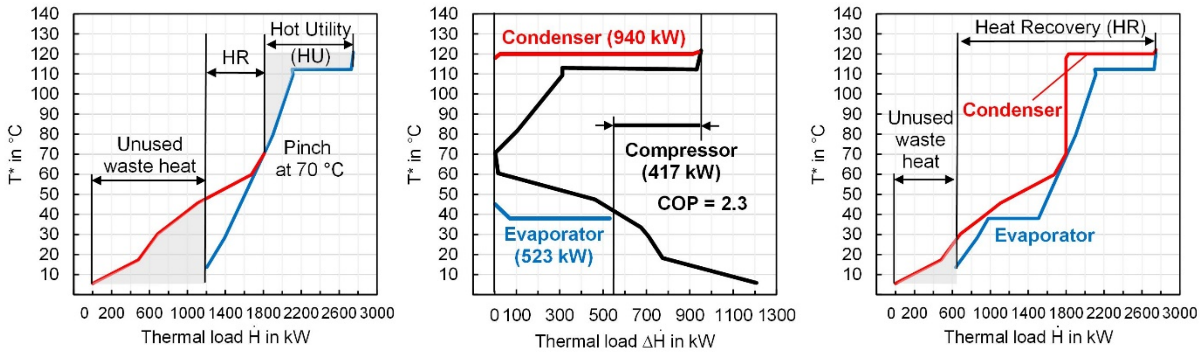

Figure 4-7: Example of a Pinch analysis with HP integration for an industrial process with dryer (TIXOTHERMTM). CC (left), GCC (middle) and CC after HP integration (right). [15]

Based on the *Pinch analysis*, it can be identified which part of the heat recovery in processes should be carried out by heat exchangers and which part by HPs. In general, it is economically advantageous to use heat exchangers for as much heat recovery as possible, as they are significantly cheaper. It should be noted that the *Pinch analysis* is conducted for one stationary operating point at a time. Dynamic changes in the process are not considered in this method. However, further developments are ongoing, e.g., in the so-called *Heat Exchanger Network Synthesis* approach.

Another option for developing concepts is *physical modelling*. In contrast to *Pinch analysis*, there is no defined procedure here. *Physical modelling* offers the possibility of analysing components such as HPs or entire systems with the accuracy required for the concept development. Different dependencies between components in a heat recovery system or in the overall system can be modelled and analysed in detail. Also, influences on the process in which the heat recovery system is to be integrated or on the product can be analysed. It is also possible to investigate different operating points and boundary conditions, not only in the stationary case but also in the dynamic case. Physical models can also be used for controller development or operational optimization. *Physical modelling* offers a wide range of possibilities for concept development, but a corresponding information base is necessary for this.

Mathematical optimization offers the option of identifying a cost-optimal concept from a large number of possibilities. Here, the best concept is identified with the help of an algorithm, considering the defined boundary conditions. Another advantage of optimization is the ability to simultaneously consider technical, ecological and economic aspects. Other criteria, such as site-specific aspects, can be included in the optimization either as a boundary condition or by causing costs.

In general, a distinction can be made between linear and non-linear optimization. As the name suggests, the optimization model must be a linear model for linear optimization. To obtain a linear model, simplifications must be made. However, the advantage is that the computing time for the linear optimization is significantly lower, and a global optimum can be guaranteed as a result. With non-linear optimization, on the other hand, non-linear effects can also be considered in the model. However, this can lead to significantly higher computing times, and a global optimum cannot be guaranteed. *Mathematical optimization* as a method for concept development is particularly advantageous for large systems. In general, the appropriate method for concept development must be selected. It may also be necessary or useful to use all three methods or two of the methods presented to identify good concepts. In IEA HPT Annex 58 Task 2[3], HP integration concepts were prepared for different applications, such as brick drying or spray drying, as well as HP concepts such as steam generation. These can be used as support for concept development.

4.5. Will it pay off?

During concept development, various KPIs are used to evaluate a concept solution or compare it with other concept solutions. Figure 4-8 shows examples of different KPIs. Economic (e.g., operating cost and investment cost) and non-economic (e.g., space requirement and implementation ability) KPIs can be used to evaluate concepts. When evaluating the investment costs, not only the cost of the component itself but also the integration costs must be taken into account, as these can make a major contribution.

Different KPIs do not lead to the same result. Depending on the KPI selected, a different concept solution may be the best choice. Each company must decide how important a particular KPI is to them compared to others and weigh it accordingly. The comparison of different concept solutions using several KPIs is illustrated schematically in Figure 4-8.

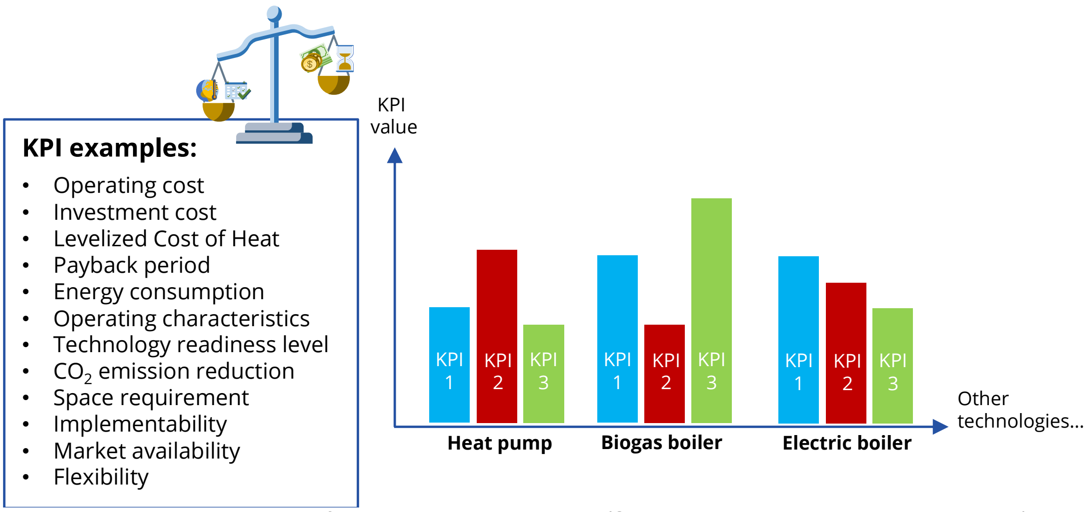

Figure 4-8: Evaluation of concepts based on KPIs (Source: Danish Technological Institute)

When creating a decarbonization strategy, the reducing CO_2 emissions must play a primary role. Nevertheless, the economic evaluation criteria play a key role in most companies. KPIs are not only required for the evaluation or selection of a concept, but they can also indicate when it is reasonable or

[3] IEA HPT Annex 58, Task 2 – Integration Concepts https://heatpumpingtechnologies.org/annex58/task-2-integration-concepts/

feasible to implement the technology (e.g., TRL and market availability). Furthermore, supply security and redundancy are important issues for companies when selecting and developing concepts. As already mentioned, avoided cooling costs increase economic efficiency and should therefore be taken into account here.

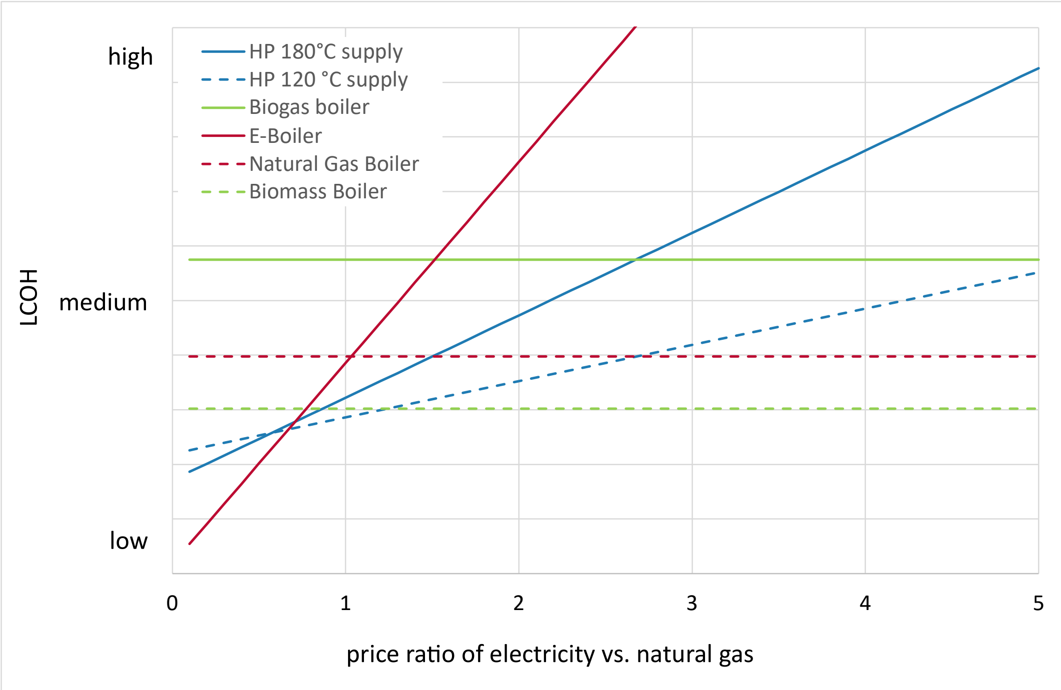

Figure 4-9: Example for the evaluation of different concepts using the KPI Levelized Cost of Heat (LCOH) (Source: Paderborn University and Danish Technological Institute)

An example of a KPI for the economic evaluation and comparison of different concepts are the Levelized Costs of Heat. These describe the costs for the supply of 1 MWh of heating supply over the lifetime considering demand-related, operation-related and capital-related costs. In Figure 4-9, this KPI is compared as a function of the *electricity-to-natural gas price ratio* for different concepts. As the biogas boiler and biomass boiler concepts are independent of the *electricity-to-gas price ratio*, a horizontal line results for these concepts. There is also a horizontal line for the natural gas boiler, as only the electricity price and not the gas price was changed when varying the *electricity-to-gas price ratio*.

The electric boiler (E-Boiler) shows the strongest cost increase with an increasing *electricity-to-gas price ratio* as it is significantly more dependent on the electricity price than both HP concepts (HP 120°C supply and HP 180°C supply). Among the HP concepts, the HP with a supply temperature of 180°C shows a significantly greater increase than the HP with a supply temperature of 120°C. The reason for this is that the HP considered here to have a supply temperature of 180°C, which requires more electrical energy and, therefore, has a lower COP than the HP assumed to deliver a supply temperature of 120°C.

5. How to derive the decarbonization path?

Once the concepts for achieving a decarbonized system have been developed, they need to be implemented. The development of a roadmap supports the implementation process. Following the steps described in the previous chapters provides the basis for developing such a roadmap and thus realizing the strategy. This chapter contains information on what should be considered when preparing such a roadmap. In addition, a theoretical example of a roadmap is given and explained in more detail.

5.1. How to define an implementation roadmap?

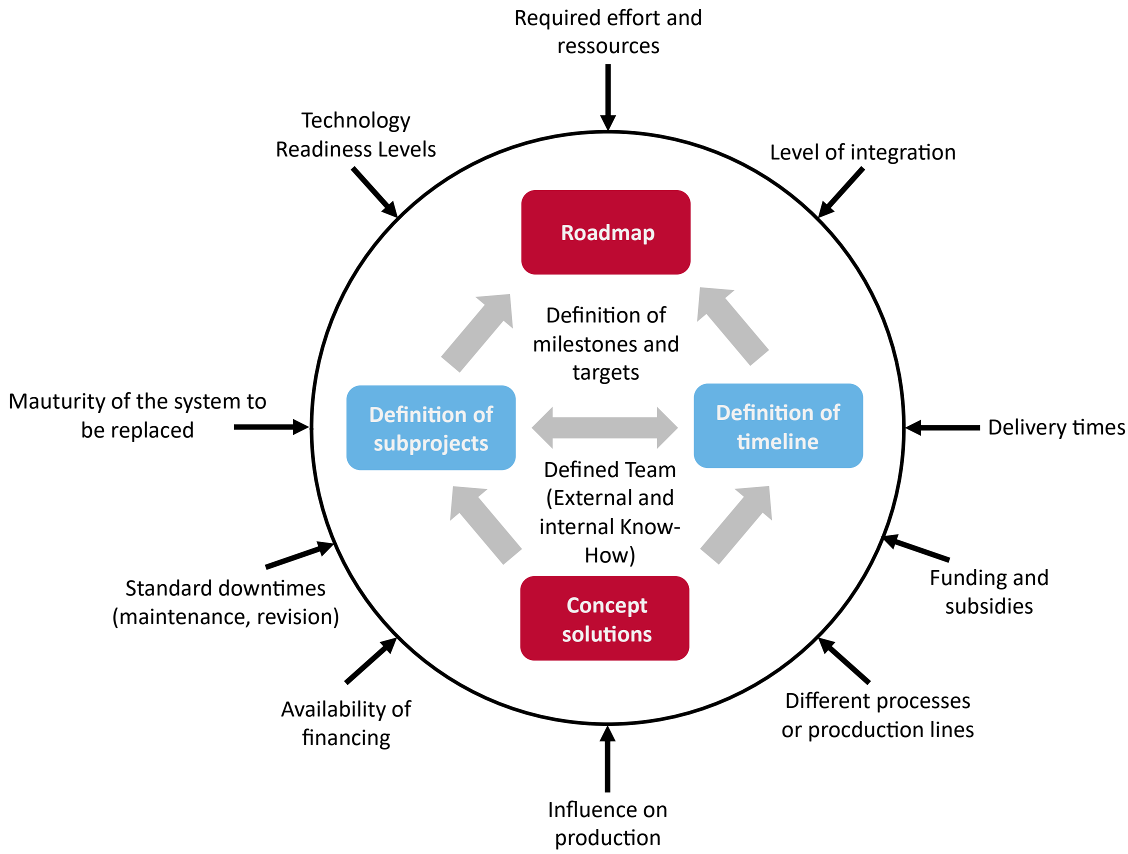

Figure 5-1: Development of a roadmap based on the concept solutions developed (Source: AIT Austrian Institute of Technology GmbH)

The development of a roadmap is not straightforward. It is an interactive process. The starting point is the concept solutions developed for the site under consideration, which are to be implemented to achieve the goal. Based on the concept solutions, subprojects, and the timeline can be derived. The implementation team should also be defined. To define the team, the required expertise should be identified, and whether this know-how is available within the company or whether external know-how is required. The roadmap can be created using the subprojects and the timeline, whereby milestones and interim targets should be created or adjusted. When developing a roadmap or when defining subprojects and the timeline, a number of factors should be considered. Some of these are shown in Figure 5-1. These factors include, for example, delivery time or TRL of a technology, as these can significantly influence the timeline.

To reduce the risk of technologies with a lower TRL level, they could first be implemented and assessed on a meaningful, smaller scale to gain operating experience. The upgrade or implementation on the full scale could then occur later in another subproject. However, care should be taken to ensure sufficient time between the two projects to gain operational experience. Another tip to minimize the risk is to include redundancies in the system. For example, the old supply unit can be retained as a backup system until sufficient experience with the technology has been gained and confidence in the technology has been established.

When implementing the roadmap, it is also important to reassess the status and targets and, if necessary, adapt the roadmap and strategy accordingly. Once a concept solution has been implemented, its impact can be assessed even better. This can lead to deviations from the previously estimated impact.

In addition, new boundary conditions may be identified during implementation that were not taken into account during the development of the concept solutions and, therefore, the implementation of the concept solution or part of it is not possible. It is, therefore, a good practice to consider backup strategies or solutions.

With a well-thought-out and elaborated roadmap, it is easier to implement a long-term strategy well and on time, and to identify problems and deviations at an early stage.

5.2. How can a roadmap look like?

Figure 5-2 shows an example of a roadmap for decarbonizing Scope 1 emissions. The roadmap was created for a theoretical industrial site with processes that require both hot water and steam. This demand is covered by fossil fuels in the current status (time period of the database). This current status is also used as a reference scenario for evaluating the included measures. The aim is to completely decarbonize (Scope 1 emissions) the site by 2040. The interim target is to achieve a decarbonization level of 50% (Scope 1 emissions) by 2030 compared to the reference scenario.

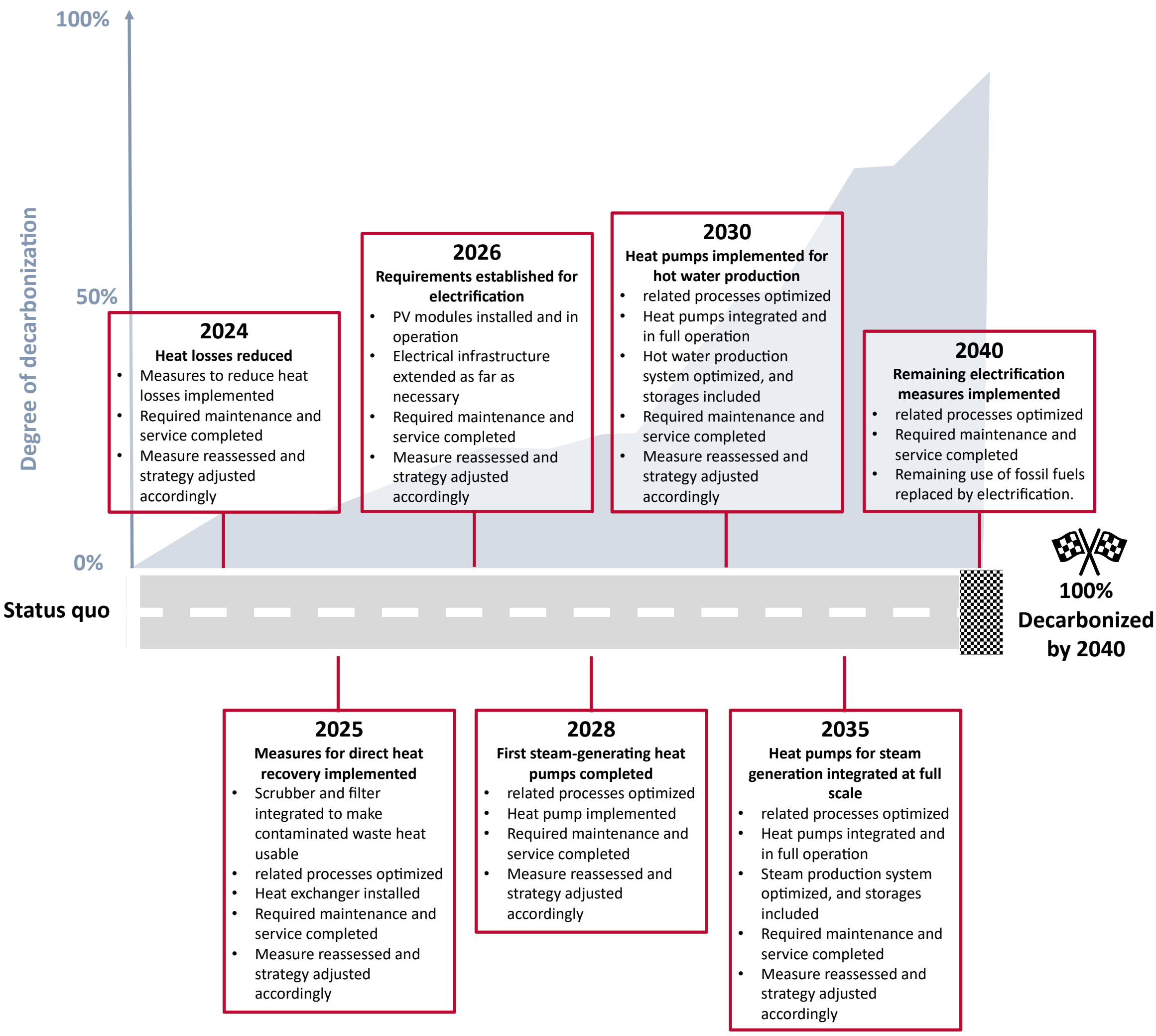

Figure 5-2: Roadmap example for the decarbonization of an industrial location (Source: AIT Austrian Institute of Technology GmbH)

The first subproject in this roadmap will implement defined measures to reduce heat losses. This project should be completed by the end of 2024, the implemented measures reassessed, and the strategy adapted accordingly. The reassessment of the measures and the strategy adjustment are included in all subprojects. Also, the necessary maintenance and service measures are also to be conducted in all subprojects. The second subproject includes measures for direct heat recovery using heat exchangers. The subproject also considers the integration of necessary cleaning units such as filters and scrubbers that need to be integrated to utilize contaminated waste heat streams. Process optimization measures are also implemented here to make these measures as efficient as possible. This subproject is to be launched in such a way that the measures are completed by the end of 2025. This roadmap also includes a subproject for expanding the electrical infrastructure and installing PV systems. This is particularly important regarding the following installation of HPs. This sub-project should be completed by 2026. This roadmap also includes two subprojects for the integration of steam-generating HPs. In the first project, a defined steam pressure level can be supplied with a defined number of HPs and operating experience can be gained. In the second subproject, all planned steam-generating HPs are then to be integrated. The associated process optimization measures and the integration of needed storages are also planned in both subprojects. The first subproject on steam-generating HPs should be completed by the end of 2028 and the second by 2035. In between (by 2030), the subproject for the integration of hot water HPs, including corresponding process optimization measures and storage integration, is also to be completed. In the final subproject, the remaining fossil fuel requirements are also to be replaced by electrification measures so that no Scope 1 emissions are generated by the end of 2040.

6. Conclusion

Developing a decarbonization strategy is a complex process involving many factors. Furthermore, the development process is not linear, as shown schematically in Figure 6-1.

The starting point for developing a good strategy is defining the overarching goal and identifying the product and process requirements and the available waste heat sources. Information on the current energy supply also contributes to the strategy development process. Moreover, the available technology options and the drivers strongly influence the strategy development process. Other boundary conditions at the location under consideration also have a significant influence.

Another important part of the strategy development process is identifying the best concept solutions for the site. A good database is essential to developing good concepts, as the best concept solutions depend significantly on the process, the site and the boundary conditions under consideration. Different evaluation criteria can play a role in selecting the best concept solution. The most suitable criteria and the importance of the individual criteria must be determined. In general, there is nothing such as one concept that is best for all processes and sites.

The overarching goal should be clearly communicated at the beginning of the strategy development process. The intermediate targets can change during the development process, especially during the development and evaluation of concept solutions and roadmap preparation. This means that the processes *definition of goals and targets* and *development and evaluation of concept solutions* can influence each other.

A roadmap can be derived based on the developed and selected concept solutions, goals and targets. It is important to end up with a roadmap that can be realistically implemented, clearly understandable for the people concerned and whose meaning and importance is communicated. Developing a decarbonization strategy is not easy, but achieving the most efficient decarbonized site in the shortest possible time is essential.

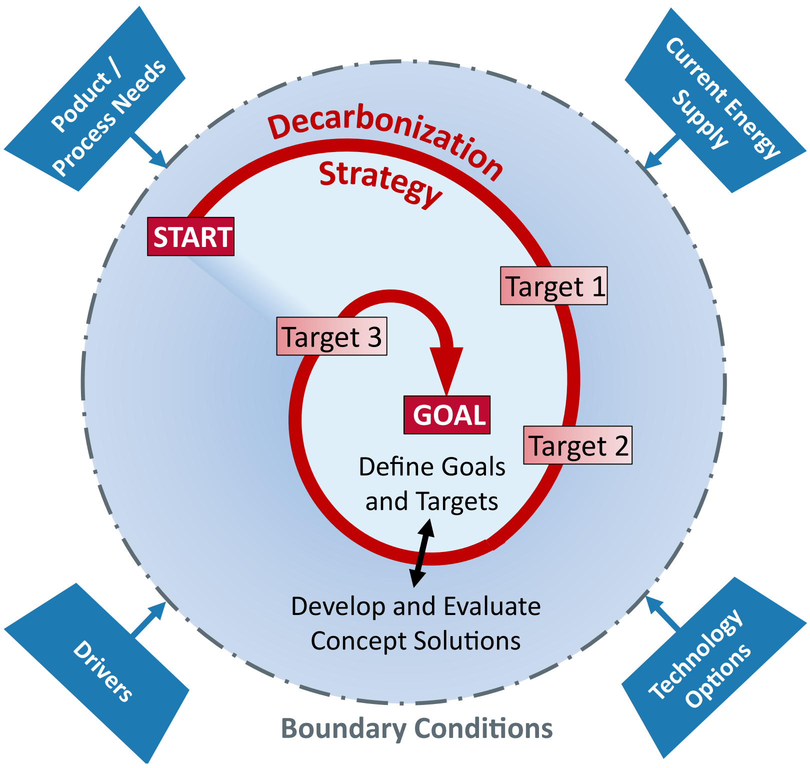

Figure 6-1: Connections in the development of a decarbonization strategy (Source: TU Graz and AIT Austrian Institute of Technology)

7. References

[1] World Business Council for Sustainable Development and World Resources Institute, The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard, 2004. https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf (accessed 7 December 2023).

[2] R.-H. Hechelmann, A. Paris, N. Buchenau, F. Ebersold, Decarbonisation strategies for manufacturing: A technical and economic comparison, Renewable and Sustainable Energy Reviews 188 (2023) 113797. https://doi.org/10.1016/j.rser.2023.113797.

[3] F. Dupond Holdt, A. Kuijers Hostrup, T. Petersen, H. Madsbøll, B. Zühlsdorf, Development of decarbonization strategies of industrial process heating applications - Experiences and case studies, in: Book of Presentations, Denmark, 2024.

[4] International Energy Agency, Energy Technology Roadmaps: A guide to development and implementation, 2014.

[5] Science Based Targets initiative. https://sciencebasedtargets.org/ (accessed 16 February 2023).

[6] P.C.S. Faria, N. Labutong, A description of four science-based corporate GHG target-setting methods, SAMPJ 11 (2019) 591–612. https://doi.org/10.1108/SAMPJ-03-2017-0031.

[7] C. Dugast, Net Zero Initiative: A Framework for Collective Carbon Neutrality, 2020. https://www.carbone4.com/files/wp-content/uploads/2020/04/Carbone-4-NZI-Guidelines-april-2020-2.pdf (accessed 6 February 2024).

[8] S. Moser, S. Goers, K. de Bruyn, H. Steinmüller, R. Hofmann, S. Panuschka, T. Kienberger, C. Sejkora, M. Haider, A. Werner, C. Brunner, J. Fluch, A. Grubbauer, Renewables4Industry. Abstimmung des Energiebedarfs von industriellen Anlagen und der Energieversorgung aus fluktuierenden Erneuerbaren: Endberichtsteil 2 von 3. Diskussionspapier zum Projekt Renewables4Industry. Endberichtsteil 2/3, FFG-Nr. 858974, 2018.

[9] Austrotpapier, Sector Report 2016/17. (in German: Branchenbericht 2016/17), 2017. http://www.austropapier.at/fileadmin/austropapier.at/dateiliste/Dokumente/Downloads/Jahresberichte/BB16_-_ganzer_Bericht__LowRes_.pdf (accessed 1 December 2017).

[10] I.C. Kemp, Pinch analysis and process integration: A user guide on process integration for the efficient use of energy, second. ed., Elsevier/Butterworth-Heinemann, Amsterdam [u.a.], 2007.

[11] J.J. Klemeš, P.S. Varbanov, S.R.W.W. Alwi, Process Integration and Intensification, De Gruyter, Berlin, Boston, Mass., 2014.

[12] M. Philipp, G. Schumm, F. Schlosser, R. Peesel, U. Holzhammer, Basic issues of waste heat recovery. Exploiting efficiency improvement potentials in industry through waste heat utilisation. (in German)., BWK Energie-Fachmagazin (2016) 36–39.

[13] M. Philipp, F. Schlosser, R.-H. Peesel, G. Schumm, U. Holzhammer, Sector coupling process heat / electricity in German industry: Integration of renewable energies into the heating sector. (in German), BWK Energie-Fachmagazin (2017) 57–60.

[14] C. Arpagaus (Ed.), Hochtemperatur-Wärmepumpen: Marktübersicht, Stand der Technik und Anwendungspotenziale, 1st ed., VDE Verlag, 2018.

[15] C. Arpagaus, F. Bless, S. Bertsch, P. Krummenacher, D.A. Flórez-Orrego, E.A. Pina, F. Maréchal, N. Calame Darbellay, F. Rognon, S. Vesin, P. Achermann, C. Jansen, Session Keynote: Integration of High-Temperature Heat Pumps in Swiss Industrial Processes (HTHP-CH) (494): 14th IEA Heat Pump Conference, 15-18 May 2023, Chicago, Illinois, USA. https://www.hpc2023.org/wp-content/uploads/gravity_forms/3-7075ba8a16c5f78b321724d090fb2a34/2023/05/0494_HPC2023_Full_Paper_Arpagaus_v02.pdf (accessed 20 February 2024).

www.heatpumpingtechnologies.org

Heat Pump Centre
c/o RISE - Research Institutes of Sweden
PO Box 857
SE-501 15 BORÅS
Sweden
Tel: +46 10 516 53 42
E-mail: hpc@heatpumpcentre.org

www.heatpumpingtechnologies.org

Report no. HPT- AN58-4