

Final report

1. Project details

Project title	Efficient Energy Mapping and Analysis for Optimization and Green Transition of Industrial Processes (EEMAP)
File no.	64022-1073
Name of the funding scheme	EUDP 2022-I
Project managing company / institution	Viegand Maagøe
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Project partners	Viegand Maagøe, Danmarks Tekniske Universitet, IPU.
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2. Summary

Project summary

The industrial sector is expected to account for 14% of Denmark's CO₂e emissions by 2030¹, highlighting the need for a green transition that prioritizes energy efficiency. EEMAP is software tool developed to support this effort by reducing the costly barriers associated with the efforts of conducting energy mappings and analysis.

Results:

- Developed the EEMAP tool for Efficient Energy Mapping and Analysis for Optimization and Green Transition of Industrial Processes, making energy mapping faster and more cost-effective.
- Reduced mapping completion time from weeks to days, improving accessibility for SMEs.
- Piloted with three companies, confirming opportunities for energy savings.
- Supported decision-making in corporate strategy implementation and regulatory compliance.

Conclusions: EEMAP has effectively assisted SMEs in overcoming challenges in energy mapping. By lowering the resources needed, the tool allows companies to adopt more efficient practices, which contributes to reducing CO₂ emissions and supports the green transition. EEMAP also aids companies in meeting energy management regulations and helps digitize their energy systems for better optimization.

Perspective: EEMAP will continue to promote faster and more cost-effective energy mappings, encouraging more companies to adopt energy-efficient practices. Future updates to the tool will focus on the user-friendliness of the tool and expanding its availability both nationally and internationally. With increasing regulatory demands for energy audits and certified Energy Management Systems, EEMAP will become increasingly relevant for companies aiming to meet these requirements. Ultimately, it will support businesses in optimizing energy use and achieving their sustainability targets.

¹ (Klima-, Energi- og Forsyningsministeriet, 2024)

Projektresumé

Formålet med projektet

Industrisektoren forventes at udgøre cirka 14 pct. af Danmarks CO₂e-udledninger i 2030 og kræver derfor en gennemgående grøn omstilling med bl.a. fokus på energieffektivisering for at reducere deres klimaaftryk. Softwareværktøjet EEMAP er blevet udviklet mhp. at reducere den omkostningsfyldte proces i at lave en energikortlægning.

Resultater:

- Udviklingen af EEMAP til Effektiv Energikortlægning og Analyse med fokus på Optimering og Grøn Omstilling af Industrielle Processer, hvilket gør arbejdet med energikortlægning hurtigere og mere omkostningseffektiv.
- Tiden til at gennemføre energikortlægning er reduceret fra uger til dage, hvilket forbedrer tilgængeligheden for små og mellemstore virksomheder (SMV).
- Gennemførte pilotprojekter med tre virksomheder, der har bekræftet mulighederne for optrævlingen af energibesparelserprojekter.
- Et værktøj, som understøtter beslutningsprocessen i implementeringen af virksomhedens strategi og overholdelse af reguleringer.

Konklusioner: EEMAP har effektivt hjulpet SMV'er med at overvinde udfordringer inden for energikortlægning. Ved at reducere de nødvendige ressourcer muliggør værktøjet adoptionen af mere effektive praksisser, der kan bidrage til at reducere CO₂-udledningen og understøtter den grønne omstilling. Derudover hjælper EEMAP virksomhederne med at opfylde energistyringsregler og digitalisere deres energisystemer for bedre optimering.

Perspektiv: Fremtidige opdateringer af værktøjet vil fokusere på brugervenlighed og udvide tilgængeligheden både nationalt og internationalt. Med stigende regulatoriske krav til energirevisioner og certificerede energistyringssystemer vil EEMAP særligt være relevant for virksomheder, der sigter mod at opfylde disse krav. I sidste ende vil det støtte virksomheder i at optimere energiforbruget og nå deres bæredygtighedsmål.

3. Project objectives

Implementing the green transition is a costly and a resource-intensive task that requires a clear, comprehensive strategy right from the start. A crucial element for developing a robust strategy and ensuring the project quality is having a solid informational foundation which can be found by an energy mapping. Unfortunately, many companies skip this step and move directly to project execution, as conducting such mappings often are time-consuming and expensive. The approach of skipping an energy mapping can result in suboptimal solutions and missed opportunities for optimizing resources in the production site. In response to these challenges, the partnership of DTU, IPU, and Viegand Maagøe developed the software tool EEMAP.

The objective of the project was to develop a tool accessible to small and medium sized enterprises, who typically face barriers in their work with energy mapping. Energy mappings offer numerous benefits and significant economic value. The project aims to enhance the following aspects:

- Increased energy efficiency
- Electrification of industrial processes
- Utilizing excess heat to district heating projects
- Developing company strategies for reaching zero CO₂ emissions

EEMAP is tool designed to be used by energy experts or consultant who typically conduct energy mappings. The tool can also be used by employees at the production facility with relevant energy-related knowledge for tasks such as updating the existing mappings in response to process changes or calculating on alternative process structures.

The software builds on the framework of creating an initial mapping of the process in its simplest form using mass balance calculations to enable a straightforward presentation of the process flow. Hereafter, the model can be refined to include a higher level of detail, by adding information to calculate energy flows and solve energy balance equations.

Inspired by current work practice

The tool framework is inspired by the current work practices associated with conducting an energy mapping. Typically, energy consultants have an initial meeting at the facility where they together with the facility managers create a rough sketch of the mapping to ensure that all important process parts are included, and the connections are properly understood. This sketch is usually done by hand to provide a visual representation of the process for discussion. The drawing is afterwards translated and transferred to an advanced Excel sheet, where the calculations are made. The Excel sheet is often complex and challenging to interpret, particularly for those who were not involved in the initial energy mapping process. Consequently, any changes in project members usually requires onboarding to ensure they can work with the Excel sheet effectively.

Uncertainties in the mapping are identified by comparing the purchased energy with the consumed energy to define the mapping degree of the total energy consumption, with a low mapping degree indicating the need for another iteration of the energy mapping. Once an acceptable level of the mapping degree is achieved, the consultant refines the process and elaborates on each component to generate results that can be used to analyse and identify specific energy saving opportunities.

Table 1 - Process steps in energy mapping with and without EEMAP

Process steps		Without	With EEMAP
1	Initial meeting with process	Hand sketches	EEMAP
2	Request for more data	Mail	Mail + EEMAP
3	Add all information in Excel	Excel	-
4	Calculate mass and energy balance	Excel	EEMAP
5	Analyse and evaluate mapping degree	Excel	EEMAP
6	Identify projects for optimization (via Pinch Analysis, Heat Recovery Network, etc.)	-	EEMAP
7	Report	Word/Excel	Word/EEMAP

EEMAP has refined this aspect of the energy consultant's workflow by reducing the number of formats that the information runs through (hand sketching, mails, Excel, Word) and thereby also the potential sources of error, by only having one main system of interaction, EEMAP. The user's workflow is furthermore optimised by offering a module-based component library that enables the user to easily drag and drop standard process components and add information to calculate the mass balance or energy balance at once.

The user can furthermore adjust the level of detail by easily expanding the number of components and go from a low-fidelity mass balance mapping to a detailed energy mapping. EEMAP makes it possible to create an energy mapping in a matter of 2-4 days, compared to the current 2-4 weeks/month.

Partner companies

EEMAP was developed in collaboration with six partner companies from various sectors of the industry, and each representing a range of different production processes (view table 2). To get the most out of the companies' input, we divided the companies into two groups. With group 1, also known as the development group, participated in the scoping and development steps of the tool to ensure that industry-specific aspects were taken into consideration. In practice, this meant involving Group 1 in recurring test and feedback sessions of the tool to ensure usability and enhance the user experience (UX).

Furthermore, applying real data from the companies in Group 1 to simulate the energy mappings provided valuable insights. This process helped determine the accuracy and applicability of the developed methodology, establishing it as the backbone for software development. Additionally, it helped identify the criteria for defining standard components and which components should be included in the component library. The selection of these components was influenced, among other factors, by those that were frequently observed in the initial energy mappings of the Group 1 companies.

Table 2 - List of partner companies, their industry and role division in the project

Company	Industry	Group
FF Skagen	Manufacture of fish meal	1
Sonoco Skjern	Manufacture of paper and cardboard	1
Ovodan	Manufacture of egg powder products	1
Royal Unibrew	Manufacture of soft drinks: production of mineral water and other bottled water	2

PPG Scandinavia	Manufacture of paints, varnishes, and similar surface treatment products, printing inks, and sealing materials	2
Avista Green	Manufacture of refined mineral oil products	2

Group 2, referred to as the test group, was engaged after the tool's development to test the hypothesis that EEMAP could significantly reduce the time required to conduct an energy mapping. Their production sites were used to test whether the functionalities worked as intended in real-world applications. Furthermore, the facility managers provided with feedback on any necessary adjustments to the calculations and user experience.

Presentation of the partner companies

Ovodan processes eggs to egg powder and has production facilities in Odense. Here the processes are run from process steam and directly fired gas.

- For EEMAP the facilities can be considered specialized, however the processes can be simplified to a relatively simple process flow. This means that the model is ideal for working with EEMAP as a tool, since no significant challenges arose from mapping the process. Instead, more general issues could be identified as the model reached a final stage relatively quickly.

FF-Skagen produces fishmeal and fish oil and is located in Skagen. Gas and oil boilers deliver 10 bar steam to power their processes. The steam is also utilized for space heating. Their process utilizes several advanced steps like evaporator columns in series reusing the steam generated from the former to power the next and a dryer for their fishmeal.

For the project about 470,000 tons of fish was used as a yearly input, yielding about 32,000 tons of fish oil and 84,000 tons of fishmeal.

- For EEMAP the interconnectedness of their processes are very interesting to model, requiring several steps of heat recovery both in the evaporators but also in heat exchangers connecting different parts of the process.

Royal Unibrew is a brewery located in Faxe. They brew beer and produce several different soft drinks. Their production is powered by a hot-water system and a heat recovery system in large part. The hot-water system is powered by oil and gas. Their production consists of 10 lines in the bottling plant and a complex brewing process in the brewery. Both require heating and cooling for multiple purposes.

- For EEMAP the complexity of the plant is very relevant. The sheer number of components needed for the process mapping is a good test for the usability of EEMAP.

Skjern Paper is a paper producer located in Skjern, who repurpose old paper and use wood chips for the production. The process is first pulping the raw materials to a slurry of fine wood fibers and water, followed by an extraction of the water in various ways mechanically and then thermally. There is a significant thermal energy use as steam is used to evaporate the water in the final stages. Furthermore, a significant amount of electric energy is used to remove the water by pressing, vacuum and filtering. The transport of the product during the process is also electrically driven by several motors.

For the project about 75,000 tons of paper that is to be recycled is the yearly input, from these 73,000 tons of recycled paper is produced annually.

- For EEMAP the drying process being driven in part by its surplus heat is important to properly model. For an advanced and sophisticated model several two stream evaporators could be employed, however for a simple model an evaporator with recirculation of the vapor exiting accomplishes the same.

PPG Coatings produce painting and resin for professionals and for private customers. Their production is located in Gladsaxe and is contained in a large building mass. The production of the paints in and of themselves are not intensive in thermal energy use but has significant electrical energy consumption. For the paint production resin is necessary. This production is quite energy intensive and requires temperatures over 250°C. Apart from the resin that is produced on site several other ingredients are used in production: water, solvent and dry matter.

- For PPG the high temperature required for the resin production highlights the necessity of being able to evaluate the state of the products at temperatures above 150 °C. Furthermore, PPG has a relatively high share of their energy usage in their space heating, which is interesting as the building energy consumption can be further investigated.

Avista Green recycles waste oil and refines it into various oil products. The company is located in Kalundborg where the waste oil is processed and mainly through distillation different oil fractions are separated. The distillation temperatures are quite high, up to 290 degrees Celsius. Furthermore, the site is quite new and well documented in terms of processes, this allowed a detailed model of Avista Green to be developed during a day of site visit and model work and some additional mapping done remotely. This was possible even though the ability to work with high temperatures was only added after the site visit.

- For EEMAP, Avista Green ended up being a true field test of the tool. The experience provided important learnings on what was still fully not working, while mapping on site allowed fixing the issues afterwards and thereby reaching a working model. The process at Avista Green is a specialized industrial process that EEMAP successfully incorporated in a short amount of time.

Description of the tool structure

EEMAP features various analysis and reporting tools to support different aspects of energy efficiency mapping. It is organized with a left-side navigation panel containing four main sections (see Figure 1) that guide users through the stages of mapping and analysing results to identify potential energy efficiency improvements. The section-based design intentionally reduces complexity, making it easier to navigate the process of conducting an energy mapping. This structure also helps new team members to quickly get up to speed when joining or taking over a project.

Conducting an energy mapping is an iterative process, and the illustrated steps are therefore not rigidly locked into a specific sequence. The following chapter will provide a description of the different sectors and their respective functionalities in the tool.

View Appendix 8 User Guide to the tool_august2024 and Documentation on calculations for a detailed user guide, and for the component calculations.

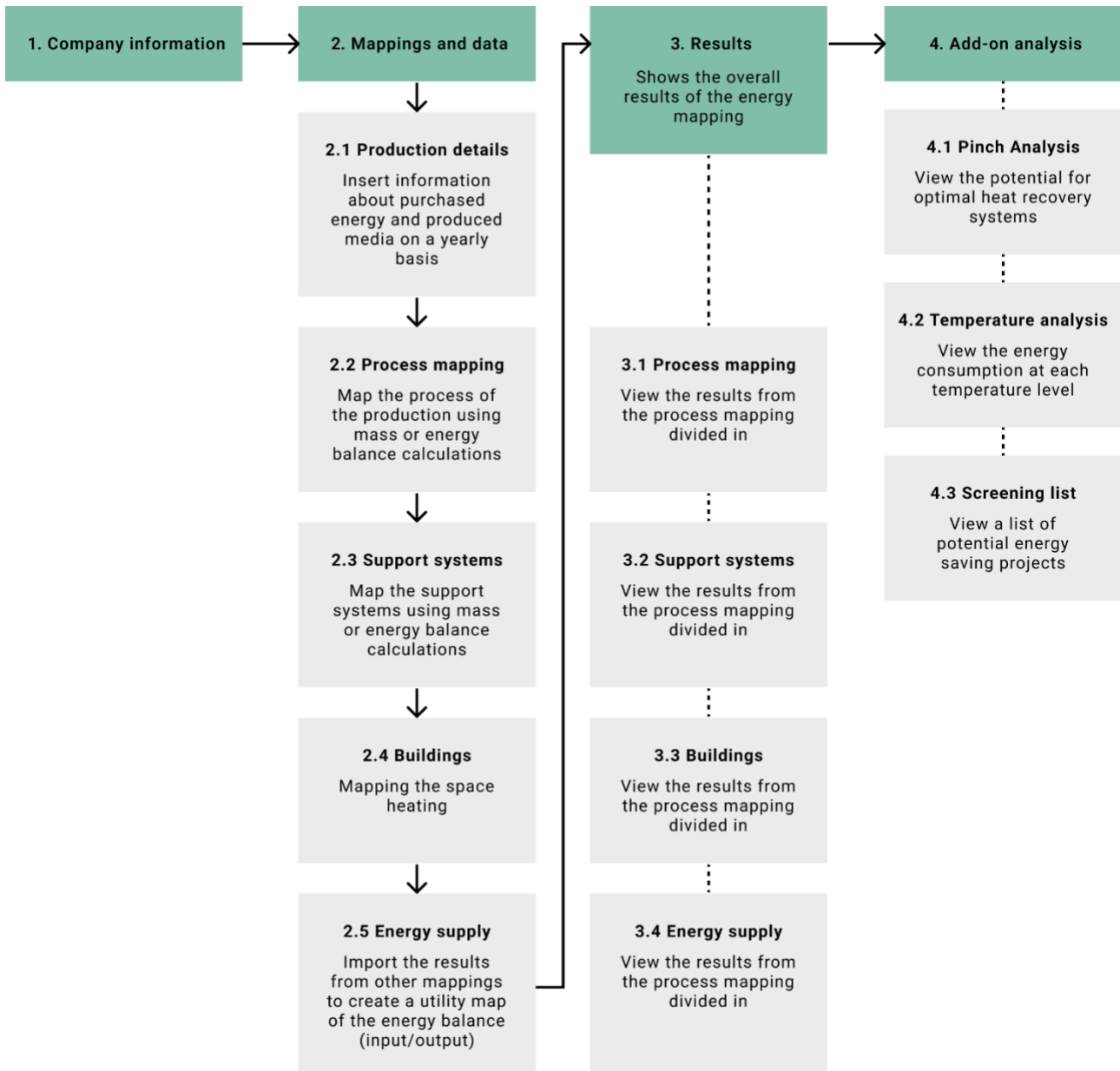


Figure 1: The arrows indicate the recommended order of using the tool. It is inevitable to not navigate back and forth between the different parts, as it is an iterative process. The dotted lines simply indicate the visual presentation in the tool.

1) Company profile

In this section, the user provides general information about the production facility. This includes company name, address, contact person information, etc. The user can additionally keep track of references used within the mapping and keep an overview of where specific data has been collected.

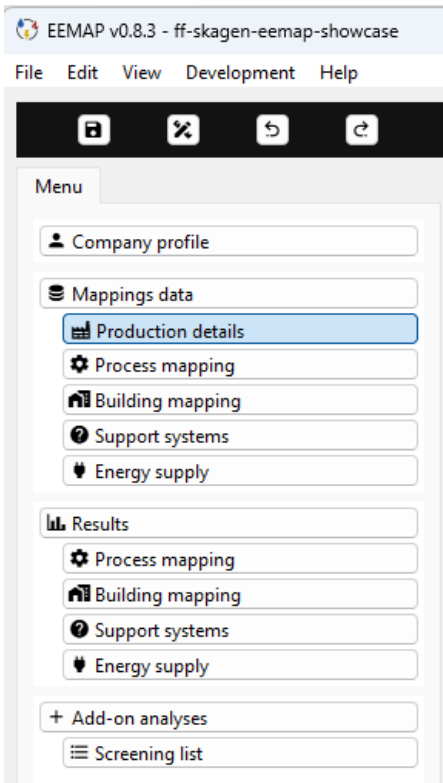


Figure 2: An overview of the different tabs in the menu bar of EEMAP.

2) Mappings data

This is where the energy mapping is built, and the calculation inputs are specified. The user is free to start building the mapping from any subsection but is recommended to follow the suggested sequence to gain the most benefit from the tool, especially during their first use.

2.1 Production details: The user specifies general details about:

- Yearly purchased energy divided on the different energy users (e.g. 10.000 kWh electricity used by 'building 1' and 123.229 Nm³ natural gas used for the evaporator)
- Basic media components (e.g. water, protein, fat)
- Yearly media consumption and production (e.g. milk and cheese)

2.2 Process mapping: the user creates the process mapping by following the steps of:

1. Access the components, by clicking on the "Components" tab next to "Menu". Here, all unit operations can be found stored in a library, categorized by their function. The process mapping is initiated by using drag-and-drop functionality to select and connect various unit operations.

2. Insert and connect all necessary components between the source (start component) and sink (end component) to accurately represent the entire process from raw materials to the final product. The lines represent process streams, linking components from input to output.

3. Define the energy source and specify energy consumption details for each component in the left menu - either as fixed values or based on the component input.

4. Once the mapping is complete, calculate the mass balance to ensure all mass flows are balanced.

5. Calculate the energy balance by switching the calculation mode from mass balance to energy balance and add the additional required information to solve the equations.

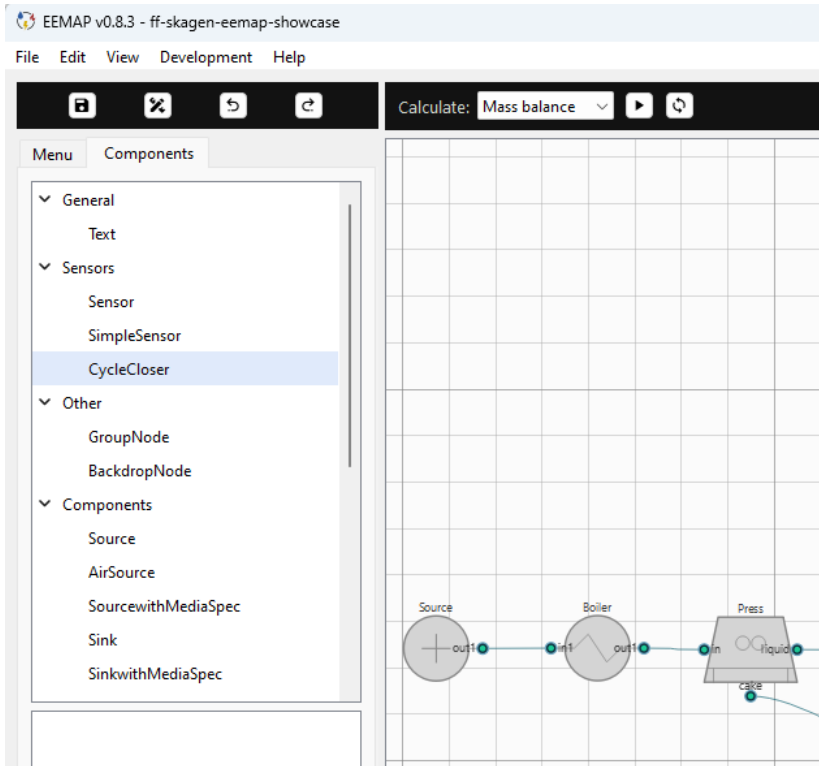


Figure 3: An overview of the Components Library, when assembling the process mapping.

Selection of components

The key philosophy of the mapping in EEMAP is to reduce the complexity of reaching a representative mapping as much as possible. The component structure of the program is designed to encourage the idea of splitting complex process steps into their basic components to lower the necessary input variables. This means that instead of a single component used to represent drying of wet paper using superheated steam several smaller steps are introduced:

1. Water stream to be utilized as steam

This allows a set amount of steam to be introduced, and as this is how the energy balance was known it made the process much more straight forward.

2. Water is heated to superheated steam at a set temperature

As the steam temperature was known this allows the temperature to be an input instead of a result of steam tables or the likes.

3. Mixing of the product and steam

The steam is mixed with the stream of wet paper mass, much like it is sprayed onto the paper in processing in the actual drying process. This allows EEMAP to do the calculation of final energy in the mix.

4. Extraction of the specific water content known to be removed by the process

Finally, the known amount of water extracted as a result of the steam drying process is removed. This allows the wet paper to reach the correct temperature out of the drying process. Consequently, later drying steps will have the correct energy consumption as the temperature rise in the product is included.

Altogether this process step could have been modelled by a very specific component requiring inputs, depending on how the process is run at different sites the inputs might be vary. Instead, simple components that mix, heat, evaporate and filter can be used to build complex process steps without having to engage with exceedingly specific and complicated components. These complicated components would also have to be developed for each process that will have to be mapped creating an overload of components to develop and to go through as a user.

Along the process few components were determined to be necessary, this includes a heat exchanger using two process streams and a drier or evaporator driven by a process stream. These allow processes that are very deeply integrated into each other to be modelled in EEMAP as well.

2.3 Building mapping: holds the information about all the buildings associated with the production plant. This includes buildings for storage, administration, production and potential other functions. Mapping the energy consumption of buildings can be done, in its simplest form, by defining a fixed value for each building. Alternatively, the user can specify a percentage of the total energy consumption each building uses, or more detailed, make a calculation (externally) based on a range of different parameters like building volume, age, condition and temperature demands. The inputs for this analysis of space heating are used to calculate an estimate of the necessary energy usage to heat the specific building. Each building component can be renamed to fit the terminology of the production company. Similarly, the final calculation is done by pressing "Play".

2.4 Support systems: used to determine the energy use for the different supporting systems that are connected to the production site, but not directly dependent to or a part of the mass flow of the process. This covers e.g. CIP-systems, air-condition, compressed air systems and so forth. In the current version of EEMAP, the support systems are simply mapped by defining the total energy consumption for each system, and an associated, specific, electricity consumption, either specified as fixed or as a percentage of the total energy consumption of the component.

2.5 Energy Supply: mapping the energy supply system for the production facility, buildings and support systems. Here, the whole energy system comes together. The mapping is created by using the following functionalities (similar to mapping the process):

- Import all 'Purchased' energy components, as defined in the subsection Production details.
- Complement imported purchased energy components with other, by finding relevant energy components, representing the plant's utility system, such as boilers, heat pumps, etc. in the left menu library.
- Start the mapping with a "Purchased" component, defining the journey of energy sources from their acquisition to full consumption (from supply, i.e., the utility system, to the demand side, i.e., operational units in the production lines that use the required energy).
- Rename components to align with the terminology used in the specific production plant.
- Insert and connect all necessary components between the purchased energy and consumed energy to accurately represent the energy flow in the energy supply. This includes conversion technologies and distribution losses. Use lines to represent energy streams, connecting components from output to input, and identify interconnections between the supply and demand sides (from output to input and input to output). Figure 4 shows an example of possible interconnections between the supply and demand sides, with colorful arrows indicating the different nature of energy streams and temperature levels.

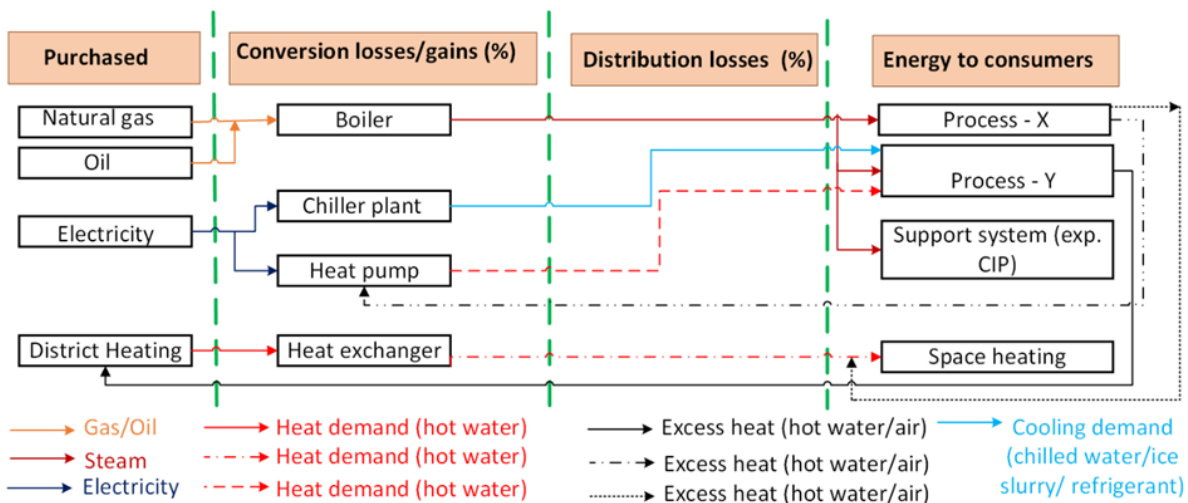


Figure 4 - An example of possible interconnections between the supply and demand sides, with colorful arrows representing energy streams. Different arrows of the same color correspond to different temperature levels of similar media

In this figure example, consider a natural gas boiler producing steam for processes. The "Conversion losses" refer to all losses related to converting natural gas into steam in the boiler, including flue gas loss, radiation loss, blowdown, deaerator losses, etc. The "Distribution losses" refer to losses incurred while distributing the steam throughout the facility, primarily due to heat loss from piping and condensate losses. Additionally,

conversion gains can be estimated, such as utilizing excess heat from the processes as a heat source for a heat pump, which can partially cover the factory's heating demand as part of the utility system.

2.6. Mapping degree: In addition, Uncertainties in the mapping are identified by comparing the purchased energy with the consumed energy to define the mapping degree of the total energy consumption, from step 5, using the following equation.

$$\text{Mapping degree} = \frac{\text{Process energy} + \text{Conversion losses} + \text{Distribution losses}}{\text{Purchased energy} + \text{Conversion gains}}$$

In an ideal energy mapping scenario, a mapping degree of 100% would be achieved. However, in practice, various factors such as measurement uncertainties, poor data quality, and generalizations of complex processes can result in deviations from this ideal. A low mapping degree indicates the need for further iteration of energy mapping. Once the mapping is complete and an acceptable mapping degree is achieved, the user can proceed to the results tab to gain an overview. and identify specific energy-saving opportunities.

3) Results

In the results tab, the user can view an overview of the total and segmented energy consumption by navigating through different mapping areas: “Process Mapping,” “Building Mapping,” “Support Systems,” and “Energy Supply.” For each area, energy consumption is displayed in a table, bar chart, and pie chart, categorized by heating, cooling, and electricity consumers. Additionally, in the process mapping overview, the user can view the mass flow distribution using a Sankey diagram, which highlights the energy flow from one state to another.

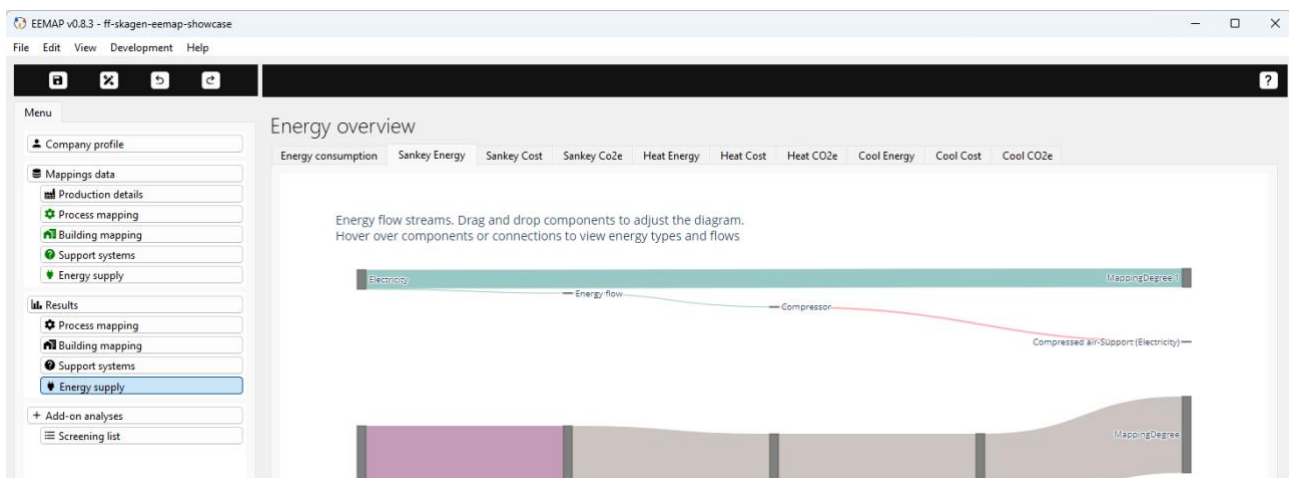


Figure 5 - Different possibilities to view the results in EEMAP

For the energy supply results there is a multitude of different views, typically required for various types of reporting, e.g. for energy audits or compliance with certification of ISO 50001. Here, the user can access a table view, Sankey Diagram, bar and pie charts of both heating, cooling and electricity. The user will also find information on associated costs and CO2-emissions for the energy demands, which in practice covers scope 1 and 2 of climate accounting according to the GHG-protocol.

By hovering over the different diagrams, the user can gain more insight into the data behind the points. Additionally, the user can adjust the view by scaling, moving connection points in the Sankey diagram, or excluding specific energy consumers from the diagrams. The diagrams can be exported via screenshots, and the tables can be copied to other software tools like Excel or Word.

4) Add-on analyses

In the last main tab, the results are used for a variation of different analysis. An energy mapping is mostly valuable by what it can be used to plan energy efficiency measures from.

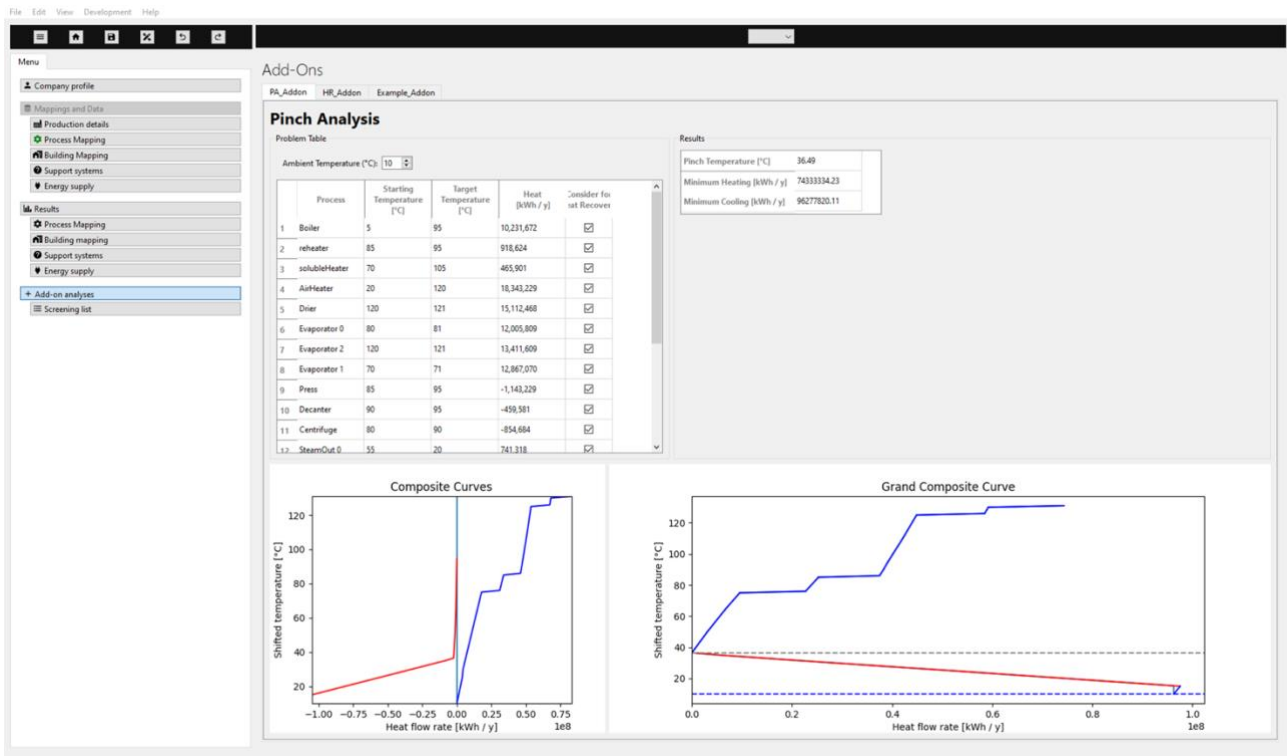


Figure 6 - Add-on analysis options showing the example of FF Skagen (Group 1)

In EEMAP, the user has 3 different analysis options: Pinch analysis, heat recovery network analysis and temperature analysis. Additionally, the user has access to a screening list that contains a large number of suggestions for energy optimization within different areas, components and sub-components. The options will be more thoroughly described in the following sections.

4.1 Pinch analysis

The Pinch Analysis tool in EEMAP automatically performs a Pinch Analysis and displays the Grand Composite Curves and the minimum utility targets from the mapped process data.

Pinch Analysis (PA) offers a powerful solution for reducing energy consumption in industry and promoting sustainable industrial practices. PA was first introduced by Linnhoff and Flower in 1978 to optimize the design of Heat Exchanger Networks (HENs) and maximize heat recovery. Soon after, the principles of Pinch Analysis were used to define the correct placement of heat engines and heat pumps in process networks. Since its development, it has been extensively applied within the process industry to improve heat recovery and design more efficient industrial systems.

PA is based on the Grand Composite Curve (GCC), which graphically illustrates the net heating and cooling requirements at various temperature levels. The GCC is derived from the process streams' temperatures and heat loads, represented by the Composite Curves (CC) and assuming a minimum approach temperature necessary for effective heat exchange. The GCC is usually represented with a shifted temperature (T^*) on the y axis, which accounts for the minimum temperature difference for effective heat exchange.

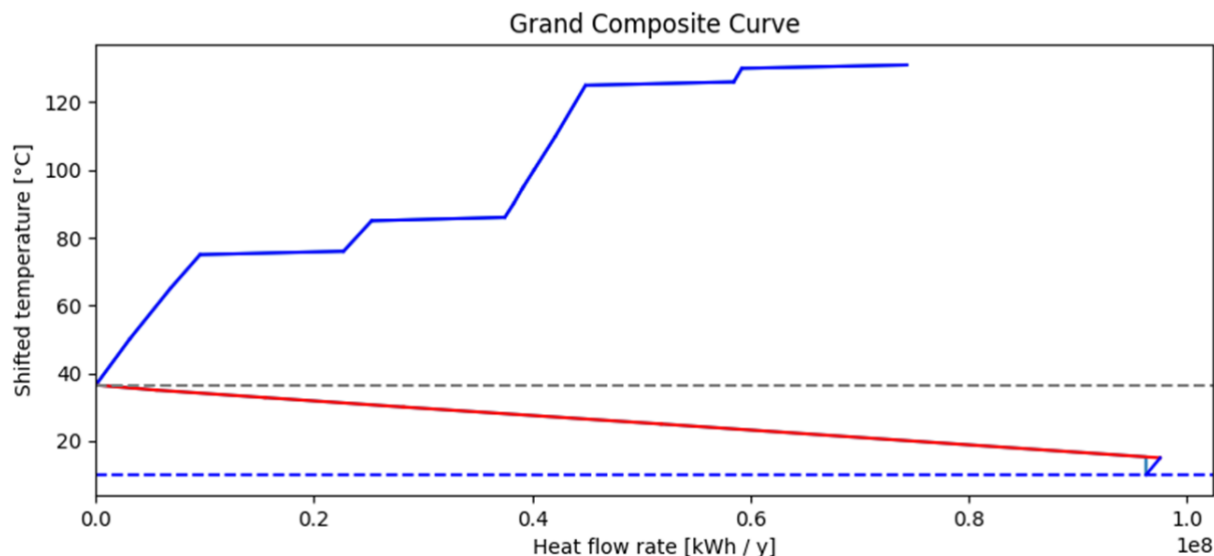


Figure 7: Example of a GCC obtained through EEMAP (example of FF Skagen, Group 1)

Key information displayed on the GCC includes the minimum heating (top of the curve) and cooling (bottom of the curve) utilities, the minimum utility temperatures, and the Pinch Temperature (in grey). This information is used to design efficient heat recovery networks. Above the pinch temperature, there is a net heat demand, while below it, there is a net cooling demand.

Results	
Pinch Temperature [°C]	36.49
Minimum Heating [kWh / y]	74333334.23
Minimum Cooling [kWh / y]	96277820.11

Figure 8: Example of the results from the GCC obtained through EEMAP (example of FF Skagen, Group 1)

The pinch temperature is crucial for decomposing and designing a heat exchanger network (HEN) according to the principles of Pinch Analysis. To meet the minimum energy targets, the following guidelines must be adhered to:

- Avoid heat transfer across the pinch.
- Do not place cold utilities above the pinch.
- Do not place hot utilities below the pinch.

Future work on exploring the heat recovery opportunities should consider the minimum energy targets as well as the insights given by the GCC and the pinch temperature to improve the efficiency of the heat recovery system on the plant.

4.2 Heat recovery network

While the algorithm for the design of energy efficient energy networks starting from the GCC are well defined and effective, the energy efficient designs are often complex and expensive. Another approach taken for the design of heat exchanger networks is considering the estimated investment costs of the elements of the network, that is, the heat exchangers to minimize the overall cost of the network though mathematical programming. These methods do not always provide the most energy efficient heat recovery system, but the most cost-efficient.

The TransHEN program presented by Hall et al. is included in the second add-on analysis in EEMAP. This method is based on GEKKO for the non-integer linear programming model and has effectively been used to design cost-effective heat recovery networks. The networks presented in the second add-on also consider the mapped heat streams, similarly to the PA, to propose a heat recovery network.

Cost Parameters

Utilities

	Cost [kr/kWh]
Hot Utility	2
Cold Utility	0

Heat exchanger costs

	Cost per Unit [kr/unit]	Cost per area [kr/m ²]
1	150000	4500

Propose network

Figure 9: Cost inputs for heat exchanger network generation in EEMAP through TransHEN

First, the unit costs of the heat exchangers as well as the heating and cooling utility are used as inputs before generating the network. Next, the heat exchanger network is generated, minimizing utility and investment costs.

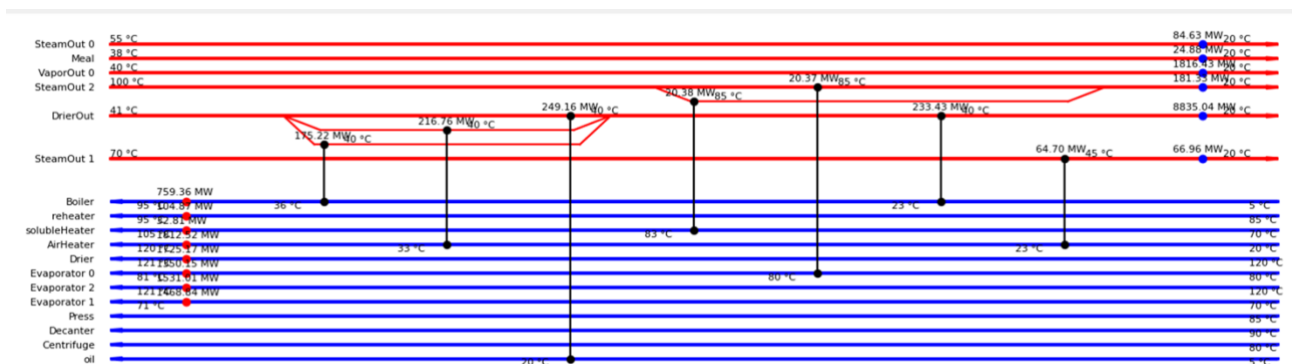


Figure 10: Example of a proposed heat exchanger network solution in EEMAP using TransHEN (example of FF Skagen, Group 1)

The heat recovery heat exchangers (black) exchange heat from hot streams (blue) to cold streams (red). The investment costs are also shown together with the economic savings the relative energy savings.

Network Results			
	Investment costs [kr]	Annual savings [kr/year]	Relative savings [%]
1	1,271,791	12,254,723	7.38

Figure 11: Economic and energy savings from the proposed heat recovery network (example of FF Skagen, Group 1)

The proposed networks can be used as preliminary starting points for the design of cost-effective heat exchanger networks that could improve the efficiency of the plant.

4.3 Mapping under uncertainty

Application of Process Integration and Pinch Analysis holds significant potential for energy efficiency improvement; however, it also presents considerable challenges. Achieving optimal efficiency requires precise data across all processes and complex analytical methods.

Previous studies have shown that conventional Pinch Analysis can yield highly uncertain results concerning heat demand, cooling demand, and process pinch points, especially when input data is variable or uncertain. The EEMAP tool addresses this issue by mapping energy consumption across processes in relation to the plant's total input energy (degree of mapping), highlighting areas of data uncertainty.

In consultancy engineering practices, improving input data quality to achieve at least 85% certainty is generally required for reliable analysis. However, as part of a research study, an uncertainty level of approximately 85% ± 10% was applied uniformly across all processes to observe its impact on pinch analysis outcomes. This study, involving six partner companies, explored the effects of uncertainty on pinch temperatures, heat recovery system design, and utility targeting. The findings underscore how energy optimization outcomes can vary significantly when uncertainty analysis is combined with data insights and engineering judgment.

Conducting these studies requires frequent adjustments and re-evaluation of all analyses for each change introduced in the processes. However, with EEMAP, iterative modifications become much simpler, as the tool automatically updates the pinch analysis and generates the grand composite curve.

4.4 Temperature analysis

The temperature analysis feature in the EEMAP tool serves as an optional add-on that provides insights into the relationship between the temperature demands of various processes and energy consumption. This analysis visually illustrates energy usage both cumulatively and per degree Celsius, enabling users to understand and gain an overview of the temperature variations. By analyzing these temperature-dependent energy demands, companies can identify opportunities for optimization and more effectively manage their energy resources. The analysis output is visual graphs – an example can be seen in the figure below.

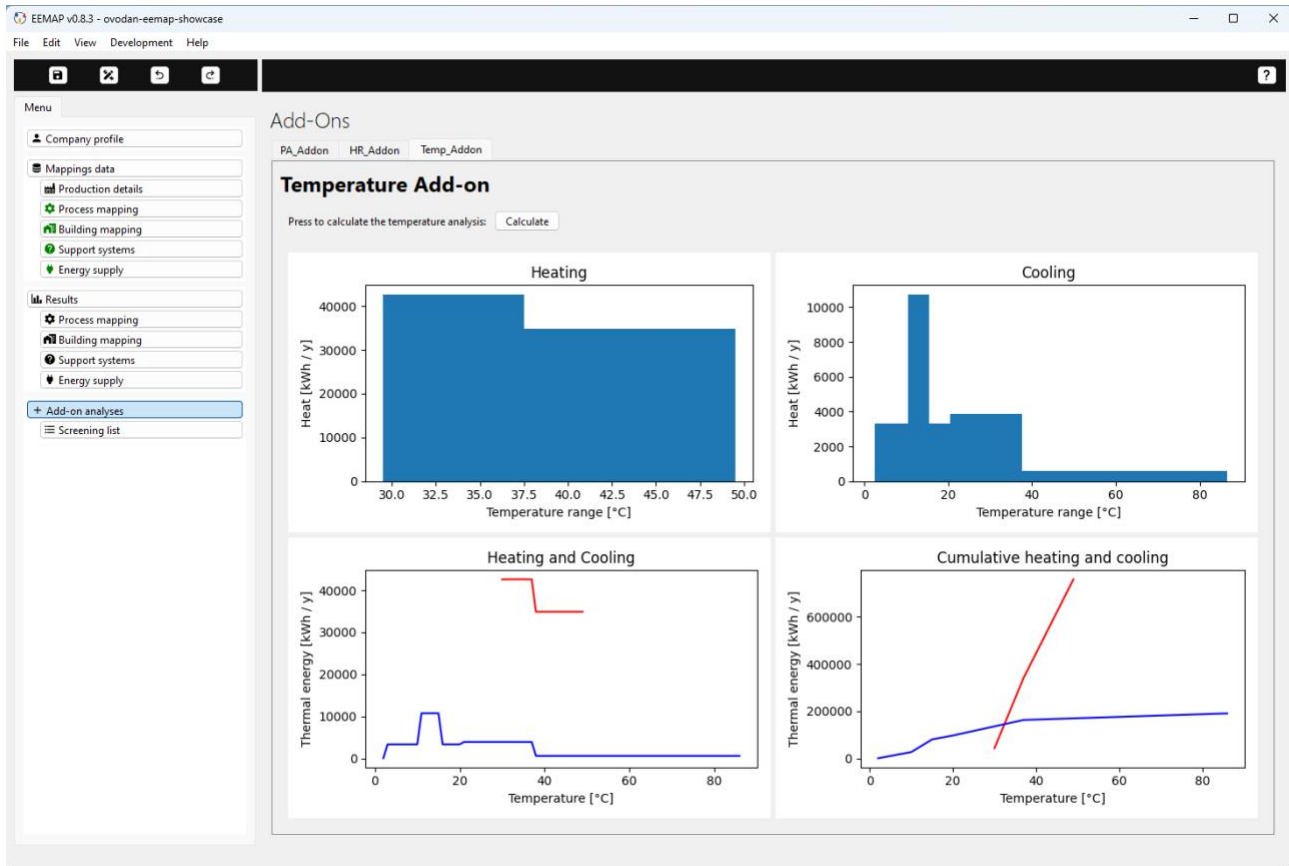


Figure 12. An example of the Temperature analysis output

4.5 Screening list

One of the most valuable outcomes of conducting an energy mapping of a company’s processes is the generation of data-driven insights into potential energy efficiency projects. To capitalize on this advantage and embed it as a core feature, EEMAP includes a comprehensive "Screening List" of potential energy savings and efficiency projects.

This "Screening List" is organized within EEMAP and is accessible via the sub-tab “Screening list”. It categorizes potential projects based on various criteria, such as the area of mapping (e.g., Process, Building, Support Systems, or Energy Supply) and system type (e.g., Ventilation, CIP, Pasteurizer), as well as by sub-system (e.g., UHT, Centrifuge). This structured approach not only provides users with a clear view of the different energy efficiency opportunities available but also facilitates easier decision-making regarding where to invest in energy-saving measures (see Figure 12).

ID	Mapping area	System type	Sub-system	Area	Title	Description
B1	Building	Ventilation		Heat recovery	Rotary heat exchanger	Proper heat recovery efficiency is vital. Use rotary heat exchanger if air streams can be mixed. This will result in a high heat recovery efficiency close to ~80% recovery.
B2	Building	Ventilation		Heat recovery	Cross flow heat exchangers	Use heat pipes / cross flow heat exchangers if mixing air streams is not an option. Will result in ~60-70% recovery.
B3	Building	Ventilation		Heat recovery	Water loops	Use water loops to transport heat recovery when the intake and outlet are not in close proximity. Will yield approximately 50-60% recovery.
B4	Building	Ventilation		Heat recovery	Ventilation KPI	Displaying heat recovery efficiency on screen or having it as a KPI will support operating personnel in catching malfunctions.
B5	Building	Ventilation		VSD & Control	Air exchange rate	Air change should fit the application. Design ventilation systems to meet the specific needs of the building, avoiding over- or under-ventilation, which can lead to increased energy consumption.
B6	Building	Ventilation		VSD & Control	Demand driven	Shut down ventilation / reduce air change in off hours.
B7	Building	Ventilation		VSD & Control	Demand driven	Control the system by demand using sensors and VSD. Separating buildings into different zones, can allow system to be shut off using dampers.
B8	Building	Ventilation		Insulation	Thermal	Insulation of ducts: Insulate ducts to reduce

Figure 13 - Screenshot of the screening list

By leveraging this organized and detailed screening list, users can quickly identify and prioritize projects based on their specific needs and potential impact. This feature turns EEMAP into a powerful tool for planning and executing energy efficiency strategies, thereby enhancing the overall value and effectiveness of energy management initiatives within any organization.

Additional benefits of using EEMAP

1) Rapid and iterative energy mapping

In summary, models created in EEMAP can be developed rapidly using straightforward assumptions, allowing for quick initial analyses. While these early models offer a basic level of accuracy, their primary advantage is the ability to quickly become operational and to be refined iteratively. Typically, the initial models consolidate multiple process steps into single components, providing companies with a broad overview of their processes. This high-level perspective can then be incrementally detailed to improve model accuracy. Throughout this process, data and knowledge gaps are revealed, which can help companies in prioritizing their efforts on the most energy-intensive or unexpectedly critical areas of the production.

2) Supporting tool for ISO 50001 and Mandatory Energy Audits

Mappings done in EEMAP can easily be maintained and updated to reflect changes in the actual plant. This is particularly relevant in the context of energy management standards such as ISO 50001, which require companies to maintain a comprehensive overview of their energy consumption, distribution, and opportunities for improving energy efficiency. With the introduction of new regulations, an increasing number of companies will be required to conduct mandatory energy audits and implement certified energy management systems. Large companies have already been subject to these requirements in recent years.

During an energy audit or the implementation of ISO 50001, companies must account for at least 90% of their energy consumption, allowing them to exclude only up to 10%. Although the current version of EEMAP does not automatically ensure ISO 50001 compliance, it is a valuable support tool for achieving it as it allows the companies to create and update an energy mapping with minimal effort. This is especially

beneficial for companies with multiple sites, that need to manage their energy mappings either centrally at the company level or locally at each site. This ensures that energy data is continuously and systematically updated, providing the most accurate representation of the company's energy consumption.

- Moreover, EEMAP's output can be directly used for reporting purposes in both mandatory energy audits and ISO 50001 documentation, simplifying the compliance process. This reduces the effort required for obtaining energy audits and certifications, as the detailed energy mapping provided by EEMAP covers a significant portion of the required documentation, making the overall process more efficient and accessible

Automating Pinch Analysis for Process Integration studies

Pinch Analysis is a powerful method in process integration studies, highlighting minimum energy requirements and guiding the design of heat recovery networks to meet those needs. It also aids in optimizing utility systems by identifying ideal temperature levels, which can be valuable in early-stage studies.

For example, Pinch Analysis can guide decisions about using pressurized water instead of steam as a utility or determine suitable temperatures for refrigeration systems and integration points for heat pumps. By identifying the pinch point temperature, it can set boundaries for heat pump integration: the condenser and evaporator points are constrained to operate above and below the pinch point, respectively. Similarly, multiple utility levels can be identified through the Grand Composite Curve, by analyzing the net heat demand below any given temperature or net cooling demand above any given temperature. The versatility of Pinch Analysis for energy efficiency has led to an extensive body of literature and numerous derived methods, showcasing its applications across various industries.

Recent studies highlight that data acquisition is often the most time-consuming and costly step in performing Pinch Analysis. Furthermore, even with the required data, companies may lack the expertise to use Pinch Analysis effectively for energy efficiency improvements. Automating Pinch Analysis within EEMAP can bridge this gap. EEMAP not only simplifies data acquisition but also provides an automated energy-saving analysis, making Pinch Analysis more accessible and practical for industrial applications.

3) Simulating different scenarios for electrification or optimization purposes

Lastly, the analysis methods applicable in EEMAP provide a comprehensive set of tools that supports optimization of the processes. As the users can easily duplicate a mapping and modify components to simulate different scenarios for electrification or optimization, such as the integration of heat pumps.

In terms of electrification of processes (not involving heat pumps specifically) technologies like MVR and resistive heating could also be integrated using EEMAP. Determining the temperature at which surplus steam could be available and at which temperature it is needed means MVR technology could be considered. Determining the average load required for a specific heating step in the process is also a good starting point for figuring out the CAPEX for a resistive heater.

Feedback from the partner companies

The companies involved in the project have shown varying levels of engagement with their models and the tool. The feedback provided by the companies is listed below:

- **Royal Unibrew** expressed strong interest in using EEMAP mappings for their energy management and sharing them across their organization, despite being unable to run the software independently on their own computers due to the company's strict security policy. As a result, they could only test EEMAP during

physical workshops with all project members present. Idea: Implementing the application in a web-based format could potentially solve this issue.

- **Avista Green** found the results valuable but expressed concerns about having the necessary time and resources to integrate them into their existing ways of working with their energy management system.
- **FF Skagen** leveraged the EEMAP model to develop an energy project aimed at reducing energy consumption and CO₂ emissions in their drying process. The model allowed them to test the projects impact before committing to more costly and detailed modeling, offering both environmental and financial benefits.
- **Skjern Paper** is interested in exploring additional heat recovery opportunities within their process. Like FF Skagen, they used the EEMAP model to assess potential benefits without incurring additional modeling costs, helping to quantify possible CO₂ reductions and financial savings.

In conclusion, feedback from the companies indicates that, despite some technical challenges, EEMAP is recognized as a valuable tool for modeling energy processes. It not only aids in improving energy efficiency but also helps companies better understand the financial implications and environmental benefits of their energy management initiatives.

The software architecture

EEMAP has been developed using "Qt for Python" (PySide6) and is built on several open-source Python packages. Further development has been made to some of these packages, contributing to the open-source ecosystem. The specific packages that have been modified are detailed below.

- NodeGraphQt
A package of basic functions for nodes (objects) on a graph (canvas) used to visualise the mappings in Mappings and Data. Developed in PySide2 and updated to PySide6 in this project, along with major adaptation of the nodes for use as EEMAP component models.
- Tespy
A component-based package for calculating mass balances and thermodynamic processes. Further developed with ideal incompressible mixtures, equation-solver robustness, and numerous new components adapted to EEMAP.
- CoolProp
Package used to specify the media components in the section Production Details. Thermodynamic properties of foods based on concentration of protein, carbohydrate, fat, water, etc. have been added.
- Plotly
Package used for visualization of diagrams in the Results section (sankey diagrams, bar charts, pie charts). It has not been further developed in EEMAP.
- GEKKO
A package for optimization with an interface for python used in the Add-on Analysis. A methodology has been developed by DTU in collaboration with the university behind the package, for optimizing heat exchanger networks. It must be clarified whether this work can be used in EEMAP as there is

an external contribution without clarification about the license of the code. In the first release, heat exchange optimization is not a part of the program.

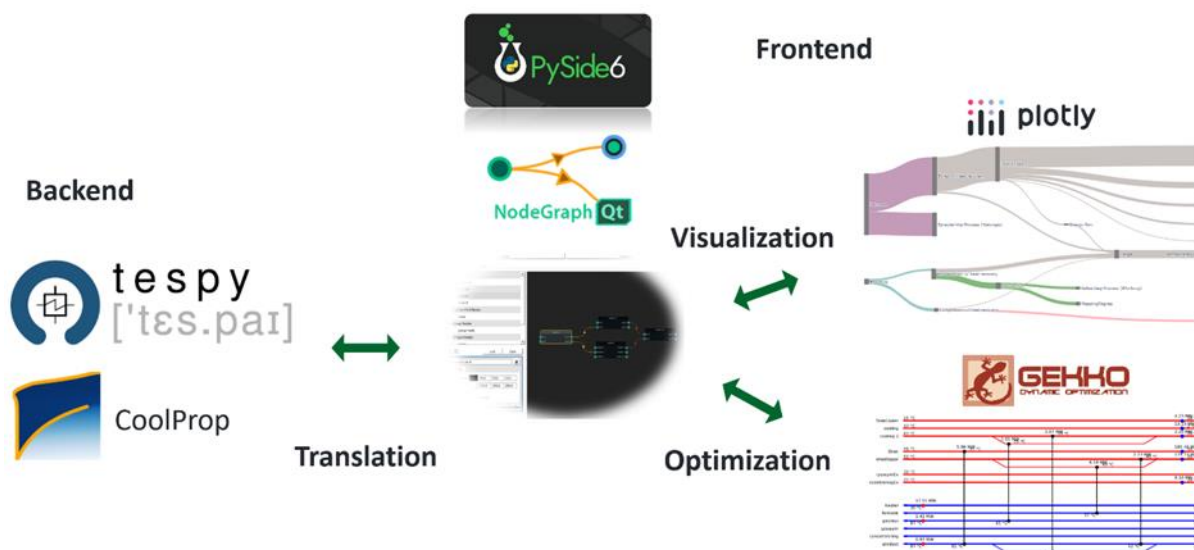


Figure 14 - Graphical visualization of the packages used and their coherence

Figure 13 indicates graphically how the packages are used. Tespy, Coolprop and GEKKO serve as the backend (calculators) and Qt for python (PySide6), NodegraphQt and Plotly serve as the frontend (user interface). The EEMAP program is thus python code that uses the Qt framework for the user interface and python code that binds the underlying packages together.

The calculations made in the tool can be described by showing the correlation between the user input and the calculated output.

In the “Mapping’s data” section, the following information is provided, and calculations/simulations are made:

- **Production details:** Information on energy input and product/media input
- **Process mapping:** Thermodynamic modelling of the process
- **Building mapping:** Modelling of buildings' individual heat/cold needs
- **Support systems:** Estimation of energy for sub-processes
- **Energy supply:** Energy inputs are linked to consumption from process mapping, building mapping and support systems.

In the “Results” section, results are visualized for the process mapping, the building mapping, the support systems and the energy supply systems.

Finally, in the “Add-ons” section, different add-ons have been developed for displaying cold/heat curves in the form of heat-temperature curves, composite curves (pinch analysis) and the previously mentioned heat exchanger network optimization.



Figure 15 - Graphical visualization of the EEMAP results

Most of the time has been spent on the development of the mapping data part, as this simulates the product's path through the process, as well as the buildings and support system, and the connection of these in the "energy supply". This is further visualized in the figure below.

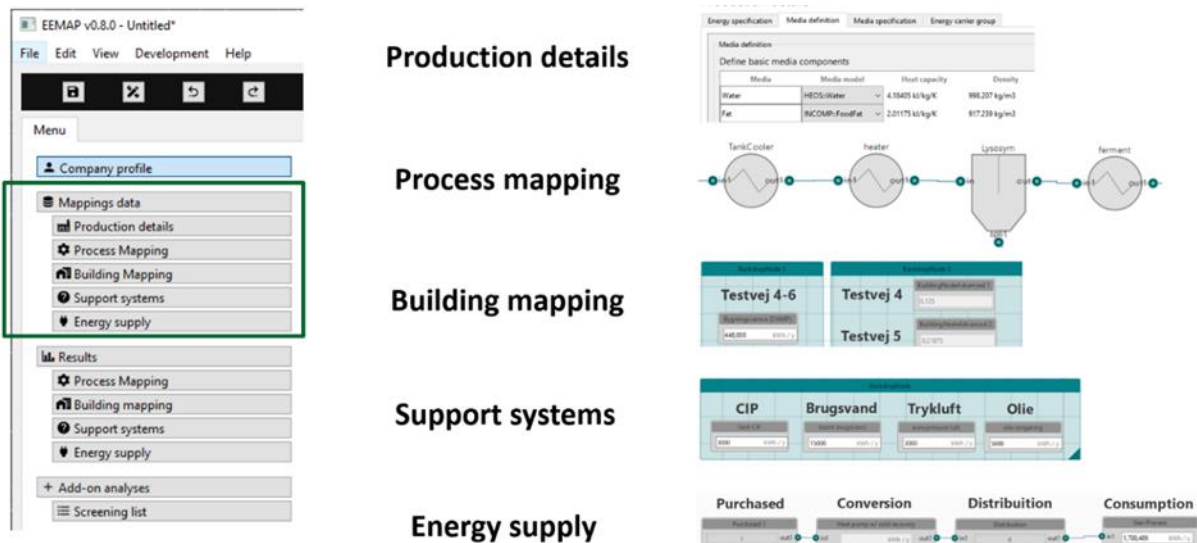


Figure 16 – Graphical visualization of the different mapping areas.

4. Project implementation

The project was initiated with a kick-off meeting with all associated project members and EUDP present. Hereafter, the project group scoped, energy mapped and prepared for the remaining and main part of the project. The first workshop was planned and held in Skagen in November 2022, during which EEMAP was further scoped, and the development company, FF Skagen, underwent an energy mapping of their production process.

After the first workshop, the project group met up for coordination and status meetings as planned and hosted a row of workshops on site at the different companies involved. A minimum viable product description was created and approved by the project group, and a mock-up of EEMAP was made in EEMAP to facilitate the first design draft and development direction for EEMAP. Second workshop was hosted at Ovodan in Odense February 2023, for which the project group had created a prototype of EEMAP, and the development companies contributed with their insights from practical experience with energy management in production companies. An early version of EEMAP had also been constructed, in which the mathematical modelling was implemented and run successfully during the presentation. The feedback and discussions were used for furthering the development of EEMAP.

Having a prototype and associated feedback from practical profiles made it possible for the project group to gear up the programming process, and after the second workshop the early version of EEMAP was shaped into an usable tool. The third workshop was held at Avista Green in Kalundborg August 2023, where the remaining 3 test companies were brought into the project and all participants had been asked to download a version 1 of EEMAP to have locally on their computer. During this workshop, the first version of EEMAP was tested, debugging tasks were planned, and the participants gave further feedback on user-friendliness and usability. The participants were presented with the current findings and version of EEMAP and asked to create a simple process model by following a task description.

The fourth and last workshop was held at Skjern Paper in May 2024, with all the project participants invited. The purpose of the was to share experiences in using the tool daily at the development and test companies, to show the last updates, to discuss how the project results can be used in the contest of identifying project optimisation opportunities and finally discuss how the tool could be improved in the future.

During each of the fourth workshops the host company, provided a site tour showcasing production and utility facilities. This gave the opportunity for the participants to share experiences and get an insight the different production setup. The insight was used as basis for all the physical and online workshops to discuss the different elements of developing the tool.

At each workshop, the participants helped shape the tool through scoping, testing and development discussion. The whole project was planned in phases and split in 9 work packages in which the project was scoped, development companies were mapped, and the software was designed and programmed. EEMAP was finalized by hosting a release party in June 2024 at IPU in Virum, during which all project members were invited to participate, either as speakers or audience guests. For the release party, more professionals were invited to listen and gain insight into the project process and project outcome. The turnout gathered around 20 participants attending in person, along with additional online attendees from Danish and international stakeholders.

The group included university researchers and employees from various production companies, all of whom could benefit from using EEMAP for energy mapping. The international participants were invited through our network ITES Task XV (Industrial Excess Heat Recovery) and the COST CA22110 LIAISE COST Action network "Cooperation, development and cross-border transfer of Industrial Symbiosis among industry and stakeholders (LIAISE)". Before and during the project's execution, the project group members conducted a

thorough risk assessment to identify and manage both opportunities and risks. The primary goal of the project was to decrease the time resources required to obtain an energy mapping.

One of the main risks identified was the possibility that this goal might be unattainable. There was a concern that the tool might not support the intended efficiency improvements, leading to only an insignificant reduction in the time required for energy mapping. This would undermine the project's primary objective and could render the effort less impactful than anticipated.

Another critical criterion for the success of developing EEMAP was ensuring that the software provided a user-friendly alternative to existing tools or Excel-based models. This criterion was closely linked to the goal of reducing time resources, as a user-friendly interface would streamline the process and make it more accessible. If the software failed to achieve a high level of user-friendliness, it would similarly affect the project's success. Users might find it difficult to adopt or integrate into their workflows, negating the intended time-saving benefits.

Additionally, several specific risks were identified:

1. Complexity and Intuitiveness:

- Risk: The tool might become too complex and not intuitive, reducing its user-friendliness.
- Preventive Measure: In the latter part of the project, focus will be on enhancing user-friendliness. This might also lead to simplifying some operations compared to the original plans.

2. Calculation Engine Efficiency:

- Risk: The calculation engine might struggle to find solutions, particularly when mapping is expanded.
- Preventive Measure: Emphasize the development and testing of robust solutions. This will be part of debugging, testing, and work package WP8.

3. Security System Challenges:

- Risk: Some companies' security systems have blocked the installation of EEMAP, which could limit its adoption.
- Preventive Measure: The EEMAP program is signed by IPU through a certificate that allows the recipient to verify that the software is indeed from IPU and not harmful. Users should download the program and run the installer from their desktop or personal document folder to avoid installation issues related to permissions.

In summary, the primary risks associated with the project include the potential failure to significantly reduce the time required for energy mapping, the possibility that the software will not be user-friendly, the complexity of the tool, difficulties with the calculation engine, and installation challenges due to security systems. The project team continuously monitors these risks and takes proactive measures to address any issues that arise, ensuring that the project stays on track to achieve its goals.

The project milestones were ultimately reached, although not all within the initially planned time schedule. Some work packages and milestones had to be rearranged or postponed. During the project, participants faced personnel shortages and changes, which made it more challenging to deliver certain planned work packages as anticipated.

For instance, work package 3 experienced both delays and extensions. As a result, the outcomes from some work packages were not implemented in the tool as expected. In certain cases, the planned sophistication of these implementations had to be scaled back or simplified due to the delays and resource constraints.

These adjustments meant that while the core objectives of the project were met, some aspects of the tool did not achieve the level of refinement originally envisioned. Despite these challenges, the project team adapted by rescheduling tasks and modifying their approach to ensure that key deliverables were still achieved, maintaining the overall integrity and goals of the project.

The project encountered a few unexpected challenges. One of the main issues was the limited availability of personnel resources, which made it more difficult to complete some of the work packages according to the initial plan. This constraint necessitated the reallocation and extension of certain tasks, thereby impacting the overall project timeline.

Additionally, a significant portion of the project members lacked prior experience in designing and developing a software tool from scratch. This inexperience meant that the time initially allocated for programming and developing the tool was optimistic. As a result, the tool development process required more time for refinement than originally anticipated. The lack of expertise led to an underestimation of the complexity and time required to achieve the desired level of sophistication and functionality in the tool.

Another notable challenge was the collaboration among three different organizations. Although all parties were committed, coordinating efforts, and aligning objectives across different organizational cultures and working styles proved to be more difficult than expected. Ensuring effective communication, managing differing expectations, and harmonizing workflows required considerable effort and flexibility from all participants.

These unforeseen problems highlighted the importance of flexibility and adaptability in project management. The project team had to adjust their approach, extending deadlines and reallocating resources to ensure that key objectives were still met. Despite these setbacks, the team has delivered a functional and effective tool, albeit with some features less refined than initially hoped. This experience underscored the value of allowing additional time for refinement, the benefits of having team members with relevant development experience in future projects, and the need for robust collaboration strategies when multiple organizations are involved.

5. Project results

The original objective of the project was ultimately obtained, but not without encountering several significant obstacles that required adjustments to the project plan.

Obstacles Encountered:

1. Limited Time Resources:

The availability of time resources was less than expected, making it challenging to complete some work packages on schedule. This necessitated the reallocation and extension of certain tasks, which impacted the overall project timeline.

2. Inexperience with Software Development:

Many project members lacked prior experience in developing a software tool from scratch. This inexperience led to an underestimation of the time required for programming and development. Consequently, more time was needed for refinement to achieve the desired level of sophistication and functionality.

3. Collaboration Challenges:

Coordinating efforts among three different organizations proved more difficult than anticipated. Ensuring effective communication, managing differing expectations, and harmonizing workflows across diverse organizational cultures required considerable effort and flexibility from all participants.

4. Complexity and User-Friendliness:

There was a risk that the tool would become too complex and not intuitive, reducing its user-friendliness. This was a critical aspect as user-friendliness was closely tied to the goal of reducing time resources.

5. Calculation Engine Efficiency:

The calculation engine faced challenges in finding solutions, especially during mapping expansions. Robust development and testing were necessary to address these issues.

6. Security System Challenges:

Security systems in some companies blocked the installation of EEMAP, limiting its adoption. Ensuring that the program was properly signed and providing clear instructions for installation helped mitigate this issue.

Changes Made to Mitigate Obstacles:

1. Enhanced Focus on User-Friendliness:

In the early part of the project, the focus sharpened towards enhancing the user-friendliness of the tool. Some operations were simplified compared to the original plans to ensure the tool was intuitive and easy to use.

2. Robust Development and Testing:

Emphasis was placed on developing and testing robust solutions, particularly for the calculation engine. This was incorporated into the debugging, testing, and work package WP8 to ensure reliable performance.

3. Flexible Scheduling and Resource Allocation:

The project team adapted by rescheduling tasks and reallocating resources to address the personnel shortages and inexperience. This allowed key objectives to still be met, even if some features were less refined than initially hoped.

4. Security and Installation Guidance:

The EEMAP program was signed by IPU with a certificate, enabling users to verify its authenticity and safety. Users were instructed to download the program and run the installer from their desktop or personal document folder to avoid installation issues related to permissions.

5. Workshops and Continuous Feedback:

Regular workshops and feedback sessions were held to gather input from practical profiles and ensure the tool development stayed on track. These workshops helped shape the tool through scoping, testing, and development discussions.

In conclusion, while the project faced several unexpected challenges, the original objective was achieved through flexible project management and strategic adjustments. The experience highlighted the importance of allowing additional time for refinement, leveraging relevant development expertise, and maintaining robust collaboration strategies when multiple organizations are involved.

EEMAP provides a framework to understand energy and has necessitated that the process steps are communicated to an external part in simple terms. This means that EEMAP enables understanding of processes across different departments internally as well. While this focus on ensuring the agreement of the process steps at the company was a part of the original scope it was meant mostly for the people working with the process in different ways. E.g. a maintenance worker who is an expert on the steam distribution but has no knowledge of the centrifuge preparing the product, or an operator of a bottling line not seeing the fermentation steps for the beer.

This aggregating of energy and process information has been shown to be of interest to management as well. A simple model providing an understanding of a complex system and providing graphical feedback in the form of Sankey diagrams, grand composite curves and temperature analysis plots allows an overview of the process without detailed understanding of each step.

Finally, it is an occasion for the company to go through their available energy data from one end to another. In this process knowledge gaps are identified and an understanding of magnitudes between different energy consumers is achieved. EEMAP by design both alleviates and highlights the knowledge gaps through assumptions and presents the energy consumptions of different components or subsystems as a result. When building the model inputs like the total consumption of electric motors or the steam consumption of a single component can be surprising to the company though they already had the data in house.

EEMAP is ultimately a tool for energy mapping, but due to the speed of which a rudimentary mapping can be produced the actual energy managers of the site can much easier attend during the whole session. This means that the deeper understanding of their own data goes directly to the person in charge of managing the systems. The end goal of the model means that a product is also produced from the mapping process.

The project has already shown promising commercial results. Six companies have been mapped using the EEMAP tool and have expressed interest in utilizing it for various initiatives. During the tool's release event, there was considerable interest in its potential, with multiple production companies in attendance.

Post-project, Viegand Maagøe plans to market the tool through industrial networks and energy audit consultants, while DTU will incorporate it into academic courses. Revenue generation is expected shortly after development, with broad market adoption anticipated within 0-1 year.

However, the tool requires further development to reach its full commercial potential. While initial results align with expectations, ongoing enhancements are essential for broader market adoption and long-term success.

The target group for the EEMAP tool consists primarily of production companies that either need or seek to conduct an energy mapping of their processes, supporting systems, buildings, and supply systems as a e.g. a part of their green transition.

EEMAP can be offered in two main ways:

- **Stand-Alone Software Tool:** Companies can use the EEMAP tool for internal use, allowing them to independently carry out detailed energy mappings.
- 1. **Energy Mapping Service:** EEMAP is provided alongside consultancy services, where production companies gain access to the tool in combination with expert support to map and analyze their processes.

These options provide flexibility and added value by catering to different needs, enabling companies to optimize energy usage, enhance efficiency, and align with sustainability goals.

The dissemination of the project results has occurred through various communication activities and has been presented at multiple significant platforms:

Conferences and International workshops:

- **Industry Decarbonization Knowledge Exchange, Danish Embassy, France – November 2022:** At a knowledge-sharing workshop organized by the Danish Energy Agency in Paris, EEMAP was introduced to a range of French companies and stakeholders.
- **ECOS Conference, Spain – June 2023:** The EEMAP tool was presented at the 36th International Conference on Efficiency, Cost, Optimization, Simulation, and Environmental Impact, showcasing its capabilities and advancements in energy mapping.
- **IEA Conference, Gothenburg – 2023:** The EEMAP tool was highlighted, focusing on its impact on energy efficiency and sustainability.
- **Decarbonization of the Danish Industry Workshop, DTU Construct, Denmark – September 2023:** In a knowledge-sharing workshop between Denmark and the USA, the EEMAP tool was featured in the session "Projects and Research Activities," emphasizing its role in industrial decarbonization.
- **Knowledge-Sharing Workshop, DTU Construct, Denmark – June 2024:** EEMAP and its applications were presented to participants from Korea's Institute of Machinery & Materials (KIMM), supporting international collaboration on energy efficiency.

Educational Courses:

- **Danida Fellowship Center Course:** In August 2023 and August 2024, the EEMAP tool was featured in a course titled "Energy Efficiency and Energy Management in Buildings and Industry." This event saw participation from about 10 countries, spreading awareness and knowledge about the tool's applications and benefits.

Online Platforms and Media:

- **LinkedIn:** Multiple posts have been made to engage the professional community, sharing updates and insights about the EEMAP tool's development and applications.

- **Podcast:** An episode titled "From Spreadsheet to Human Language"² discussed the transformation and user-friendly aspects of the EEMAP tool, making its technical functionalities more accessible to a broader audience.

These diverse platforms have facilitated widespread dissemination of the project results, ensuring that the tool's benefits and functionalities are communicated effectively to both academic audiences and industry professionals worldwide.

² The episode is in Danish called: *Digitalisering: Fra regneark til menneskesprog*. Can be heard on any streaming services.

6. Utilisation of project results

The development of the EEMAP software tool will support the option of energy mapping in the process industry and the work associated with reaching target towards a green transition. The tool has demonstrated that the time and costs the companies normally spend on energy mapping can be reduced from several weeks to only a few days. This unlocks the bottleneck that the companies are facing in investing in starting up in the right way.

The EEMAP tool promotes the use of energy mapping in the industry and thereby supports the sector's green transition, digitalization of energy systems, and identification of potential optimization areas with minimal resource input.

Additionally, the project contributes to the development of methods for process integration and energy efficiency. This will improve the competitiveness of Danish companies through reduced energy consumption and CO₂ emissions, which will be necessary to meet national climate targets and customer's demand.

On a commercial level, the tool will also benefit supporting organizations in the industry (e.g. consultant companies and equipment suppliers). The EEMAP tool will create opportunities for these organizations to work with a larger share of the industry, which to some point is not using these services today. After the baseline mapping has been completed, then the mapping will create a lot of opportunities for developing and implementing projects, that will other vice not had been identified. Industries can get a commercial advantage by improving energy performance and their carbon food print, using the EEMAP tool as a steppingstone.

Commercial utilization of results: The effect of using the EEMAP tool is in a short term expect to increase the turnover and employment, both for the partners directly involved in the EEMAP project, but also for potential users outside the project e.g. consultants, project developers, equipment suppliers and end users. Looking at it from a consultant's perspective, then the turnover can be increased significantly both directly by using the EEMAP tool and especially indirectly by the number of projects that will be generated based on the uses of the tool. When looking at it from an equipment supplier perspective then it is expected that the additional generation of projects will lead to increased sales. And when looking at it from an end user perspective then fasting forward to a green transition by using the EEMAP tool will then increase their attractiveness and thereby the sales. Employment is expected to increase to some extent with the increased turnover.

There has already been shown an international interest in the EEMAP tool and therefor i is expected that the EEMAP tool will slowly be used internationally.

Competitive market analysis: There are no direct competitors for the EEMAP tool. However, competition may arise from Excel-based models, which are cheaper but lack the same level of depth and sophistication. Process simulators used in the chemical industry also pose competition, but they serve a different purpose.

The tool is expected to outperform these due to its efficiency and level of detail, for the use of supporting the green transition for the industry.

Market Barriers and Entry Solutions: The main market barriers are:

- The current user interface is not fully intuitive, making it difficult to use without extensive introduction.
- Users must have some background knowledge in the simulation of energy systems.
- There is a lack of information channels that can continuously ensure an ongoing flow of information about the EEMAP tool.
- A maintenance organization is not yet in place. This will be a long-term barrier if the EEMAP tool is not kept updated and maintained.

To overcome the above barriers, the project organization has several plans to continuously support and develop the market for the EEMAP tool:

Step 1: Secure additional funding to make the EEMAP tool more user-friendly and reduce the need for background knowledge in energy system simulation. It is expected that this can be achieved with an additional year of focused development.

Step 2: Establish an organization that can operate, develop, and maintain the EEMAP tool on a financially sustainable basis. It is also crucial that the organization continuously supports market development through information and showcasing.

Initial financial support is essential for the EEMAP tool if the goal is to onboard as many users as possible while keeping the cost of using the tool minimal. In the future, a high number of users can help make the EEMAP tool more financially sustainable.

Contribution to energy policy objectives: The project supports national and international strategies in reducing the carbon footprint. The EEMAP tool is designed to reduce support identification of energy and CO₂ reduction projects in a cost-efficient way. Furthermore, several support mechanisms are implemented in the tool that supports e.g. electrification, which is one of several ways of converting away from the use of fossil fuels.

Ph.D. involvement and dissemination: The results from the project have been shared on academic and industry-related platforms, contributing to both teaching and knowledge dissemination. Several articles and conference presentations have been performed in the scientific community and industry.

A conference paper titled "*Efficient Energy Mapping for Supporting the Green Transition in Industry*" has been published in the ECOS Proceedings 2023 (Scopus indexed). The paper presents a streamlined methodology for energy mapping in industrial facilities. The primary goal of the study was to develop a generic, holistic, and flexible process mapping methodology, using a manual approach as the foundation and a step toward creating the EEMAP tool. Manual mapping data from FF Skagen and Ovodan successfully illustrates the model's performance.

- [Efficient energy mapping for supporting green transition in industry — Welcome to DTU Research Database](#)

Additionally, there is potential for the submission of two papers to scientific journals. The first paper builds on the conference paper, providing an in-depth explanation and showcasing the mass and energy balance model derived from a manual mapping approach developed over years of consultancy. This model forms the backbone of the EEMAP software and is demonstrated through manual mapping data from participating companies.

The second paper aims to validate the performance of the methodology implemented in EEMAP for the participating companies, comparing it to manual mappings. It also examines the potential for energy savings, utility targeting, and electrification through pinch analysis and the GCC generated by EEMAP. Furthermore, the impact of input data uncertainty on pinch analysis and final energy-saving outcomes can be evaluated, considering variations in the mapping degree."

Furthermore, three theses that been performed, two on a master level and one on a Bachelor level, with the following titles:

- Energy Efficiency and Electrification Strategies for a Chemical Plant
- Electrification and heat recovery solution in Skjern Paper Mill.

- Efficient Industrial Energy Mapping: Contributions to the EEMAP Tool

In addition, the EEMAP project built close collaboration and synergy with two other concurrent projects at DTU Construct: *Sustainable Process Heating with High-Temperature Heat Pumps Using Natural Refrigerants (SuPrHeat)* and *Electrified Industrial Symbiosis (ICEIS)*. This collaboration enabled the exchange of concepts and methodologies that enriched EEMAP's capabilities.

For instance, in the SuPrHeat project, funded by EUDP, models and concepts developed by a Ph.D. student were adapted and integrated into EEMAP as part of the tool's add-on analysis. Additionally, energy mapping results from EEMAP from various companies were used to test and refine the concepts developed in the Superheat project. Furthermore, a knowledge-sharing and software development collaboration was established between DTU and the Ahuroa Center for Smart Energy Systems in New Zealand to support the adoption of the SynHeat procedure for Heat Exchanger Network Design.

Moreover, EEMAP demonstrated significant potential for energy optimization in industrial facilities, a critical step in designing district energy networks within symbiosis parks. This potential was highlighted in the ICEIS project, funded by the Willum Foundation in collaboration with GreenLab and various industrial partners. Project conclusion and perspective

7. Project conclusion and perspective

The EEMAP project has successfully developed a software tool that significantly reduces the time and costs associated with energy mapping in the process industry. While energy mappings usually take several weeks, EEMAP enables this process to be completed in just a few days, making it more accessible and less resource intensive. EEMAP addresses the main barriers that companies, especially small and medium-sized enterprises (SMEs), face in energy mapping. The tool allows more companies to conduct comprehensive energy analyses, which are crucial for identifying energy-saving opportunities and improving energy efficiency.

Testing EEMAP with three companies has demonstrated that the tool can deliver satisfactory energy mappings with minimal follow-up in a short time, confirming its value as an effective instrument in companies' green transitions. EEMAP supports the digitalization of energy systems by making energy mapping easier and more precise, contributing to a more strategic approach to energy optimization and CO2 reduction.

The project also contributes to the development of new methods for process integration and energy efficiency, which will enhance the competitiveness of Danish companies. This is critical for achieving national climate goals, where the industry plays a key role in reducing CO2 emissions. Commercially, EEMAP creates growth potential for both consultancy firms and production companies by identifying and exploiting optimization opportunities that are often missed in traditional mapping processes.

While EEMAP has already shown promising results, further development is needed, particularly to make the tool more user-friendly and reduce the need for specialized knowledge of energy systems. The next steps include securing additional funding for the continued development of the tool and establishing an organization to handle the operation, maintenance, and marketing of EEMAP on a financially sustainable basis. This will ensure the tool's long-term success and expand its use both nationally and internationally.

EEMAP supports Denmark's and international energy policy goals by providing a cost-effective way to identify energy-saving measures and reduce CO2 emissions. By making energy mapping more accessible and useful, EEMAP helps drive the green transition forward, not only in Denmark but also across borders. The project's results show that EEMAP has the potential to become a central tool in the future of energy management and the optimization of industrial energy use.

The EEMAP tool, though functional, requires further development to enhance its features and commercial potential. The next steps include continued refinement to improve user-friendliness and functionality, alongside efforts to market the tool through industrial networks and energy audit consultants.

The project's outcomes are anticipated to significantly influence the future development of energy mapping tools and methodologies, particularly considering increased regulatory demands on energy audits and energy management systems. The introduction of mandatory energy audits for companies with energy consumption exceeding 10 TJ and the requirement for certified Energy Management Systems (EnMS) for those using more than 85 TJ underscores the urgent need for efficient, user-friendly tools like EEMAP.

By lowering the barriers to conducting comprehensive energy mappings, EEMAP is well-positioned to promote wider adoption of energy-efficient practices across various industries. This broader adoption is crucial for accelerating the green transition, as more companies will be equipped to optimize their energy use and reduce their carbon footprints. Furthermore, the insights and experiences gained from this project will likely guide the future design and development of similar tools, contributing to the creation of even more robust, accessible, and regulation-compliant solutions in the energy efficiency sector.

8. Appendices

The appendices provide a comprehensive list of all the files presented or utilized throughout the duration of the project. The table of content is as follows.

- Code Doc_initial.pdf
- Code Overview_2024-03-07.pdf
- Defining the components_2023-10-23.pdf
- Development Status 2_2022-01-10.pdf
- Development Status 3_2024-03-07.pdf
- Development status and evaluation of Tespy_2022-01-10.pdf
- Documentation on calculations.pdf
- ECOS conference_poster
- ECOS paper - EEMAP methodology.pdf
- Feedback session exercise 2 and 3_2024-02-29.pdf
- Mapping state-of-the-art.pdf
- Project status to EUDP_2024-03.pdf
- Project status to EUDP_2024-08.pdf
- Project status with companies_2024-04-18.pdf
- Screeninglist_idea catalogue.pdf
- Screeningliste - idekatalog 00c fmh evaluated workshop.pdf
- Simplifying the component structure_.pdf
- Sneak Peek Party_General Presentation.pdf
- Sneak Peek Party_Technical Presentation_2024-06-18_v2.pdf
- Software Architecture Considerations_2023-02-28.pdf
- User Guide to the tool_august2024.pdf

Workshop presentations:

- Workshop 1 @FFSkagen_2022-10-10.pdf
- Workshop 2 @Ovodan_2023-02-28.pdf
- Workshop 3 @Avista_2023-08-29.pdf
- Workshop 3_DTU @Avista_2023_08_29
- Workshop 3_Live demo of the tool_2023-08-29.pdf
- Workshop 4 @Skjern Paper_2024-05-22.pdf
- Workshop 4_DTU @Skjern Paper_2024_05_22

Publications

- Case description on Viegand Maagøes website: [Digital Tool Makes Energy Mapping Faster, Easier, and Cheaper](#)
- Podcast on Spotify: [Digitalisering: Fra Regneark til Menneskesprog](#)

LinkedIn posts:

- https://www.linkedin.com/posts/fridolin-holm_eemap-energioptimere-ugcPost-7054754634464137217-ZmYq?utm_source=share&utm_medium=member_desktop

- https://www.linkedin.com/posts/fridolin-holm_eemap-energyfutureinindustry-activity-7062758190706253824-KouQ?utm_source=share&utm_medium=member_desktop
- https://www.linkedin.com/posts/nasrin-arjomand-kermani-0253a7129_start-activity-7061607615973216259-pkkj?utm_source=share&utm_medium=member_desktop
- https://www.linkedin.com/feed/update/urn:li:activity:7168947195281412096?updateEntityUrn=urn%3Ali%3Afs_feedUpdate%3A%28V%2Curn%3Ali%3Aactivity%3A7168947195281412096%29
- [Energy Mapping fast and cheap - Viegand Maaqøe \(viegandmaagoe.dk\)](https://www.viegandmaagoe.dk)
- https://www.linkedin.com/posts/ipu_ipu-eemap-energymapping-activity-7201582666209525760-1ZD1?utm_source=share&utm_medium=member_desktop