# Efficient energy mapping for supporting green transition in industry

***Nasrin Arjomand Kermani[a*], Martin Ryhl Kærn[b], Rikke Hovedskov Andersen[c], Jorrit Wronski[b], Fridolin Müller Holm[c], Brian Elmegaard[a]***

[a] *Department of Civil and Mechanical Engineering, Technical University of Denmark, Lyngby, Denmark, nasker@mek.dtu.dk, CA, brel@dtu.dk*
[b] *IPU, Virum, Denmark, mrk@ipu.dk, jowr@ipu.dk*
[c] *Viegand & Maagøe A/S, Copenhagen, Denmark, ran@viegandmaagoe.dk, fmh@viegandmaagoe.dk*

**Abstract:**

The process industry is facing the green transition from conventional to renewable energy sources. Executing it in a cost-effective manner will require increased energy efficiency, electrification, and clear overall strategy from the beginning. A prerequisite to strong strategy is an energy mapping which describes the energy use within an industrial facility, and often very expensive and time consuming.

The primary goal of the proposed process mapping methodology is to effectively obtain production and energy data from industrial plants in a short time that can be analyzed to provide a generic, holistic, and flexible model. The model is a step to creating a software tool to generate energy flow mappings for industrial end users to make decisions with energy optimization in mind. In addition to the documentation of energy flows, the tool supports the continuous improvement of the energy mapping itself and the actual energy use.

The required data is collected by reviewing existing specifications of production facilities, complemented with interviews with personnel working in the production lines as well as other on-site investigations. The information is then entered into the developed model with energy flow mapping as an output. The model's output can then be used to get an overview of the primary energy used and identify the future opportunities for energy optimization, electrification and decarbonization of industrial sites. A couple of industry use cases have been shown to successfully illustrate the performance of the model.

**Keywords:**

Energy mapping, Generic model, Support tool, Green transition, Decarbonization of industry

## 1. Introduction

The global challenge of achieving emission reductions and climate neutrality requires prioritizing resources across various industries and sectors worldwide. In many countries, including Denmark, the manufacturing industry is a significant contributor to energy consumption and greenhouse gas emissions. In Denmark, the manufacturing industry accounts for 160 PJ or 21% of energy consumption [1]. Therefore, when it comes to industrial processes, it is essential to optimize energy use. However, energy mapping can be costly, as it requires a detailed understanding of the process at hand.

Recent studies indicate that 20% improvement in energy efficiency in Europe will not be achieved with current trends, even with implementation of all existing policies aimed at reducing primary energy use [2]. This is due to the presence of various barriers that hinder the adoption of energy-efficient technologies and practices. Sorrell et al. [3] has categorized the existing barriers in a taxonomy, collecting the most important contributions that have emerged in the literature and dividing them into economic, organizational, and behavioral aspects. They proposed fifteen different barriers that were identified as important contributions in literature. The high cost associated with gathering, analyzing, and applying information, as well as Lack of information, which may result in missed opportunities for cost-effective energy efficiency has been highlighted in different barrier categories of this study. In addition, the increased perceived cost of energy conservation was mentioned as one of the barriers to industrial energy efficiency investments in Greece [4].

Moreover, Bunse et al. [5] conducted a review of methodologies for incorporating energy efficiency performance into production management and found that most industrial companies still lack effective methods to address energy efficiency comprehensively and practically. According to the authors, the gap between industrial needs and scientific literature can be attributed primarily to several reasons. These include the complexity of production sites, which often operate multiple production processes to meet business needs; the variability in energy intensity factors across different products produced at a given site; the fact that specific energy use depends on production rate is typically analyzed in isolation from production operations (i.e. process equipment and technical services upgrades), rather than in conjunction with cycle time and energy usage (i.e. cycle time and energy usage analyzed together to determine process significant energy users (SEUs)). Consequently, the potential for misleading conclusions when attempting to take all variables associated with energy efficiency into account. Additionally, the authors noted that analyzing thermal energy usage is more complicated in practice than analyzing electrical usage.

Currently, the existing software designed for energy mapping have a common focus of the entire process operation. This requires a high level of detail and a large amount of input parameters. These parameters will in many cases not be known, which means that the use of such tools results in having to focus and spend unnecessary efforts on details which may be of little importance for the actual energy optimization. The other alternative would be using excel software. Building on Excel, the approach is challenged when it comes to complex systems as even in a simple case the program becomes too slow to be usable. Moreover, to produce correct results, the user must have a decent experience with energy mapping and the calculation tool.

Energy mapping is currently required under the European Union's Energy Efficiency Directive (EED) [6]. It is the first step in performing mandatory energy audits every four years, which aims to develop projects that increase energy efficiency. Additionally, companies complying with the DS/EN ISO 50001 "Energy Management Systems" must perform an "Energy Review" that consists of the same core ideas, establishing Key Performance Indicators (KPIs) and locating significant energy users (SEUs).

The primary goal of this study is to develop a generic, holistic, and flexible process mapping methodology that effectively obtains production and energy data from industrial plants in a short time. The goal is to describe, in detail, at least 85% of thermal energy use at any industrial facility, using only a few days on site with qualified staff and one additional day for preparations and fine-tuning. This will enable the efficient and cost-effective creation of energy mappings, which is an important contribution to the transition towards a greener process industry. Cheaper and faster energy audits alone are expected to increase the number of energy mappings created each year, reducing energy use and quantifying optimization potential [7]. Furthermore, a number of studies [8,9] have demonstrated that the impact of energy efficiency measures can extend beyond just energy savings at various levels, such as the process, facility, and organizational levels. These measures can also lead to non-energy benefits, such as increased productivity, improved product quality (resulting in reduced scrap or rework costs), reduced costs of environmental compliance, decreased carbon and emission footprint, and lower waste disposal expenses, among others. Worrell et al. [10] have compiled a comprehensive list of non-energy benefits associated with energy efficiency technologies.

In addition, the model presented in this study is a step towards creating a software tool that generates energy flow mappings for industrial end-users, enabling decision-making with energy optimization in mind. The tool supports the continuous improvement of the energy mapping itself and actual energy use. It also serves as the foundation for a continuous generation of energy savings, turning a single-shot approach to energy mapping into an ongoing cyclic process, aligning well with the current trend towards increasing energy efficiency targets.

Such a tool can provide sufficient data from numerous manufacturers required to train machine algorithms designed for energy management in different types of processing activities, introducing the digital twin concept for industrial energy systems, intelligent recommendations, and demand-side management in the future.

# 1. Method

## 1.1. Generic process mapping approach

The primary goal of the proposed process mapping methodology is to effectively obtain production and energy data from industrial plants in a short time that can be analysed to provide a generic, holistic, and adaptable model covering the following perspectives.

- Generic in nature so that it can be applicable to diverse production plants from small and medium sized companies (typically facing obstacles towards energy-efficiency measures) to big sized companies.

- Pursuing a holistic perspective of the relationship between manufacturing processes and energy used, including all relevant process and energy flows.
- Adaptable to changings of production environment such as equipment relocation or process improvement.
- Providing the data set for multi-dimensional evaluation with respect to energy savings, electrification, and carbon neutrality strategies in all relevant fields of actions as well as supports for the continuous improvement of the energy mapping.

In general, the model is a step toward creating a software tool to generate energy flow mappings for industrial end users to make decisions with energy optimization in mind.

The methodology consists of 4 main steps and several sub-steps illustrated in Figure1 and described in the following text. These steps are generally applied to all production lines that can be scaled up and/or aggregated to factory level. The outcome of the calculations and data validation also forms the basis for an iterative improvement of the quality of the energy mapping. Gradually adding more sensor data and reducing uncertainties one node at a time guarantees that the user can maintain an overview of the overall plant operation while working with individual components.

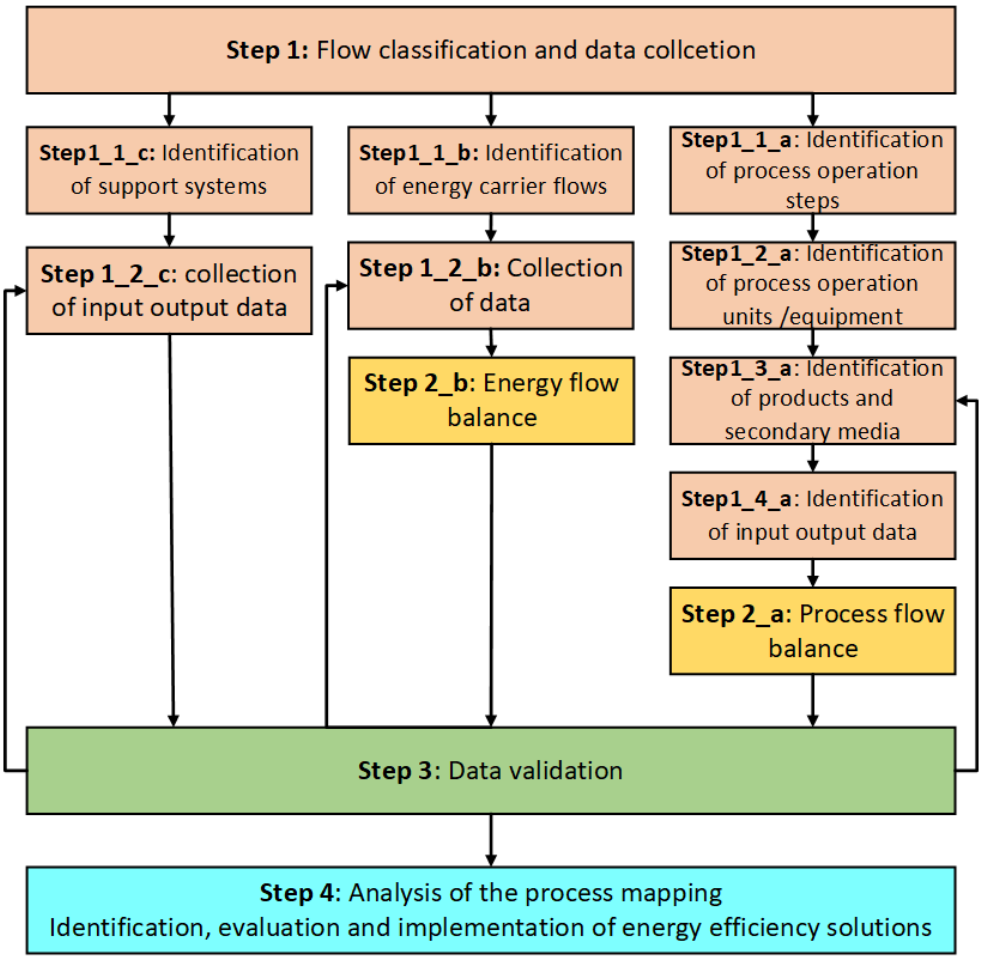


**Figure. 1.** The Proposed *methodology consists of 4 main steps and several sub-steps*

**Step 1: flow classifications and data collection**

Effective flow classifications and data collection are essential for developing a comprehensive understanding of energy use within the production plants. Such understanding will lead to identification of the areas of energy inefficiency and waste, consequently development of strategies for overall energy efficiency improvement in future. Flow classifications refer to categorization of energy usage in terms of its source, form, and utilization within a production process. This involves identifying the various inputs and outputs of energy within the facility, as well as the ways in which energy is transformed and used by different machines, equipment, and production lines. Data collection is the process of gathering and analyzing information on energy usage in a production environment which in practice can be done in many different ways.

To further understand the amount of energy use in a production plants, it is crucial to map out the flow of energy within an industrial facility, categorize energy usage, and analyse its correlation with production processes and outputs. Raw materials are consumed in production processes which convert them into products, along with some by-products that may or may not be desirable. These processes often require a significant amount of energy, which is partially utilized for value-added activities that contribute to the final form and composition of products. However, the remainder of the energy is wasted in the form of heat losses and emissions. The process needs to be understood, not just the operation of the equipment but the actual energy requirement from the process. This is achieved by establishing a process flow balance, which involves tracing the flow of the product going through process operations (POs) from start to finish and accounting for the mass and energy balance of each PO which briefly explained in step 2. Energy mapping uses streams to follow the conversion paths of different forms of primary inputs like chemical energy, electrical energy, and thermal energy.

The concept of flows makes it possible to design a node-based meta structure that can serve as the basis for a software application. Such a node-tree can be stored, and internal utility functions can be used to access information and to validate data. The data structure should be designed with many different processes in mind and be tested with a variety of applications and industries. By applying these steps to a production environment, the relationship between process, equipment, and energy usage is highlighted and can be used to understand how production activities function within an industrial facility and how energy and production are interrelated.

**Production flow (sub-steps :1_1_a -1_4_a)**

**Step 1_1_a: identification of the process operation steps**

The whole production line can be further divided into different process operation steps. Each process step can be defined and labelled according to production specifications or internal factory documents. Understanding of the current production system and breaking it down into appropriate steps will provide a solid foundation for the energy mapping and future assessments. This involves identifying the individual process steps, their sequence, and the inputs and outputs for each step.

**Step 1_2_a: identification of the process operation units/equipment**

Once an industrial process has been selected, the next step is to describe the existing process steps and their conventional unit operations and equipment. This can be achieved by assuming that the product flow passes through several blocks, which can be arranged in parallel, series, or loops. Each block represents a unit operation with the highest energy demand, such as pasteurization, boiling, evaporation, drying, and distillation, along with their respective subprocesses, if applicable. The equipment used for each process is then identified, along with the quantity of equipment per step. Although a real production plant may consist of many process operation units and components, we only focus on those with the highest energy demand. Additionally, it is important to note that there may be many interconnections between the process step and process equipment, as well as primary and secondary production flows, but this needs to be simplified to illustrate that each product will only take one main path through the process.

To ensure consistency throughout the energy mapping process, the basic operational blocks developed in the previous step should be reused. This requires testing the proposed blocks and interconnections in different production plants and maturing them to form a strong foundation for future implementation in the software tool.

**Table 1.** list of process operation units and equipment that we can include in this part.

| Process operation units and equipment | | | | |
|---|---|---|---|---|
| **Mechanical** | **Thermal (indirect)** | **Thermal (direct)** | **Electric** | **Heat transfer** |
| - Collector<br>- Mixing, stirring, suspension, sedimentation, wetting, absorption<br>- Splitters<br>- Separation of flows, filtration, extraction, centrifuge, decanters, press | - Evaporator<br>- indirect drying<br>- Boiling<br>- Baking<br>- Distillation<br>- Reactor | - Drying<br>- Stripping | - Compressor<br>- Induction cooker | - Warm up<br>- Cooling<br>- Pasteurization<br>- fermentation |

**Step 1_3_a: identification of the products and secondary media**

the amount and type of raw materials used in the production process, as well as the flow of products through the process, should be recorded annually and updated regularly. This information can be used to track changes in the amount and type of raw materials used in the production process, as well as changes in the flow of products through the process.

Apart from the main production flow, it is important to identify the secondary media used in each operation unit to heat up, cool down, pasteurize, or wash the main product flow. These secondary media could be anything that is used to transfer heat to or from the product flow, such as air, water, or steam etc.

For example, in a drying operation, hot air might be blown into the dryer to heat up the product. In a pasteurization or washing operation, hot water might be sprayed into the unit to pasteurize the main product or to wash the equipment used in the production line. In some cases, steam might be injected directly into the product flow to increase temperature of the product flow, change the consistency etc. in all these cases, the secondary media requires energy which should be accounted in the energy use of the operation unit process.

In addition, this information can also be used to evaluate the effectiveness of different energy-saving strategies, such as optimizing the use of secondary media or using alternative methods to heat up, cool down, or pasteurize the product flow in future**.**

**Step 1_4_a: collection of input output data**

In this step, all inlet and outlet data of the product and secondary flows in production lines are collected, along with their respective state conditions such as temperature, pressure, mass flowrates, specific heat, and other relevant parameters.

If energy meters are installed at this step, the information can be gathered from the energy monitoring system. Otherwise, the required data are collected by reviewing existing production specifications complemented with interviews with personnel such as production associates, supervisors, and managers, as well as other on-site investigations, information from control rooms, and manual calculation of the remaining required information.

**Step 1_1_b: identification of Energy carrier flows through the facility.**

The main objective of this step is to identify the main energy supply systems, including electricity, heating and cooling utilities, and their corresponding purchasing, conversion, and transmission processes.

Energy carrier flows are the sources of energy that supply electricity, steam, or other forms of energy required for powering equipment, heating, and cooling in an industrial plant. These sources can either be purchased from outside (i.e. electricity from the grid or heat from District heating network) or generated on-site by converting primary energy sources such as natural gas, oil, coal, biomass or renewable sources such as solar, wind, or geothermal energy.

To convert primary energy sources into usable energy, various types of equipment such as boilers, cooling systems, heat pumps, turbines, generators, and motors are used. These systems can transform energy from one form to another. Heating utility refers to systems or equipment that provide heat energy to a process or facility. The source of heat energy can be steam, hot water, thermal oil, or combustion gases from a furnace, boiler, or heat pump. On the other hand, cooling utility removes heat energy from a process or facility by consuming a certain amount of electricity depending on the system's coefficient of performance (COP). Cooling utilities can be supplied through cooling towers, chillers, or refrigeration systems, and the source of cooling energy can be air, water, or other fluids. These heating and cooling utilities are commonly used in various industrial processes such as chemical reactions, food processing, and manufacturing, where temperature control is critical. The temperature and flow rate of the heating and cooling utilities are usually monitored and controlled to ensure that process conditions are maintained within the desired range.

Energy transmission refers to the distribution of energy from the source to the end-use consumers, which can involve various transmission systems, such as pipelines for transporting natural gas or liquids, electrical grids for transmitting electricity, and piping systems for delivering steam or hot water or cooled fluid. The end-use consumers can be divided into different categories of production flow, support systems, space heating or even direct delivery to district heating network.

In addition to supplying energy, industrial plants can also implement various energy recovery and conservation measures to improve efficiency and reduce costs. Heat recovery systems can capture waste heat from one process and reuse it in another, reducing the need for additional energy input. Compressed air systems can be optimized to reduce energy consumption, and motors and pumps can be upgraded to more energy-efficient models.

**Step 1_2_b: collection of data**

Data collection for electricity consumption, heating, and cooling utilities in an industrial plant typically involves gathering information on various aspects, such as:
Electricity consumption: This typically involves identifying the equipment with the highest electricity consumption, such as motors of pumps, fans, compressors, and conveyors. The common methods of collecting electricity consumption data can be smart meters, manual meters, and billing data.

Heating and cooling utilities: This includes the amount of heat generated by the heating equipment (e.g., boilers, furnaces, heat exchangers), the type of fuel used (e.g., natural gas, oil, biomass), and the efficiency of the heating systems. It also includes the amount of cooling generated by the cooling equipment (e.g., chillers, cooling towers, heat exchangers), the type of refrigerant or cooling medium used (e.g., water, glycol), and the efficiency of the cooling system.

Waste heat recovery: Any waste heat that is recovered from the process equipment or buildings and reused for other applications. This includes information on the heat recovery equipment (e.g., heat exchangers) and the amount of heat recovered.

The required data for the last parts can be collected through various means, such as using sensors and meters installed on the heating and cooling equipment and piping network to monitor temperature, pressure, flow rate, and energy consumption. Data can also be collected manually by taking measurements at specific intervals or by reviewing equipment logs and maintenance records or interviewing personnel.

**Step 1_1_c: identification of support systems**

In an industrial plant, support systems are crucial for the efficient and safe operation of the facility. One important support system is Cleaning in Place (CIP), which allows for the cleaning of process equipment and piping without disassembly. Additionally, industrial plants may have other support systems in place, such as:

- Compressed air systems: These systems provide compressed air for powering pneumatic tools and equipment used in various industrial processes.
- Water treatment systems: Since industrial processes often require large amounts of water, water treatment systems may be necessary to ensure that the water is safe for use and meets the required quality standards.
- Waste treatment systems: Industrial processes can generate waste products that must be treated or disposed of properly to prevent environmental contamination.
- HVAC systems: Heating, ventilation, and air conditioning (HVAC) systems are essential for creating a comfortable and safe working environment for plant personnel. These systems can also play a role in the operation of certain processes.

**Step 1_2_c: collection of input output data**

To collect energy data for support systems in industrial plants, it is typically necessary to gather information on equipment specifications and energy requirements for running the systems that support the main production process. Energy meters can be installed on the equipment to measure usage, while energy bills and consumption records can be reviewed to track energy use. Here are some examples of energy data that may be collected for support systems:

- Electrical power consumption: Monitoring the power consumption of motors, pumps, and other electrical equipment used to support the manufacturing process can help determine the energy usage of support systems.
- Steam consumption: Measuring the amount of steam used to support the manufacturing process can help determine the energy usage of the steam system.
- Water consumption: Measuring the amount of water used to support the production process can help determine the energy usage of the water supply and treatment systems.
- Compressed air consumption: Measuring the amount of compressed air used to support the production process can help determine the energy usage of the compressed air system.

**Step 2_a Process flow balances**

This step involves conducting energy and mass balances for each unit operation that comprises the industrial processes. Inlet and outlet process streams, along with their respective state conditions (such as temperature, pressure, mass flow, specific heat, etc.), which are collected in previous steps, are used to determine the energy and mass balances of the production through the facility based on the first law of thermodynamics.

By conducting the process flow balance, we can understand the energy requirements of the process. Each cooling and heating demand yields a specific energy demand that can be calculated. These demands will vary depending on the amount of product that is input into the model. All these individual demands are then summed up to establish the process energy requirement, both in terms of heating and cooling. These energy demands can be reduced and optimized.

**Step 2_b: Energy flow balance**

An energy flow balance is carried out in addition to the process flow balance, to describe the energy flow through and the efficiency of the utility systems at the process site. It involves four overall sub-steps: Purchase, Conversion, Distribution, and Energy Use. The starting point of this balance "Purchase" is the energy bill, based on energy consumed as purchased fuels.

To illustrate, consider the example of a natural gas boiler producing steam for a process. In the "Purchase" sub-step, the purchased energy is examined from the company's bookkeeping to determine the gas input for the boilers. In the "Conversion" sub-step, all conversion losses related to producing steam from the natural gas in the boiler are accounted for, including flue gas loss, radiation loss, blowdown, and decoration. Additionally, conversion gains can be estimated, such as the introduction of valuable heat from waste heat through a heat pump.

The "Distribution" sub-step involves accounting for all distribution losses related to distributing the steam on the process facility, mainly consisting of heat loss from piping and condensate losses. Subtracting all losses from the known purchased amount yields the amount of steam consumed on site. Finally, the "Energy Use" step is the output of the energy flow balance.

**Step 3: Data validation**

In an ideal energy mapping scenario, the energy flow balance output (i.e. "Energy use" calculated in step 2-b) should equal the energy requirement calculated from the process flow balance(calculated in step 2-a). However, due to measurement uncertainties, poor data quality, and generalizations of complex processes, some deviation from this ideal situation can be expected. The accuracy of the energy mapping can then be determined as following.

$$Accuracy = \frac{(Process\ energy\ reueirment + Conversion\ losses + Conversion\ gain + DIstribution\ losses)}{(Purchased\ energy + Conversion\ Gains)} \quad (1)$$

**Step 4: Analysis of the process map (including evaluation of energy efficiency solutions and implementation)**

Once all the necessary data has been collected, the energy mapping analysis can be completed, and the outputs can be generated. The immediate outputs of a thorough energy mapping exercise include:

- Simple energy overview: This involves identifying trends, patterns, and areas of high energy demand within the production line. Such an analysis can help identify significant energy users (SEUs), equipment KPIs, and efficiencies that can be easily developed and maintained to comply with ISO certifications.
- Pinch analysis: This involves analysing the energy use in the process in relation to the temperature requirements. The analysis determines the minimum possible demands for heating and cooling utilities. This information can be used for further process integration studies, the integration of heat pumps into the process, and the optimal selection of utilities.

## 1.2. case studies

The methodology was implemented on two divers case studies to provide a preliminary assessment of its quality. Case study 1 involved a production plant for fishmeal and fish oil, while case study 2 covered a production plant processing eggs into various forms. The site descriptions and outcomes of the implementation are detailed below. It should be noted that the proposed method was evaluated up to the end of step 3, while step 4 will be continued in future work.

### 2.2.1. Case study 1

The production site specializes in the manufacturing of fishmeal and fish oil, operating 24/7. The plant processes fish by-products, such as the remains of fish that are not used for human consumption, to create high-quality protein and oil products. The process begins with the delivery of raw materials to the plant, where they are sorted. The fish are then cooked and pressed to extract the liquid portion, which is separated into fish oil and water. The solid portion is dried and ground into fishmeal. The resulting products are packaged and shipped to customers worldwide. Fishmeal is a valuable source of protein and other nutrients used in animal feed, while fish oil is a rich source of omega-3 fatty acids, which are essential for human health and used in dietary supplements, pharmaceuticals, and other industrial applications.

### 2.2.2. Case study 2

A production site specializes in processing eggs into various forms, including liquid egg products, egg powder, and egg yolk, which have a wide range of applications in the food industry, such as baked goods, sauces, dressings, and mayonnaise. The production process begins with the collection of eggs, which are then broken and filtered before undergoing pasteurization. The pasteurized eggs are then blended and homogenized, followed by drying and packaging to produce the final products.

## 2. Results and Discussion

The first three steps of the proposed methodology have been implemented in two production lines (case study 1 and 2) and the required data has been collected and evaluated. The results provide a visual representation of the process and energy relationship for the two presented production lines and are briefly summarized below.
It should be noted that for case study 2, the mass flow rate and corresponding data presented are scaled due to confidentiality issues, but still represent the correct percentage of data accuracy.

## 2.1. Case study 1

Figure 2 shows the general overview of the process steps and process units (sub-step 1_1_a and 1_2_a of the proposed methodology). The process steps identified for the plants are main production line produce fish meal, Oil cleanser and Deodorization. The identified process step related to the main production line includes process operation units cooker, presser, dryer, decanter, evaporator, centrifuge. While the Oil cleanser and Deodorization including process operation units such as centrifuge, filter, stripper, and scrub.

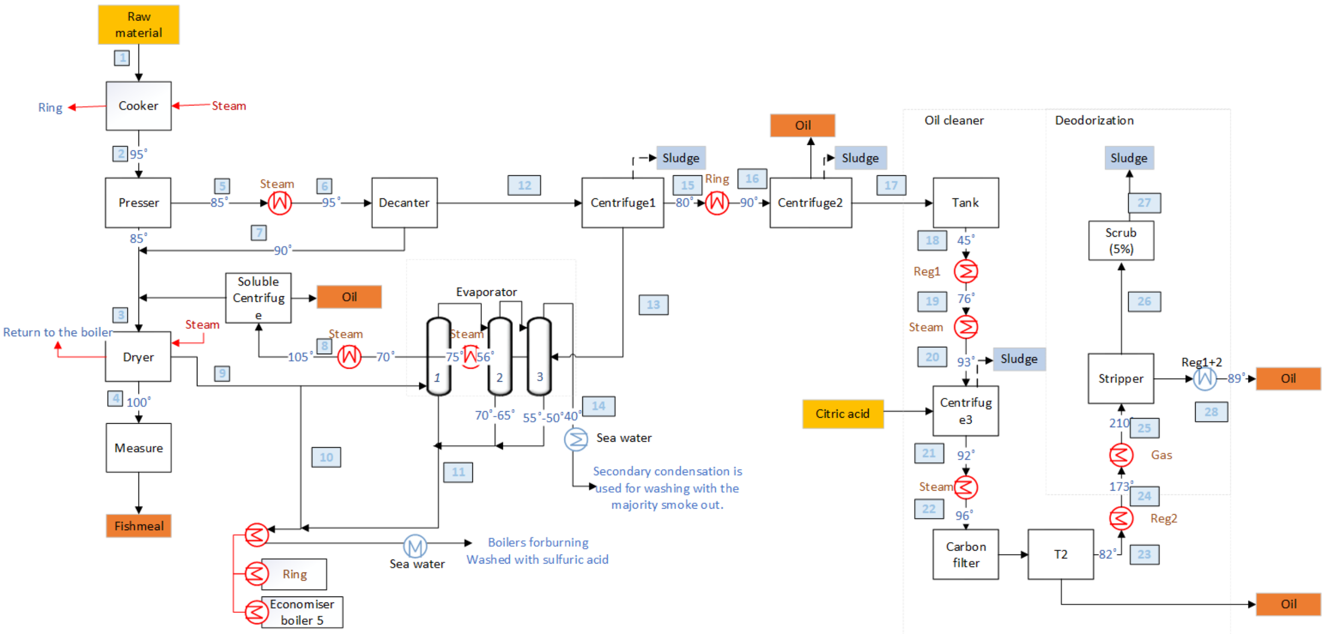


**Figure. 2.** Illustrating process step and process operation units for case study 1, corresponding to step 1_1_a and 1_2_a of the proposed methodology

Figure 3, presents the process flow balance (sub-step 2-a) taking into account the process step related to main production line produce fish meal and process operation units that influence the mass balances or final the energy use. The required data including the temperature, mass flows and recipes (fraction of water, fat and solid) are introduced as an input, output data of the main production flow.

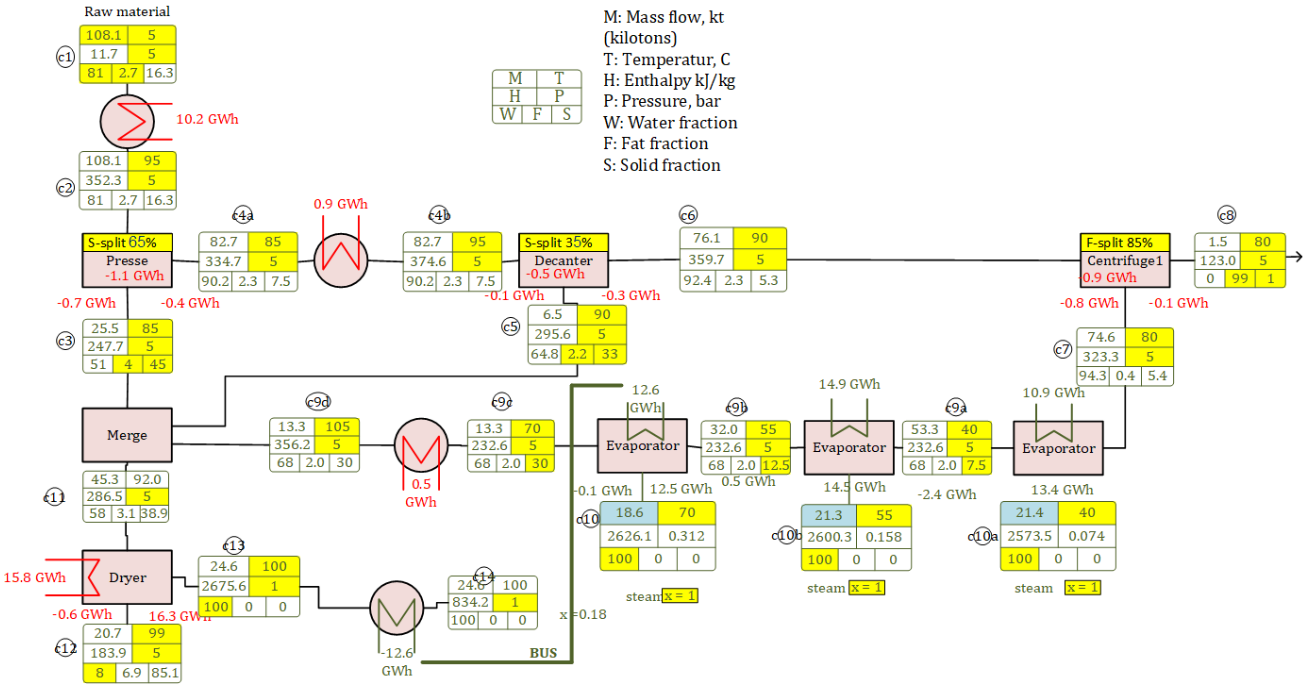


**Figure. 3.** Mass and energy balance for case study 1, corresponding to step 2_a of the proposed methodology

It should be mentioned that the mass and energy balance presented in figure 2 belongs only to type of material, however in practice the company has handled three different types of raw materials equal to 108143, 919221, and 70293 tons /year which requires in total 73242561 Kwh heating demand.
Table 2 presents steps 1_1_b, 1_2_b and 2_b including identification of energy flows, data collection and energy flow balances for the presented case study. The steam is generated by process flue gas waste heat recovery boiler and stem boilers. The later mainly run on natural gas.

**Table 2.** presents a list of the unit operation units and equipment that we can include in this part.

| Heating utility | | | | | |
|---|---|---|---|---|---|
| | | **Purchase fuel** | **Conversion losses** | **Distribution losses** | **Energy (steam) to end-use consumers** |
| **Equipment** | 5 steam billers Using Natural gas and oil , with 0.92-0.94% slightly differ for different boilers | Natural gas: 115184432 KWh<br><br>Oil: 7619 KWh<br><br>Total steam produced: 22993535 KWh | 6-9%<br><br>≃1701522 KWh for each boiler depending n efficiency<br><br>Total steam: 105954221 KWh | 3%<br><br>3178626 KWh<br><br>Total steam: 102775585 KWh | Production flow: 73.242.562 Kwh (obtained from step 2_a)<br><br>Space heating: 6.277.252 Kwh<br><br>Delivery to district heating 13.026.300 Kwh |

Finally, from step 3, Eq.1, 88% accuracy of the mapping can be obtained.

## 2.2. Case study 2

Figure - 4 illustrates the production flow and corresponding process steps (sub-step 1_1_a and 1_2_a) as well as the process flow balance (sub-step 2-a) white egg and blending line including the process unit operation heating, cooling, extraction, fermentation, concentration, spray drying, and pasteurizer .

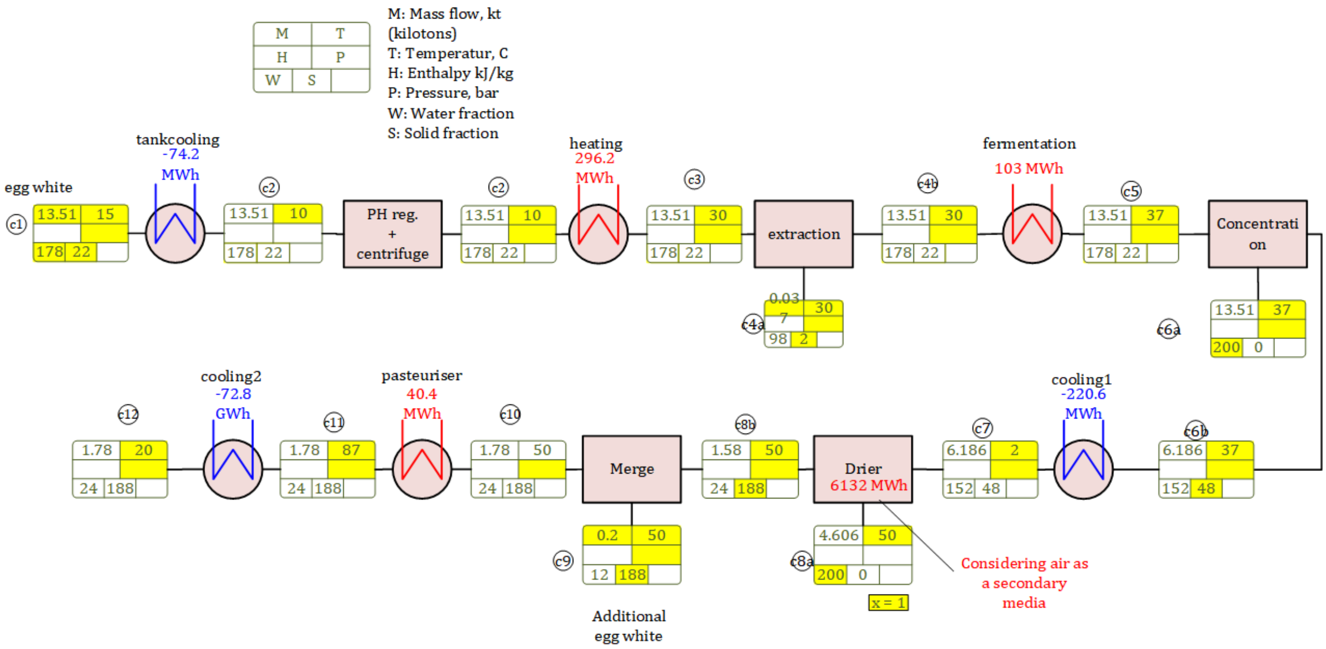


**Figure. 4.** Mass and energy balance for case study 2, corresponding to step 2_a of the proposed methodology

# Conclusion

The paper presented a generic methodology to accelerate the energy mapping of production lines. The performance of individual process steps is modelled with a few inputs following steps presented in the following methodology. Process operation units representing different operation steps are identified. Few readily available data are collected. The rest are defined by exploiting engineering judgment like the experience of the involved industrial partners visiting the plant, and estimated default values. Being able to bypass blind spots with regards to sensor data allows us to continue the work without costly and time-consuming measurement campaigns. The procedures developed in the proposed methodology thus enable the user to complete an energy mapping that may have been much more difficult to carry out otherwise.

The methodology was implemented in two different case studies as example of Danish food production lines and beneficial results are shown.

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