Energy use categorization with performance indicators for the food industry and a conceptual energy planning framework

Citation for the original published paper (version of record):
Kanchiralla, F., Jalo, N., Thollander, P. et al (2021). Energy use categorization with performance indicators for the food industry and a conceptual
energy planning framework. Applied Energy, 304. http://dx.doi.org/10.1016/j.apenergy.2021.117788

(article starts on next page)

Applied Energy 304 (2021) 117788

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Energy use categorization with performance indicators for the food industry and a conceptual energy planning framework

Fayas Malik Kanchiralla *, Noor Jalo, Patrik Thollander, Maria Andersson, Simon Johnsson

Department of Management and Engineering, Division of Energy Systems, Linköping University, SE-581 83, Sweden

HIGHLIGHTS

- A novel taxonomy for the monitorization of energy use in the food industry.
- Energy end use and CO_2 emissions analysis based on the suggested taxonomy.
- Potential energy performance indicators are suggested for the food industry.
- A novel energy planning framework in an industrial context is suggested.

ARTICLE INFO

Keywords:
Food industry
Energy end-use
Energy performance indicator
Energy planning
Industry

ABSTRACT

Energy efficiency improvements can enhance industry's decarbonization. A major challenge however is that the energy efficiency potential often remains untapped, due, among other things, to the lack of information on energy end-use and available energy efficiency measures. Further, this lack of information also makes the deployment of energy efficiency difficult to monitor and evaluate. The creation of a standard or taxonomy on how to categorize energy end-use for major industries would help to close this knowledge gap. This paper presents a novel taxonomy for energy end-use in the food industry, with four hierarchical levels. Further, results show that the production process utilizes two-thirds of the total energy used in the food industry and only one-third is used for support processes. Another result is that heat processing and space heating are the most intensive unit processes in terms of energy and carbon dioxide emissions for production and support processes, respectively. The paper also presents an array of energy performance indicators for the identified energy-intensive processes. The case study was carried out in the Swedish food industry. However, taxonomy and energy performance indicators can be generalized internationally. In addition to the above results, this research presents a novel concept of the energy planning framework, which helps with simple and effective planning of energy improvement activities in an industrial context. The energy planning framework can help in benchmarking, setting targets, and monitoring energy performance in the industry.

1. Introduction

A 60% increase in food demand is expected by 2050, as the global population continues to grow, and an increase in the energy demand from the food industry is also expected [1]. In 2018, industrial energy use accounted for 38% of Sweden's total energy use [2], of which the food industry accounted for 3.5% [2]. The European Union (EU) has set an ambitious target of 32.5% Energy Efficiency (EE) improvements by 2030 [3] and Sweden aims to achieve net-zero CO_2 emissions by 2045 [4]. In response, industries have started paying significant attention to EE, a move that will also help them to reduce the environmental impact associated with Energy End-Use (EEU). However, as reported by the International Energy Agency (IEA), the year 2018 saw the lowest rate of EE improvement since 2010, highlighting the need to gear up technical efficiency to meet the climate mitigation targets [5].

For energy planning and implementation of energy efficiency measures (EEMs), comprehensive knowledge of energy use at the process level is of utmost importance [6]. EEU categorization according to a standardized taxonomy would be an effective way to improve the EE potential [7]. Such a taxonomy would enable industries to learn how

* Corresponding author.
E-mail addresses: fayka161@student.liu.se (F.M. Kanchiralla), nooja264@student.liu.se (N. Jalo), patrik.thollander@liu.se (P. Thollander), maria.h.andersson@liu.se (M. Andersson), simon.johnsson@liu.se (S. Johnsson).

https://doi.org/10.1016/j.apenergy.2021.117788
Received 16 February 2021; Received in revised form 30 August 2021; Accepted 1 September 2021
Available online 9 September 2021
0306-2619/

energy is used in operations with more harmonized EEU data [8]. In addition to the EEU data, there should be indicators for measuring and monitoring energy performance. ISO 50006 defines these indicators as energy performance indicators (EnPIs) [9]. EnPIs help organizations to understand the deployment levels of the potential and target levels for improvement [6]. With the lack of general EEU categorization and performance indicators in the industry, EE improvements and CO_2 reductions are likely to never reach their full potential. Further, monitoring and evaluation would be greatly facilitated by a harmonized way of categorizing energy end-use. In a study of industrial small and medium-sized enterprises (SMEs) emanating from various countries, it was found that there was no harmonized way of categorizing energy end-use data, which in turn made a comparison between different international datasets very difficult [10].

Technical efficiency should be combined with effective energy management practices to extend the EE potential [11]. For most of the non-energy-intensive industries and industrial SMEs in particular, the energy management practices are underdeveloped [12], often due to a lack of energy planning and a lack of a strategic approach to the issue [13]. The objective of energy management is to establish the systems and processes needed to improve energy performance in an organization [14]. As per ISO 50001, energy planning should lead to activities that continuously improve energy performance consistent with the energy policy [14]. It can be understood that energy planning is one of the crucial pillars of effective energy management. ISO 50001 provides a conceptual diagram for energy planning [14], but it does not provide comprehensive guidelines for industries to tap their EE potential. Such guidelines need to be deployed, taking the particular industry and company's needs into account.

Several studies have developed taxonomies for industry-wise categorization of energy use, for example in the wood industry [15] and the engineering industry [16]. The food industry is very diverse in terms of the variety of products produced within the industry and involves different categories of production processes. The industry includes heterogeneous operations related to meat and fish processing, fruit and vegetable preservation, beverages, dairies, bakeries, and processing of oils and fats, etc. [17]. Several studies have categorized energy use within the food industry, but each of them follows different concepts. For example, Seck et al. [18] used 11 energy vectors, whereas Leduc et al. [19] classify processes into four major processes with some sub-processes. This disparity shows the difficulty in comparing the EEU results of different studies in the same sector. The need for a reference energy system that is generic for every sector is also mentioned in the above studies.

For this study, there are four main aims: the primary aim of this paper is to present a taxonomy to facilitate EEU categorization of the processes in the food industry into a process tree with hierarchical levels. The second aim is to identify the energy-intensive processes and related CO_2 emissions in the sector. The third aim is to identify suitable EnPIs for the intensive production processes. The study is carried out as multiple case studies of Swedish food manufacturers. The final aim is to develop a conceptual Energy Planning Framework (EPF) that can form the basis for energy management for all industries.

To the authors' knowledge, the attempt to develop a hierarchical taxonomy for energy use generic to the food processing industry is novel in nature. This will help in increasing the knowledge on the energy end-use in the processes and will enhance credible comparison by bringing them into the same platform. This taxonomy is supported by a case study to demonstrate how this taxonomy can be useful in comparing processes in terms of energy use and CO_2 emissions, but the scope of the case study is limited to the Swedish food processing industry. In addition to the above, developing a novel EPF will help industries with fair benchmarking and monitoring of energy improvement activities. Along with the proposed taxonomy and EnPIs, the proposed EPF will help to overcome barriers such as lack of knowledge and information and enhance energy management practices in industries. The outcome of this publication is relevant for the decision-makers in the food industry, guiding them towards EE improvements, as well as for trade associations and public authorities that wish to categorize data from multiple companies in order to monitor and evaluate EEU progress.

Table 1
Various aggregation levels of taxonomy defined by Kanchiralla et al. and their definitions [16].

Levels	Definition
Level 1: Energy carriers	This level characterizes the supply side of the energy flow.
Level 2: Major processes	This level characterizes the role of energy in value addition. The production process refers to the processes which are directly needed to produce a product and the support process refers to processes that support production processes.
Level 3: Unit processes	This level refers to unit processes that are classified based on the purpose of energy flow to a process, which is the effect that the process delivers.
Level 4: Sub-unit processes	This level characterizes the energy end-use of different technologies or methods used for the unit process.
Level 5: Equipment/tool	This level characterizes individual machinery that uses energy for its operation. Different sub-unit processes can be carried out using different types of machinery.

2. Research background

2.1. Taxonomical classification of EEU

One of the first attempts to classify energy use is suggested by Söderström, with processes classified based on the unit process concept [6]. Söderström developed a generic taxonomy by classifying processes into two main categories, production and support processes, and further down to unit processes for each category [6]. This method has been used in many studies, for example for the methodology of energy auditing [20], to study EEU of SMEs in different countries [10], to explain a bottom-up approach [21], study of EE implementation for wood, food, and metal SMEs, etc. [8]. However, this classification is general and could not allocate some of the production processes specific only to some industrial sectors [16]. Also, it lacks hierarchical classification that facilitates information retrieval and benchmarking between the manufacturing systems [16].

Some recent studies have adapted this classification to the specific industrial sector to enhance the feasibility of implementation. One of them is the paper by Johnsson et al. on the wood industry, which is based on supply chain flow [15]. Another concept based on the level of disaggregation is mentioned by Seck et al. [18]. A similar concept is used by Kanchiralla et al. [16] for the engineering industry, with this study defining five disaggregation levels based on several attributes as shown in Table 1. With the increase in the disaggregation levels, the level of the analysis precision of the energy system increases, but the quantity of data needed also increases [18].

Several studies have classified the energy use of the food industry, but each applies different concepts. Drescher et al. classified EEU in the food industry into direct use (process use and non-process use), indirect use (fuels for boilers), and unallocated EEU (by-products of energy sources) [22]. Process use involves process heating, process cooling and refrigeration, machine operation, electrochemical processes, and others [22]. Non-process use involves facility support, facility heating, lighting, ventilation, refrigeration, outside transportation, and conventional electricity generation [22]. A study of the agro-food chain stated that at any stage of the food chain, energy use may comprise direct use by a specific production process, plus indirect use [23]. In a report by the U.S. Environmental Protection Agency, the energy use in the processes is classified as manufacturing processes, processes to maintain food safety, and facility functions [24]. The manufacturing processes gather intensive processes such as process heating and cooling [24]. Processes to

Table 2
Research gap between literature studies and industrial needs described by May et al. which makes implementation of performance indicators challenging [35].

Research gap	Description
Gap 1	Only a few of the indicators of the state of the art are suitable for energy management applications within a manufacturing facility
Gap 2	The difficulty of benchmarking EE between manufacturing plants, which is sometimes inapplicable
Gap 3	Limits in technological monitoring, such as the absence of reporting information about how energy is used within the processes in the manufacturing facility
Gap 4	The lack of guidelines on EnPI selection
Gap 5	The lack of development of supporting tools to be used by energy management during EnPI development

maintain food safety are motor-driven systems, while facility functions cover lighting, ventilation, and heat [24]. A study by Kamiński and Leduc categorized the processes within the European food industry into four main categories: process heating (boiling, drying, pasteurization, evaporation), process cooling and refrigeration, processing machinery (fans, pumps, ventilation, mixing, compressed air), and non-process operation (building heating and lighting) [19].

Ladha-Sabur et al. studied the energy use of different food products to differentiate energy-intensive products from non-intensive ones [1]. Malagié et al. classified the production processes of the food industry into material processing, storage requirements, processing techniques, preserving techniques, and packaging of finished products [17]. The Best Available Techniques (BAT) document recommends categorization of the food processes into reception and storage of raw materials, size reduction of raw material, processing of materials, product storage & dispatch, and cleaning activities [25]. In addition to the generic study, it may be noted that there are studies on the energy flows of a specific type of food industry, such as the fruit and vegetable industry [26], the potato crisp manufacturing industry [27], and the meat industry [28]. The difference in these concepts shows the difficulty in a credible comparison of energy use in the sector.

2.2. Energy performance indicators

ISO 50006 defines an EnPI as a "quantitative value or measure of energy performance defined by the organization". Since the EnPI is a gauge, it is very important to define the boundary of EnPIs [29]. Performance measurements are essential for energy planning, monitoring, and control [6]. A study by Sommarin et al. stated that the EnPI boundary is categorized into overall figures, production-process-specific, and support-process-specific [21]. ISO 50006 specified that the levels of EnPIs are categorized into the organizational, system, and process levels [9]. The same boundary levels are adopted in the study by Andersson and Thollander on the Swedish pulp and paper industry [30] and Kanchiralla et al. on the Swedish engineering industry [16]. The organizational EnPIs target overall energy use that can fit any industrial organization [16]. The system-level EnPIs include EnPIs used for monitoring and controlling energy use for any industrial system [16]. Several studies have come up with EnPIs for organizational level and system level like Schmidt et al. [31] propose EnPIs for factory level to the process level, LJ Energy Pte Ltd [32] proposes EnPIs for organizational level and system level for food manufacturing plants are proposed. Kanchiralla et al. propose several EnPIs for organizational level, system level, and process levels [16].

The organizational level, system level, and support process levels are generalizable for all industrial sectors, whereas the production processes vary widely between industrial sectors [16]. Since the production processes are industry specific, EnPIs should be developed specifically for production processes in the food industry. The process level can be used for evaluating energy performance in separate processes [16], and it can also be used for aggregated levels [33]. The study by Kanneganti et al. covered three types of EnPIs, namely: plant, production line, and process [34]. A recent study by Beisheim et al. [33] proposes a method that utilizes local EnPIs and an Energy Baseline (EnB) from the process level to the evaluation of a company or site. A deviation of the performance at the site level can be allocated to single processes and their EnPIs to drive the root-cause analysis, since this is the purpose of EnPIs.

May et al. illustrated that some research gaps still exist on how EnPIs are studied and addressed in the literature and what the actual industrial needs are [35]. There are five gaps between literature and industrial needs addressed in the paper, as shown in Table 2.

2.3. Energy planning

Energy planning is an aspect of energy management aimed at establishing energy targets, functional areas, and forming an action plan [36]. Energy planning covers activities such as energy reviews, identification of energy objectives, EnPIs, EnB, and action plans [14]. ISO has various requirements concerning inputs for the energy planning step; these are very unspecific and involve a large number of concepts that require more details to assess energy performance [33]. The conceptual diagram for the energy planning process provided by ISO 50001 is shown in Fig. 1 [14]. The figure shows the three steps, inputs for this process, and outputs from the energy planning [14].

The study by Schulze et al. developed a conceptual framework for energy management that aims to build a comprehensive approach for effectively tapping the EE potential [36]. This framework defines energy planning as a means of developing energy policy, an energy strategy/target, an action plan, and risk management [36]. A study by Lee et al. provided an energy management plan that is perceived as a process of measuring energy performance, performing energy audits, analyzing the audits, improving efficiency, controlling, and looking for saving opportunities [37]. Binasova et al. modified the energy planning mentioned in ISO 50001 to what they call "the advanced approach of energy-efficient manufacturing" [38]. The study added more inputs and outputs to the energy planning and added a fourth step to the main steps, which is identifying advanced technology for improving EE [38]. Prashar adopted

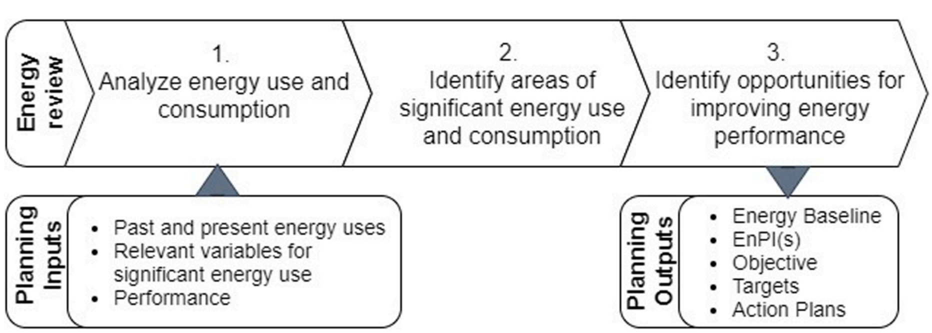


Fig. 1. Different steps of the energy planning process as per ISO 50,001 [14].

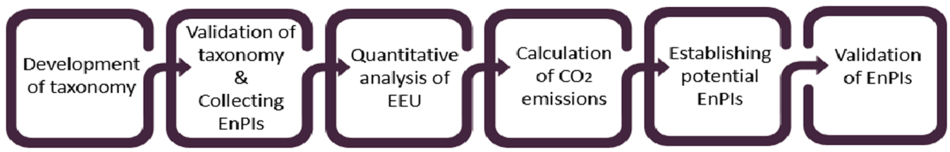


Fig. 2. Outline of the stepwise methodology used for developing taxonomy, calculating EEU & CO_2, EnPIs [16].

the Plan Do Check Act (PDCA) cycle for energy optimization in SMEs and she proposed that the planning phase include initiation, energy audit, and action plan [39]. Kanneganti et al. integrated energy planning from ISO 50001 with other standard assessment procedures to develop a reporting format to support the implementation of ISO 50001 [34]. The authors emphasized the energy assessment of intensive entities through performance indicators, in which intensive entities were named as major energy consumers [39], significant energy users [34], and energy-intensive utilities [40]. Energy planning is also widely addressed in terms of national or regional levels, but this is different from the energy planning defined by energy management at the industry level [41]. To the authors' knowledge, there is a scarcity of relevant studies aimed at formulating guidelines on the planning process for industries.

As shown in Fig. 1, the energy review is central to energy planning, and identifying the opportunities for improvement is the final step of an energy review [14]. Benchmarking is the process of identifying, analyzing, and comparing energy performance data to identify the opportunities for improvement [14]. Benchmarking can be done internally and/or externally during energy planning, which allows companies to establish an industry benchmark, a historical benchmark, and a company-wide benchmark [42]. The industrial benchmark compares a company's facility or processes against the facilities or processes of other companies [36]. The historical benchmark compares a facility's actual energy use against itself in earlier times, while the company-wide benchmark deals with comparing several facilities or processes in the same company [36]. Benchmarking is a valuable input to the identification of improvement activity and energy targets [14].

3. Methodology

3.1. Taxonomy, CO_2 Emissions, and performance indicators

The methodology used in the section for the first three aims of the study was inspired by the study by Kanchiralla et al., and the steps followed are shown in Fig. 2 [16]. The study used a variety of approaches including an axiomatic approach, an empirical approach, and quantitative analysis. One of the major highlights of this methodology is the validation of results by the end-user, i.e. the energy manager in the current study, the food industry.

1) *Development of taxonomy*: The developed taxonomy is based on hierarchical classification similar to biological taxonomy that consists of different layers. By using the axiomatic approach method, the collected literature and the non-numerical data from the audit reports are used to categorize the processes within the food industry into four levels. Literature studies were selected on the categorization of EEU processes, e.g. study by Kanchiralla et al. [16] for the engineering industry, the study by Andersson et al. [8] for industrial SMEs, the study by Ledu and Kaminski [19] for EU food industry, the study by Drescher et al. [22] for food industry, study by Campiotti et al [26] for Italian fruit and vegetable processing industries, and the study by Gonzalez et al. [43] for Food Processing Technologies. The main keywords for searching were EEU categorization of processes in the food industry and the classification of processes in the food industry. The EEU data used for this study from the audit reports of the food industry were based on the bottom-up approach. The audit reports were provided by a private energy consultancy firm. Out of 17 collected audit reports, only 15 were classified well enough to be considered in this study. The details of the audit report are shown in Table 3:

Table 3
Details of audit reports considered for the case study.

Number of audit reports collected	17
Number of audit reports selected	15
Year of the audit reports selected	[2011–2018]
Description of products manufactured in the companies considered	Meat processing, beer, biscuit industry, organic food, fruit and vegetable preserving, sauces, flour, and pasta manufacturing

The taxonomy was developed by adopting the hierarchical EEU classification developed in the study by Kanchiralla et al. [16], which is described in Table 1.

2) *Validation of the taxonomy and collecting EnPIs:* To ensure that the results of the study are in line with industrial needs, a questionnaire was developed and distributed among energy managers in certain food companies. The questionnaire aims to validate the taxonomy and collect EnPIs and it consists of three main parts. The first part is to understand energy management within companies, while the second part is designed to validate the taxonomy by collecting feedback. The last part is to collect EnPIs used by their company. The questionnaire was sent via email to twelve companies from the food sector, out of which four companies answered our questionnaire.

3) *EEU analysis:* The quantitative approach is used by taking data from the audit reports to analyze the EEU of the food industry case study. The developed taxonomy was adopted to analyze how energy is used in different processes and which carriers supply it. Inspired by Yin [44], calculating EEU on the aggregated level was done by using a bottom-up approach as shown in Equation (1). EEU_i is the Energy End-Use, i is the level number. The bottom-up method allows an in-depth analysis of production processes [45]. Sub-unit processes (level 4) were taken directly from the audit reports. The sub-unit processes were summed up to identify the energy use of unit processes (level 3). The unit processes were further summed up to form the energy use of each of the major processes (level 2). For the demand side, the major processes were also summed up to identify the total energy use by the industry. The total energy use can also be calculated using a top-down approach from the supply side by summing up the share of each carrier. The reason for checking both supply and demand sides is to ensure accurate results. The unit used for EEU is MWh.

$$EEU_i = \sum \mathrm{EEU}_{(i+1)} \tag{1}$$

4) *CO_2 emissions analysis*: The quantitative method is used after identifying the exact share of carriers for a process. Emissions can be calculated by multiplying the energy use of a carrier (MWh) by its emission factor ($kgCO_2/MWh$). After that, the emissions of all carriers related to the process are summed up to identify the total emissions of the process as shown in Equation (2). EEU_n is the Energy End-Use, n is the energy carrier, EF_n is the Emission Factor of carrier n, x is the number of carriers

$$AnnualEmissions = \sum_{n=1}^{x} (EEU_n) \times EF_n \tag{2}$$

In this case study, different energy carriers are used by companies, including electricity, district heating, heavy oil, diesel, Liquified Petroleum Gas (LPG), and biomass. Different energy carriers have different emission factors, which also may vary depending on the season and

Table 4
Carbon dioxide emission factors for different energy carriers considered for this study.

Energy Carrier	CO_2 Emission Factor ($kgCO_2$/MWh)	Year of Data
Nordic Electricity (average mix)	59	2013 [47]
Nordic Electricity (marginal)	728	2017 [48]
Swedish District Heating (average mix)	46	2015 [49]
Swedish District Heating (marginal)	267	2017 [48]
Heavy Oil	274	2017 [50]
Diesel	222	2017 [50]
LPG	234	2017 [50]
Biomass	345	2017 [50]

region; this especially holds for electricity and district heating [46]. Table 4 shows the energy carriers identified in the companies and their related emission factors.

Emission factors vary massively depending on the selected source. For this study, emission factors for fossil fuels were taken from the Swedish Environmental Protection Agency [50]. As mentioned, emission factors for electricity and district heating vary according to the season and region. For this study, emission factors for electricity relate to the Nordic Electricity Mix since it is traded through Nordpool, which is a joint electricity market for Northern European countries. [48]. Meanwhile, the emission factor for district heating uses the Swedish Mix since it is traded locally [48]. For this study, two scenarios are considered for both electricity and district heating due to the variation of their emission factors throughout the year. For the first scenario, the emission factors are taken according to the average Nordic electricity mix [47] and the average Swedish district heating mix [49]. In the second scenario, the marginal Nordic electricity mix, and the marginal Swedish district heating mix are considered [48]. The average electricity is merely a description of the life cycle emissions from generating 1 MWh of electricity [51]. Marginal electricity is electricity produced by marginal sources. The marginal sources in the Nordic region are coal-fired power plants for marginal electricity and oil-fired combined heat and power plants (CHP) for marginal district heating according to previous studies [52].

5) *Identifying potential EnPIs*: An axiomatic approach was used for collecting and studying EnPIs in the food industry. The same questionnaire used in step (2) was used to collect EnPIs from different companies. The questionnaire was shared with the food companies and many works of literature were studied and analyzed in this concern, including general guidelines in ISO 50,006 [9], the study by Kanchiralla et al. [16] for the engineering industry, the study by Schmidt et al. [31], for manufacturing processes, and study by LJ Energy Pte Ltd [32]. Variables such as boundary definition and process characteristics are considered while analyzing the EnPIs in previous studies. A previous study on the Swedish engineering industry [16] shows already developed EnPIs for organizational, system, and process levels. Only the production processes vary widely between different industrial sectors. The EnPIs at the organizational level, system level, and support process level are general and suit any industry, hence the same can be adopted by the food industry. The scope of this study is to identify EnPIs for intensive production processes only. Various works of literature were evaluated and the EnPIs were identified, considering the relevant variables linked with the energy performance of production processes and their attributes.

6) *Validating EnPIs by food companies*: Another questionnaire was designed to validate the EnPIs and consists of two main parts. The first part comprises lists of EnPIs proposed for the food companies in which the production EnPIs are developed by the study, while the other EnPIs are taken from the literature, including support, system, and organizational-level EnPIs. The second part of the questionnaire consists of three questions related to the importance of EnPIs to the companies, the applicability of EnPIs to their factory, and open suggestions for other EnPIs to be added to the study. This questionnaire was sent via email to sixteen companies from the food industry and only one company responded to the questionnaire.

3.2. Energy planning framework

The conceptual approach was used to construct the EPF. The evidence for the parameters required for the framework was shortlisted by scrutinizing various concepts mentioned in different kinds of literature. The base of the framework was adopted from ISO 50,001 and it was integrated with the concepts mentioned in various studies, which were shortlisted to form the structure of the framework. The attributes for the steps were then critically analyzed before they could form the basis for inputs to the energy planning.

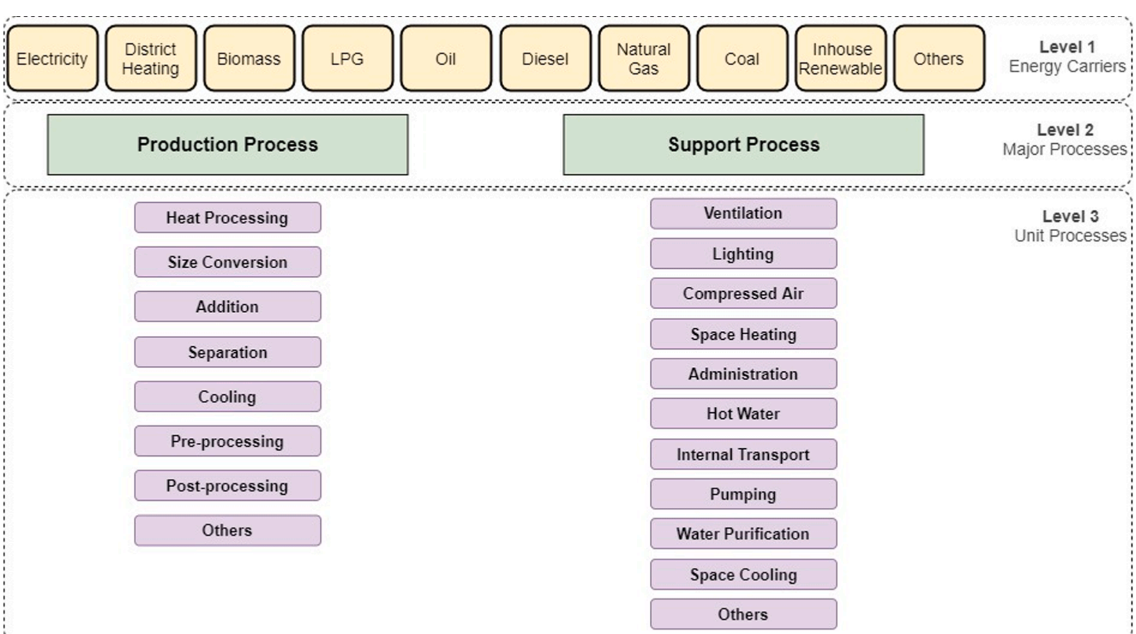


Fig. 3. Categorization of level 1, level 2, and level 3 in the taxonomy of the food industry.

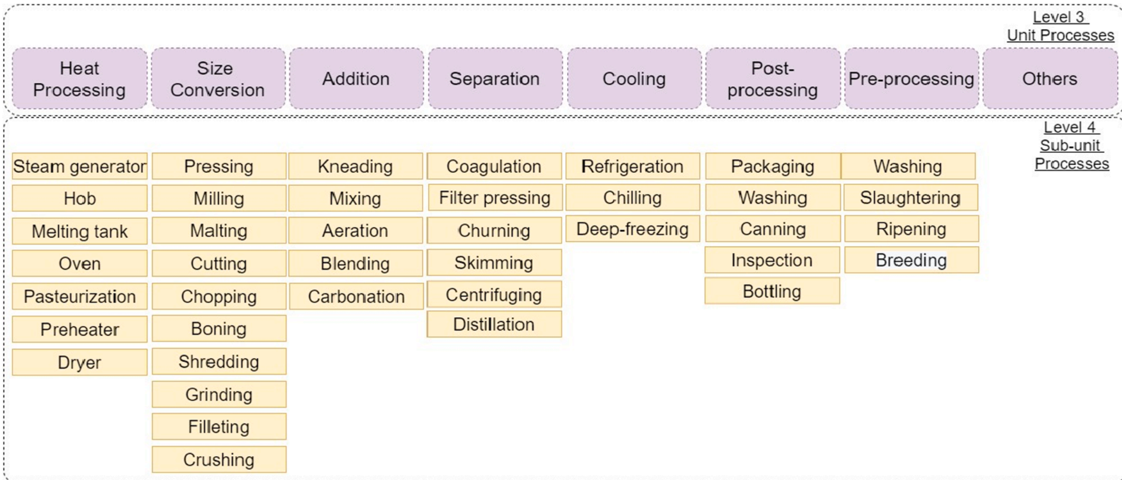


Fig. 4. Level 3 and level 4 categorization of the production process in the food industry.

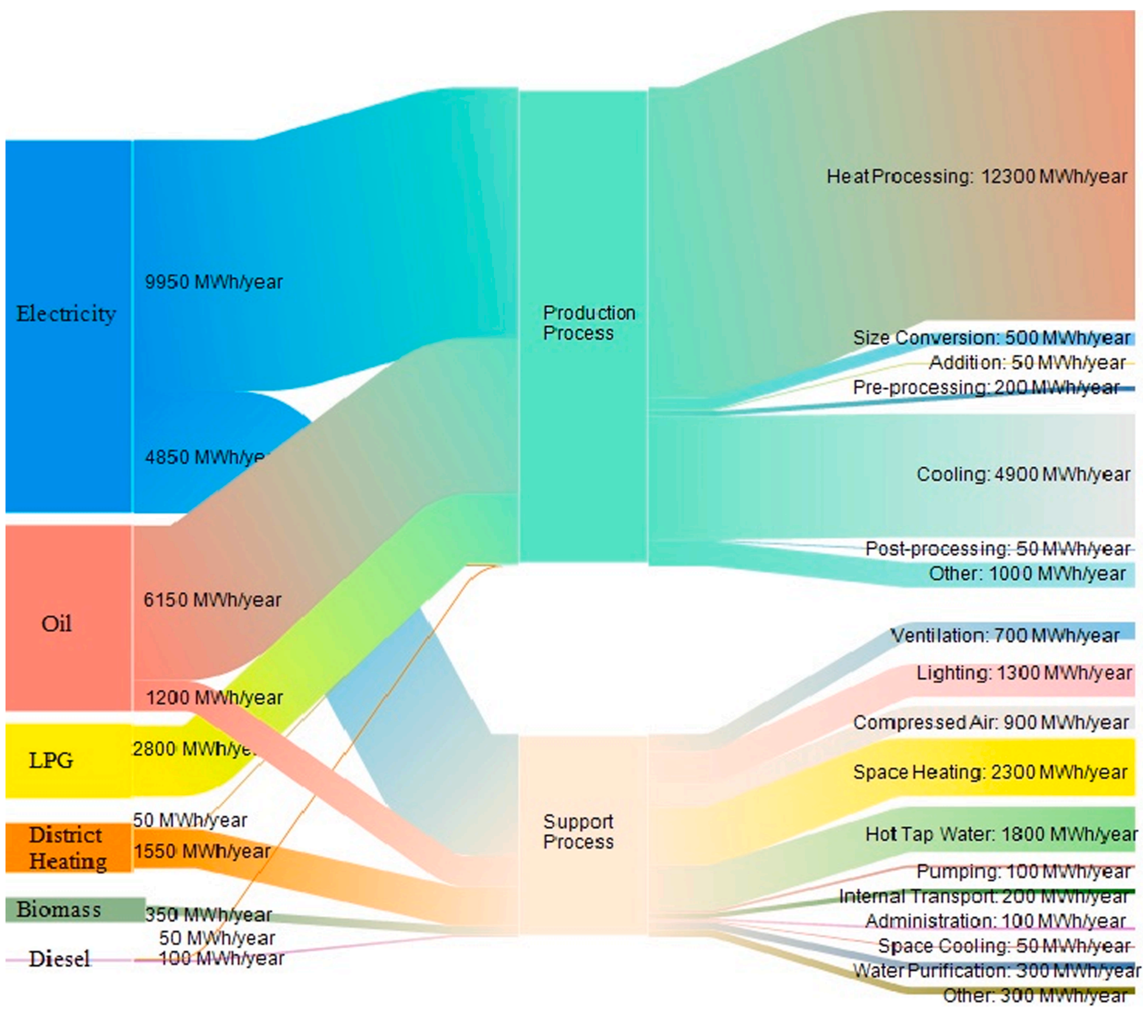


Fig. 5. EEU for each level of taxon processes and energy carriers in the Swedish food industry (values are rounded to the nearest 50 or 100).

3.3. *Methodological limitations*

Certain limitations exist in this study. First, not all the collected audit reports of the food industry were detailed enough in terms of energy use. Second, the data has considerable heterogeneity due to the variety of sizes and production volumes. Third, external transportation (for example the transportation of goods out of the company) is excluded. Fourth, one of the major limitations is the lack of data that are relevant to EnPI development. Fifth, the industry lacks similar research in this field, so comparison and contrast were not always feasible. Finally, energy data are not available at the instrument level in the case study, so it is not considered in either the EEU categorization or EnPI

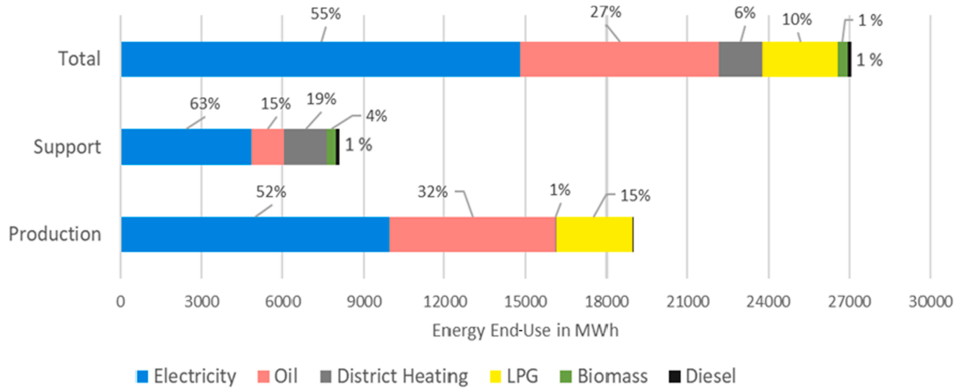


Fig. 6. Share of EEU from different energy carriers for the production and support processes of the food industry. Percentage in order of electricity, oil, district heating (DH), LPG, biomass, and diesel.

development.

4. Results and analysis

4.1. Taxonomy of EEU for the food industry

Collecting literature studies and audit reports, and adopting the hierarchical classification developed by Kanchiralla et al. [16], has enabled a hierarchal EEU taxonomy for the food industry to be developed. After considering the energy flow as the attribute for classification, a four-level taxonomy has been developed.

Fig. 3 shows that level 1 gathers nine key energy carriers as relevant supplies to the food industry, excluding "Others". Level 2 shows the two major processes, which are production and support. Level 3 gathers unit processes for each major process separately. For support, ten unit processes are gathered, while there are seven unit processes for production, excluding "Others". Level 4 (see Fig. 4) gathers the technologies derived from unit processes, which are sub-unit processes. It can be noted that support processes are not further subdivided into level 4. The "Others" category among unit processes and sub-unit processes are undefined. Level 5 on equipment is excluded from this study due to the unavailability of data at this level. The developed taxonomy was validated by four food companies.

4.2. Energy End-Use

The energy data from the audit reports are used to analyze the EEU, which is studied by adopting the taxonomy approach in section 2. Fig. 5 shows the results of the energy analysis of the food industry; it can be seen how energy flows through different hierarchies and is distributed to various categories defined in the taxonomy. As shown in Fig. 5, EEU varies widely between processes. The annual EEU is 27,050 MWh/year, of which 19,000 MWh/year is the EEU of production, while 8,050 MWh/year is the EEU share of support processes. It can be noted that 70% of the total energy is utilized for production in the food industry, which shows that the production processes are more intensive for the food sector. The remaining 30% of the energy is used by the support processes.

Fig. 6 shows the supply-side (that is the total share of energy from energy carriers used in the industry) for the production processes and the support processes. It can be noted that the main energy carrier used for production and support is electricity, followed by heavy oil. The use of heavy oil in production is more than support, due to the intensive use of heat in the production-related processes. Other carriers such as biomass and diesel are used within the industry, but their share is very small compared to other carriers.

Fig. 7 shows the share of EEU per unit process at level 3 for both production and support unit processes. Appendix A shows the

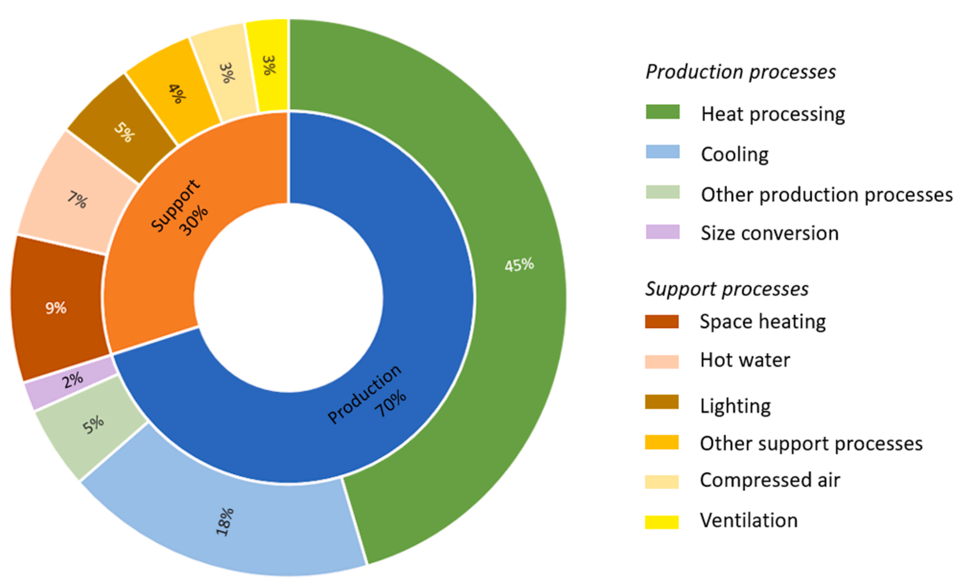


Fig. 7. The share of EEU for different unit processes for both support and production processes in food industry. Processes with a share of less than 1% are included in other production processes and other support processes, respectively.

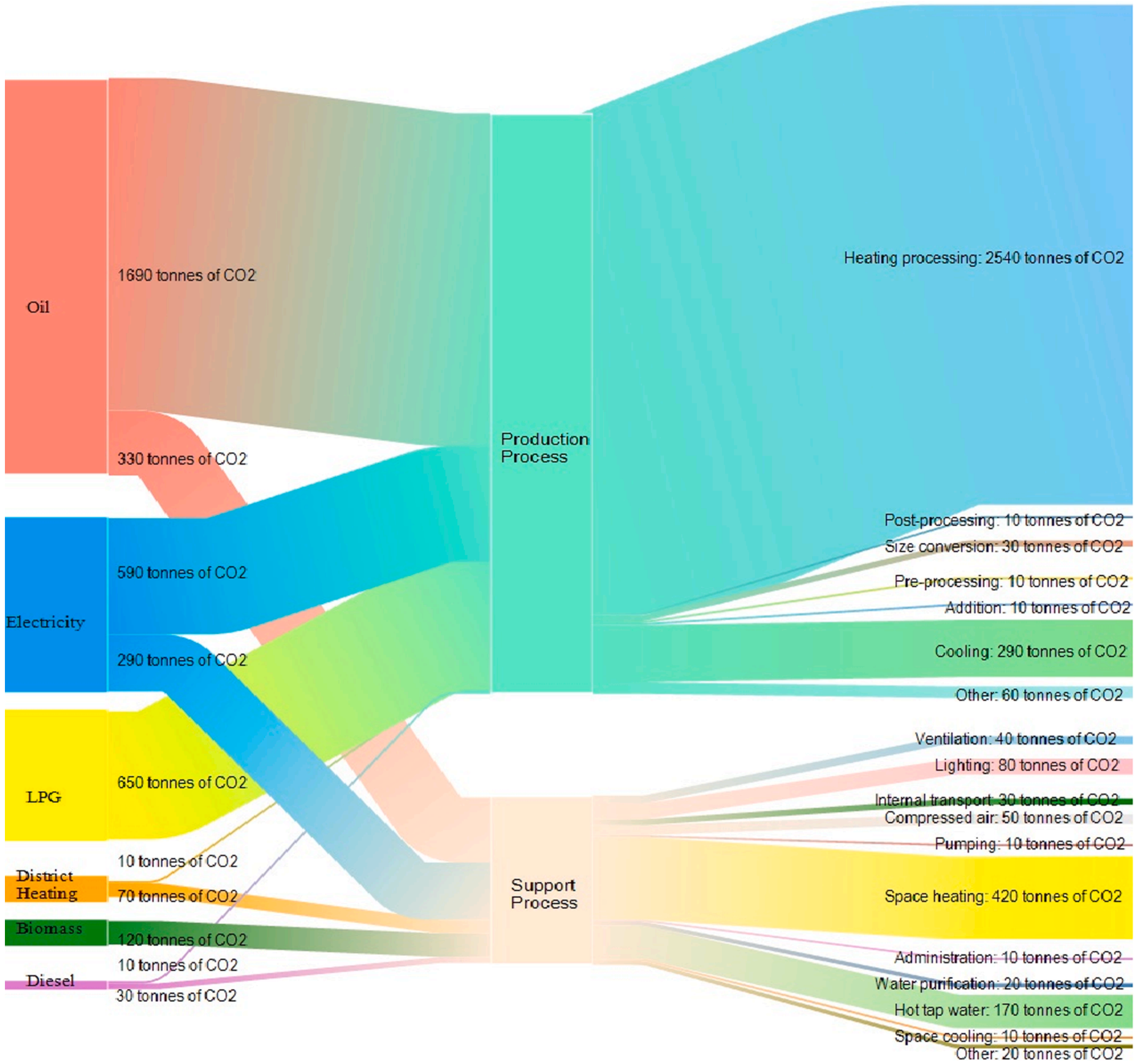


Fig. 8. CO_2 emissions for each category at different levels of taxon in the food industry based on scenario 1, where average Nordic electricity and average Swedish district heating are considered.

distribution of energy from each carrier to each production unit process and support unit process in Fig. A1 and Fig. A2 respectively. It can be noted that space heating and hot tap water are the most energy-intensive unit processes among the support processes, and all the companies are located in Sweden, which is known for its cold climate. Lighting is the third most energy-intensive support unit process. Among the production unit processes, heat processing is the most energy-intensive due to the heat requirements for several processes, and due to the use of fossil fuels as the supply. Cooling is the second most energy-intensive process since the production involves a demand for refrigeration and deep-freezing technologies, which are intense in terms of energy use. Size conversion is the third most intensive production unit process. Processes where the energy requirement is less than 1% are not shown in the figure, and it may be noted that the energy required for space cooling is much less in the case study. This is particular to cold countries like Sweden, where space cooling is not required, but this may change with geography.

4.3. CO_2 emissions

The CO_2 emissions are also calculated based on the taxonomy, and EEU in section 4.2 is used as the basis for the calculation of emissions. CO_2 emissions are calculated by considering emission factors in two scenarios. The average Nordic electricity mix and the average Swedish district heating mix are considered as the first scenario, as presented in Fig. 8. From the case study, the total contribution of emissions is 3,790 tonnes of CO_2. Production processes are responsible for 2,950 tonnes of CO_2, while support processes are responsible for about 840 tonnes of CO_2 annually.

Emissions from production processes are more than three times the emissions from support processes, due to the massive use of oil and LPG besides electricity. Oil is responsible for the largest share of emissions compared to the other energy carriers. Meanwhile, most of the support processes' emissions have resulted from the use of oil and electricity, with a slight share of diesel, biomass, and district heating. In terms of unit processes, heat processing is the most emission-intensive, followed by cooling and hot water. Fossil fuels have high emission factors; therefore, they contribute to a high share of emissions even with slight energy use.

The marginal Nordic electricity mix and the marginal Swedish district heating mix are considered for calculating CO_2 emissions in the second scenario, as presented in Fig. 9. The total contribution of emissions is 14,040 tonnes of CO_2 annually, with production processes responsible for 9,610 tonnes of CO_2, while support processes are responsible for 4,430 tonnes of CO_2. Electricity is the most intensive emission carrier, due to the intensive use of electricity within the industry and the high emission factor for marginal electricity, which is

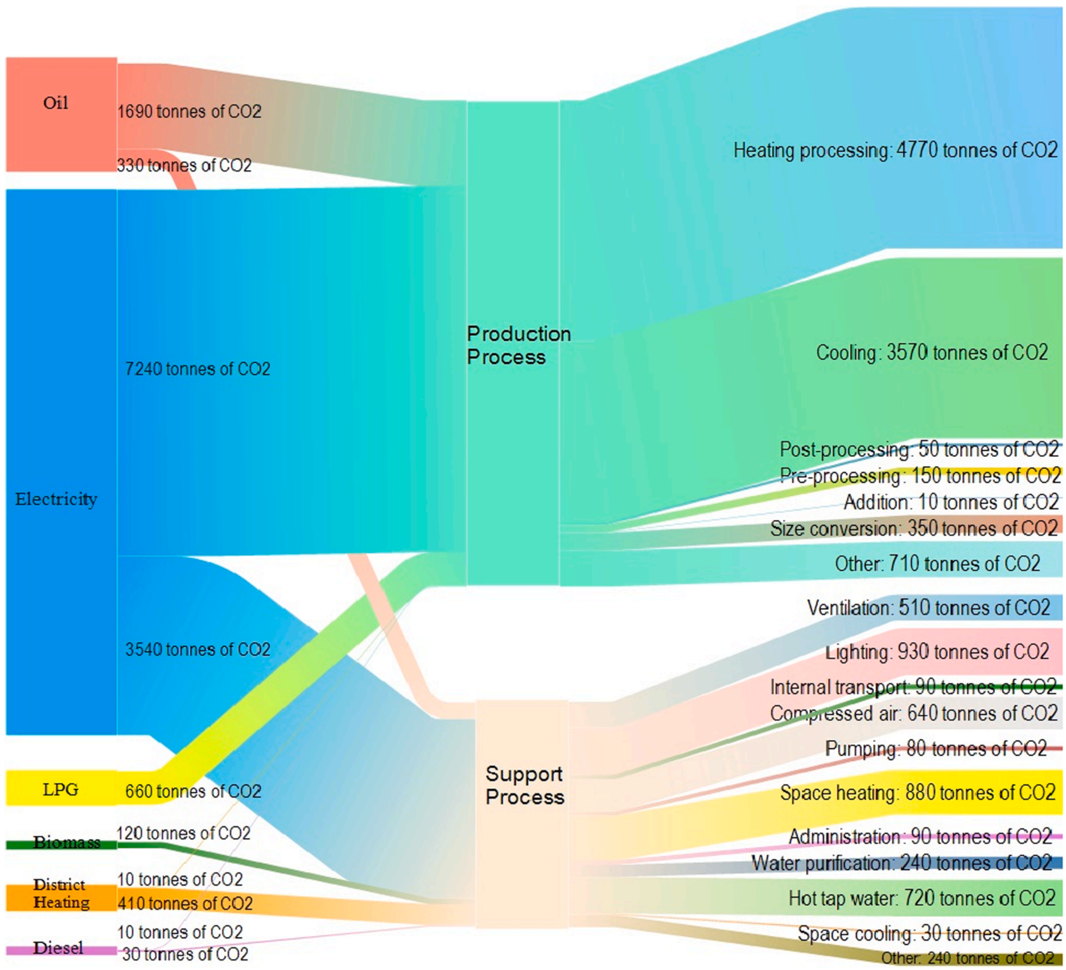


Fig. 9. CO_2 emissions for each category at different levels of taxon in the food industry based on scenario 2, where marginal Nordic electricity and marginal Swedish district heating are considered.

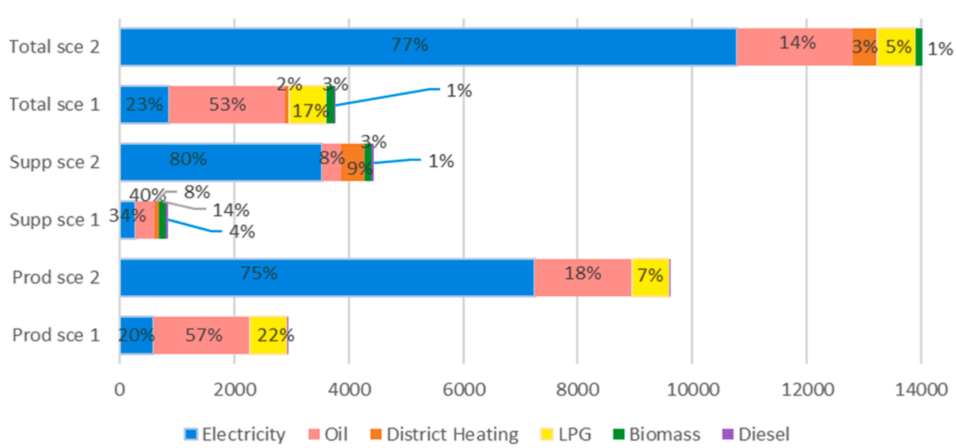


Fig. 10. Share of CO_2 emissions from different energy carriers for the production and support processes of the food industry. Sce1 represents Scenario 1 and Sce 2 represents Scenario 2. Percentage in order of electricity, oil, district heating (DH), LPG, biomass, and diesel.

generated by coal condensing power plants during the majority of the year. Also, the share of district heating increased slightly, although it is not used intensively due to using the marginal Swedish district heating emission factor, which is higher compared to the average Swedish one. Appendix A shows the distribution of CO_2 from each carrier to each production unit process and support unit process for scenario 1 in Figs. A3 and A4. Also, emission values for each carrier at the unit process level for scenario 2 are shown in Figs. A5 and A6.

Fig. 10 shows each energy carrier's share of total emissions according to both scenarios. Also, it shows the contribution from each carrier to each of the production and support processes according to the two scenarios. It can be noted how the total emissions in scenario 2 exceed scenario 1 due to the higher emission factors of both electricity and district heating. Quantities of CO_2 emissions remain constant for the

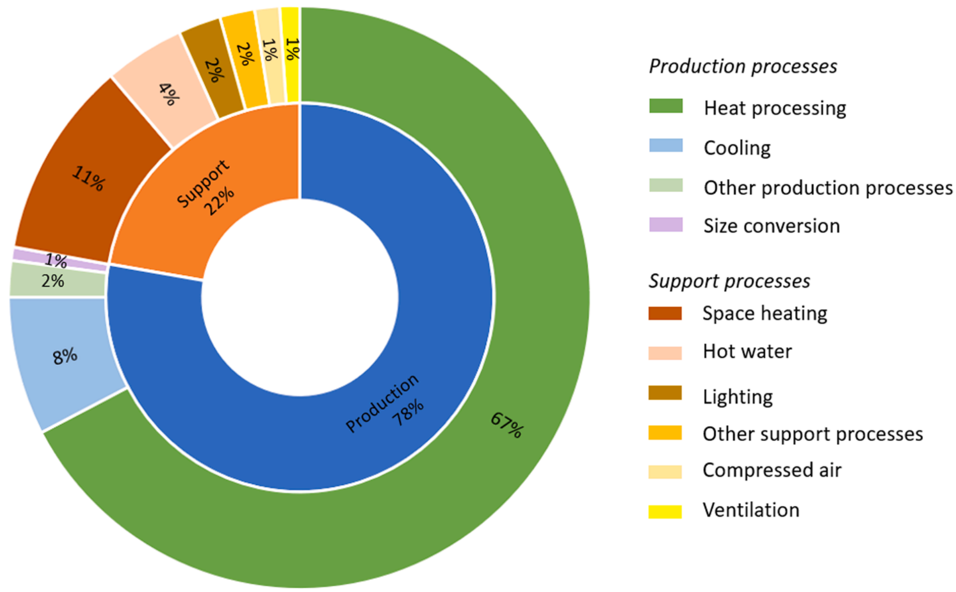


Fig. 11. The share of CO_2 emissions for different unit processes for both support and production processes in the food industry (scenario 1). Processes with a share of less than 1% are included in other production processes and other support processes, respectively.

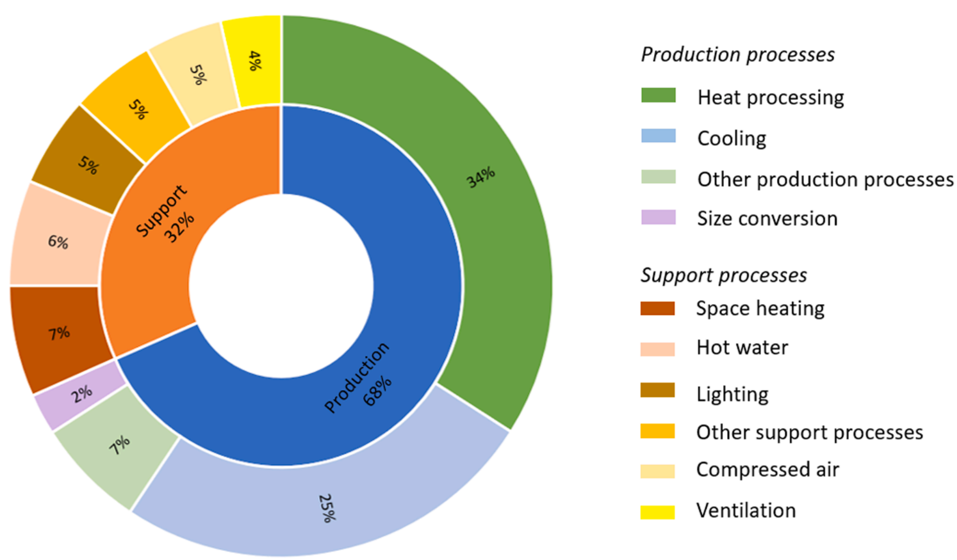


Fig. 12. The share of CO_2 emissions for different unit processes for both support and production processes in the food industry (scenario 2). rocesses with a share of less than 1% are included in other production processes and other support processes, respectively.

other energy carriers, although their percentages change between both scenarios, which is due to the change of quantities and percentages for both electricity and district heating. This has a major impact on both the production and support categories. In production, emissions from electricity are 75% in scenario 2 and 20% in scenario 1. In support, the share of electricity increases from 34% in scenario 1 to 80% in scenario 2.

Figs. 11 and 12 represent the emission contribution for all unit processes according to scenarios 1 and 2 respectively. In the first scenario for support processes, space heating is the most intensive, followed by hot tap water and lighting respectively. The reason for this is that both space heating and hot tap water are supplied by oil and other fossil fuels. In the second scenario, lighting is the most intensive, followed by space heating and hot tap water. The reason for the increase in these processes is the high emission factors for the marginal Nordic electricity. In both scenarios for production processes, heat processing is the most emission-intensive, followed by cooling and size conversion, respectively. The ranking of the first scenario can be explained by the reliance of heat processing on fossil fuels, which are emission intensive. In the second scenario, although heat processing decreases as a percentage, it is still constant in terms of quantity of CO_2 emissions, but the CO_2 emissions contribution from both cooling and size conversion increases due to the marginal Nordic electricity consideration.

Table 5
Collected EnPIs from different types of food industries.

Company	*Product Range*	*EnPIs*
Company A	*Pasta, mayonnaise and related products*	*KWh/tonne of steam* *Idle load in kWh*
Company B	*Chocolate and candy*	*MWh/tonne of production*
Company C	*Bread, toast*	*KWh/kg of products* *KWh/line*
Company D	*Beer*	*None*

Table 6
Identified EnPIs for the production processes for the food industry.

Production Process Level – Food Industry		
Unit Process	**EnPI**	**Characteristic**
General for all Production Unit Processes	*CO_2 emissions (kg)/energy use in process (MWh)*	Ratio
	Fossil fuel consumption (kWh)	Absolute
	Total energy use (kWh/type of energy carrier)	Absolute
	Total energy savings (MWh) from EEM/year	Absolute
	Total energy use (kWh)/production (hours)	Ratio
	Energy use (kWh) during peak hours	Absolute
	Peak demand in month (kW)	Absolute
	Total electricity use (kWh)	Absolute
	Percentage of total energy use at idle versus total energy use of the process (%)	Ratio
	Actual energy use to actual output/rated energy use to rated output	Statistical
Heat processing	*The conversion efficiency of a boiler (%)*	Ratio
	Energy (kWh)/amount (tonne) of steam produced	Ratio
	Energy (kWh)/volume (m^3) of heated space	Ratio
Cooling	*Coefficient of Performance (COP) for cooling systems*	Ratio
	Energy use (kWh)/(m^3) of the cooling space/year	Ratio
	Energy (kWh)/tonne of material	Ratio
Size conversion	*Energy (kWh)/cross-section (m^2) of material*	Ratio
	Energy (kWh)/volume (m^3) of material	Ratio

4.4. *Energy performance indicators in the food industry*

EnPIs collected from four companies using the questionnaire are shown in Table 5.

Inspired by a previous study [16], EnPIs have been developed to meet the needs of the food industry. The EnPIs have been developed for energy-intensive production unit processes, which are primarily heat processing, cooling, and size conversion, and generally for all other processes. The EnPIs have been developed using collected data from companies, and by investigating EnPIs from different studies. The general EnPIs can be used to control and monitor EEU for all production processes. Other EnPIs are process-specific, and they meet the needs for a unit process specifically, as shown in Table 6.

The five intensive support unit processes for the industry are space heating, hot tap water, lighting, compressed air, and ventilation, with EnPIs for these unit processes already developed in a previous research study [16]. All the EnPIs were validated by one of the biggest bread companies in Sweden, which stated that EnPIs have the greatest impact on their energy use. The company also stated that they have more interest in production EnPIs than other EnPIs, due to the cost required to establish such EnPIs and due to the complexity of explaining their fluctuations. The company suggested that "kWh/line" should be added to the production EnPIs and they expressed their interest in future EnPIs that target specific technology types especially for support processes, which was not part of this study.

4.5. *Conceptual energy planning framework for industries*

From the results of this study, both taxonomy and EnPIs are integrated to form the EPF, as shown in Fig. 13. The aim is for this framework to support industries by giving them more detailed and practical guidelines to follow. The framework is general to suit all industries, but there might be some details that apply to specific circumstances. The framework consists of the following eight steps:

1) *Categorize processes according to a standardized taxonomy*: Categorization of processes should be done according to a standardized taxonomy. The companies should identify and map their internal processes into major processes, unit processes, and sub-unit processes according to the taxonomy. The details of the internal processes can be identified mainly from a previous energy audit report if the company already has it. If not, the company can make use of processes described in the standard operating procedures. It should be noted that the categorization of the processes is recommended before auditing.
2) *Calculate EEU for unit processes:* Calculating EEU for identified unit processes requires energy audits or energy monitoring. Thorough classification of EEU and types of energy carriers can be used to build EEU for unit processes within a facility as well as the related emissions.

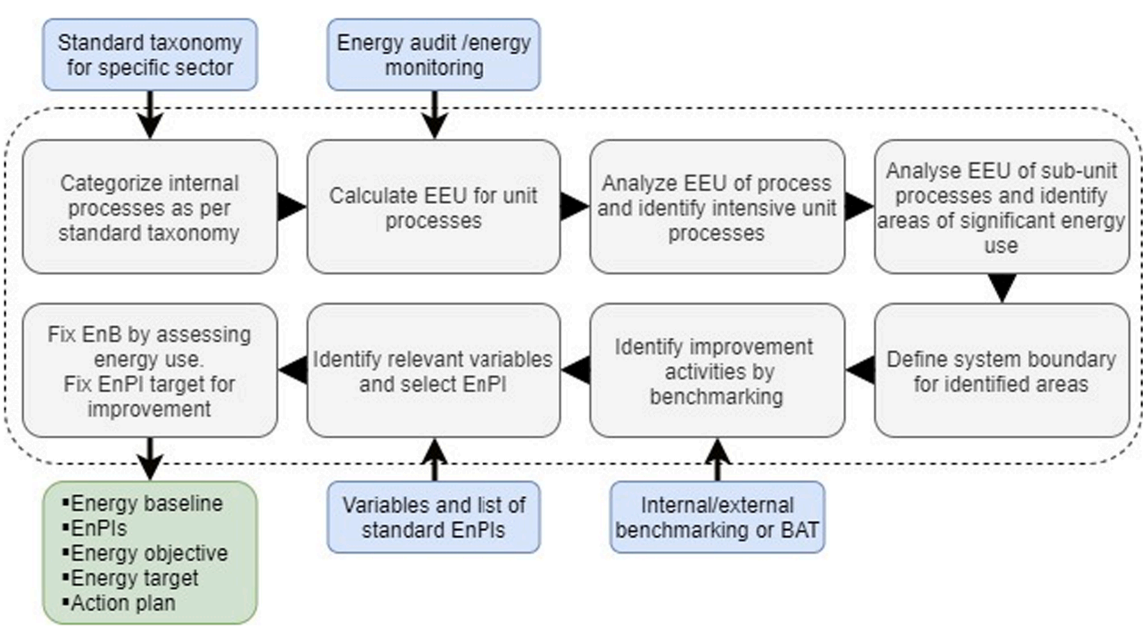


Fig. 13. Energy planning framework.

3) *Analyze EEU of processes and identify intensive unit processes:* EEU obtained in the second stage should be scrutinized at the unit process level to identify the unit processes that have high energy usage. These processes may be referred to as intensive unit processes. This comparison helps energy managers with the prioritization of unit processes for further investigation of the sub-unit processes.
4) *Analyze EEU of sub-unit processes and identify areas of significant energy use:* Further EEU of sub-unit processes should also be analyzed to identify which technologies use more energy. In addition, this should be expanded to a broader system level (e.g. production line or department level) as this helps in identifying where exactly the energy is used more. This may be referred to as areas of significant energy use (it may be at an organizational level, system level, or process level). It is important to define the area of significant energy use, as it gives a comprehensive as well as a broader picture. For example, on some operation lines, only a specific sub-unit process may be using more energy, or in another case, there may be multiple interlinked sub-unit processes that consume more net energy.
5) *Define system boundary for identified areas*: After identifying the area of significant EEU, system boundaries should be defined to provide a credible comparison. The system boundary is a key element in determining what might be a process, system, or organization. The definition of the system boundary is important to effectively focus on the significant area of energy use. For the system and organizational level, the target boundary can be narrowed, if possible, to sub-boundaries that can quantify energy flows in detail.
6) *Identify improvement activities by benchmarking:* The areas of significant EEU may now be scrutinized using benchmarking to identify the improvement activities. Benchmarking may be internal or external. Internal benchmarking makes use of good practices within an organization. External benchmarking allows comparison with other existing technologies in other organizations. External benchmarking can also be based on BAT or Best Available Techniques Reference Documents (BREF).
7) *Identify relevant variables and select EnPI:* After identifying the improvement activity, it is important to monitor the energy performance. The selection of EnPIs is highly dependent on the relevant variables. Relevant variables should characterize the parameters that affect energy use, such as production hours, weather, area, etc. Separating variables with significant impact on energy performance from the variables with low impact is important for further data analysis in order to determine the significance of relevant variables. Based on the relevant variable, appropriate EnPIs can be selected.
8) *Fix EnB by assessing energy use and fixing EnPI target:* After the selection of EnPIs, the quantitative value of the baseline period, i.e. EnB, should be fixed based on the present system. The energy objective and energy target should also be finalized and quantified for assessment after the implementation period. Once the objective is set, an action plan should be drawn up for the implementation of the identified improvement activity.

5. Discussion

The study integrates standard EEU taxonomy and standard EnPIs into energy planning, leading to the development of an EPF. The study is, to the authors' knowledge, unique as it not only provides a standard taxonomy for EE and a list of potential EnPIs for the food industry, but also sets guidelines for effectively utilizing these parameters via energy management through the EPF. The EPF is also very general, so that it applies to all types of industries that have a standard taxonomy and list of potential EnPIs.

5.1. Taxonomy and EEU categorization in the food industry

The study presents an EEU taxonomy for the food industry by adopting the science of classification, hence distinguishing itself from other studies on the food industry. The reason behind not adopting the BAT guidelines is that the BAT categorization [25] is very broad and can be described as categorization on an aggregated level. In contrast, the taxonomy built in this study is on a disaggregated level, since it adopts the hierarchical classification of EEU as the basis for classification [16]. Like a study on the wood industry [15] and the engineering industry [16], this study presents the carriers used to supply the industry, their share, and their related emissions, while other studies [17,22,25] neglect the supply side in their categorization. Including the supply level helps in identifying energy transition opportunities for reducing emissions.

This taxonomy is similar to EEU categorization of the food SMEs developed by Andersson et al. [8], which is more simplified. The support unit processes are the same, except that water purification and pumping are added to this study. However, some major differences exist regarding production unit processes. Andersson et al. [8] presented six production unit processes, most of which, with the exception of cooling/freezing, are considered sub-unit processes in this taxonomy. For example, mixing in this study is considered a sub-unit process under the “addition” unit process. The reason for such differences is that the categorization by Andersson et al. [8] is based on the categorization by Söderström [20]. Meanwhile, this study is based on a hierarchal classification that is extended to include sub-unit processes [16]. Also, the EEU categorization by Andersson et al. is not comprehensive. The reason might be that their categorization included only the processes used in the food SMEs, which do not usually have a large variety of processes due to small production volumes. The taxonomy presented in this study is more generic, because it is based on both literature and audit reports from the food industry. The importance of hierarchical categorization lies in being able to obtain information about EE in entities with different hierarchies in the system [53]. This enhances the monitoring and analysis of energy use for the optimization of EE potential in the industry [42]. One of the limitations of previous studies is that, with the advancement of technology, there are no clear attributes that define the addition of new specialized processes to the taxonomy. The classification method in this study uses the classification methodology listed by McCarthy for manufacturing processes [54]. This allows the extension of the categories, based on an evolutionary change in the process. This means that, as more technologies or methods are developed, the taxonomy can be continuously refined.

5.2. Allocation of EEU and CO_2 emissions in the food industry

The case study on the food industry shows more awareness of where and how energy is used. It can be noted from the case study that 93% of energy within the production process is utilized for three unit processes: heat processing, cooling, and size conversion. CO_2 emissions for these processes are 97% for scenario 1 and 90% for scenario 2 for the production process. This is in line with the report by the U.S. Environmental Protection Agency [24], which highlights that the heating and cooling systems have the highest energy requirement. In another study [8], the majority of the production processes are not categorized. For the support processes, six processes – mainly space heating, hot water, lighting, compressed air, ventilation, and water purification – utilize 90% of the energy. CO_2 emissions for these processes are 92% in scenario 1 and 88% in scenario 2. This is in line with the previous study [8], where space heating, hot water, ventilation, lighting, and compressed air are the major end-users of energy. Water purification is not classified in this study. The results can be taken as a reference for future studies and planning, and used to target the energy-intensive processes. The limitation of these recommendations is that they result from one case study, and thus further research is needed, as it may be different for some other companies. These recommendations can therefore not be seen as representative of the whole food industry but even so, the study contains major novel elements on which further research can be built. Also, this study does not underestimate targeting any other unit processes with efficiency measures and indicators, but highlights the importance of prioritizing the intensive ones.

In terms of emissions, the emissions caused by major processes, unit processes, and sub-unit processes are calculated according to two scenarios. It can be seen that the total emissions of the industry from scenario 2 are more than the total emissions from scenario 1. This can be explained by the fact that in scenario 2 the marginal electricity is produced from coal-fired power plants, while the marginal district heating is produced using oil-fired CHP [48].

5.3. Implications of indicators on the industry

EnPIs play an important role at different levels of energy management [55]. However, there is more focus on the aggregate level, leaving out sub-systems and equipment levels in the industrial organizations [36]. Relevant EnPIs are important on an aggregated level, such as for a site or a company, or a disaggregated level, for example processes, unit processes, and sub-unit processes. As stated by Beisheim et al. [33], the process level EnPIs can be used to indicate the root cause of deviation at the site level, making an understanding of the cause-effect relationship more feasible. Relevant EnPIs based on defined boundary levels enable easier benchmarking. Easier benchmarking enhances the selection of the right EnPIs and motivates companies with modest experience to apply them, since there is a lack of decision-supporting tools in energy improvements through EnPIs, which is also a problem for firms [35]. Providing relevant EnPIs for the food industry can assist the industry's decision-makers in estimating the EE potential and deciding on improvement measures [15]. Indicators vary with the situation and there is no single indicator that can be used for all cases, due to the variety and complexity of processes [42]. This calls for standardization of EnPIs at different levels to eliminate the difficulty of benchmarking, since plants with similar production processes can be easily benchmarked [42].

Studies aimed at enhancing the application of EnPIs provide a conceptual framework for energy management [36]; however, it is not well structured in terms of EnPI development and selection [35]. This study develops EnPIs for production unit processes in which the defined boundary for the EnPIs is the process level boundary. The support EnPIs identified in the literature defined their boundaries and can be directly adapted to the food industry [16]. Applying EnPIs to intensive processes helps to monitor the performance of such processes, since they lack energy monitoring [35]. One of the highlights of the EnPIs developed in this study is that the EnPIs address the research gap highlighted by May et al. [35]. The first research gap – lack of indicators suitable within a manufacturing facility [35] – is addressed by proposing specific EnPIs for the food industry. The second gap of difficulty in benchmarking between plants [35] is addressed by standardizing the EnPIs for processes specifically. This is similar to the EnPIs developed in the study of the engineering industry [16]. This study tried to have the EnPIs validated by companies. While validating the EnPIs, only one company provided feedback. If more responses had been received, more EnPIs that meet industrial needs could have been collected and presented in this study.

5.4. Enhancing performance of the energy planning

To the authors' knowledge, this is one of the first attempts to construct an EPF for energy management in industries. This EPF can address the remaining research gap highlighted by May et al. [35]. The third gap regarding the absence of energy reporting [35] can be resolved by following the guidelines on energy use calculation using the taxonomy. The fourth gap concerning lack of guidelines for EnPI selection [35] is resolved by the use of variables and boundaries, as mentioned in the EPF. The fifth gap – lack of supporting tools for EnPI development [35] – is closed by standard EnPIs for processes and systematic identification of improvement activity. Thus, the EPF provides very clear and practical guidelines for energy planning in the industry, which can enhance energy performance.

In previous studies, some authors have highlighted the importance of energy auditing in energy planning (eg: study by Micieta et al. [38]), while some authors address the importance of EnPIs in energy planning to evaluate the performance of significant energy users (eg: study by Muniz et al. [56]), and some authors highlight the importance of identifying the advanced technology (eg: study by Micieta [38]). Another highly relevant study by Prashar [39] adopts the PDCA cycle in energy management. This study highlights the need for an energy audit in energy planning, but it does not address the need for standard taxonomy for the audit, and it also suggests selecting EnPIs before benchmarking [39]. This shows the absence of a comprehensive perspective on energy planning among authors, or only a partial focus. The EPF addressed in this study provides guidelines on how different inputs such as audits, EnPIs, taxonomy, and benchmarking should be used in various stages of planning. By adopting a standardized taxonomy for audits, it enhances the in-depth categorization of EEU. The deep analysis of EEU at different hierarchical levels helps companies to direct their EEMs, especially at the most intensive unit processes, sub-unit processes, and equipment level if possible. The EPF enables constructive data collection through the guidelines for benchmarking and comparison at different levels. It also allows external benchmarking with the market and competitors, plus internal benchmarking to compare at the facility level, system level, or process level. Such knowledge improves the selection of improvement measures and technologies. Integrating the EnPIs along with the significant variables and boundary helps in the credible comparison and monitoring of the improvement activity. The EPF provides a uniform way to use different inputs of energy planning in a systematic way, which helps with credible comparisons, effective monitoring, and formulation of achievable targets and action plans. This EPF also addresses the gap between research and industrial needs, so that the EE potential within the industries can be tapped efficiently. The developed EPF is general for all industries and only forms the guidelines for effective planning. For future studies with more knowledge about increased adoption of the EPF, the framework can be developed with more in-depth details specific to each type of industry.

5.5. Policy implications

The standard taxonomy can be used by policymakers for energy reporting from the respective sectors, thus allowing for credible comparisons of different industries. The intensive processes identified in the study can be used as a pivot for targeting the policies and industrial practices towards EE implementation and emission reduction. This paper recommends the widescale implementation of EPF across industries to improve energy management. The standard practice eases the consolidation of EE potential at the regional level and national level, which helps policymakers and decision-makers in their development of regulations and policies.

This output from the study also helps the administrators to create a database of BAT at the national level, similar to the BREF developed by Integrated Pollution Prevention and Control and the Industrial Emission Directive [25]. The advantage of creating the national-level BAT is that the documents can be updated based on the deployment level at the national level and also considering regional factors such as weather, energy cost, emission factors, etc. This national-level BAT can also integrate a sector-specific benchmarking tool built with EnPIs that enables energy managers to estimate EE potential with BAT and decide on improvement actions to be implemented.

6. Conclusion

The study presented a novel taxonomy, based on hierarchical classification, that can serve as a theoretical basis for a credible comparison of energy use and performance within processes. This paper analyzed the energy and CO_2 intensity of processes in the Swedish food industry via a case study and found that 70% of the total energy goes to the production process. This paper also suggested potential EnPIs for intensive production processes. This paper introduced a comprehensive EPF model that provides guidelines to integrate taxonomy, audits, EnPIs, and benchmarking for effective energy management.

The suggested taxonomy consists of several hierarchy levels covering energy carriers, major processes, unit processes, and sub-unit processes, and allows an evolutionary development with the advancement of technology. This forms a basis to construct databases of energy use, downstream CO_2 emissions, energy efficiency mapping, BAT databases, and carbon mitigation measures. The analysis of energy use in the case study using the suggested taxonomy shows that 70% of the energy goes to the category “production”. The most energy-intensive production unit processes are heat processing, cooling, and size conversion, which account for more than 93% of the energy used in the production process. Lighting, ventilation, compressed air, space heating, and hot tap water are the most energy-intensive support unit processes, accounting for about 86% of the total energy used in support processes. Although emissions vary from one scenario to another, heat processing and cooling are the most emission-intensive unit processes, followed by size conversion. Space heating, lighting, and hot tap water are emission-intensive support unit processes in both scenarios, and their order changes from one scenario to another. The study developed EnPIs only for the intensive production processes, as most of the support processes are common across the different types of industry and only the share of energy varies by industry. EnPIs for support processes are already available in different studies. One of the findings in this study is that currently, the energy management practices and use of EnPIs are not very common in the food sector.

As highlighted by previous studies, this study also acknowledges the existing gap between the industry and research. The main purpose of the EPF developed in this study is to close this gap for any type of industry sector that has a clear taxonomy of processes based on energy use. The EPF is an upgrade of the energy planning guidelines described in ISO 50001, which gives a comprehensive procedure by including the practical elements of energy management. The study suggests that companies adopt the EPF and customize it for their technologies, thus making it more company-specific. Further future studies can be done on developing an in-depth framework for each type of industry and conducting surveys to understand the effectiveness of EPF for closing the gap and for effective energy management.

Overall, the study contributes toward extending the EE potential, since it is not focused on technical efficiency alone, but rather extends to include guidelines for effective planning, which is among the energy management practices. The study is unique in the food industry by adopting a novel taxonomy and creating an EPF that contributes to effective energy planning and improving the EE potential within the industry. The study calls for sector-specific taxonomies, in which the EPF can be applied to other firms with similar taxonomies. Also, the study calls for policies on energy and emission-intensive processes to reduce their impact. In addition, it calls for the energy transition to replace fossil fuels with cleaner energy sources such as utilizing bio-waste in the food industry to produce biofuels.

CRediT authorship contribution statement

Fayas Malik Kanchiralla: Conceptualization, Methodology, Validation, Investigation, Writing – original draft. **Noor Jalo:** Conceptualization, Methodology, Validation, Investigation, Writing – original draft. **Patrik Thollander:** Validation, Writing – review & editing, Supervision. **Maria Andersson:** Validation, Writing – review & editing, Supervision. **Simon Johnsson:** Validation, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

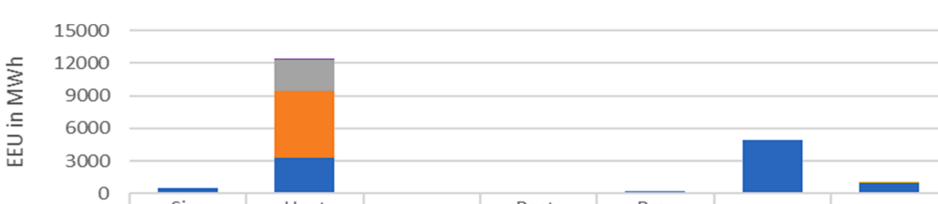
The authors would like to thank the participating companies for their patience in filling out the questionnaires. Special thanks to Curt Bjork, Elias Andersson, Danica Djuric Ilic, and Roozbeh Feiz Aghaei for providing this study with their valuable inputs and fruitful discussions. Finally, the authors would like to thank the Swedish Environmental Protection Agency and the Swedish Agency for Marine and Water Management for funding the research project “Carbonstruct” to which this publication belongs.

Funding

This study was funded by the Swedish Environmental Protection Agency and the Swedish Agency for Marine and Water Management, research project Carbonstruct, project no. 802-0082-17.

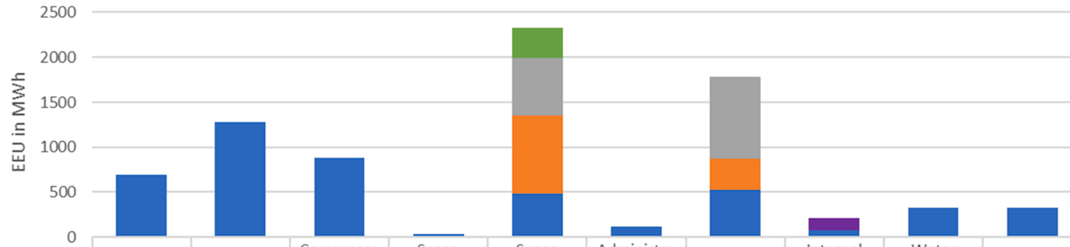
Appendix

See Fig. A1, Fig. A2, Fig. A3, Fig. A4, Fig. A5 and Fig. A6.



	Size Reduction	Heat Processing	Adding	Post-processing	Pre-processing	Cooling	Others
Diesel	0	22	0	0	0	0	0
LPG	0	2795	0	0	0	0	0
DH	0	0	0	0	0	0	53
Oil	0	6155	0	0	0	0	0
Electricity	479	3332	13	66	201	4899	959

Fig. A1. Energy use for the unit processes in the production category based on the case study of the Swedish food industry.

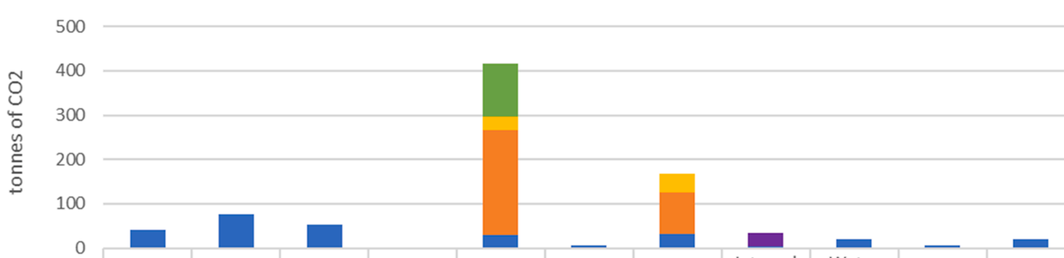


	Ventilation	Lighting	Compressed Air	Space Cooling	Space Heating	Administration	Hot Water	Internal Transport	Water Purification	Others
Biomass					343.27					
Diesel								135.5		
District heating					635.13		918			
Oil					870		344			
Electricity	694.8	1278.9	883.8	35	483.6	119.9	524.5	78	330	323.622

Fig. A2. Energy use for the unit processes in the support category based on the case study of the Swedish food industry.

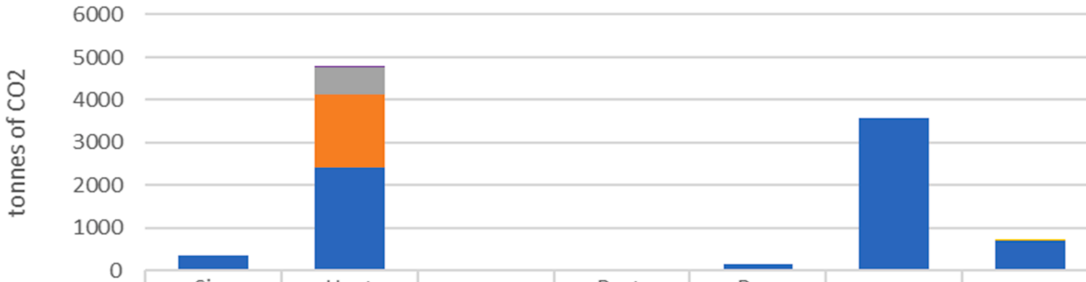
	Size Reduction	Heat Processing	Adding	Post-processing	Pre-processing	Cooling	Others
Diesel	0	5	0	0	0	0	0
LPG	0	655	0	0	0	0	0
DH	0	0	0	0	0	0	2
Oil	0	1688	0	0	0	0	0
Electricity	28	197	1	4	12	289	57

Fig. A3. CO_2 emissions for the unit processes in the production category based on the case study of the Swedish food industry (Scenario 1).



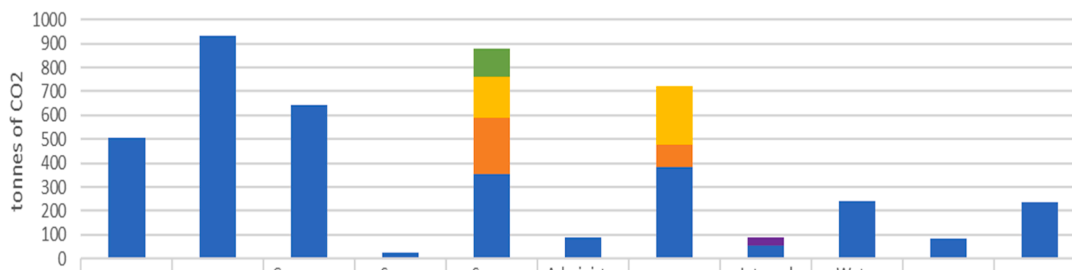
	Ventilation	Lighting	Compressed Air	Space Cooling	Space Heating	Administration	Hot water	Internal Transport	Water Purification	Pumping	Others
Biomass	0.00	0.00	0.00	0.00	118.63	0.00	0.00	0.00	0.00	0.00	0.00
Diesel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.12	0.00	0.00	0.00
District heating	0.00	0.00	0.00	0.00	29.22	0.00	42.23	0.00	0.00	0.00	0.00
Oil	0.00	0.00	0.00	0.00	238.66	0.00	94.37	0.00	0.00	0.00	0.00
Electricity	40.99	75.46	52.14	2.07	28.53	7.07	30.95	4.60	19.47	6.79	19.09

Fig. A4. CO_2 emissions for the unit processes in the support category based on the case study of the Swedish food industry (Scenario 1).



	Size Reduction	Heat Processing	Adding	Post-processing	Pre-processing	Cooling	Others
Diesel	0	5	0	0	0	0	0
LPG	0	655	0	0	0	0	0
DH	0	0	0	0	0	0	14
Oil	0	1688	0	0	0	0	0
Electricity	349	2426	9	48	146	3566	698

Fig. A5. CO_2 emissions for the unit processes in the production category based on the case study of the Swedish food industry (Scenario 2).



	Ventilation	Lighting	Compressed Air	Space Cooling	Space Heating	Administration	Hot Water	Internal Transport	Water Purification	Pumping	Others
Biomass	0.00	0.00	0.00	0.00	118.63	0.00	0.00	0.00	0.00	0.00	0.00
Diesel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.12	0.00	0.00	0.00
District heating	0.00	0.00	0.00	0.00	169.58	0.00	245.11	0.00	0.00	0.00	0.00
Oil	0.00	0.00	0.00	0.00	238.66	0.00	94.37	0.00	0.00	0.00	0.00
Electricity	505.81	931.04	643.41	25.48	352.06	87.29	381.84	56.78	240.24	83.72	235.60

Fig. A6. CO_2 emissions for the unit processes in the support category based on the case study of the Swedish food industry (Scenario 2).

References

[1] Ladha-Sabur A, Bakalis S, Fryer PJ, Lopez-Quiroga E. Mapping energy consumption in food manufacturing. Trends Food Sci Technol 2019;86:270–80.

[2] Energimyndigheten, "Energiläget," 2020. [Online]. Available: http://www.energimyndigheten.se/globalassets/statistik/energilaget/energilaget-i-siffror-2020.xlsx. [Accessed 14 Oct 2020].

[3] European Commission, "2030 climate & energy framework," European Commission, [Online]. Available: https://ec.europa.eu/clima/policies/strategies/2030_en. [Accessed 20 June 2020].

[4] Swedishepa, "Sweden's Climate Act and Climate Policy Framework," 12 December 2019. [Online]. Available: http://www.swedishepa.se/Environmental-objectives-and-cooperation/Swedish-environmental-work/Work-areas/Climate/Climate-Act-and-Climate-policy-framework-/#. [Accessed 1 April 2020].

[5] International Energy Agency, "Energy Efficiency 2019," IEA Publications, Paris; 2019.

[6] Soederstrom, M. Industrial electricity use characterised by unit processes-a tool for analysis and forecasting. In: UIE XIII Congress on Electricity Applications, Birmingham pp. 77-85, 1996.

[7] Andersson E, Arfwidsson O, Bergstrand V, Thollander P. A study of the comparability of energy audit program evaluations. J Cleaner Prod 2017;142:2133–9.

[8] Andersson Elias, Karlsson Magnus, Thollander Patrik, Paramonova Svetlana. Energy end-use and efficiency potentials among Swedish industrial small and medium-sized enterprises - A dataset analysis from the national energy audit program. Renew Sustain Energy Rev 2018;93:165–77.

[9] International Organization for Standardization, ISO50006:2014 Energy Management Systems, Stockholm: Swedish Standards Institute; 2014.

[10] Thollander P, Paramonova S, Cornelis E, Kimura O, Trianni A, Karlsson M, Cagno E, Morales I, Jiménez Navarro JP. International study on energy end-use data among industrial SMEs (small and medium-sized enterprises) and energy end-use efficiency improvement opportunities. J Cleaner Production 2015;104:282–96.

[11] Backlund Sandra, Thollander Patrik, Palm Jenny, Ottosson Mikael. Extending the energy efficiency gap. Energy Policy 2012;51:392–6.

[12] Moshfegh, B. Competitive, Climate Neutral and Competitive Gävleborg 2050; 2014.

[13] Thollander, P, Palm, J. Improving Energy Efficiency in Industrial Energy Systems: An Interdisciplinary Perspective on Barriers, Energy Audits, Energy Management, Policies, and Programs., New York: Springer, 2013.

[14] International Organization for Standardization, "ISO 50001," Swedish Standards Institute, Stockholm; 2011.

[15] Johnsson S, Andersson E, Thollander P, Karlsson M. Energy savings and greenhouse gas mitigation potential in the Swedish wood industry. Energy 2019;187:115919.

[16] Kanchiralla FM, Jalo N, Thollander P, Andersson M, Johnsson S. Energy end-use categorization and performance indicators for energy management in the engineering industry. Energies 2020;13(2):369. https://doi.org/10.3390/en13020369.

[17] Malagié, M, Jensen, G, Graham, JC, Smith, DL. Encyclopaedia of Occupational Health and Safety. In: International Labour Office, [Online]. Available: http://www.ilocis.org/documents/chpt67e.htm. [Accessed 20 Feb 2019].

[18] Seck GS, Guerassimoff G, Maizi N. Heat recovery with heat pumps in non-energy intensive industry: A detailed bottom-up model analysis in the French food & drink industry. Appl Energy 2013;111:489–504.

[19] Leduc G, Kamiński J. Energy efficiency improvement options for the EU food industry. Polityka Energetyczna – Energy Policy J 2010;13(1):81–96.

[20] Rosenqvist J, Thollander P, Rohdin P, Söderström M. Industrial Energy Auditing for Increased Sustainability-Methodology and Measurements. London: IntechOpen; 2012.
[21] Sommarin P, Svensson A, Thollander P. A method for bottom-up energy end-use data collection – results and experience. in *Eceee Industrial Summer Study Proceedings 435–439*. 2014.
[22] Drescher S, Rao N, Kozak J, Okos M. Review of energy use in the Food Industry. Proceedings ACEEE Summer Study on Energy Efficiency in Industry. 1997.
[23] Joint Working Party on Agriculture and the Environment, "Improving energy efficiency in the Agro-Food chain," Organization for economic co-operation and development, 2017.
[24] U.S. Environmental Protection Agency, "Energy Trends in Selected Manufacturing Sectors: Opportunities and Challenges for Environmentally Preferable Energy Outcomes," Sector Strategies, 2007.
[25] European Comission, "Best Available Techniques (BAT) Reference Document in the Food, Drink and Milk Industries," 2018.
[26] Campiotti CA, Latini A, Scoccianti M, Biagiotti D, Giagncovo G, Viola C. Energy efficiency in Italian fruit and vegetables processing industries in the EU agro-food industry context. Rivista di Studi sulla Sostenibilita 2014;2:159–74.
[27] Wu H, Jouhara H, Tassou SA, Karayiannis TG. Modelling of energy flows in potato crisp frying processes. Appl Energy 2012;89(1):81–8.
[28] Alcázar-Ortega M, Álvarez-Bel C, Escrivá-Escrivá G, Domijan A. Evaluation and assessment of demand response potential applied to the meat industry. Appl Energy 2012;92:84–91.
[29] Enno A, Arne E. Buildings and Energy - a systematic approach. Lund University Publications; 2007.
[30] Andersson E, Thollander P. Key performance indicators for energy management in the Swedish pulp and paper industry. Energy Strategy Rev 2019;24:229–35.
[31] Schmidt C, Li W, Thiede S, Kornfeld B, Kara S, Herrmann C. Implementing Key Performance Indicators for Energy Efficiency in Manufacturing. Procedia CIRP 2016;57:758–63.
[32] LJ Energy Pte Ltd, "Assessment Framework for Energy Efficiency Benchmarking Study of Food Manufacturing Plants," The National Environment Agency, Singapore, 2016.
[33] Beisheim B, Krämer S, Engell S. Hierarchical aggregation of energy performance indicators in continuous production processes. Appl Energy 2020;264:114709.
[34] Kanneganti H, Gopalakrishnan B, Crowe E, Al-Shebeeb O, Yelamanchi T, Nimbarte A, et al. Specification of energy assessment methodologies to satisfy ISO 50001 energy management standard. Sustainable Energy Technol Assess 2017;23:121–35.
[35] May G, Taisch M, Prabhu VV, Barletta I. Energy Related Key Performance Indicators – State of the Art, Gaps and Industrial Needs. Berlin, Heidelberg: Springer; 2013. p. 257–67.
[36] Ottosson M, Thollander P, Schulze M, Nehler H. Energy management in industry - A systematic review of previous findings and an integrative conceptual framework. J Cleaner Prod 2016;112:3692–708.
[37] Lee J, Yuvamitra K, Guiberteau K, Kozman TA. Six-Sigma Approach to Energy Management Planning. Strategic Planning Energy Environ 2014;33(3):23–40.
[38] Micieta B, Binasova V, Kubinec L. Information and Communication Technology Enabled Energy Efficiency. International Scientific Book; 2015.
[39] Prashar Anupama. Adopting PDCA (Plan-Do-Check-Act) cycle for energy optimization in energy-intensive SMEs. J Cleaner Prod 2017;145:277–93.
[40] D'Emilia G, Di Gasbarro D, Gaspari A, Natale E. Uncertainty evaluation of EnPIs in industrial applications as a key factor in setting improvement actions. J Phys 2015;655:012016. https://doi.org/10.1088/1742-6596/655/1/012016.
[41] Terrados J, Almonacid G, Jorge A. Energy Planning: A Sustainable Approach. London: IntechOpen; 2010.
[42] Bunse K, Vodicka M, Schönsleben P, Brülhart M, Ernst FO. Integrating energy efficiency performance in production management – gap analysis between industrial needs and scientific literature. J Cleaner Production 2011;19(6–7):667–79.
[43] Rodriguez-Gonzalez O, Buckow R, Ko T. Energy Requirements for Alternative Food Processing Technologies—Principles, Assumptions, and Evaluation of Efficiency. Comprehensive Rev Food Sci Food Saf 2015;14(5):536–54.
[44] Yin RK. Case study research: Design and methods (applied social research methods). Australasian Emergency Nursing J 2009;12(2):59–60.
[45] Jacek G. Energy efficiency in the agricultural and food industry illustrated with the example of the feed production plant. in *International Conference on the Sustainable Energy and Environment Development*. 2016.
[46] Goldberg A, Reinaud J, Taylor RP. Promotion Systems and Incentives for Adoption of Energy Management Systems in Industry – Some International Lessons Learned Relevant for China. Washington D C: Institute for Industrial Productivity; 2011.
[47] Nordic Energy Research, "Nordic Energy Technology Perspectives 2016, Cities, flexibility and pathways to carbon-neutrality," www.nordicetp.org, 2016.
[48] Nordenstam Lena, Djuric Ilic Danica, Ödlund Louise. Corporate greenhouse gas inventories, guarantees of origin and combined heat and power production - Analysis of impacts on total carbon dioxide emissions. J Cleaner Prod 2018;186:203–14.
[49] Energiforetagen, "Energiforetagen," [Online]. Available: https://www.energiforetagen.se/sa-fungerar-det/fjarrvarme/fjarrvarmeproduktion/. [Accessed 25 Feb 2019].
[50] Naturvardsverket, "Naturvardsverket," [Online]. Available: https://www.naturvardsverket.se/Stod-i-miljoarbetet/Vagledningar/Luft-och-klimat/Berakna-dina-klimatutslapp/. [Accessed 02 Mar 2019].
[51] Garcia Rita, Freire Fausto. Marginal Life-Cycle Greenhouse Gas Emissions of Electricity Generation in Portugal and Implications for Electric Vehicles. Resources 2016;5(4).
[52] Werner S. District heating and cooling in Sweden. Energy 2017;126:419–29.
[53] McCarthy I, Paul I. Organisational diversity, evolution and cladistic classifications. Omega 2000;28(1):77–95.
[54] McCarthy I. Manufacturing classification: Lessons from organizational systematics and biological taxonomy. Integrated Manufacturing Syst 1995;6(6):37–48.
[55] Millán G, Llano E, Globisch J, Durand A, Hettesheimer T, Alcalde E. Increasing Energy Efficiency in the Food and Beverage Industry: A Human-Centered Design Approach. Sustainability 2020;12(17):1–13.
[56] Muniz RN, Stefenon SF, Buratto WG, Nied A, Meyer LH, Finardi EC, Kühl RM, Silva de Sá JA, Pereira da Rocha BR. Tools for Measuring Energy Sustainability: A Comparative Review. Energies 2020;13(9):2366. https://doi.org/10.3390/en13092366.