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Name: **Dill**	Vorname: **Katharina**
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Erstprüfer: **Prof. Dr.-Ing Helmut Horn**	Zweitprüfer: **Dipl.-Ing. Peer Schuback**
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Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

Systematization of Energy and Operating Data Monitoring Systems as Standardized Measure to Increase Energy Efficiency in Industry

Master Thesis

Katharina Dill

Matrikelnummer: 2066507

ENERGY EFFICIENT INTO THE FUTURE

Erstprüfer: Prof. Dr.-Ing. Helmut Horn

Department Maschinenbau und Produktion

Fakultät Technik und Informatik

Hochschule für Angewandte Wissenschaften Hamburg

Zweitprüfer: Dipl.-Ing. Peer Schuback

Envidatec GmbH

Veritaskai 2

21079 Hamburg

Abstract

The present thesis deals with energy management in general and energy monitoring systems in particular. Against the background of global resource scarcity and rising energy prices, it gets more and more important to increase the efficiency of energy usage. Based on the international standard ISO 50001, requirements for a systematized energy and operating data monitoring system are developed. In this context, legal provisions in different countries are examined. The lineup of costs versus the benefits of monitoring systems underlines their potential compared to other energy efficiency measures. In order to simplify the implementation of such systems in industrial companies, this thesis has the objective to develop a standardized approach. Two selection processes based on defined assessment criteria and weighting factors are the result. This leads to the identification of main energy consumers first and in the second step to a ranking of consumers that are recommended to be integrated in a monitoring system. The method is implemented using a spreadsheet program combined with the JEVis system of the Envidatec GmbH. The application to an existing industrial company verifies the reasonable functionality.

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List of Abbreviations

A/C	Air Conditioning
ANSI	American National Standards Institute
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety)
CEN	Comité Européen de Normalisation (European Committee for Standardization)
CIS	Commonwealth of Independent States
CO_2	Carbon Dioxide
dena	Deutsche Energy Agentur (German Energy Agency)
DIN	Deutsches Institut für Normung (German Institute for Standardization)
EEG	Erneuerbare-Energien Gesetz (Renewable Energies Act)
EN	Europäische Norm (European Standard)
EnergieStG	Energiesteuergesetz (Energy Tax Act)
EnPI	Energy Performance Indicator
EU	European Union
GUTcert	GUTcertifizierungsgesellschaft für Managementsysteme mbH
IEA	International Energy Agency
ISO	International Organization for Standardization
IT	Information Technology
JEDB	JEVis Data Base
JEVis	Java Envidatec Visualization
LEEN	Lernende Energieeffizienz-Netzwerke (Learning Energy Efficiency Networks)
PDCA	Plan-Do-Check-Act
PU	Production Unit

SET Plan	Strategic Energy Technology Plan
StromStG	Stromsteuergesetz (Electricity Tax Act)
TEHG	Treibhausgas-Emissionshandelsgesetz (Greenhouse Gas Emissions Trading Act)
UBA	Umweltbundesamt (Federal Environment Agency)
VDI	Verein Deutscher Ingenieure (Association of German Engineers)
WCED	World Commission on Environment and Development

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1 Introduction

This thesis was written in cooperation with the organization Envidatec. The company's incentive was the prospect of a tool which will simplify the implementation of energy and operational data monitoring systems in future projects. On the one hand, this includes raising the awareness of monitoring systems as potent energy efficiency measure and on the other hand, reducing the effort for the system's implementation. In order to introduce the reader to the subject, this first chapter sets out the underlying motivation, before the actual task is defined. Furthermore, the structure of the thesis and an overview of its contents are outlined.

1.1 Motivation

Energy utilization is the basis of industrialization and prosperity. For many years the world considered energy as an almost endless resource. Mostly fossil fuels have been used unmindfully. The idea of sustainability did not come up before the eighties. With the Brundtland Report of 1987 the World Commission on Environment and Development (WCED) marked a symbol for long-term sustainable and environmentally friendly development on a global scale [1]. Yet, not all countries in the world pursue a sustainability strategy.

Today's society is confronted with the task of being forced to meet the energy market's challenges. On the one hand, there is the growing world population which aims for a consistently good or improving standard of living. On the other hand, there is the progressive shortage of resources. The increase of demand with decreasing supply at the same time is leading to a rise in global energy costs. This problem will intensify in the future. The World Energy Outlook 2012 released by the International Energy Agency (IEA) forecasts that electricity prices will increase by 15% in real terms on average by 2035, due to higher fuel prices, increased use of renewable energy sources and, in some regions, CO_2 pricing [2, p. 3].

In addition, there are global agreements that are supposed to tackle the consequences of decades of neglect of environmental aspects in the use of fossil energy sources. Increased concentrations of carbon dioxide and other greenhouse gases are said to cause the climate change. In mutual conventions some industrialized, threshold and developing countries commit to reduce the emissions of climate-relevant gases. The pioneer is the Kyoto protocol that was passed in 1997 and expired at the end of 2012. [3] The negotiations of how the reduction of emissions will be regulated afterwards still carry on. At least, the international climate conference in Durban in 2011 had the outcome of a second Kyoto commitment period from January 1, 2013 and a global judicial agreement, in which all countries shall participate, is in preparation. [4] The European Union (EU) sees itself in the lead and develops action plans and strategy papers in order to take on responsibility in this matter [5, p. 5]. Nevertheless, in Europe as world's leading region when it comes to energy efficiency [6, p. 9], still at least 20% of its energy use are wasted due to inefficiencies [6, p. 3].

Some countries address the issue by installing renewable energy plants. This enhances the sustainability and facilitates the containment of emissions. The costs for the change of the energy infrastructure, however, are an additional burden.

Rising energy prices especially affect the industrial sector, since production processes usually require large quantities of electricity and heat. Especially high energy intensities appear in the metal production and processing with 46.1 MJ per € of gross value. The CO_2 intensity of the manufacturing industry is at 0.95 kg CO_2 per €. [7, p. 25] In order to stay competitive, many organizations are dependent on savings from energy efficiency measures. This often comes along with little investment funds and resulting low willingness to invest [8].

The idea of standardized management systems reaches back to the seventies. It evolved from the application in quality management. [9, p. 15] One current international standard is the ISO 50001 containing requirements for energy management systems with guidance for use and therefore is a tool for all types of organizations to meet the described challenges. "*The purpose of this International Standard is to enable organizations to establish the systems and processes necessary to improve energy performance, including energy efficiency and intensity. The standard should lead to reductions in cost, greenhouse gas emissions and other environmental impacts, through systematic management of energy.*" [10, p. 6]

1.2 Task Definition

Background of this thesis is that industrial processes are often not optimized for energy efficiency. This problem is partially intensified by regulatory diversities in different countries. As lined out in the motivation, organizations are socially and economically under pressure to reduce their energy consumption and thereby costs. Energy and operating data monitoring is an effective instrument for energy saving that requires little investments only, but it is not yet acknowledged as such.

Consequently, this thesis is supposed to demonstrate how production's efficiency can be improved according to ISO 50001, at which the primary objective is to develop a standardized procedure for the implementation of monitoring systems. General approaches will simplify the application to specific processes later. For this purpose, assessment criteria have to be found, that help to justify the first implementation step, the selection process of measuring points. Resulting requirements for the processes, like process dynamics for example, have to be detected. The compliance with the standard has to be observed at all times.

As the focus is on increasing energy efficiency, economic aspects, which result from the monitoring, are also included in the analysis.

The developed algorithm should be applicable with the JEVis system, the software solution for energy management systems of Envidatec. At last, the scheme shall be verified on the basis of an exemplary project of Envidatec.

1.3 Outline and Structure

Subsequent to this first chapter the second chapter provides background information on important terms and on the Envidatec GmbH. Contents of the international standard ISO 50001 and energy efficiency measures in general with focus on monitoring is part of chapter three. The fourth chapter describes the economic and statutory aspects associated with energy and operational data monitoring systems. This includes monetary benefits, which are held against the costs. Legal regulations concerning the topic energy management in different countries of Envidatec's target markets are compared. In chapter five the use of standardization is explained before the procedural method for the development of a standardized procedure for the implementation of monitoring systems is presented. Requirements for the procedure deduced from the demands of such a system are clarified as well. In chapter six the description of the actual procedure begins as it exposes how the input of a monitoring system is standardized by developing a generalized starting point for designing a measuring concept. The data processing and outputs of the monitoring system is subject of chapter seven. The following chapter eight then outlines the realization in a spreadsheet program and the connection to Envidatec's JEVis system including how JEVis functions can support the procedure. Afterwards, the system is applied to a real project in order to verify its functionality. The last chapter finally reviews the work as a whole and contains conclusions with regard to future developments.

2 Background

For the better comprehensibility of this thesis, the second chapter first gives some definitions of important terms, which are deemed to be known hereinafter. Furthermore, background information on the Envidatec GmbH as company which supports this thesis is provided. At the end of this chapter, Envidatec's own system solution, the JEVis system, is presented considering its options to be of importance for the realization of the procedure developed in this thesis.

2.1 Terminology

This part distinguishes some important terms used in this thesis. This helps the reader to follow up on definitions and to differentiate between the terms.

Looking at the title of this thesis, there is set out the target of increasing energy efficiency. Efficiency in industrial organizations is defined as amount of output per unit of energy. In contrast, energy intensity can be described as amount of energy per unit of output. A visual clarification of these ratios provides Figure 1. Increasing energy efficiency and decreasing energy intensity are synonymous. [11, p. 3] Both terms suggest that improvements result from producing more output with the same amount of energy or getting the same output with less energy input.

Figure 1: Illustration of energy efficiency (left) and energy intensity (right); [11, p. 3]

The next important term is energy management. A definition can be found in the VDI code 4602. These guidelines are published by the Association of German Engineers (VDI). Corresponding to the mentioned code, energy management describes a systematic co-ordination of the four energy applications procurement, conversion, distribution and utilization in order to cover requirements. It is further characterized as future-oriented and organized. Energy management considers ecological as well as economic objectives. [12, p. 3] In this context, an energy management system is the systematic implementation of energy management in an organization. It covers the organizational and information structures required for the implementation but also the needed technical resources like hardware and software. [12, p. 8] According to the VDI 4602, the use of an energy management system has certain benefits. Some of the main objectives are satisfaction of user or process requirements, comfort and display requirements, securing energy provision, reducing energy costs, reducing plant and equipment costs, creation of an ecological example-setting function and improving overall economic efficiency. As it is likely that some of the objectives are in conflict to each other, the most important strategic task in energy management is the determination of individual targets. The progress and achievement of these goals is to be reached with specific measures and must be monitored. [12, p. 4] Further content and elements of energy management systems are set out in the ISO 50001 which is examined more closely in the following chapter 3 Energy Management System.

Consequently, energy monitoring and energy controlling are parts of an energy management system. Along the lines of the energy management system, the alliance of monitoring and controlling with the word system, describes the combination of organizational components with correspondent software and hardware. The distinction of the two terms results from the wording itself. Monitoring systems focus on the visualization of collected and saved values in displays, in tables, as diagrams or in graphics [12, p. 27]. This leads to more transparency of the energetic situation [13, p. 5] and can serve as basis for comparisons against limit values [12, p. 27]. Monitoring systems include not only energy data but operational data as well. Energy controlling, however, is used in addition to monitoring. It describes the continual analysis of energy consumption. The controlling results help to identify energy saving and other improvement potentials or can be used for benchmarking. It allows cause-based cost assignment and plausibility checks as well as the construction of performance indicators. [13, p. 5] Reports are an important outcome of the analysis [12, p. 15] as they are basis for consumption forecasts and energy-related decision-making processes. A summary of the most important functions and elements can be seen in Figure 2.

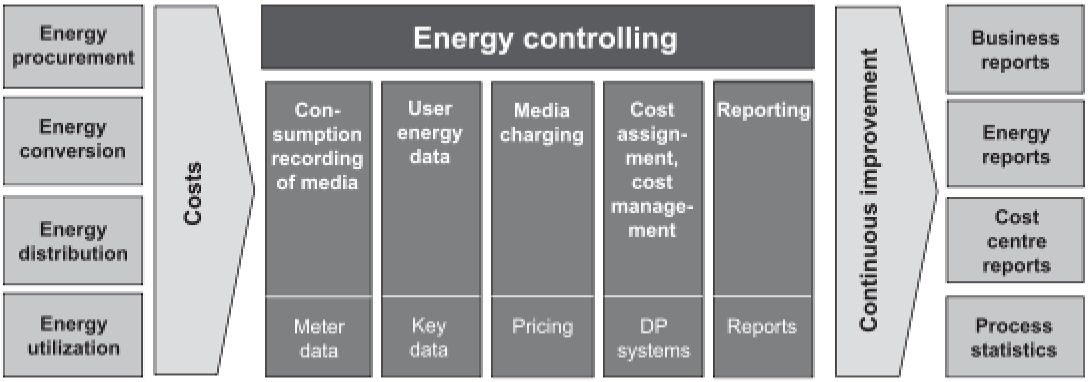


Figure 2: Structure and sequence of energy controlling; [12, p. 15]

Although it is an illustration of energy controlling the basic elements of energy monitoring and energy management in general can be found as well. For example, the four mentioned energy areas of the energy management are the input and the data acquisition from the monitoring process sorted after media is the first part of the middle sequence.

For the title of this thesis, the term monitoring was chosen instead of controlling, because the focus is on the data acquisition and visualization as basis for decisions concerning operational management. As will be seen in the course of this thesis, some components rather attributed to energy controlling will be regarded anyhow.

2.2 Envidatec GmbH

The Envidatec GmbH was founded in Hamburg in 2001 as independent company out of E.ON's competence center for energy efficiency. Energy efficiency counseling and energy management systems according to the international standard ISO 50001 are the company's core competencies; this motivates the interest in the assigned problem. The firm has specialized in innovative energy management concepts, which help all kind of organizations worldwide to reduce their energy consumption and therefore their energy costs. Envidatec so contributes to the reduction of global CO_2-emissions. [14, p. 2]

In this context, the Envidatec GmbH offers the holistic support of energy efficiency projects. These start with the identification of potentials and the revealing of suitable measures in energy and diagnosis audits. Afterwards Envidatec supports the implementation as it connects the customers with organizations providing the needed hardware. The software integration for a computer-aided monitoring system is done by Envidatec itself. For this purpose, the company developed its own system solution further described in the next subsection. Finally, the continual data analysis and controlling basing on the monitoring system serves as verification of the operating effectiveness. Envidatec also offers trainings, not only on their software but on various subjects dealing with the field of energy management in the wider sense of the term. [15, p. 4] The basis for their work is the Plan-Do-Check-Act (PDCA) Management Cycle as seen in Figure 3. It represents the foundation for energy management systems in compliance with ISO 50001.

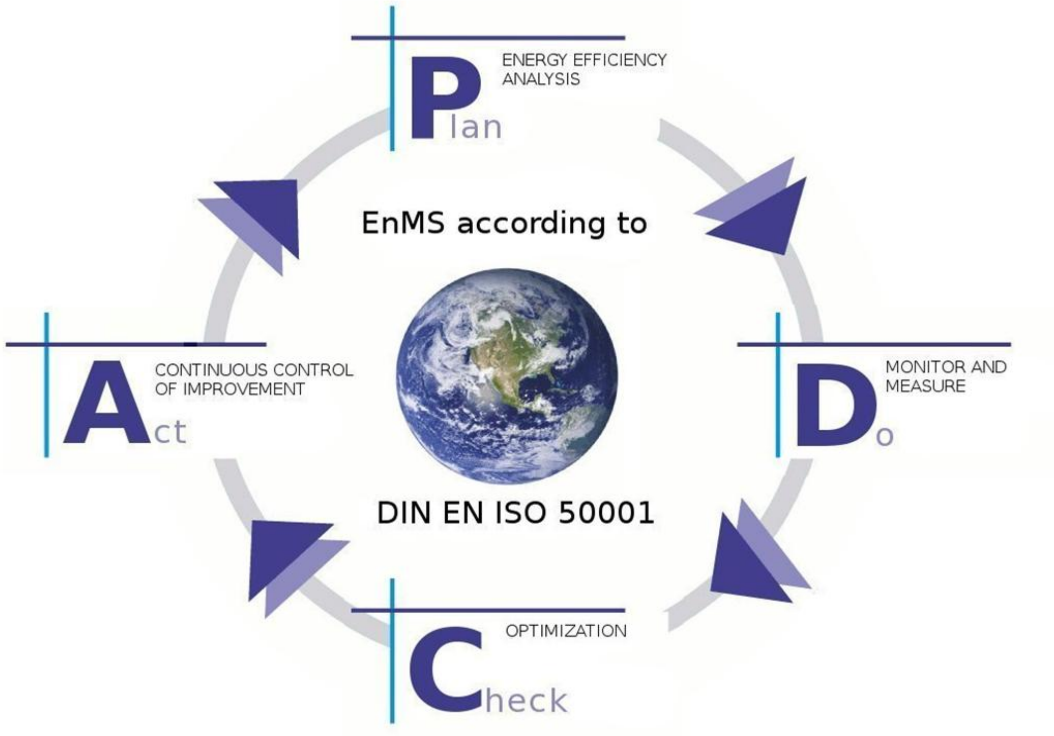


Figure 3: PDCA-Cycle as foundation for energy management systems; based on: [16, p. 12]

To meet the different demands of the broad client groups, Envidatec's employees cover a wide range of qualifications as engineers specialized on electronics, environmental technology or automation. The programmers employed at Envidatec take care of the further software development. Moreover, long-term strategic relationships with institutes, networks, energy suppliers and service providers extent Envidatec's possibilities as they enhance the knowledge base [17].

The company's international orientation is constantly increasing. In 2004 Envidatec started a branch office for research and development in Vienna, Austria. Out of this scientific center the omtec Energiemanagement GmbH was founded together with the BTM Holding GmbH and the Ing. Emmerich Czernohorszky GmbH as Austrian company representation in 2007. The rising demand in energy efficiency projects in the Commonwealth of Independent States - CIS countries, led to the foundation of the Russian branch office in Yekaterinburg two years ago. [15, p. 2] In addition to actual subsidiaries, Envidatec built up a constantly growing co-operation network with resellers, technology as well as research and development partners.

For instance, the international university network also includes universities from additional countries like Great Britain, Poland or Peru. This university network mainly bases on the JEVis system. [18]

2.3 JEVis System

As mentioned before, the Envidatec GmbH developed its own system solution for the implementation of energy and operational data monitoring as part of energy management systems. It is the open source software JEVis, which stands for Java Envidatec Visualization. In 2012 JEVis has been certified by the international certification institute DQS to be in compliance with ISO 50001 [19]. The system can be applied as hosting solution My-JEVis or as standalone in-house installation [20, p. 6] but is generally applicable to all branches of trade [19].

The software development started in 2003. Six years later the concept has been altered to a more flexible and sustainable design. Out of this new system generation the idea of an open source software evolved in 2011 which culminated in the foundation of the OpenJEVis community. Since 2012 the website OpenJEVis.org serves as communication and exchange platform for the community members. The number of different participants using the JEVis system for educational reasons, research projects or as commercial application is constantly rising. The distributed software development via the community paves the way for the use of extended resources as it can be reverted to the experience and knowledge of different interest groups. [21, pp. 2,5] Another advantage of the community is the constant quality assurance as new developed software parts underlie a routine testing cycle. In this way, detected bugs and desired features are reported to the developers directly. As the community is not limited to certain countries, the software is multilingual. [19]

The JEVis system is designed as decentralized modular construction. The overall intention is to monitor and analyze energy and operational data in order to optimize processes and reduce energy costs. [19] To reach this target, single modules with specific functions work as a coherent unit. In this way, the software is more flexible and new functions can be integrated more easily. Which sub-projects exist within the system and how these parts are connected to each other can be seen in Figure 4.

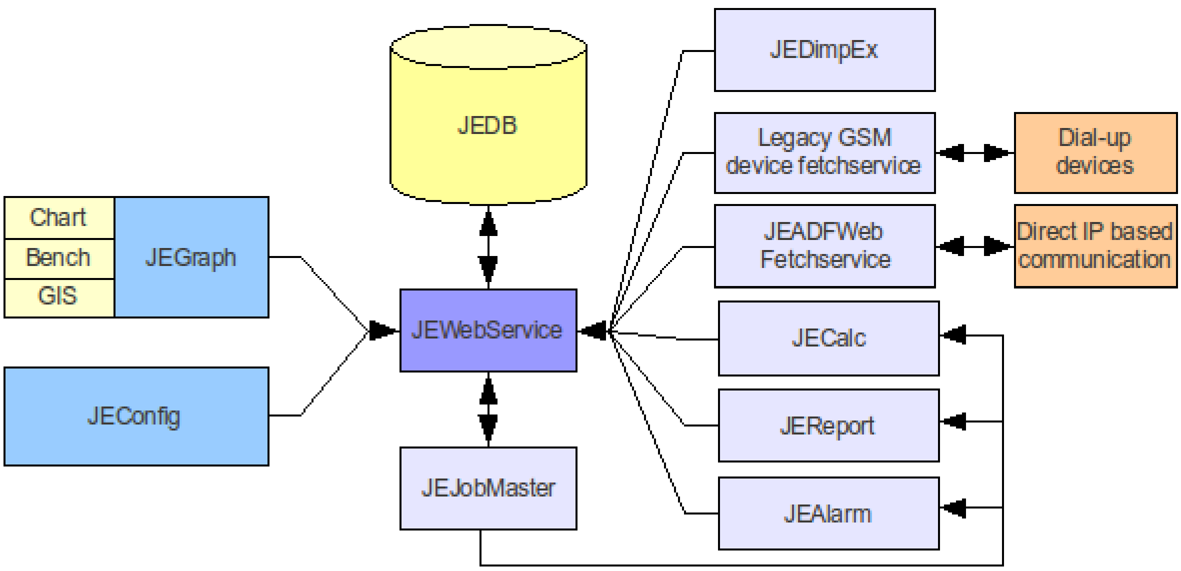


Figure 4: JEVis system architecture; [20, p. 5]

JEGraph and JEConfig are the functions with graphical user interface. They are used for the data configuration, visualization and analysis as well as the administration of measuring points. The real-time data processing also includes the definition of thresholds and benchmarks and as back-end services the generation of reports and the raising of alarms. With the function JECalc data calculations can be done via a gateway to Octave, a calculation software compatible with MATLAB. The system so becomes interoperable for applications in the fields of mathematics, enterprise resource planning or simulations [21, p. 4]. The interface to various data sources for communication simplifies the automated data fetching. The advantage of automated data monitoring in contrast to manual solutions is the high data resolution and actuality. All information is stored in a database (JEDB). The transmission is encoded to protect the data from unauthorized access. From there, raw and processed data can be exported via gateway to external systems. As all components are written in Java, the software can be installed on any established operating system. Additionally, using the internet, it is possible to access the software from any location. [20, p. 5]

So far, every customer requires the finding of its own specific monitoring solution. Hence, educes the idea of a standardized process, which simplifies the implementation of monitoring systems systematically and makes them accessible to an expanded application area. In this process the idea of customer-specific solutions should be kept up as far as possible.

3 Energy Management System

The new standard ISO 50001 officially replaces the old EN 16001 in Europe since April 2012. This chapter summarizes the contents of the standard with regard to the implementation of energy management systems. In this context, measures for increasing energy efficiency are deduced. Based on this information, the third paragraph refers to monitoring as energy efficiency measure in particular.

3.1 Contents of ISO 50001

The scope of the international standard ISO 50001 has already been referenced in chapter 1.1 Motivation. It leads organizations to an improvement of energy performance through systematic energy management. The contents of the standard can be divided in single topics resulting in one coherent process of continual improvement. They all have in common, that every step of the implementation and maintenance of the energy management system must be documented. An overview of the whole energy management system model according to the standard can be seen in Figure 5. This model serves as basis for a short outline of the contents.

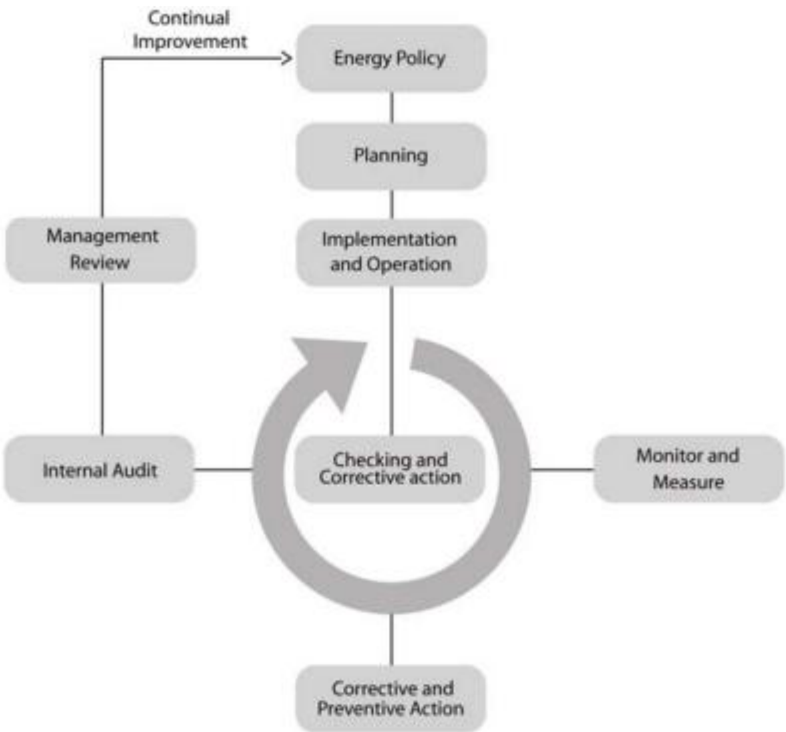


Figure 5: Energy management system model; [10, p. vi]

The descriptive part of the standard starts out with the role of management responsibility. The top management must support the energy management system and communicate its importance throughout the organization. A management representative has to be appointed, who can stand in and overlook the correct system implementation and performance. The commitment of the top management is essential for the success of an energy management system. [10, pp. 4-5]

The next topic is the topmost box in the scheme, the energy policy. It is a strategic fixation made by the top management about the long-term targets of the organization concerning the rational use and purchase of energy. An important character of the targets is the measurability in order to allow for the possibility of following up on the degree of target attainment. It is also set out, how the defined targets are to meet under the requirement of fitting the company's nature and scale. The claim of continual improvement is part of the energy policy. As the energy policy constitutes the framework of an energy management system, this postulation refers to all subsequent parts of the system as well. [10, pp. 5-6]

Energy planning is the next step in the process. In order to design the management system appropriately, legal and other requirements must be clear beforehand. By developing, maintaining and recording an energy profile the organization analyzes its energy consumption, identifies the areas of significant energy use and prioritizes opportunities for improving energy performance. Based on the energy profile, an energy baseline is established. This is used to assess energy performance and improvements towards the set out targets with the help of energy performance indicators. The energy planning also includes the time frame and resources, defining the aimed achievement of concrete individual targets. The planning of operational targets is recorded in so called action plans which include the assigned responsibilities as well. [10, pp. 6-7]

Then, the next step is the actual implementation and operation. All persons working on behalf of significant energy uses must be competent, well trained and aware of the importance of their work. To establish comprehensibility and reproducibility, major aspects are communication and documentation including the management of documents. Operational control ensures that those operations associated with significant energy use are carried out effectively. For significant energy consuming facilities opportunities for improving the performance by design, modification or renovation of these assets shall be evaluated. In addition, this part regulates what has to be considered for the purchase of energy, services and goods. [10, pp. 7-10]

Checking performance is the summarizing title of the four boxes belonging to the circled arrow in Figure 5. Key characteristics determining the energy performance must be monitored, measured and analyzed. The compliance with legal and other requirements is to evaluate regularly. The effectiveness of the energy management system is checked with the help of internal audits. Furthermore, the organization must take preventive and corrective actions against nonconformities. The mentioned recording of all phases of the energy management system must be organized and controlled. [10, pp. 10-11]

The last point in the system deals with the management review and therefore declares what is needed as input and what is expected as output of such a review. Important aspects of the management review are the adaption of energy targets and the initiation of energy efficiency measures. [10, pp. 11-12]

Identified drawbacks of the standard mostly trace back to impreciseness. For example the standard only requires the conformity of energy targets with the company-specific energy policy and general legal requirements. Absolute energy requirements are not defined. This has the effect, that energy management systems are greatly different between companies. [22, p. 13] Another flaw is the missing description of demanded measuring technology. The standard does not prescribe an automated data acquisition but some requirements like the continual error checking cannot reasonably be realized otherwise. [23] Furthermore, the standard does not name specific measures of how energy efficiency targets could be achieved. Therefore, the following subchapter describes different approaches that can be adopted.

3.2 Energy Efficiency Measures

There are several general strategies to increase energy efficiency. This paragraph is not supposed to describe all single measures but to outline the different approaches and to give examples for a better understanding. An overview of the different strategies can be seen in Figure 6.

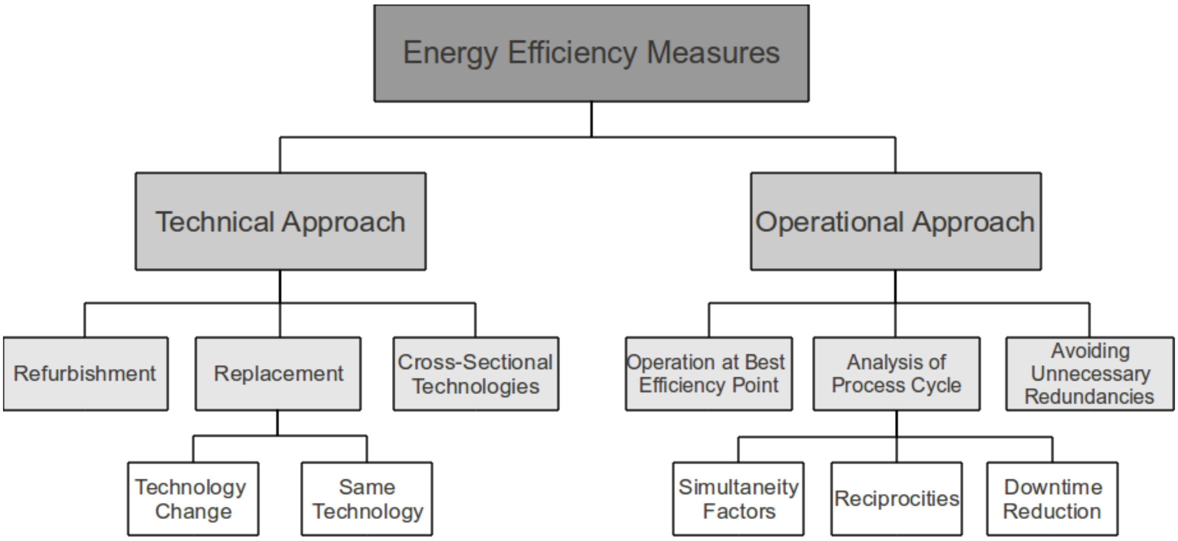


Figure 6: Different approaching paths to reach increased energy efficiency

The first option is the replacement of obsolete technologies by more up-to-date applications. The main emphasis of this approach is on the change of technology. Over the time there might have been new ways developed with the same effect on the output but with a different mode of action for instance. Similar to this is the simple exchange of an old machine by a new one of the same type. The difference is in whether the replacement includes a change of technology or not. Obviously, these are the most expensive measures but can be recommended in some cases anyhow. Especially where the former used technology is really outdated or where the old machine is not working properly anymore. It is valid in any case, that the savings due to effaced inefficiencies must amortize the investment within a reasonable time.

In opposition to a total exchange, some inefficient technologies can be refurbished. Here the old machines are not disposed but modernized instead. This is the more common procedure as the cost-benefit ratio often is better than for a new acquisition. Sometimes small changes in the design or the replacement of single parts within a bigger application already lead to a satisfactory increase in efficiency. Continuous control of parts mainly exposed to wear or defects can prolong the time before a reconstruction becomes necessary. A typical example is the monitoring and repair of compressed air pipelines which have leakages all the time.

In combination with the replacement of assets, the use of highly efficient cross-sectional technologies must be taken into consideration. Examples are electric drives, pumps, compressed air systems, air conditioning systems, heat recovery and waste heat utilization concepts, production of heating and cooling energy as well as lighting systems. [24]

Another approach maintains the technical structure as it is and only changes the mode of operation. Process cycles can be optimized when machines run at their best efficiency points. Therefore this should always be targeted for. Furthermore the analysis of the operating states and the process cycle itself can detect reciprocities. Simultaneity factors give an impression of which machines have to run at the same time and where one machine can redundantly replace another. Redundancies decrease the operating hours of single facilities and can thereby increase their lifetime as well as they increase the reliability and availability of whole processes. On the other hand, unnecessary redundancies must be avoided. It is evident that the use of two machines for something that could just as well be done with only one machine, always leads to higher energy intensity. This goes along with the sequence of processes. Especially in producing industries there often are some machines that are depending on the output of another machine at an upstream stage of the production chain. For each process it has to be assessed whether the waiting machine can be shut down, operated on standby or at least on a lowered state or if it must be kept running permanently. Here the energy needed for running the machine must be balanced against the probably of increased wear due to more frequent startup and shutdown cycles. At the same time the sequence of processes within the production cycle itself can be questioned. This might help to reduce downtimes.

Despite all these different approaches there is a lack of extensive strategic implementation. A large part of identified potentials for energy efficiency are neglected because they are technically complex and (or) require high startup investments. From an economic point of view they are therefore considered as little attractive. [7, p. 75] Even more important it gets to augment the acceptance of monitoring systems as energy efficiency measure with minor investment costs.

3.3 Monitoring

A first device for the inspection and visualization of energy consumption has already been tested in 1979. This appliance displayed the electricity consumption and made savings of up to 12% possible. These achievements are traced back to the scientifically proven increase of motivation that occurs when consumers are aware of their usage and can follow up on their savings. Of course, this is just true, if at the same they have an option to influence the energy consuming processes. This shows, however, that the idea of monitoring systems is no modern and innovative phenomenon. [25, p. 12] The IEA picked up the concept in 2012's energy factsheet. The agency endorses the implementation of monitoring systems as they see the opportunity of increasing energy efficiency through measurements and analyses.

It is regarded as contribution to achieve the three energy goals "*economic gains, energy security improvements and environmental protection*". [2, p. 4]

Monitoring is often regarded as tool for describing the current energy situation whereas the potential for variance analyses is mostly unused. Envidatec's experience demonstrates that pure information diverted in corrective actions may lead to savings of 3-15%, depending on factors like the technological maturity, already implemented measures and the general corporate philosophy. To achieve higher acceptance in industrial organizations it is important to make them aware of the capability of monitoring solutions. More advantages pleading for monitoring are obvious. The graphical visualization helps to better compare different energy flows as the perception of graphics is better than of plain numbers. Additionally, dependencies between processes and correlations of energy flows are easier to detect. This becomes clear when looking at the example in Figure 7. The upper graph shows the power of an air conditioning system whereas the bottom graph visualizes the resulting temperature in the room cooled by this A/C unit. It is clearly evident that the failure of the air conditioner leads to unsteady temperature changes in the surrounding room. It can be seen how the increased cooling action before the breakdown results in a sharp drop in temperature whereas the lasting period of non-functioning leads to a logarithmic increase of the room temperature. To enhance the visualization of this effect, the respective parts of the temperature curve exceeding a certain average temperature are colored in red.

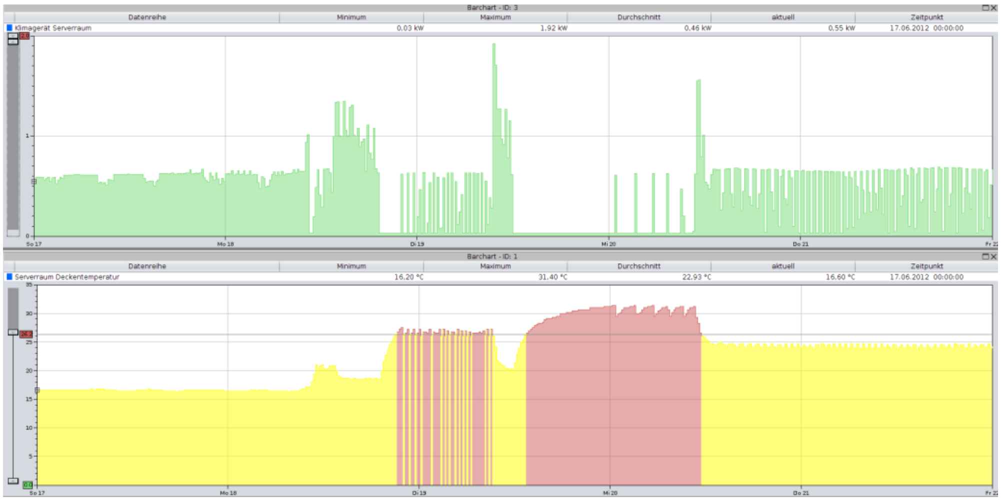


Figure 7: Visualization of dependencies between two data rows; [26]

Since monitoring leads to more rational and efficient energy use, the energy costs of an organization can be reduced. Furthermore, the complete transparency of energy flows allows for a cause-based cost assignment and might serve as basis for investment decisions. The characteristic energy values that can be created with the help of a monitoring system enable the benchmarking against other organizations. [27, p. 13] The medium-term cost saving potential is often underestimated where organizations expect short payback periods of investments only [7, p. 75]. Both can be anticipated for monitoring systems. Expanded to a condition-monitoring, maintenance costs become predictable and the availability of machines is prolonged. Condition-monitoring can prevent failures due to wearout, so that it gets viable especially for high complex processes, where a breakdown is particularly severe. [28]

To utilize these advantages, monitoring systems must fulfill certain requirements. Prerequisites are an integrated data acquisition system as well as responsible staff members with the needed know-how and motivation to keep track of data trends. The aim is to reach availability, security and quality of processes with least possible personnel expenses because this leads to minimization of costs. This is influenced by efficiency factors and the mode of operation as well as the state of maintenance. Therefore it is expected of a monitoring system to check whether processes run optimally using measured, calculated, analyzed and validated data. The monitoring system should also be capable of identifying possible reasons for deviations. [29, p. 21] All incidents that occur must be registered and documented. Further requirements are the acquisition, processing, validation and archiving of data. A fault message must indicate the malfunctioning of one of these basic functions. Other required functions are the visualization of data in diagrams, graphics or tables as well as comparisons of measured values against thresholds. Figure 8 shows how this function is put into practice within the JEVis system. With the help of two sliders on the left side of the graph the thresholds are defined. All values above the encircled area appear red and the ones below the lower threshold are green. All values in between the limitations are colored yellow.

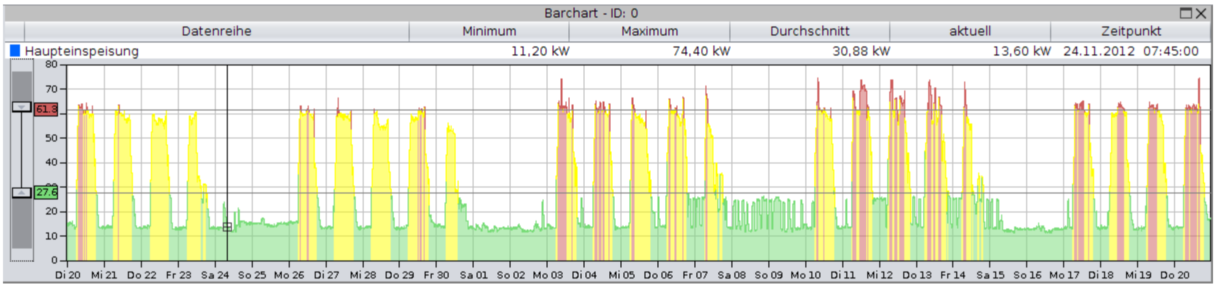


Figure 8: Illustration of the JEVis threshold function; [26]

The enhancement in respect of analysis and diagnosis leads to additional requirements such as key figure calculation, target-performance comparison, short- and long-term saving of values, recognition of emerging interferences, prognoses and the recommendation of control operations. [29, pp. 27-28]

Opponents of monitoring systems might invoke certain counter-arguments. First, it is difficult to assess high complex, cross-linked and constantly changing flows of various materials [7, p. 75]. In addition, the implementation and operation of the system requires investments, of which the amount depends on the dimensioning of the system. These investments are needed for measuring technique, the data acquisition system and for labor costs. The latter results from the need of a person in charge who is hired for this job or who assesses and analyzes the data besides the usual commitments and duties. The effort for the monitoring system is dependent of the company size. It is also understandable that technology is always prone to error. Consequently, false alarms or mistakes in the data transmission and processing cannot be ruled out [28]. Another argument that might be held against monitoring systems is that if an external company supervises the monitoring, it gets insight into internal information. This requires a high level of confidentiality and a trustworthy external company with appropriate experience.

4 Economic and Statutory Aspects

Like all economic decisions, the implementation of energy and operating data monitoring systems must be negotiated with respect to financial viability. Besides achievable savings in terms of energy and money the installation and operation of such a system is connected to costs as well. Therefore this chapter analyzes the monetary gain of monitoring systems and opposes them to occurring costs. The third subsection deals with country-specific legal provisions. As Envidatec's main activities are currently concentrated at markets in Germany, Austria and CIS countries it is examined which legislative regulations exist in order to cause incentives for organizations to implement energy management systems.

4.1 Monetary Gain of Monitoring Systems

The use of monitoring systems leads to financial savings. These savings can be categorized in strategic and direct savings [30, p. 7]. The differentiation is dependent on the temporal occurrence and whether they are in form of avoided costs or of actual savings.

Typical strategic savings result from reduced failure rates. As most breakdowns build up slowly, a monitoring system could perceive a malfunctioning so that the total outage of an asset can be avoided. Where this is not possible the costs may at least be reduced to a minimum because a reserve unit can be supplied in time [30, p. 9]. It must be differentiated between detectable and undetectable problems. Some become directly visible whereas the later are only recognizable when processes develop a certain trend or single physical parameters change [31, p. 94]. It is common to monitor the mechanical and electric conditions as well as to observe temperature changes. The resulting savings depend on the general failure probability, the detection rate and the costs arising from a breakdown. [30, p. 8] An undetected defect may just as well lead to a plain excess of energy consumption without further impact on the production output. This kind of defect will not be detected before the annual billing of energy costs. Similar to this are avoidable costs of demand charges for grid-bound energies which could be economized using load management and control. [32, p. 2]

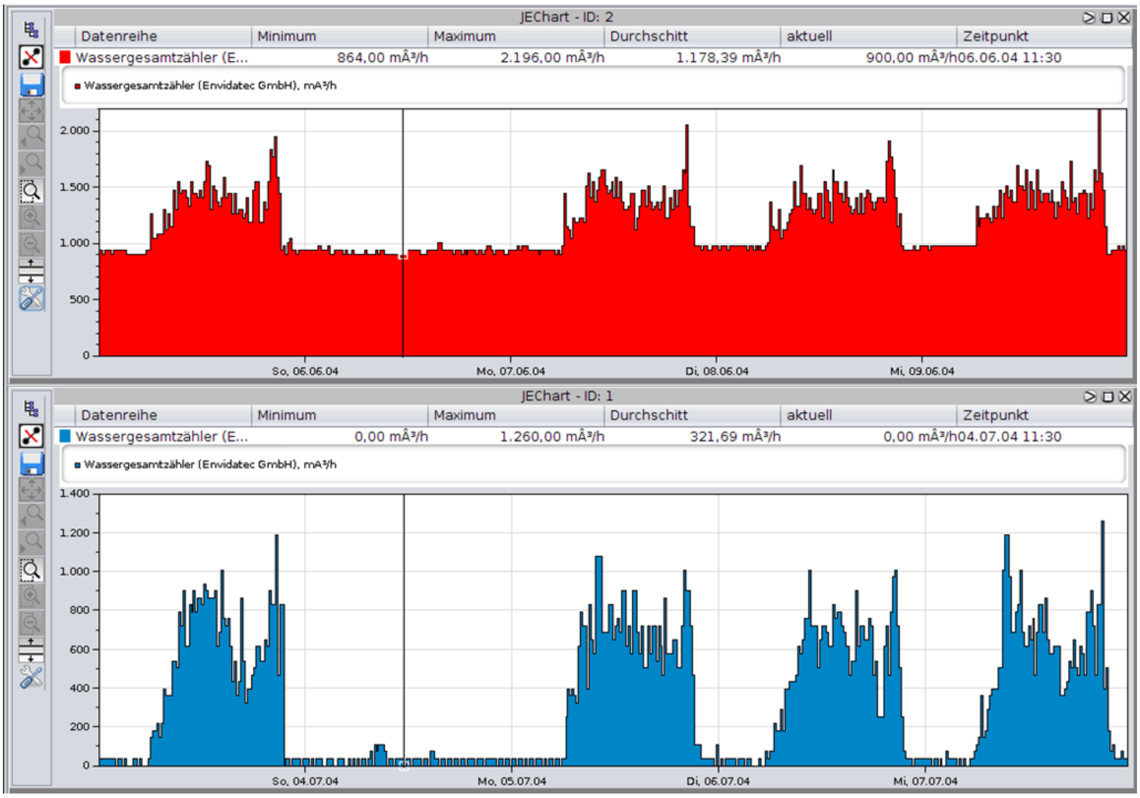


Figure 9: Water consumption with (red) and without (blue) leakage; [33, p. 20]

An example of how the earlier detection of irregular behavior leads to savings can be seen in Figure 9. The picture shows the water consumption before and after a leakage was detected. The water wasted because of the leakage is apparent from the increased base load in the red graph compared to the blue one, which in contrast only contains the amount of water actually consumed for internal processes. In the worst case, without the visualization of measured data this immense excess consumption would not have been detected before water leaked to the surface or with the arrival of the annual water bill.

A quantification of these savings cannot be generalized but depends on the extent of excess consumption, the time elapsed before detection and the costs per unit. For long periods or expensive energy sources like compressed air undetected wastes can cause substantial costs. In combination with alarming integrated in an automated monitoring system the savings can be significant as has been investigated in a bachelor thesis written at Envidatec [34]. The following Figure 10 shows the schematic result of this survey. The topic alarming will be discussed more deeply in chapter 7 Data Processing.

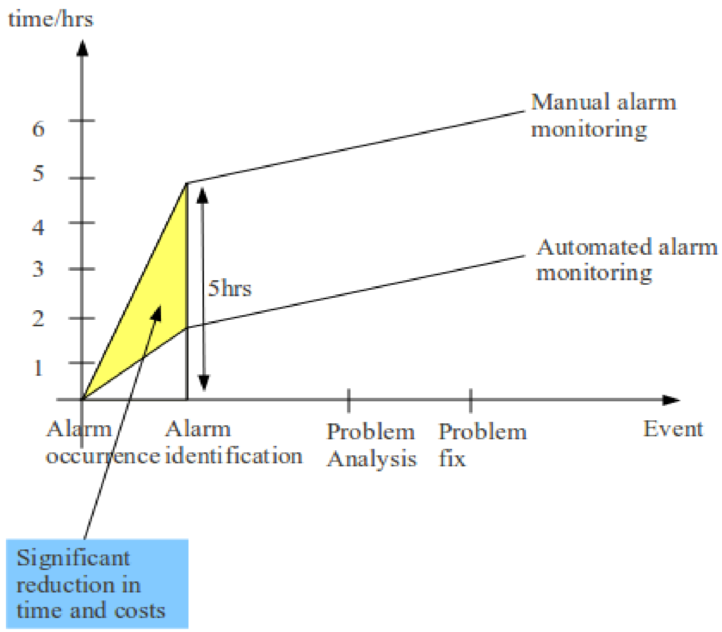


Figure 10: Benefit of automated alarm monitoring compared to manual alarming; [34, p. 13]

Linked to breakdowns are other costs that might be reduced or totally avoided with the help of monitoring systems and in this way increase the monetary gain. Collateral damages for instance are personal injuries or damages of other production factors that occurred because of the malfunctioning of a system. These might happen directly by the failing facility or indirectly because of power blackouts or the like [30, p. 9]. Delay of deliveries may lead to contractual penalties. The resulting damage to the company's reputation or loss of orders are further examples for indirect costs that should be avoided strategically. [35, p. 210] It is not possible to estimate the general costs that arise out of these damages [30, p. 9].

Direct savings occur due to the avoidance of direct costs. The most obvious ones are savings resulting from detected inefficiencies. Energy and operational data management systems are capable of finding inefficient operating states or inefficient technology in general, so that the persons in charge are able to react appropriately in order to reduce wastes of energy. [32, p. 1] These findings will directly result in decreased energy bills for resources and in addition lead to higher availability and reliability of assets [30, p. 11]. In case of organizations affected by the Greenhouse Gas Emissions Trading Act (TEHG) the reduction of energy consumption will have further positive effects due to a diminished amount of needed greenhouse gas allowances.

Another direct effect is the loss of income resulting from production outages. Linked to this are damages to work pieces or tools. Additionally, after a breakdown production machines need some warm-up time and produce goods of inferior quality during that period. Similar to this, in the meantime between occurrence and detection of misbehavior a machine is likely to produce defective goods. [35, p. 210] In general, the close monitoring of process behaviors may also lead to reduced maintenance costs. It is supported by the idea that a monitoring system may remind the user of maintenance intervals. This goes along with the fact that the knowledge gained about a monitored facility helps to prepare decisions on replacement investments. It is explained through the constitution and long-term behavior of facilities assessed by the monitoring system. So decisions on exchanging machines can be postponed and the saved money might even yield an interest income instead. [30, p. 10] In return, the optimal time for a new investment can be detected more easily as well. Here the monitoring system can also be of help, as machines can be designed after the actual demand and overdimensioning is prevented. [32, p. 1]

4.2 Costs of Monitoring Systems

In contrast to the various options for savings, the costs of monitoring systems are easily understandable. On the one hand there are initial investments for the installation and on the other hand there are annual costs.

The initial costs include the measurement technology and its installation. These costs depend on the amount of meters and the type of measurement. Naturally, the measuring devices get more expensive the more complicated the measurement is. This is comprehensible best for media in pipelines. For automated systems costs for analyzing software, data loggers and the integration of these components into existing as well as newly installed measuring points augment the initial costs. As the JEVis solution of Envidatec is open source software, their customers can exclude the purchase of software from the costs. For research and educational reasons even the license is free. The license fees for commercial users, however, depend on the amount of measuring points. [21, p. 9]

The annual costs consist of operating costs and accounting costs for depreciations. All initial investments including technical devices as well as software can be written off over prescribed periods. In contrast to these accounting costs, the operation of the monitoring system causes tangible costs. They result from personnel costs for the analysis and processing of incoming data. Additionally, the system needs maintenance which can lead to costs in the amount of 10-12% of the initial costs. They are caused by aging and wear which necessitate the exchange of defective or obsolete parts. [36]

However, the costs for monitoring systems are comparatively small and pay off quickly with short payback periods.

4.3 Legal Provisions

Increasing energy efficiency is a global task. Nevertheless the legislative arrangements to reach energy goals vary widely in different countries. In this context, the EU has launched a roadmap towards a carbon-reduced and energy efficient Europe including prescribed energy targets and schemes like the Strategic Energy Technology (SET) Plan. The actual implementation though is incumbent upon the Member States. Consequently, each European country has its own energy policy. Outside the EU the situation is even more differentiated, if actual energy policies exist at all. A significant aspect of energy politics in general is the definition of energy use. As energy management systems on the other hand represent an effective way of saving energy, this subsection takes a look on different legal provisions that create incentives for the implementation of energy management systems. Explicitly, differences between Germany, Austria and the CIS countries Russia, Ukraine and Kazakhstan are illustrated as these countries represent Envidatec's current main target markets.

4.3.1 Germany

In Germany there are several regulations motivating the implementation of energy management systems according to DIN EN ISO 50001. As a first point, the implementation and certification itself can be subsidized, if certain criteria are fulfilled. For this purpose, an Energy Efficiency Fund has been established out of the Energy and Climate Fund. According to a draft of guidelines, announced by the German government in July 2012, the certification of energy management systems in compliance with DIN EN ISO 50001, the certification of energy controlling systems, the purchase of measuring technology and the purchase of technology for data processing are eligible. The last two aspects are subsidized up to 20% respectively 8,000 € and the named certifications are even funded up to 80%. The maximum grant for a certification according to DIN EN ISO 50001 is 8,000 € whereas the certification of individual energy controlling systems is subsidized up to 1,500 €. The certification of an energy controlling system requires the assurance of energy-saving potentials proven by an energy use analysis and an energy consumption analysis including the single energy flows and their distribution among the various energy-consuming facilities. Furthermore, measures for the realization of the detected saving potentials must be identified. The consumption as well as the savings have to be monitored with an appropriate function. [37]

Another incentive for energy management systems results from reduced rates of taxation and tax capping. By allowing a rebate for producing companies the economic competitiveness of organizations shall be maintained. The legal basis is §55 of the Energy Tax Act (EnergieStG) and §10 of the Electricity Tax Act (StromStG). An amendment of these laws is effective since January 1, 2013. In each of these Acts the parts 1 and 2 describe the extent of tax reliefs and the subsequent parts define that an energy management system certified according to DIN EN ISO 50001 is mandatory for the tax relief. The existence and operation of this energy management system must be proven for the claim year. In the claim years 2013 and 2014 the organization can get a tax relief, if it can be shown that the company started with the implementation in the claim year or prior to that. [38, pp. 35-36], [39, pp. 5-6]

For small and medium sized enterprises there are special regulations, as they are allowed to implement alternative systems for improving their energy efficiency. These alternatives must be in compliance with the requirements of DIN EN 16247-1. [38, p. 36], [39, p. 6]

As second precondition for the granting of a tax relief, yearly target values for the reduction of energy intensity must be reached. This is a requirement of the German government which does not apply to single organizations but obliges industry as a whole. [38, p. 36], [39, pp. 5-6] The defined target values can be seen in Table 1.

Table 1: Target values for the reduction of energy intensity; [38, p. 48], [39, p. 9]

Claim Year	Base Year	Target Value
2015	2013	1.3%
2016	2014	2.6%
2017	2015	3.9%
2018	2016	5.25%
2019	2017	6.6%
2020	2018	7.95%
2021	2019	9.3%
2022	2020	10.65%

The target values are held against a base value. This basis is defined as the yearly average of energy intensity in the period between 2007 and 2012. The percentage then describes the reduction of energy intensity compared to the base value. Every claim year has an assigned base year in which the respective reduction must be apparent. For instance, for a claim in 2015 it must be proven that the energy intensity in 2013 was 1.3% below the yearly average of 2007 to 2012. The Act constitutes that the target values for the claim years 2019 till 2022 must be reevaluated in 2017 and adapted if necessary. Here, the new target values must exceed the 5.25% of the base year 2016. [38, p. 48], [39, p. 9]

Both §55 EnergieStG and §10 StromStG contain a provision for the situation that the target values have not been reached. To receive 60% of the tax relief, at least 92% of the target value for reducing energy intensity must be reached. In case the target value is accomplished to at least 96%, yet a share of 80% of the potential tax relief is granted. [38, p. 36], [39, p. 6]

Another regularity which motivates energy management systems is the special equalization scheme according to §40 et seq. of the Renewable Energies Act (EEG). It affects companies with purchased energy of at least 1 GWh and energy costs accounting for at least 14% of the organization's gross value added. [40, p. 42] Depending on the amount of purchased energy the Renewable Energies Act levy is reduced to 10% of its regular value for the share between 1 GWh and 10 GWh respectively 1% for the share between 10 GWh and 100 GWh. For an electricity procurement above 100 GWh the allocation for this share is only 0.05 €ct/kWh. [40, p. 43] Considering the current regular price of 5.277 €ct/kWh, which can be obtained from [41], this minimal value means a reduction to less than 1%. For organizations consuming more than 100 GWh at an energy intensity exceeding 20%, 0.05 €ct/kWh is the levy valid for the complete amount of purchased energy. [40, p. 43]

The remarkable savings per kWh that are possible with the appropriate energy intensity might lead to a neglect of energy efficiency aspects. Thus, to prevent the encouragement of inefficient energy usage, for organizations with an energy purchase of more than 10 GWh an imperative requirement for the participation in the special equalization scheme is a certification, that potentials for energy saving are assessed and the energy data are acquired after a recognized standard. [40, p. 42] Besides others this can be an energy management system according to ISO 50001.

4.3.2 Austria

Like Germany, as EU Member State Austria is obliged to obey the guidelines of the European Commission. To implement the targets of the EU, the Austrian ministry of economics and environment developed an energy strategy in March 2010. Besides others, one goal of this strategy is to ensure the supply of energy through energy efficiency in all relevant sectors. Consequently various measures were set up but only some of them have been implemented so far. [42] One measure foresees the draft of an energy efficiency law with according regulations for the single Länder. An aspect could be that energy management systems, organizational energy concepts and energy consulting become prerequisites for the access to funding. [43, pp. 6-7] Additionally, the investment in newer and more efficient technologies shall be subsidized, if the organization makes use of energy consulting and energy management systems. For energy-intensive industries a threshold is defined, above which organizations must develop energy concepts [43, pp. 10-11]. How these measures will be designed in detail has not been clarified yet. A first draft of this energy efficiency law from 2012 foresees that all energy consuming enterprises have to take energy efficiency measures depending on their size and energy consumption. According to this draft, energy management systems after ISO 50001 are mandatory for large and medium-size enterprises. [44, p. 9]

4.3.3 Russia, Ukraine & Kazakhstan

Mechanisms comparable to the ones in Germany do not exist in CIS countries. In fact, neither in Russia nor in Ukraine there are any legal regulations which would motivate the implementation of energy management systems according to ISO 50001. [45] Some organizations in these countries, however, voluntarily have energy management systems more or less in compliance with the international standard. The majority of these companies just see the gain in terms of image. At a guess, only 20% of the organizations with energy management implemented the system out of the hope to increase their energy efficiency. [46]

In contrast to Russia and Ukraine, in January 2012 the Kazakh government launched the Law of the Republic of Kazakhstan on Energy Saving and Energy Efficiency. The act constitutes a legal, economic and organizational basis for aspects concerning energy conservation and energy efficiency. The Law came into force in summer 2012. According to Article 10 of this law, the implementation of an energy management system in compliance with the international standard for energy management, which means ISO 50001, is mandatory for organizations consuming energy resources in the amount equivalent to fifteen hundred or more tons of fuel per year. This Article will be effective to its full extent from January 1, 2014. [47] Compared to Germany, the implementation of such a system in Kazakhstan is not associated with tax savings or other subsidies.

5 System Requirements

The system developed in the course of this assignment will contain a level of standardization as high as possible under given prerequisites. This chapter outlines what thereby is expected of the system. It helps to understand why systematic approaches are useful and how they lead to standardization. In this context it is explained why standardization is an important tool to simplify and optimize various processes. The procedural method adapted in this thesis is described in the second subsection. Additionally, the third part of this chapter summarizes ideas and requirements concerning content and configuration of the system that were drawn up preliminary to the research. This includes assumptions regarding the organizational structure and the processes that shall be improved, as well.

5.1 The Use of Standardization

Standardization describes the process of harmonizing methods, types, procedures, services and other generalizable properties with the aim to build common standards. The content of these standards are uniform parameters or procedural methods that the standardized object has to fulfill to be in accordance with the respective standard. They therefore indirectly describe the way of how an unstandardized object has to change in order to meet the standard's demands. Normally, standards cover a wide application range. This reflects the objective of standardization to aggregate a variety of different use cases in one unifying standard. [48, p. 4] As exemplification, Figure 11 illustrates how standardization helps to simplify problem solving. Where before everyone had its own solution for the same problem, standardization systematically leads to a specific solution.

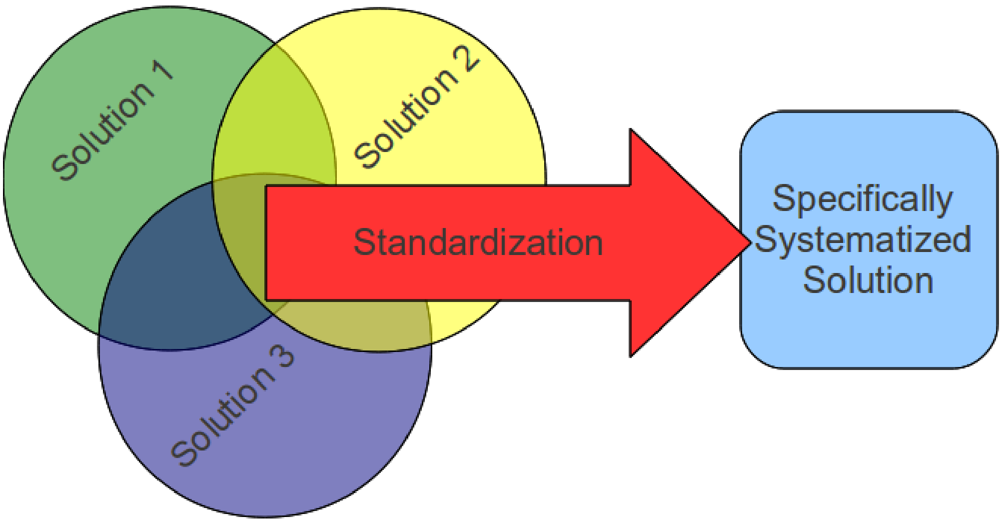


Figure 11: Process of standardization

The process of standardization bases on a consensus of the concerned parties, which underlines the voluntary character of standards. Therefore, openness and transparency are prerequisites of the standardization procedure. The motives of defining standards can be very different. One of the more important purposes is the establishment of compatibility and interchangeability. [49] In addition, all standards and procedures described therein must be comprehensible for the user and all results have to be reproducible.

The importance of standards is reflected in the numerous national and international standardization organizations like the American National Standards Institute (ANSI), German Institute for Standardization (DIN), European Committee for Standardization (CEN) or the International Organization for Standardization (ISO), just to mention a few [48, p. 7]. It must be kept in mind that although the organizations are independent, their standards are often harmonized. For example, the ISO 50001 is published as DIN EN ISO 50001 in Germany.

Industry, consumers and government are the three stakeholders benefiting from standards the most. The advantage of standards for research projects lies in the ability to test in accordance with internationally agreed principles. [49] The significance for this thesis is that standardization may help to raise the awareness and increase the acceptance of monitoring systems as energy efficiency tool. The easier the setup of such a system the more organizations will be interested and the faster the implementation can take place. Also, the process of implementation as well as the methods within the monitoring system itself become more transparent.

5.2 Procedural Method

The objective of this thesis is to develop a way of standardizing the implementation of data and energy data monitoring systems. As described above, the definition of a standard results from a procedure. A scientific approach of modeling was adapted as procedural method to solve the problem. Figure 12 shows the general line of action.

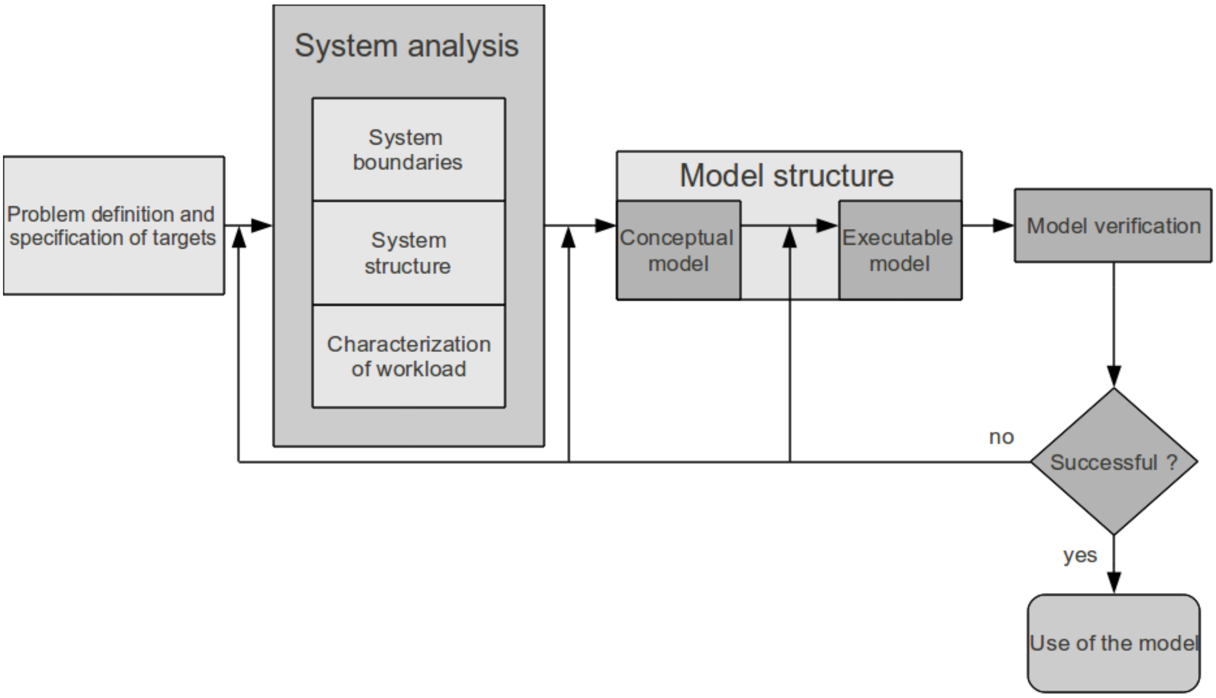


Figure 12: Scientific approach of modeling; based on: [50]

The first task is to define the problem precisely, including the range and capability of the system, as well as to formulate the targets, that shall be reached by the procedure. This point is the basis for the subsequent steps as it is defined once and not altered unless the further analysis reveals the impossibility of reaching the set out targets. Consequently, the following paragraph 5.3 System Analysis describes which findings were drawn up preliminary to the process development of this thesis. This includes besides the problem definition also the second step of the modeling approach, the system analysis. In the case of this assignment the underlying system are industrial processes in general, since they have to be systematized in order to develop a common monitoring system. The resulting system description includes the system's boundaries, the system structure and the characterization of the workload. Important outcomes of this analysis are the system's components, influencing factors from outside the boundaries and connections or interactions between the various components. It also helps to find aspects, that can be neglected and as a consequence contribute to the simplification of the model.

After all abstract preliminary ideas and requirements are clear the actual modeling can be done. The first draft is a conceptual model that is transferred into an executable model. In this thesis the first model is carried out as a tool in a spreadsheet program as it is set out in chapter 8 Computer-Aided Realization.

Before the model can finally be used, its functionality must be verified. If the verification is unsuccessful, the model must be adapted. Sometimes some minor changes in the executable model are sufficient but it is also possible that the underlying conceptual model needs changes. In some cases it will also be required that the system structure itself must be looked at again and altered accordingly. The process adaption via going back to earlier stages of the system is comparable to the circular process of continual improvement as it is set out in the ISO 50001. It must be clear, however, that just the use of the model in experiments can really proof whether the specific targets are reached. In the case of this thesis the application to an exemplary project of Envidatec will lead to this gain.

Another important point for the modeling that is not depicted in Figure 12 is the documentation of all phases. This is a requirement resulting from the standardization's prerequisite of being comprehensible and reproducible. This idea is underlined by the ISO standard's demand for documentation. Furthermore, in a well documented approach it is easier to detect inconsistencies.

5.3 System Analysis

The task definition in the introductory chapter has already set out the problem definition as well as the targets aimed for as outcome of this thesis. The objective is to find a procedure preferably applicable to all kinds of industrial organizations. In accordance with the procedural method and to simplify the process of standardization, the monitoring system is structured in single parts. In this way, the measurement concept is identified as critical phase for the success of standardization. In the second subsection specific thoughts about upcoming demands on monitoring systems in the industrial sector are explained. This includes findings concerning the nature of the data, the analyzed processes and specifications of the interaction between the system and its users.

5.3.1 Structuring of the Monitoring System

As a first step, the structure of monitoring systems has been analyzed in general. The results are individual phases and parts that can be looked at independently before they are combined to one diagnostic system. The succession of parts at the implementation of a monitoring system is in dependence on the illustration in Figure 13.

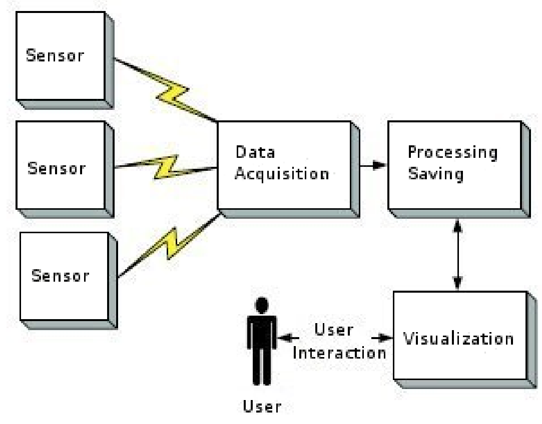


Figure 13: Principle structure of an energy monitoring system; based on: [25, p. 13]

For an efficiently working monitoring system the interaction between the user and the system is crucial. Without the users' reaction on information received from the system, the energy efficiency cannot be improved.

To start at the beginning, every monitoring system needs data as input. As will be seen in the following chapter6 Development of the Measurement Concept, these data are operational data and (or) energy data. At least for the accumulation of energy data, sensors are needed. As Lord Kelvin said in 1883, *"If you cannot measure it, you cannot improve it!"* [51] Consequently, the first and most important part is the development of a measurement concept. To generalize the way of defining measuring points hence contributes most to the system's workload.

After a standardized way of data acquisition is found, the next step is the data processing and saving. These steps of the implementation process in parts already are standardized at Envidatec due to their software solution. How certain standard procedures like visualization are put into practice with the help of the JEVis system will be clarified later. With the data processing the elements generally referring to controlling systems come in to action. At Envidatec the computer-aided system secures the measurability of performance and thus the success of the monitoring system to reach the target of increased energy efficiency.

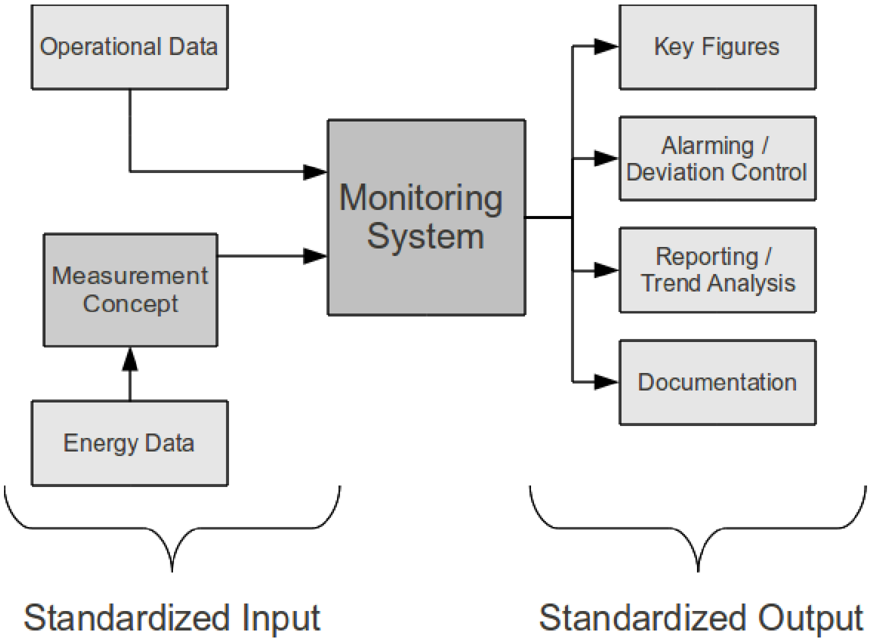


Figure 14: Workflow for a standardized monitoring system

As can be seen in Figure 14 the task after finding a standardized input is to generalize the output of the monitoring system which results from the data processing. Output elements that were chosen for this design are key figures, an alarming system as deviation control, a reporting structure and the handling of documentation. Although the final design will differ between companies, for these certain elements it is possible to develop an initial solution. These basic templates must later be augmented according to the individual needs of the companies and regularly improved according to the idea of continuous improvement.

Here the first limitation of a standardized energy and operational data monitoring system becomes apparent. It is not possible to find an output solution tailored to the needs of all kinds of industrial organizations to an equal extent due to the various sizes and branches on the market. The comparability required by standardizations is even more difficult to implement because the outcome of the mentioned system outputs will greatly differ between companies. Experience proves that it even cannot be guaranteed that the key figures of one company are similar to another firm of the same branch [23]. Other boundaries of the system might appear during the process design and then will be addressed at the appropriate passage.

5.3.2 Requirements for the System Configuration

Preliminary to the system design, some ideas were collected in order to define requirements that must be thought of during the implementation process. How these thoughts are realized in the end is not part of this chapter but will become clear in the course of the thesis.

The first question refers to the data basis itself. It must be decided what kind of data shall be included in the monitoring system. Obvious are energy flows by quantity and type. Additionally, material flows describing input and output of the analyzed processes as well as monetary flows are needed as reference parameters. Other information needed for comparisons or the generation of key figures might be aspects like heated area, attended time, number of employees or ambient temperature [52, p. 26]. The type of information also includes, whether it is raw data information which requires interpretation or reassessed information as the result of an analysis or calculation.

The next query is about the constancy and reliability of the identified energy data flows. The underlying idea refers to the measuring technology. It must be clarified, at which location the sensors are installed, and with which regularity the data is collected from them. A key point here is the measuring accuracy resulting from the average measurement range and sensor sensitivity. The possibility of reading errors because of manual readouts must be minimized. To meet certification requirements the metering precision in an energy management system is partly obliged.

Connected to this is the question of how information must be provided for the person concerned. Examples are a value that has to be read off an on-site display or off a central data acquisition station. It also is a question whether reports are sent out to the receiver because of a detected indication or compulsory with a preset regularity or both. This would indicate a differentiation between standard reports and an alarming system.

This goes along with the issue of where and how fast the information has to be available. First, the responsibilities must be clear, will say the process owner who is able to assess and interpret the data and react appropriately. The person in charge must have access to the information in time so that he can intervene where necessary. Again, the information is either available on-site only or is collected centrally. In some cases it might be advisable or even necessary to inform the top management as well. The time that elapses before an error in the run of process is detected or indicated as unusual behavior depends on process dynamics. Consequently, each process has a range of normal behavior. Deviations out of this range can be temporary and self-regulating but they also might indicate an erroneous processing that needs intervention. The decision between these two possibilities often is connected to the time during that the misbehavior is apparent before it is reported and must be clear for each process. If this specific process information is not available, the person in charge will not be able to intervene effectively.

This evokes the question after the decision-making process concerning regulative intervention in general. As set out already, certain information can lead to necessary interventions into a process. Here, the decision-making process must be clear. This means, it has to be given knowledge if the top management orders the intervention or if the process owner can decide on the necessity of regulation himself. Some processes might also be automated, so that software conducts the operation and no manual surveillance is necessary at all. Generally, the decision-making process must be determined after the type of indication, respectively escalated after importance and maturity.

Next, influencing factors and the measuring points themselves are to be looked at. Whereas some measured process-related parameters just selectively influence the surrounding process and no other factors, some other measurement points are of the type that they require the measurement of additional parameters. This suggests a correlation of parameters like between pressure and temperature. These correlations can be uni- or bidirectional. Intensity of connections can differ and a various amount of parameters can be affected. Another possibility is that there is no direct correlation but that more information is needed to enable a comprehensive picture. An example for this is the temperature measurement of for flow and return flow of a heating system. When configuring the measuring concept these dependencies must be taken into account. The configuration can get arbitrarily complex, especially when dependencies cannot easily be characterized.

Similar to this challenge is the inclusion of external influencing factors. Instead of resulting from a process itself they influence the system from the outside. Relevant impacts are all parameters that influence the course or the result of the considered process. This means that each system can have its own influencing factors. External influences are parameters like climate conditions as ambient temperature or air humidity but the market situation or competitive environment can have an external impact on the process as well. This is because things like pricing pressure, legal requirements or changes in the value chain might influence the production capacity. For the measuring concept only dependencies on energy-related factors must be considered. Non-energetic factors become relevant for the generation of key figures.

Another requirement of the system is that is must be easy to adopt. The tool is supposed to support the process of project management at Envidatec. Therefore Envidatec's customers who want to implement energy management systems must be able to work with the tool without long trainings. [23] This is essential for the continual improvement process where the customer should be in the position to repeat the decision making process self-dependently. This refers to the selection of measuring points for the constantly improving measuring concept in particular.

6 Development of the Measurement Concept

Basing on the system requirements found in the previous chapter, this part describes the chosen approach to define the conceptual implementation process of the measurement concept. Figure 15 illustrates the process of finding the measuring points that shall be included in the monitoring system. The surrounding circle is supposed to clarify, that according to ISO 50001 it is a recurrent procedure for continuous change and improvement.

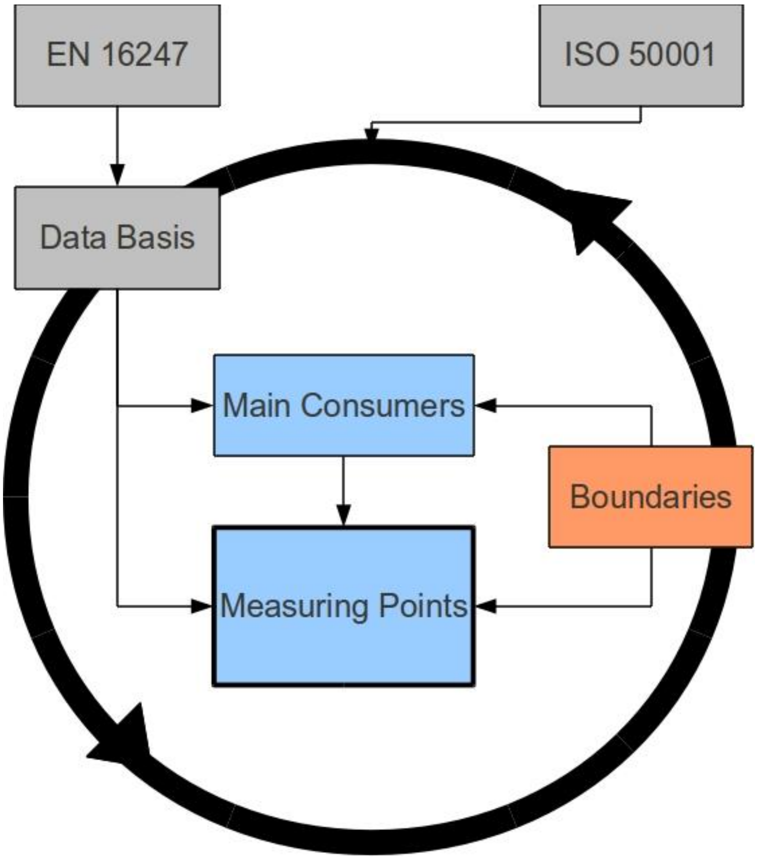


Figure 15: General process to identify measuring points

The first steps are the identification of major energy consumers and the deduction of suggested measuring points. Certain boundaries limit these processes, so that they have to be presented beforehand. As input for the selection processes a reliable data basis is required. Therefore this chapter also describes which information is needed and how a data basis can be built up best. A useful orientation is the European standard EN 16247, which describes the proceedings of diagnostic audits.

6.1 Boundaries

As already declared, every monitoring system is based on a certain amount of measuring points. It is obvious, however, that this amount is restricted, respectively converges a maximum. Accordingly, it does not make sense to constantly increase the amount of measuring points, especially the more exist already. With regard to the target of increasing energy efficiency, it is more important to identify the measuring points that belong to the energy flows with the highest potential for improvement.

Another bounding factor is the economic viability. Implementing measuring technology always induces an investment. Compared to an investment in tangible assets like new production machines or buildings the capital expenditure for measuring technology is minimal. Still, it has to be considered that the revenue resulting from a monitoring system is comparatively small. In order to gain reasonable payback periods, the initial expense for measuring equipment should not exceed a realistic saving potential over the beheld period. The reference period is set at one year. As described in chapter 3.3 Monitoring, experiences of Envidatec show that monitoring systems can reduce energy costs by around 5% as they increase the transparency of energy flows and help to avoid energy relevant misbehaviors. Consequently, the budget for investments in measurement devices is defined as 5% of the total energy costs per year. The actual costs are highly depending on the existing monitoring network. Neglecting the fact that the procedure bases on estimates and therefore precise propositions cannot be made, the targeted scenario is a payback period of one year.

Keeping in mind, that the measurement concept is part of the management cycle for continual improvement and as a result the definition of relevant and to be included measuring points is repeated annually, the boundaries needs to be adapted. This is because yearly investments of 5% of the year's overall energy costs would at some point lead to an unreasonable amount of measuring points without contributing to the increase of efficiency anymore. Respectively, the outcome of the selection process must define at which point the installation of additional measuring points is no longer advisable. In theory there are two different ways to approach this problem.

The first option is that the percentage, which limits the budget is lowered in predefined steps. The advantage is the fixed forecast of how the budget decreases and when the year "n", when the process of adjusting the measuring points is finished, will be arrived. The principle is visualized in Figure 16.

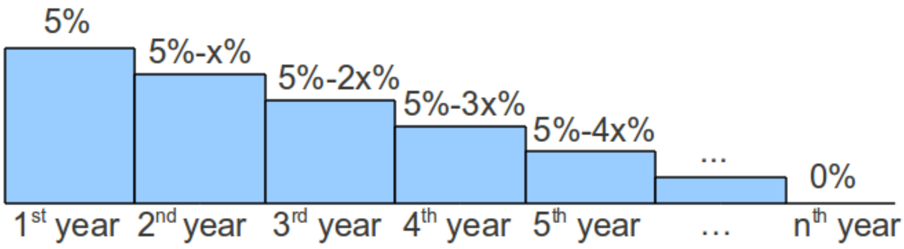


Figure 16: Adaption of the budget in predefined steps

On the other hand, this model also has some disadvantages. First, the definition of steps only is an arbitrary choice that most probably only suits a selection of organizations. This exactly describes a situation which, in the course of a standardized procedure, must be avoided. Second, the fixation of budget does not respect the actual demand. Whereas some organizations may need more meters than projected by the selection process, others may have a measurement concept after the first cycle, that already displays all important and energy relevant measuring points. Nevertheless, this option with predefined steps would then prescribe the installation of further, unnecessary measuring devices. Of course, this can be the situation after any of the cycles. The intended saving of budget would therefore lead to the unreasonable amount of meters that was to be avoided in the first place. To prevent this case, the organization concerned has no other option but to always question the practical issue of the recommendation generated by the procedure. It goes without saying that this cannot be the intention of a systematized process.

The second option is realized by an appropriate process design. The selection process has to include certain constraints, that lead to the decision, whether further measuring devices are needed or not. The constraints have to be of the type that they are deduced from the system itself. In this way, the actual customer-specific demand is represented better. For this thesis, the factor finally limiting the integration of further consumers into the monitoring system is the share of energy consumption. As will be explained in the course of this chapter, only consumers making up for 80% of the total energy consumption maximum are included in the decision-making process of whether they should be monitored or not. In this way, it is not necessary to adapt the percentage determining the budget because an amount of measuring technology, exceeding the reasonable amount required for certification reasons, is prevented in an early stage. After the limit has been reached, it does not matter if there still is a budget because there are no more consumers to select from.

As an alternative way of sensibly limiting the amount of measuring points, the energy target, which the organization aims for, could be taken as boundary. If the aspired saving rate was

2% for example, the measuring points would be adapted respectively, so that this target can be reached. For now, this option is not pursued any further because the degree of precision needed for an exact forecast of savings is too high. Instead, the energy targets are rather used to proof the effectiveness of the monitoring system.

6.2 Definition of the Current Energy Situation

According to ISO 50001 the energy baseline is a "*quantitative reference providing a basis for comparison of energy performance*" [10, p. 2]. It is essential to define this baseline in order to evaluate improvements. The energy baseline is diverted from the current energetic situation. Hence, the actual status must be analyzed. This analysis is done best with an energy audit as it is described in the European standard EN 16247. In addition to the depiction of saving potentials, another helpful output of such an energy audit is the substantial data basis that is collected during the process. In view of the target of implementing an energy and operating data monitoring system, these data serve as profound basis. In compliance with paragraph 5.3 of EN 16247, the following information should be collected where possible [53, p. 9]:

- List of energy consuming systems, processes and facilities
- Detailed characteristics of the audited object including known adjustment factors and how the organization expects to influence the consumption
- Historical data: Energy consumption; adjustment factors; relevant, connected measurements
- Internal development and occasions in the past that might have influenced the energy consumption during the documented period
- Documents of construction, operation and maintenance
- Energy audits or previous assessments in relation with energy and energy efficiency
- Actual and planned tariff or reference tariff to protect the economic confidence
- Other relevant economic data
- Status of the energy management system

In general, the data collected can either be technical information like documentation of power and consumption measurements, documentation of meter readings, load curve data provided by the energy supplier, machine lists and data sheets. Or the information can be business data like energy supply agreements, energy bills as well as operation and maintenance costs. [52, p. 25]. At the same time, relevant influencing factors like the production output, number of employees, heated area or ambient temperature should be documented. This additional information can later be needed for the determination of key figures. [54, p. 7] As will be shown in chapter 7.1 Performance Indicators key figures are essential for the assessment of processes, since they reflect the performance. Changes in efficiency will be visible in altered key figures.

In order to get a reliable data basis, the energy consumption of the past years is to collect in dependence of specific periods. A commonly used way is the documentation of each month. Where possible, at least three years should be assessed [54, p. 7] to get a better picture of what is the normal situation and to identify deviations that occurred because of an especially cold winter for example. A further more in depth analysis of the energy input should be conducted for the last complete year minimum. [54, p. 8]

Clearly defined responsibilities are another important input. This means, that in addition to the pure information it is necessary to note, where these data come from and who administers them. Otherwise after a while, it will be impossible to trace back and reproduce information.

6.3 Identification of Main Energy Consumers

As already mentioned, it is important to identify the measuring points which can contribute to increasing energy efficiency the most. In order to get to this point, it is reasonable to find the main energy consumers in a first step.

Some consumers' consumptions may not be tracked individually, yet. There it is helpful to use estimations basing on connected load and duration or degree of utilization or to perform temporary measurements. [52, p. 25]

A consumer is not a single unit perforce. It can just as well be a plant component, a complete system, a consumption group or an entire consumption area. Familiar examples are the grouping of single lamps to one consumer lighting or the collective measurement of computers and connected devices as information and communication technology. The definition of consumers depends on the organization, complexity and differentiability during the measurement. It is important to regard, that the classification must be detailed enough to identify the main consuming parts. [54, p. 8]

For the identification of these major consumers out of all consumers, a decision making process has been developed, basing on certain assessment criteria. Subsequently, it is set out which criteria were selected and explained, what they imply and how they are applied.

6.3.1 Assessment Criteria

The following assessment criteria are a selection of possible decisive factors. For the selection it was taken into consideration what best defines an important or major consumer. Shares of total energy consumption and share of total energy costs were the result. To further distinguish the different consumers, the CO_2-emissions associated with the different types of energy were selected as third assessment criterion. Another reason why this last criterion was selected is that in this way, the global energy target to reduce greenhouse gas emissions is also accommodated.

The various criteria are weighted with different factors describing their importance so that they influence the decision making process accordingly. The justification of how the weighting factors were appointed is set out as well.

6.3.1.1 Share of Total Energy Consumption

Derived from the definition of energy intensity, it is a goal to reduce the amount of energy per unit of output. It comes naturally to mind that the potential of reducing energy intensity is biggest in processes where a lot of energy is needed. Therefore, the first criterion is the share of the whole energy consumption. In order to be able defining the shares of single consumers, it is essential to know the total energy consumption as well as the energy used by the consumers in question. Whereas the total amount should always be known from annual accounts, the exact energy demand of single consumers is often unidentifiable. In these cases, the consumption must be estimated by multiplying the average load by the operating hours. The shares of total energy consumption must be calculated as the share of all energy sources combined. To simplify the process, in a first step the shares can be calculated for the different types of energy individually but then they must be weighted with the percentage the energy source is holding in comparison to the others.

To compare the different types of energy, they all have to be converted to a common unit. Suitable reference units are tons oil equivalent (TOE), Tera joule (TJ) [55] or the general unit kilowatt hour (kWh) and respective multiples [52, p. 27]. Depending on the chosen target unit, conversion factors for the different types of energy are needed. In this thesis all energies shall be converted to kWh. A corresponding list of conversion factors is shown in Table 2. For clarity reasons, the depicted factors partly are averaged values. They are sufficient for a rough estimation.

Where available, however, it is better to use the exact energy content of the used medium. This information can often be found on invoices of the energy supplier. As can be seen, for this survey, water is treated like an energy source as it contains energy in form of heat.

Table 2: Energy content of different energy sources; [56], [57, p. 13]

Type of Energy	Conversion Factor
Electricity	1 $\frac{kWh}{kWh}$
Heated Water *)	1.1612 $\frac{kWh}{Km^3}$
Biogas	9.9697 $\frac{kWh}{m^3}$
Heat/Cooling Energy	0.278 $\frac{kWh}{MJ}$
Natural Gas	9.7699 $\frac{kWh}{m^3}$
Fuel Oil	11.641 $\frac{kWh}{kg}$
Other Fuels	11.469 $\frac{kWh}{kg}$
Coal	8.191 $\frac{kWh}{kg}$

*) only valid for temperatures below 373.15 K; otherwise vaporization enthalpy and energy content of steam must be regarded

After all shares have been determined, the different consumers must be sorted. Finding an appropriate classification of this criterion is quite difficult. This is because of the variety of different energy infrastructures in the industrial sector. For example, it is understandable that the classification of a metal producing organization with two electric arc furnaces as major energy consumers, together being responsible for up to 80% of the whole energy use, needs a less finely graduated differentiation than a producing company with an assembly line consisting of a variety of many smaller machines. Thus, the defined percentages must be adapted if the use of the procedure reveals, that the chosen classification is not reasonable. The current classes can be seen in Table 3. So far, the smallest share of the whole energy consumption is up to 1% whereas the highest category is for consumers with a share of over 20%. Depending on the percentage category, the consumers are classified with a value between 1 and 5. The higher the share of the total consumption, the higher is the assigned value.

Table 3: Classification - Share of total energy consumption

Share of Total Energy Consumption	
≤ 1%	1
≤ 5%	2
≤ 10%	3
≤ 20%	4
> 20%	5

It is evident, that the amount of consumed energy is a major characteristic for the ranking of different energy consumers. To take this importance into account, the weighting factor for this criterion has been set to 2.

6.3.1.2 Share of Total Energy Costs

From an economic point of view, the decrease of energy costs is a measurable indicator of higher efficiency and a desirable outcome of an improvement process. For an organization's management a reduced energy bill is the most tangible result because it is visible directly.

For the determination of the shares of the total energy costs, it is essential to know the total costs as input value. It is obvious that an energy consumer considered a main consumer is connected with comparatively high energy costs. This is because of the higher amount of energy units that has to be bought, compared to a smaller consumer. As a result, one way to detect a major contributor is to analyze the share of total energy costs. Where exact costs cannot be allocated to the single consumers, for an estimation, the consumption determined beforehand is multiplied by the common price per energy unit.

The objective is to represent as many different organizations as possible. As already explained by means of the previous criterion, the huge variety of industrial companies with just as many different energy infrastructures must be taken into consideration. Consequently, here again the found solution cannot be but a first draft. If in the validation process of this standardized procedure it is found, that the classification does not lead to the desired variety in factors, because too many consumers belong to the same category, the percentages must be adapted accordingly. As can be seen in Table 4, the differentiation into classes is analogous to the percentages in Table 3. A share of the total energy costs below 1% is assigned with the neutral value 1, whereas a share exceeding 20% leads to the highest category 5.

In contrast to the share of total energy consumption, in this category it might occur that a consumer does not contribute directly to the total energy costs. This is the case with consumers using waste heat for example. For these consumers, Table 4 contains the classification 0.

Table 4: Classification - Share of total energy costs

Share of Total Energy Costs	
0%	0
≤ 1%	1
≤ 5%	2
≤ 10%	3
≤ 20%	4
> 20%	5

Compared to the other assessment criteria in this first process of identifying the main energy consumers, energy costs can be regarded as the most important basis of economic decision-making. Since the costs result from multiplying the consumption by the price per energy unit, the energy costs are a multiple of the consumption. Notwithstanding, the combination of these two criteria is necessary, because the rate per unit of energy varies between the different types of energy. Still, the weighting factor for the share of energy costs must be rated higher and is therefore set to 3.

6.3.1.3 CO_2-Emissions

As mentioned in the preface, the criterion classifying the consumers after their CO_2-emissions further distinguishes the different consumers from each other. It is an additional factor for more in depth evaluation. CO_2-emissions reflect the environmental impact associated with the generation and use of energy and therefore are a quality characteristic. Generally, it can be differentiated between direct and indirect CO_2-emissions. Direct emissions result from combustion processes for instance, whereas indirect emissions originate from the generation of effective energy like electricity or heat. [54, p. 8] In the indirect case, the implied CO_2-amount is dependent on the primary energy used as source for the generation. Thus, the emissions depend on the type of energy as well as on the origin. For example, it makes a difference whether electricity is produced in a coal fired plant or with a wind turbine.

For the assessment of energy consumers after their impact on the environment, they are sorted after the used medium. As most consumers convert one type of energy to another, it must be kept in mind that this criterion targets the input medium. Direct and indirect emissions are both included for this purpose. The assigned factors are summarized in Table 5. It must be kept in mind that all classifications strongly depend on the defined system boundaries taken into account for the life cycle assessment of different energy sources.

Table 5: Classification - CO_2-emissions

CO_2-Emissions	
Biogas	1
Electricity (RE)	1
Waste Heat	1
Water	1
Electricity (mix)	2
District Heat	2
Steam	2
Cooling Energy	3
Compressed Air	3
Natural Gas	3
Fuel Oil	4
Other Fuels	4
Coal	5

Electricity generated from renewable energies has the smallest impact and consequently the lowest value 1. This is because, neglecting the production of the renewable energy plants themselves, the electricity's CO_2-emissions equal zero. The same value has been assigned to biogas. This is because biogas is CO_2-neutral per definition as only vegetable substances or derivatives are allowed to be used for the production. They are considered as neutral because during fermentation plants only emit as much CO_2 as they captured beforehand. This argumentation gives rise to controversy, however. Excluding water treatment plants from the consideration, the generation of water does not lead to any CO_2-emissions either. Waste heat has the assigned value 1 although it contains indirect CO_2-emissions. This is because the waste heat is a byproduct of another consumer that already is assessed according to its CO_2-emissions. The waste heat therefore does not lead to additional CO_2-emissions but in the contrary, improves the carbon footprint because more energy is reasonably used per unit CO_2 which is emitted either way.

The next category with the value 2 is for electricity from mixed sources, district heat and steam. The electricity mix implies CO_2-emissions because partly fossil fuels are used for the generation. District heat and steam are basically heated water. To factor in the increased energy content compared to cold water, these two are ranked higher.

Cooling energy and compressed air are both classified with the value 3. Thereby, the remarkable amount of energy needed for the generation is supposed to be reflected. The same category was assigned to natural gas which is considered to have a lower impact on the environment than fuel oil or other fuels in general which got the value 4. The highest value 5 has been saved for coal. This is because by burning coal remarkable amounts of CO_2 are directly emitted.

This criterion was rated as less important than the two before. The explanation is a smaller impact on the economic viability. Except for the costs of CO_2-certificates, which apply to organizations affected by the TEHG, the reduction of emissions has no monetary effect. Consequently, the weighting factor has been set to 1.

6.3.2 Calculation

So far, the various assessment criteria for the first selection process were defined. The whole first selection process is visualized in Figure 17.

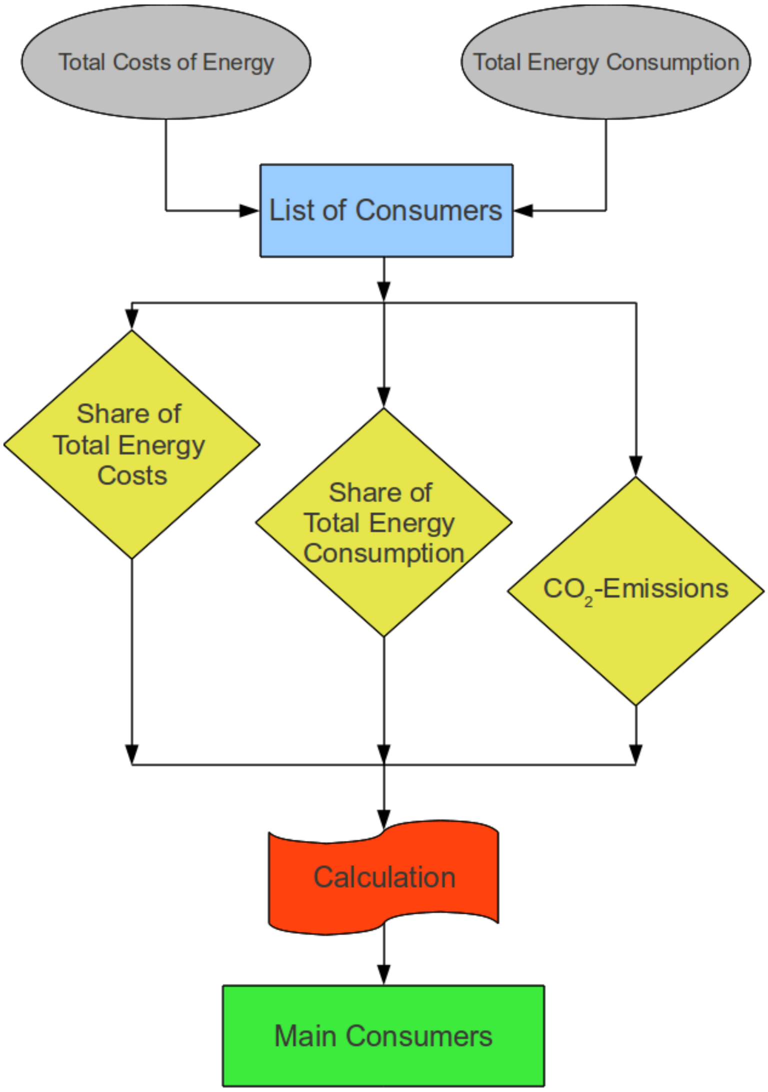


Figure 17: Flow chart of the first selection process

The total costs of energy and the total energy consumption are the needed input for further calculations. They are linked to the existing consumers or consumer groups. All consumers are evaluated with the three described assessment criteria. The weighting factors of the criteria are represented by the arrangement of the squares, so that the criterion weighted the least stands below the other ones. Each consumer can now be classified according to its properties and respective values are assigned. In order to generate the desired result – a list of the main consumers – the values have to be processed in a qualified calculation process.

In a first calculation step, all values that result from the assessment criteria are multiplied by the weighting factor of the correspondent category. Afterwards, for every consumer the weighted values are added up to a final sum. Now that each consumer has an assigned final value they can be ranked in descending order. Hence, the consumers with the highest value are on top of the list.

In a second step, the exact or estimated percentages of the criterion “share of total energy consumption” are reassigned to the consumers. Beginning on top of the list, the consumers are designated as main consumers as long as the sum of their percentages is below 80%. This limit was set, because it is a common threshold value for certification companies [58].

All consumers identified as main consumers are relayed to the second selection process, described in the adjacent section. However, it is always possible that the calculation leads to ambiguous information. It is not necessary to receive an exactly bounded result, as the second step will further sort out the consumers. Therefore, the last consumer topping the 80% limit could be transferred as well. More complicated is the decision, when the last two consumers have the same product value and just one of them can be selected. If this is the case, the composition of the final value is determining. The consumer with the highest value in the higher rated category must be taken. If this does not lead to a clear result either, an individual case-by-case decision must be made.

6.4 Identification of Measuring Points

After the first step the main energy consumers are identified. As already explained above, it most probably would exceed the budget boundary to install extensive measuring technology on all main consumers. Therefore, in a second step, the optimum measuring points shall be found. Along the lines of the first selection process, first assessment criteria were defined before the processing of the resulting values leads to a decision about which measuring points should be installed. Here, the fact that there are reciprocal effects between processes must not be ignored. Information about operating and energy data needs to be gathered in order to permit reliable statements about a process's situation. It might also be necessary to retrieve data that do not result from the process itself but that have an influence on it. Ambient temperature is an example for that. The different varieties of dependence have already been lined out in the previous chapter. How this necessity is regarded and integrated in the procedure is described in the course of this subchapter.

6.4.1 Assessment Criteria

The decision for the assessment criteria described below, bases on the preliminary thoughts outlined in chapter 5.3.2 Requirements for the System Configuration. It was taken into consideration which factors might have an impact on the effectiveness resulting from the measuring point. Next to measurability itself, the saving potential, costs for energy and for the measuring technology as well as process dynamics were found to influence the ability to contribute to increasing energy efficiency under the prerequisite of the measure's profitability.

Additionally, operating hours and the facilities' age has been identified as important when it comes to judge a measuring point's contribution to decrease energy intensity. An overview of the selected criteria with the budget as limiting factor is given by Figure 18.

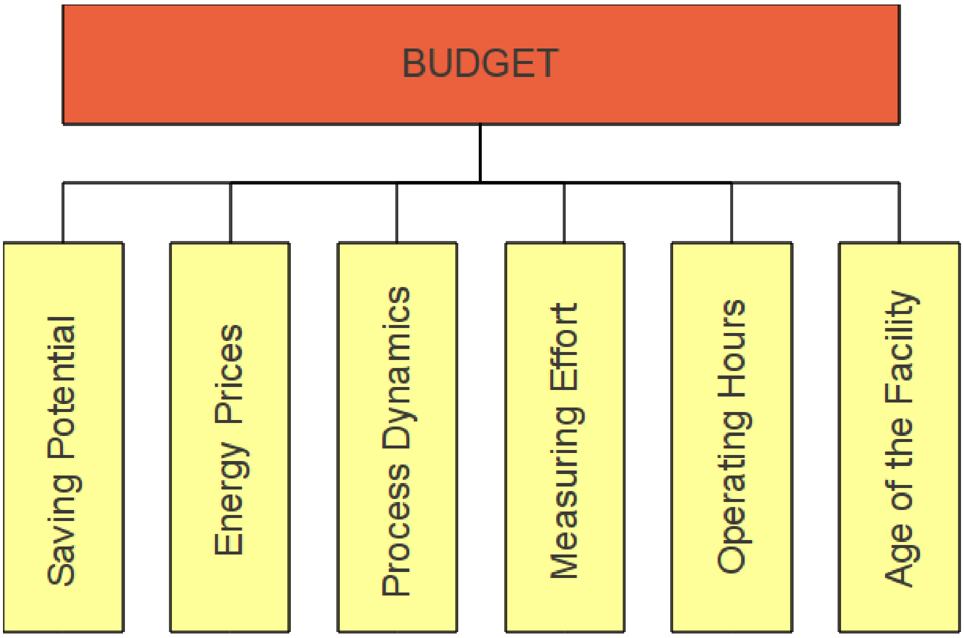


Figure 18: Assessment criteria for the identification of measuring points

Along the lines of the first selection process, the various criteria are weighted with different factors reflecting their importance so that they influence the decision making process accordingly.

6.4.1.1 Saving Potential

It is self-explanatory that a system cannot lead to savings, when there is no potential for improvement. This saving potential rather depends on the way of energy application than on the type of energy itself. This becomes more evident, looking at an example. Air by itself has no potential for efficiency because it generally always has the same properties. On the contrary, for a ventilation system, which is a typical application for air, a specific saving potential can be identified. One option to exhaust this potential could be a modulation of the operating mode.

For the allocation of values, different applications were selected and ranked after their saving potential, identified according to general experiences. It is not important to define exact saving percentages, because only the potential in comparison to the other application types matters. The rating was undertaken on the basis of a presentation held by Dietmar Gründig in the course of a conference hosted by the German Energy Agency dena in 2012 [59, p. 5]. The results were compared to and supplemented with Envidatec's company-own experiences. The highest saving potential has been assigned to lighting. This is because of often obsolete technology and no control of light intensity or need in accordance to the requirements of the users. The absolute savings in the lighting sector might not be as high as in other categories due to less installed capacity but possible relative savings of up to 70% justify the highest categorization. In comparison, the high value for compressed air results from the high power consumption of compressor stations. Here the savings mostly arise due to improved control, minimization of no-load losses and leakage checks. On the other hand, the low classification of information technology (IT) for instance leads back to the fact, that most companies usually use quite up-to-date technology with small room for improvement.

Table 6: Classification - Saving potential

Saving Potential	
No Potential	0
IT	1
Ventilation System	1
Cooling System	2
Heat Supply	2
Drive	3
Furnace	3
Compressed Air	4
Lighting	5

Obviously, the saving potential of appliances changes over the years. The potential of older assets increases because the spread to modern technologies grows. On the other hand, facilities, where saving potentials were already exhausted, must not be evaluated with the same value as the same type of asset or application without undertaken improvements. Since this selection procedure is part of a continual improvement process, these changes must be taken into consideration. Increased saving potentials are indicated by growing age of the facility. As the age is a separate assessment criterion and therefore influences the decision-making process independently of the saving potential, another way of changing the saving potential had to be found. This is underlined by the inability of being effective for reduced saving potentials, originating from technological or organizational changes made to the facility. The current solution for this challenge gives the user the option to manually inscribe a value between 1 and 5 after personal assessment of the facility's condition.

In case the assessment reveals no potential for increasing the efficiency of a certain asset at all, the procedure allows for zeroing the respective value. As will become clear during the calculation process later, the saving potential is classified as criterion for exclusion.

Not only because of this classification, is this first criterion the most important one, but also because exhausting the saving potential is the best way to increase efficiency. Therefore, this criterion can have the highest contribution to fulfill this procedure's target. To take account of the influence, the weighting factor has been initialized at 3.

6.4.1.2 Energy Prices

The criterion of energy prices must be distinguished from the similar criterion in 6.3.1.2 Share of Total Energy Costs of the first selection process. There, the focus was on the percentage compared to other consumers whereas the evaluation in this paragraph only depends on the energy type. The categorization is carried out after the rate per reference energy unit that has to be paid. Here, the actually needed amount of energy is irrelevant. Exact prices for the allocation per unit of medium are unnecessary because only the relative comparison is important for the classification. It must be kept in mind for the future that the ranking might change due to increasing prices for certain energy sources.

As can be seen in Table 7, compressed air has been identified as the most expensive medium. On the other hand, it is considered that water can be allocated with the lowest price per base unit. The same is true for energy resulting from company-owned self-generation plants.

Table 7: Classification - Energy prices

Energy Prices	
Self-Generation	1
Water	1
Fuels	2
Heat	2
Cooling Energy	3
Electricity	4
Compressed Air	5

For the definition of a weighting factor, the importance of this criterion must be held against the other criteria. Since energy prices in combination with consumption stand for costs, this criterion has an impact on the economic valuation. It must be considered as a hard factor which is why the weighting factor has been set to 2.

6.4.1.3 Process Dynamics

The term process dynamics describes the stability of a process. Some processes are hardly influenced by any surrounding factors and are also constant in their process parameters. In stable processes changes in parameters usually do not occur but in the long run. Consequently, these processes do not need to be surveyed as closely as unstable processes. The influence and influencing abilities on unstable processes are much higher because the detection of instabilities and deviations out of the normal process range is more probable. In addition, these processes react faster to regulating interventions. The premise is background knowledge about the process to differ normal self-regulating deviations from exceptional ones that require intervention.

The explained differentiation between the two simple varieties of process dynamics is represented in Table 8. The argumentation leads to the higher classification of unstable processes.

Table 8: Classification - Process dynamics

Process Dynamics	
Stable	1
Unstable	2

Compared to other criteria, process dynamics only influence the measurability and not the possibility to decrease energy efficiency itself. This relatively small impact characterizes process dynamics as soft criterion. Consequently, the weighting factor has been set to 1.

6.4.1.4 Measuring Effort

The term measuring effort is ambiguous. It describes the expenses for the measuring technology as well as the work it takes to install the meters. These two aspects are commonly related because the complexity of a measuring system goes along with the price. Another point that underlines the combination of these parts in one criterion is the fact that the invoicing normally happens together as well. It is obvious that a meter gets more expensive, the more effort it takes for installation.

An example is a non-ultrasonic flow meter, which requires a drained pipe before the measuring device can be inserted. In addition to the effort resulting from the drainage, it might lead to the situation that even the production has to be interrupted for the installation period. It is comprehensible, that the combination of all these factors by comparison leads to more effort than a thermal detector which can be attached from the outside to the device that is to be measured.

The variety of available measurement options is large. This does not count for different measurable parameters only, but also for the assortment of diverse measuring principles all leading to differing technical arrangements. This plurality cannot be fully covered within this approach. Therefore, the assessment is carried out focusing on the actual objective of the measurement. In a system aimed for reducing energy, first and foremost the energy content within an energy flow is to be determined. An exception is water, where the pure amount is often more interesting rather than the energy content. With all measurements the definite way of realization is irrelevant for a first comparative evaluation. The classification follows a general understanding of the effort needed for the energy measurement contained in different energy media. Of course, this ranking is based on the prerequisite of similar surrounding conditions and installed technical standards. Then, it is understandable that the effort increases with rising system pressure. The highest pressure is expected in compressed air pipelines followed by steam. The other pipe-bound media, water and all kinds of fuels have been sorted in the medium range. All other energy sources are unpressurized. Out of these, the needed effort for finding out the energy content of heat and cooling energy has been ranked second to last. Consequently, electricity measurements are considered to cause the lowest effort. The findings are summarized in Table 9. For the assessment of a consumer the measuring target has to be determined before the classification is applied. Thus, for each consumer it can be chosen which energy flow shall be analyzed. A compressor station, for instance, can be optimized for the electricity input or for the amount of produced compressed air. For a heating appliance it might be reasonable to optimize the heat flow which would require the measurement of both, outgoing and incoming energy flow. The decision, however, can lead to different classifications.

Table 9: Classification - Measuring effort

Measuring Effort	
Electricity (power/energy)	1
Heat (energy)	2
Cooling Energy (energy)	2
Water (volume flow)	3
Water (energy)	3
Fuel (energy)	3
Steam (energy)	4
Compressed Air (energy)	5

The process developed in the course of this thesis claims a high degree of completeness in order to be suitable for as many use cases as possible. Nevertheless, against the background of standardization, special applications cannot be represented, which is why this assessment criterion needs the option to inscribe classification values between 1 and 5 manually. This also is an opportunity for use cases not included in the current list. In a similar way, this procedure has already been applied to the criterion 6.4.1.1 Saving Potential.

The expenses for measuring technology are not negligible. This goes along with the required measuring accuracy. After a guideline for energy management systems published by the GUTcertifizierungsgesellschaft für Managementsysteme mbH (GUTcert) 75% of the accumulated energy consumption must be measured with an accuracy of 98 to 98.5%. The measurement of further 20% of the total energy consumption only foresees deviations that do not exceed 5%. For the remaining 5% of total energy consumption GUTcert accepts reasonably estimated values as in most cases the measurement effort would go beyond the resulting benefit. [54, p. 10] Considering the fact that all consumers included in this second selection process make up for around 80% of the total energy consumption (cf. 6.3.2 Calculation), the measurements require highly significant precision. The quality of measurements is also important for the detectability of savings. The fault tolerance always has to be below the possible saving potential; otherwise actual savings cannot be distinguished from simple measurement errors. [23]

As the above argumentation shows, measuring effort is an economic criterion. Still, it must be rated lower than the saving potential, so the weighting factor has been set to 2.

6.4.1.5 Operating Hours

The specification of operating hours allows the extract of valuable information. For instance, it is possible to draw conclusions about the reliability due to potential wear. Another opportunity lies in the analysis of simultaneity factors. More primal is the understanding that longer operating hours result in higher consumption and they represent a high need of availability. The more often a consumer is used, the more significant and reasonable is the assessment of potentials for optimization. For some industries, there even is an economic value of operating hours, because they are invoiced accordingly. Higher operating hours can indicate a more evenly distributed energy purchase which in some cases might be remunerated by the energy provider.

It is generally known that one year consists of about 8760 hours. Table 10 shows the subdivision of these hours into partitions. The highest value 6 applies to full time usage. In order to fall in the lowest category, an application must not be running but less than one hour per day. Of course, the accumulation of operating hours counts instead of the temporal distribution. Therefore, a facility running for two hours every other day of the year is classified in the same category as an application operating 12 hours but just for one month in total.

Table 10: Classification - Operating hours

Operating Hours	
< 300	1
300 - 999	2
1000 - 3999	3
4000 - 5999	4
6000 - 8499	5
8500 - 8760	6

In this process, operating hours are not characterized as hard criterion. They have rather been included for increasing the variety of results for the assessed consumers. Incidentally the decision-making process is enhanced. To not put too much weight to this criterion, the neutral weighting factor 1 has been assigned.

6.4.1.6 Age of the Facility

It has already been mentioned, that the age of an energy consumer often is an indicator for the efficiency. Technological progress constantly improves performance and economical consumption figures. Therefore, newer facilities generally are more efficient perforce. Another aspect is the wear of older appliances. Devices are perished by steady and excessive use as well as the exposure to sometimes adverse operating conditions irrespective consequent maintenance. Consequently, the age also is an indicator for reliability respectively the probability of failure.

The classes set for this criterion can be seen in Table 11. The value assigned increases with the years. It is assumed that the impact on efficiency is not remarkably changing for appliances older than 15 years. As a result, this group has the highest value 5. The lowest value 1 belongs to consumers which have been put into operation less than one year ago.

Table 11: Classification - Age of the facility

Age of the Facililty	
≤ 1 a	1
> 1 - 3 a	2
> 3 - 8 a	3
> 8 - 15 a	4
> 15 a	5

Similar to the criterion 6.4.1.5 Operating Hours the age is considered as soft criterion. It is used to diversify the properties of the main consumers but not to influence the decision-making process all too much. Consequently, this criterion also has received the neutral weighting factor 1.

6.4.2 Calculation

The input for the second selection process is the list of main consumers identified in the first step. Analogous to the first selection process, all main consumers receive a certain value per assessment criterion representing their individual properties. Figure 19 gives an overview of the whole procedure. Again, the weighting factors allocated to the different criteria are reflected by the position in the schematic diagram. Accordingly, the superiority of saving potentials is evident from the upper most position compared to the other criteria.

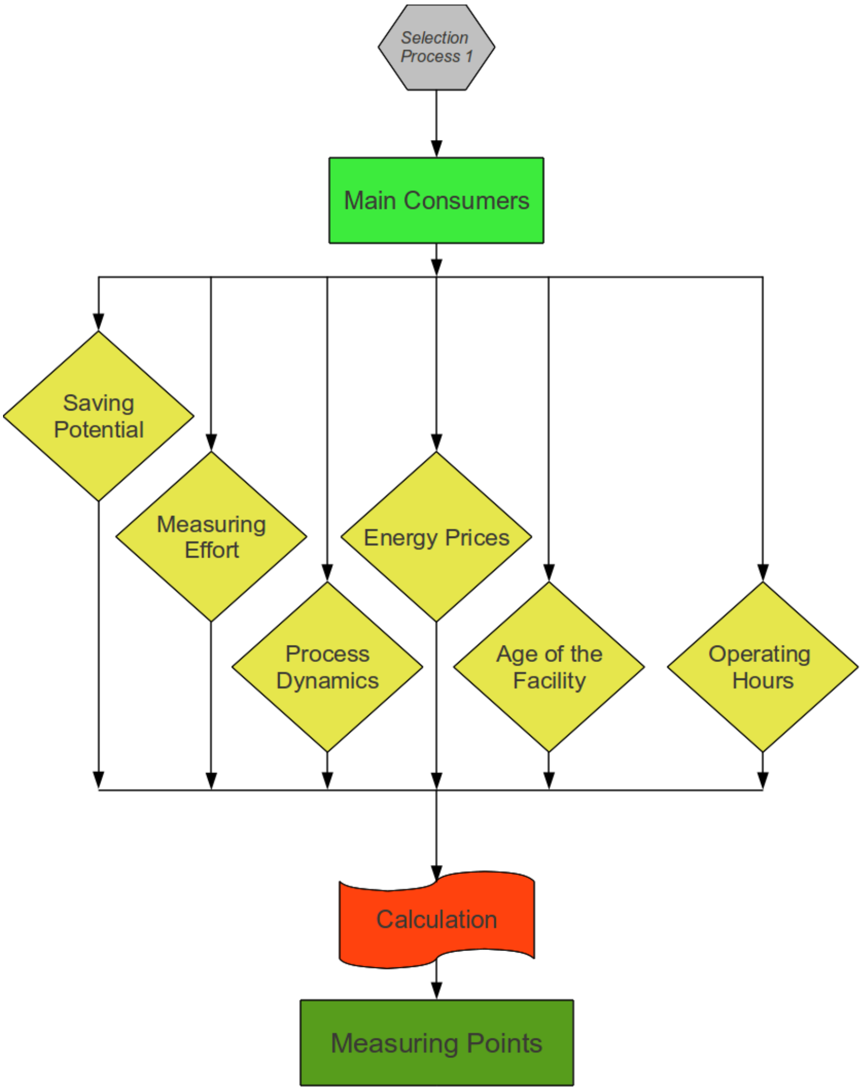


Figure 19: Flow chart of the second selection process

After all single values have been assigned to the different consumers a final value has to be calculated. The target is to receive a founded ranking of the main consumers after their ability to contribute to the increase of energy efficiency. The method of calculation of final values is the same as the one described in the first selection process. All single values are multiplied by the respective weighting factors and added up to the final value. As this second process contains more different assessment criteria, it is to be expected that a reasonable diversity of results can be reached. The ranking is made by sorting the final values in descending order. Thus, the consumer with the highest value is the one with the highest potential and therefore the most recommended one to be monitored.

This ranking alone is not sufficient for the final decision of whether this consumer should be monitored or not. All the more, because some of the consumers might be monitored already.

In the second year of applying this procedure at the latest, there will be existing measuring technology. Other explanations are the limited budget or personnel preferences of the responsible person.

The first reason is easily excluded by a yes-no query. The indication in a checklist leads to the exclusion of already monitored measuring points. Not monitored consumers so automatically are put further up the list but still in ranking order according to their final values. This option has been preferred to the alternative of not including already existing measuring points into the whole process from the first, because in this way, when all consumers are regarded, it is easier to calculate shares of energy costs and consumption. Furthermore, the observation of all consumers gives the chance of an overall assessment and comparison of monitored against unmonitored consumers. Another benefit of this option is that the consumers have to be written into the list just once and in the following years only the respective properties have to be adapted.

After distinguishing monitored from unobserved consumers, costs for installing the required measuring technology must be estimated. Here, the user has the option to respect personnel preferences as it is possible to determine consumers that shall be excluded. Additionally, this is where dependencies of measuring points have to be regarded. For example, in the case of a heater, temperature sensors are needed and the energy content of both flow and return flow are of interest. Maybe even a heat meter at the associated heat sink is essential in order to be able to gain useful information for the evaluation of the operation of the heater. These additional expenses must be considered for the allocation of costs to consumers. The assignment of costs is necessary for checking the budget. Costs for control technology are to be spread over the affected consumers. Beginning on top of the remaining ranking list it is recommended to install measuring technology up to the point where the budgetary limit is reached. Decreasing energy costs as result from increased efficiency lead to a yearly decreasing budget for new installations.

Consumers that are declined remain in the list of all consumers together with the rest. But in the subsequent years, there are more already monitored consumers and additionally the properties might change so that consumers declined in one year might be further up the list in the next year. The end of the process is reached, when all consumers of the second selection process are monitored. Considering the decision criterion of the first selection process, which constitutes that only consumers responsible for up to 80% of the total energy consumption are transferred to the second sub-process, the end of the continuous improvement process also means, that the for certification reasons required amount of consumers is monitored.

7 Data Processing

Up to this point, the standardized monitoring system mostly consists of the data acquisition only. This chapter now describes the analysis and processing of the data coming into the system. This is the part where additional processes derived from energy controlling systems are taken into account. First, universally valid performance indicators are defined. Then, the difference between alarming and reporting is explained. The last subchapter is for defining documentation standards as basis for proving the effectiveness of the monitoring system. For all mentioned aspects it must be kept in mind, that the standardization can be applied to an initial core as basis for further improvement only. Final designs are too different between companies other than that they could be generalized.

7.1 Performance Indicators

It has already been mentioned that key figures are important performance indicators. For the calculation energy and company-related data are often combined. With defining a baseline value for each figure, it is possible to track changes in performance. Here, it must be paid attention to whether the reason of improved performance really is increasing energy efficiency. The significance of Energy Performance Indicators (EnPI) often just appears in comparisons. This means the benchmarking against comparable organizations or processes as well as of one process against the same time period in past months or years. [27, pp. 12-13]

Exact EnPI are very complex. They must be adjusted to various unalterable interfering conditions that sometimes are hard to predict or even harder to calculate. Examples of these influencing conditions are weather or raw material quality. [23] Other factors complicating the definition of EnPI are inconsistent production processes. There might be more than one consumption driver of an energy source like the natural gas production or weather in the case of heat. Furthermore, the product mixture might change or the output of one product can depend on another. In the latter case, if there are delays in the upstream process chain, the EnPI of the depending product deteriorates as well although there is no chance of influencing the production process otherwise. EnPI can also be changed as result of major system updates or changes in operation. After these occurrences, it is necessary to evaluate if the baseline EnPI values are still suitable or if they need to be adapted. [11, p. 22]

The idea for this thesis is to define initial basic indicators that can be applied to all kinds of industrial organizations. For the individual usage these generalized EnPI must be adapted over the years when more experience leads to a better understanding of relevant influencing factors. As orientation for the definition serves a practical guideline for energy management systems according to ISO 50001 published by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and the Federal Environment Agency (UBA) in the year 2012. The following Table 12 summarizes the selected EnPI.

Table 12: List of basic energy performance indicators

Energy Performance Indicator	Description	Unit
Specific Energy Consumption	$\frac{Total\ Energy\ Consumption}{Production\ Output}$	$\frac{kWh}{PU}$
Specific Energy Costs	$\frac{Total\ Energy\ Costs}{Total\ Production\ Costs}$	%
Industry-Typical EnPI	$\frac{Total\ Energy\ Consumption}{Turnover}$	$\frac{kWh}{€}$
Shares of Energy Sources	$\frac{Consumption\ per\ Energy\ Source}{Total\ Energy\ Consumption}$	%
Specific Costs of Energy Sources	$\frac{Costs\ per\ Energy\ Source}{Consumption\ per\ Energy\ Source}$	$\frac{€}{kWh}$

In order to calculate these EnPI the data gathered in the run-up to the implementation of the monitoring system are needed. The baseline values are to be calculated with the energy and operational data before any energy efficiency measures have been initiated. This is the only way of following up on the development of performance and to distinguish progress from regression. This is because without knowing the initial position it is impossible to define energy targets.

7.2 Alarming

During normal operation it is always possible that unexpected behaviors occur. These occurrences generally indicate the misbehavior of a system. It is important that irregularities are detected as fast as possible in order to avoid long periods of malfunctioning. Of course, it must be differentiated between real failures and momentary deviations which do not require corrective actions. Systems vary in their dynamics and so is the time period, which elapses before a deviation is detected and recognized as misbehavior. It is typical for highly dynamic systems to sometimes overshoot and then stabilize by themselves whereas deviations in slower-acting systems generally indicate a disorder right away. In turn, the more dynamic a system, the faster it does respond to corrective intervention as well. The objective of an alarming system is to recognize any misbehavior and where necessary to alert the person in charge with information on the triggered alarm. Subsequent to the raise of an alarm, corrective actions can be initiated. Hence, alarming provides a useful supplement to on-site displays, where misbehaviors can be detected through regular checks only. An automated alarming is the best option to detect deviations in time and therefore to increase system efficiency and minimize costs for undetected wastes of energy. [34, pp. 13-14]

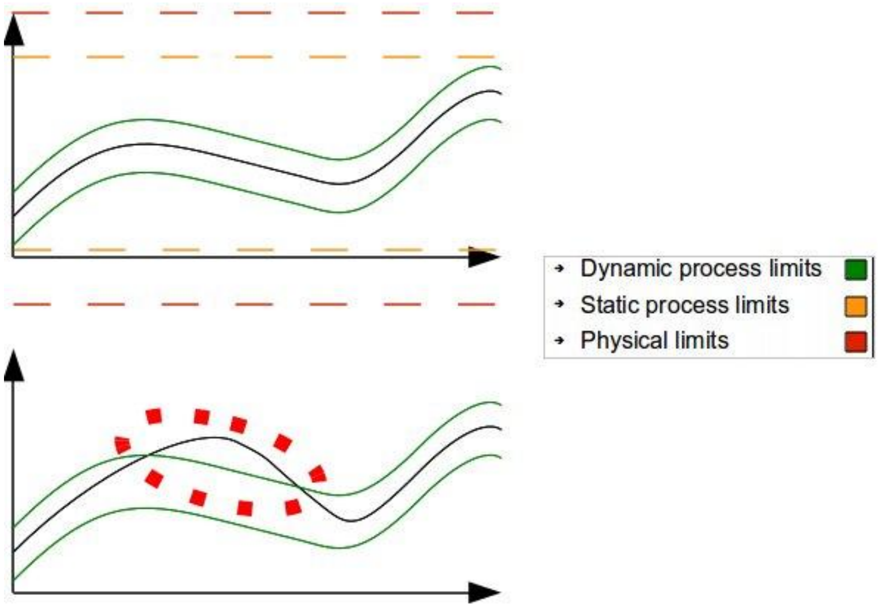


Figure 20: Types of alarming; [20, p. 18]

There are several different types of alarms respectively different limits that can be exceeded and in consequence cause the raise of an alarm. They are visualized in Figure 20. If an alarm indicates the violation of physical limits then the values detected are physically impossible like a temperature below 0 K for instance. These physical limits are defined independently of the system behavior. This kind of alarm can only be raised due to a measuring error caused by the sensor system or as result of a mistake in the data communication process leading to erroneous data files. Static process limits describe physically possible but in context of a certain system improbable process conditions. They are independent of the dynamic process behavior as well and stand for a certain value that is not expected to be exceeded. Example could be a voltage of 10 kV for a low-voltage application or a fix water consumption limit of 5 m³ per day. This type of alarm occurs due to increased consumption in case of leakages or because of measurement errors. Dynamic process limits then describe a defined range around the regular process condition. Deviations off the limits of usual behavior raise an alarm of this type. In contrast to static limits the value showing dynamic deviations is not fixed. It can be an indication for a forgotten light switch for example which would increase the respective electricity consumption of a period compared to the previous evaluation period.

7.3 Reporting

In comparison to notifications raised by alarms, reports are created periodically and without explicit trigger. The objective of reports is to summarize the most important facts about the past period. The time interval between two reports is optional but common periods would be weekly, monthly or yearly reports. The information contained in reports can be miscellaneous, depending on personnel preferences for which aspects need particular attention. In context of energy monitoring systems this is information on energy related data almost exclusively. With the help of recurrent reports it is possible to identify short- and long-term developments and trends. For the report creation it is reasonable to design a template which only needs to be filled in with data. This ensures a consistent layout for every report. In case, the reporting is supported by energy management software, the reports are generated automatically in digital form. Ideally, the documents are sent directly to the responsible person via email or a comparable electronic communication method.

With regard to a standardized energy management system, reports probably are the output that can be generalized best. Although every company might have its personnel concept of what must be included, an initial basic template with essential and universal functions can serve as starting point for individual adaptations. The recommendation is to design a monthly and a yearly report template for automated generation. In combination with a proper alarming function, shorter periods are merely unnecessary. A basic function of the monthly report is the comparison of a certain value against the same value in the last month. The yearly report analogously visualizes this value compared to the same value in the same month a year ago. This goes along with the indication of an average value and overall trends. Exemplary values are consumption data and costs. To increase the general readability of the reports, where possible, a graphical display of values is preferable to plain numbers. Moreover, the reports should not only show the values but also intercorrelate them to each other for further analyses. The selected basic function for this purpose is the distribution of the different energy sources over total energy costs and consumption in a pie chart. Other information that has been considered important is the level of achievement of the energy targets that a company must individually predefine as well as the calculated EnPI. The last function is to display the points in time with the minimum and the maximum load for each energy source.

7.4 Proof of Effectiveness

The proof of effectiveness completes the cycle of continual improvement. Since the objective of monitoring systems is the increase of energy efficiency it must be kept track of the effect certain measures have had on it. It can be distinguished between the effectiveness of corrective actions taken as response to alarms and the virtue of the monitoring system in general. The latter is measured by the achievement of predefined energy-related and financial targets, which can be tracked with the reporting function. Another hint of proven effectiveness is a positive development of performance indicators. All targets need to be measurable in order to assess the level of achievement and to prove the final fulfillment. Common energy targets are a certain percentage or nominal value of cost reduction or reduced energy consumption. Alternatively, it can be aimed for improving the proportionality between costs and consumption. To prove the effectiveness of interventions after an alarming occurrence, it is necessary to keep observing the deviated value and to check whether or not the properties normalize. It might be reasonable for statistical reasons to document the time it took to stabilize the misbehavior.

The documentation of alarming events is an example only, because clear and well-structured documentation is a general need. Otherwise, it is impossible to review and comprehend developments. Universal naming of documents and organized storage simplify the recovery of older documents. For responsible persons the access to documents must be given at any time. Of course, this requires that responsibilities are clearly defined.

Another aspect that needs checking is the compliance with legal requirements. This is a prescription of the standard ISO 50001. For example, for an energy intensive company in Germany it has to be secured that the target values for the reduction of energy intensity are achieved. It has already been described in chapter 4.3.1 Germany that failing the energy targets can lead to the denial of tax benefits. It therefore is highly recommended to keep a register of affecting legal requirements up-to-date at all times.

8 Computer-Aided Realization

In the previous chapters it has been described how a system must be built in order to comply with the defined requirements. This chapter now describes the technical implementation in form of software. First, the system model, which has been designed within a spreadsheet program, is presented including instructions for use. The second software needed for the computer-aided realization is Envidatec's JEVis system. It is demonstrated which components of the software are useful for supporting the monitoring system.

8.1 Spreadsheet Program

The first sheet of the spreadsheet program file contains a manual for the following algorithms. It is important to remember that not all cells are writable. Cells that can or must be filled with information have a yellow background color. Cells with an underlying drop-down menu are colored in gray. All other cells cannot be selected in order to prevent accidental changes to formulas or cell references. The actual system process starts with the Input-sheet seen in Figure 21. All data seen in the illustrative pictures of this chapter are completely arbitrary.

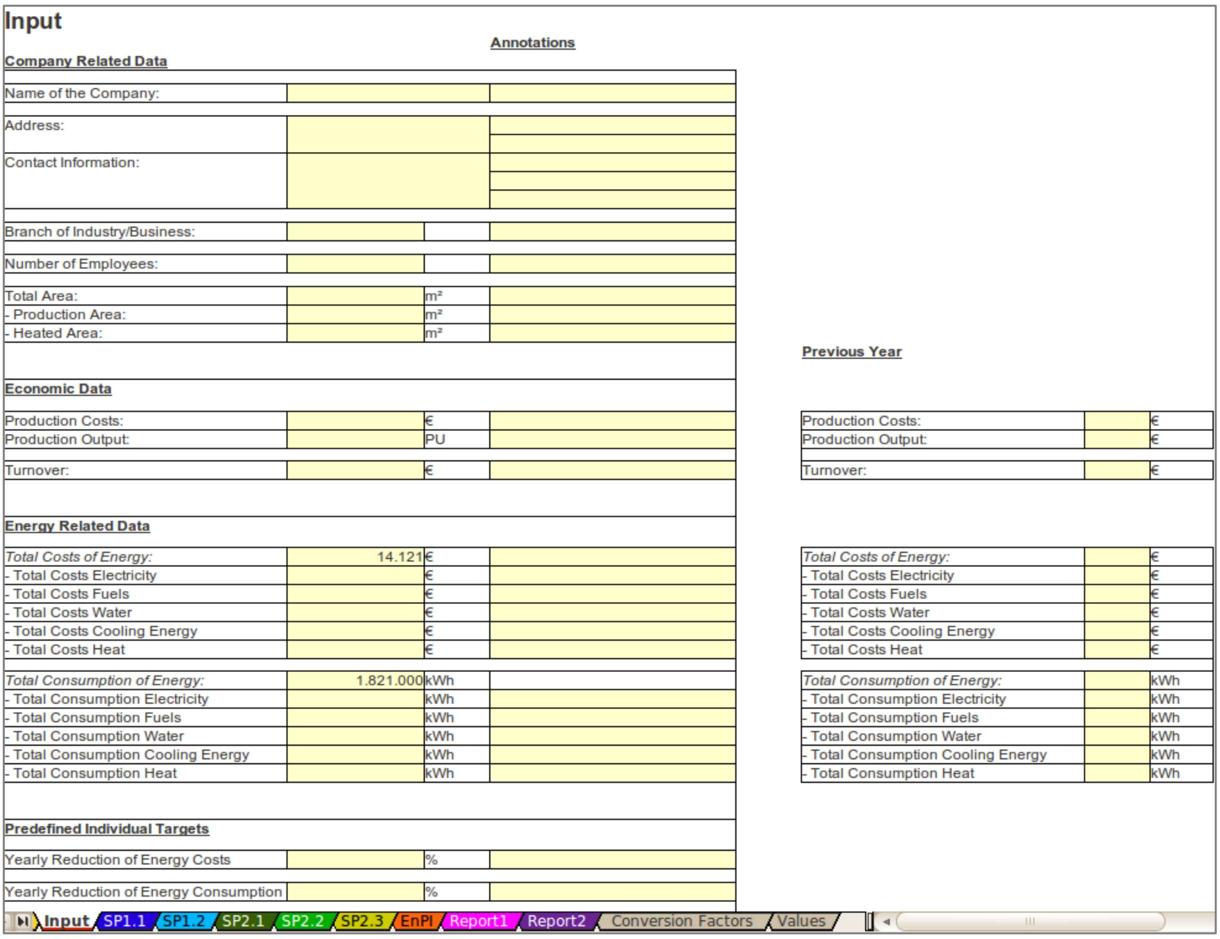


Figure 21: Spreadsheet document: Input

Possible input is information on the company like the name, address, contacts, branch of industry, number of employees and the covered area of the considered company site. These data are merely needed to assign the results to a company or to have a contact person in case of unclear entries. To avoid uncertainties from the beginning it might be useful to make annotations where necessary. Economic data like the production costs or the turnover are needed for the calculation of EnPIs later and thus should be filled in accurately. The indication of energy targets is needed to check the effectiveness of the monitoring system. In order to identify main consumers and to be able to recommend measuring points it is essential that the cells with energy related data contain information. This information is often available on energy bills. Costs and consumption of different energy sources are to be filled in separately; the document accumulates them automatically. To add up all different kinds of consumption to a total amount, all values must be inserted in kWh. Some energy sources therefore might need to be converted from other units. The sheet Conversion Factors helps with standard conversions. As can be seen in Figure 22 the amounts in m³ respectively kg only need to be entered into the yellow-colored cells and they are converted automatically. In the case of (hot) water, it must be paid attention to the fact that the output unit is kWh/K. To receive the amount in kWh this value must still be multiplied by the average water temperature in K. Of course, the automatic conversion only works if the original unit does not differ from the one indicated in the table. Otherwise, the conversion has to be done manually.

Energy Conversion

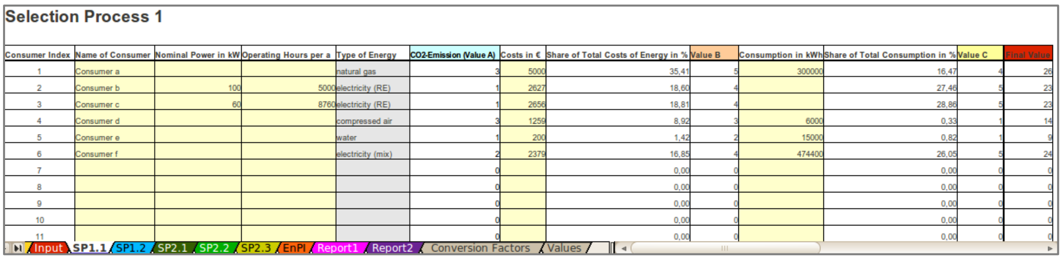
Type of Energy	Factor	Conversion from		to	
electricity	3600 kJ/kWh = 1 kWh/kWh		kWh	0	kWh
biogas	35888 kJ/m³ = 9,9697 kWh/m³		m³	0	kWh
natural gas	35169 kJ/m³ = 9,7699 kWh/m³		m³	0	kWh
coal	29484 kJ/kg = 8,191 kWh/kg		kg	0	kWh
fuel oil	41903 kJ/kg = 11,641 kWh/kg		kg	0	kWh
other fuels	41285 kJ/kg = 11,469 kWh/kg		kg	0	kWh
(hot) water	4180 kJ/(K*m³) = 1,1612 kWh/(K*m³)		m³	0	kWh/K

Other Conversions
1 J = 1 Ws
1 kJ = 0.2778 Wh
1 MJ = 0.2778 kWh
1 GJ = 0.2778 MWh = 0.02388 toe
1 kWh = 3,600,000 J = 3,600 kJ = 3.6 MJ
1 MWh = 3.6 GJ = 0.086 toe
1 toe (Tonne Oil Equivalent) = 11.63 MWh = 41.868 GJ

Input / SP1.1 / SP1.2 / SP2.1 / SP2.2 / SP2.3 / EnPI / Report1 / Report2 / Conversion Factors / Values

Figure 22: Spreadsheet document: Energy Conversion

After all necessary information has been declared, the user can continue with the first sheet of the first selection process seen in Figure 23. All relevant consumers must be listed in the second column. The corresponding nominal power and operating hours must only be indicated for the calculation of an estimated consumption value in case the actual consumption is unknown. By selecting an energy type from the drop-down menu in the gray column, the value for CO_2-emissions is assigned. Next, the consumer-related costs and consumption must be indicated where possible. If the specific costs are unknown, they can be calculated as share of the total costs of the corresponding energy source according to its share of respective consumption. The shares of total energy costs and total consumption are calculated automatically as well as the assignment of resulting values. All values are adopted as described in 6.3 Identification of Main Energy Consumers. The final values for all consumers appear in the last column. Final values are also generated if not all three categories are clarified but the significance of the final value naturally increases the more particulars are furnished.



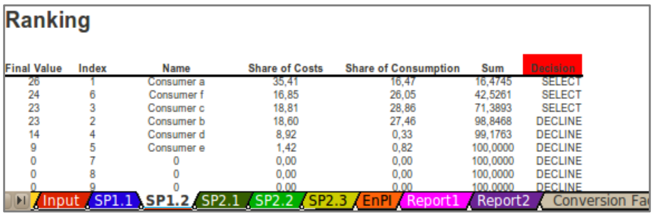
Selection Process 1

Consumer Index	Name of Consumer	Nominal Power in kW	Operating Hours per a	Type of Energy	CO2-Emission (Value A)	Costs in €	Share of Total Costs of Energy in %	Value B	Consumption in kWh	Share of Total Consumption in %	Value C	Final Value
1	Consumer a			natural gas	3	5000	35,41	5	300000	16,47	4	26
2	Consumer b	100	5000	electricity (RE)	1	2627	18,60	4		27,46	5	23
3	Consumer c	60	8760	electricity (RE)	1	2656	18,81	4		28,86	5	23
4	Consumer d			compressed air	3	1259	8,92	3	6000	0,33	1	14
5	Consumer e			water	1	200	1,42	2	15000	0,82	1	9
6	Consumer f			electricity (mix)	2	2379	16,85	4	474400	26,05	5	24
7					0		0,00	0		0,00	0	0
8					0		0,00	0		0,00	0	0
9					0		0,00	0		0,00	0	0
10					0		0,00	0		0,00	0	0
11					0		0,00	0		0,00	0	0

Input SP1.1 SP1.2 SP2.1 SP2.2 SP2.3 EnPI Report1 Report2 Conversion Factors Values

Figure 23: Spreadsheet document: Selection Process 1.1

The final values are transferred to the second sheet of the first selection process. To keep track of which consumer is meant by which final value, the name and index are transferred as well. The index simplifies the retrieve of consumers when there are more consumers than in the shown example. The ranking sheet can be seen in Figure 24. In addition to the final value, the share of costs and share of consumption are indicated as decision basis for the incident of identical final values. The ranking does not work automatically. The data must be sorted in descending order with the final value as first priority. Second sorting priority is the share of costs. If this still does not lead to a clear ranking, the share of consumption is the third criterion. The last column entitled with Decision indicates whether the consumer is considered a main consumer or not.



Ranking

Final Value	Index	Name	Share of Costs	Share of Consumption	Sum	Decision
26	1	Consumer a	35,41	16,47	16,4745	SELECT
24	6	Consumer f	16,85	26,05	42,5261	SELECT
23	3	Consumer c	18,81	28,86	71,3893	SELECT
23	2	Consumer b	18,60	27,46	98,8468	DECLINE
14	4	Consumer d	8,92	0,33	99,1763	DECLINE
9	5	Consumer e	1,42	0,82	100,0000	DECLINE
0	7	0	0,00	0,00	100,0000	DECLINE
0	8	0	0,00	0,00	100,0000	DECLINE
0	9	0	0,00	0,00	100,0000	DECLINE

Input SP1.1 SP1.2 SP2.1 SP2.2 SP2.3 EnPI Report1 Report2 Conversion Fa

Figure 24: Spreadsheet document: Selection Process 1.2

With this process, consumers responsible for up to 80% of the total consumption are transferred to the second selection process. An image of the first entry form for this selection process is depicted in Figure 25. Per default, the first two columns contain the index and name of the consumers that were selected beforehand.

Selection Process 2

Consumer	Name	Energy Application	Saving Potential (Value A	Energy Prices	Value B	Process Dynamics	Value C	Measuring Target	Measuring Effort (Value D)	Operating Hours / a	Value E	Age in a	Value F	Final Value
1	Consumer a	Heat Supply	2	heat	2	stable	1	Heat (energy)	2	4000	4	15	4	23
6	Consumer f	Ventilation System	1	electricity	4	unstable	2	Electricity (power/energy)	1	3500	3	4	3	21
3	Consumer c	Lighting	5	electricity	4	stable	1	Electricity (power/energy)	1	8760	6	1	2	34
NONE	NONE		No Value		No Value		No Value		No Value		No Value		No Value	0
NONE	NONE		No Value		No Value		No Value		No Value		No Value		No Value	0
NONE	NONE		No Value		No Value		No Value		No Value		No Value		No Value	0
NONE	NONE		No Value		No Value		No Value		No Value		No Value		No Value	0
NONE	NONE		No Value		No Value		No Value		No Value		No Value		No Value	0

Input / SP1.1 / SP1.2 / SP2.1 / SP2.2 / SP2.3 / EnPI / Report1 / Report2 / Conversion Factors / Values

Figure 25: Spreadsheet document: Selection Process 2.1

Using the four gray drop-down menus and the two yellow columns the consumers are further characterized. Depending on the indications made by the user, values are assigned for the categories Saving Potential, Energy Prices, Process Dynamics, Measuring Effort, Operating Hours and Age. The final value appears in the last column. The assignment of values as well as the calculation of the final value is realized as described in 6.4 Identification of Measuring Points. Yet again, for the functionality of the process it is not necessary to furnish all particulars but the force of expression increases with the amount of available information. Especially, as leaving out categories automatically lowers the final value. The ranking seen in Figure 26 works in the same way like the process for the identification of main consumers. The final values are transferred to the respective sheet together with the appropriate values for saving potential and measuring effort. Again, the sorting of consumers have to be initiated manually. First priority for the ranking is the final value. In case of identical final values, the saving potential and the measuring effort are taken as second and third basis for decision-making.

Ranking

Final Value	Index	Name	Saving Potential	Measuring Effort
34	3	Consumer c	5	1
23	1	Consumer a	2	2
21	6	Consumer f	1	1
0	NONE	NONE	No Value	No Value
0	NONE	NONE	No Value	No Value
0	NONE	NONE	No Value	No Value
0	NONE	NONE	No Value	No Value
0	NONE	NONE	No Value	No Value

Input / SP1.1 / SP1.2 / SP2.1 / SP2.2 / SP2.3 / EnPI / Report1 / Re

Figure 26: Spreadsheet document: Selection Process 2.2

In contrast to the first selection process, the identification of measuring points requires a third sheet for the decision. This sheet is depicted in Figure 27. The first column contains the list of all main energy consumers whereas the second column shows them in ranked order. Consumers can only be added to a monitoring system, if they are not monitored already. To exclude these consumers from the decision, the user has to indicate for each consumer whether it is monitored or not. Of course, in the first year, when no monitoring system exists, no consumers are monitored but this option gets more and more important over the years. Only consumers with the indication "no" in the gray column, appear in the fourth column. For these remaining consumers an estimated prize for the integration into the monitoring system has to be inserted into the yellow column. All costs are added up and depending on the budget defined by the total energy costs and indicated on the Input sheet, the system recommends, if consumers should be selected or declined. This decision is displayed in the last column. In this arbitrary example the budget is at about 700 €. Hence, the second consumer leading to summarized costs of 800 € is declined.

Decision

Main Energy Consumers	Ranking of Measuring Points	Already Monitored?	Remaining Measuring Points	Estimated Costs	Summarized Costs	Recommendation
Consumer a	Consumer c	yes				
Consumer f	Consumer a	no	Consumer a	500	500	SELECT
Consumer c	Consumer f	no	Consumer f	300	800	DECLINE
Consumer b						
Consumer d						
Consumer e						

Input / SP1.1 / SP1.2 / SP2.1 / SP2.2 / SP2.3 / EnPI / Report1 / Report2 / Conversion Factors / Values

Figure 27: Spreadsheet document: Selection Process 2.3

The following sheets are for the data processing respectively the generation of output of the monitoring system. A first table contains formulas for the calculation of energy performance indicators. Figure 28 shows what they look like. The indicators were selected according to the recommendation in 7.1 Performance Indicators. The cells are filled with information from the input sheet. In the application it is recommended to delete the unused lines as they will not contain any value and therefore do not have any significance.

Energy Performance Indicators

Specific Energy Consumption	$\frac{Total\ Energy\ Consumption}{Production\ Output}$	#DIV/0!	$\frac{kWh}{PU}$
Specific Energy Costs	$\frac{Total\ Energy\ Costs}{Total\ Production\ Costs}$	#DIV/0!	%
Industry-Typical EnPI	$\frac{Total\ Energy\ Consumption}{Turnover}$	#DIV/0!	$\frac{kWh}{€}$
Share of Electricity	$\frac{Consumption\ per\ Energy\ Source}{Total\ Energy\ Consumption}$	0	%
Specific Costs of Electricity	$\frac{Electricity\ Costs}{Electricity\ Consumption}$	#DIV/0!	$\frac{€}{kWh}$
Share of Fuels	$\frac{Consumption\ per\ Energy\ Source}{Total\ Energy\ Consumption}$	0	%
Specific Costs of Fuels	$\frac{Fuel\ Costs}{Fuel\ Consumption}$	#DIV/0!	$\frac{€}{kWh}$
Share of Water	$\frac{Consumption\ per\ Energy\ Source}{Total\ Energy\ Consumption}$	0	%
Specific Costs of Water	$\frac{Water\ Costs}{Water\ Consumption}$	#DIV/0!	$\frac{€}{kWh}$
Share of Cooling Energy	$\frac{Consumption\ per\ Energy\ Source}{Total\ Energy\ Consumption}$	0	%
Specific Costs of Cooling Energy	$\frac{Cooling\ Energy\ Costs}{Cooling\ Energy\ Consumption}$	#DIV/0!	$\frac{€}{kWh}$
Share of Heat	$\frac{Consumption\ per\ Energy\ Source}{Total\ Energy\ Consumption}$	0	%
Specific Costs of Heat	$\frac{Heat\ Costs}{Heat\ Consumption}$	#DIV/0!	$\frac{€}{kWh}$

Input / SP1.1 / SP1.2 / SP2.1 / SP2.2 / SP2.3 / EnPI / Report1 / Report2 / Con

Figure 28: Spreadsheet document: Energy Performance Indicators

The two remaining sheets contain the templates for a monthly and a yearly report. They have in common that they compare the current period with the past period. The respective intervals are set out by means of imported time stamps. Besides a general summarizing section at the beginning of each report, the adjacent sections are separately dedicated to the different types of energy. The applied formulas combine general functions of the spreadsheet program with specific JEVis functions needed for the import of data out of the JEVis system. By means of the monthly report, an exemplary report arrangement is visualized in Figure 29. Only the first page of the report is displayed as the following pages only contain the sections for the other energy sources. These sections are built up exactly like the exemplary electricity section. Also not displayed are the empty report pages, which after the samples are imported, will contain the pure data rows only.

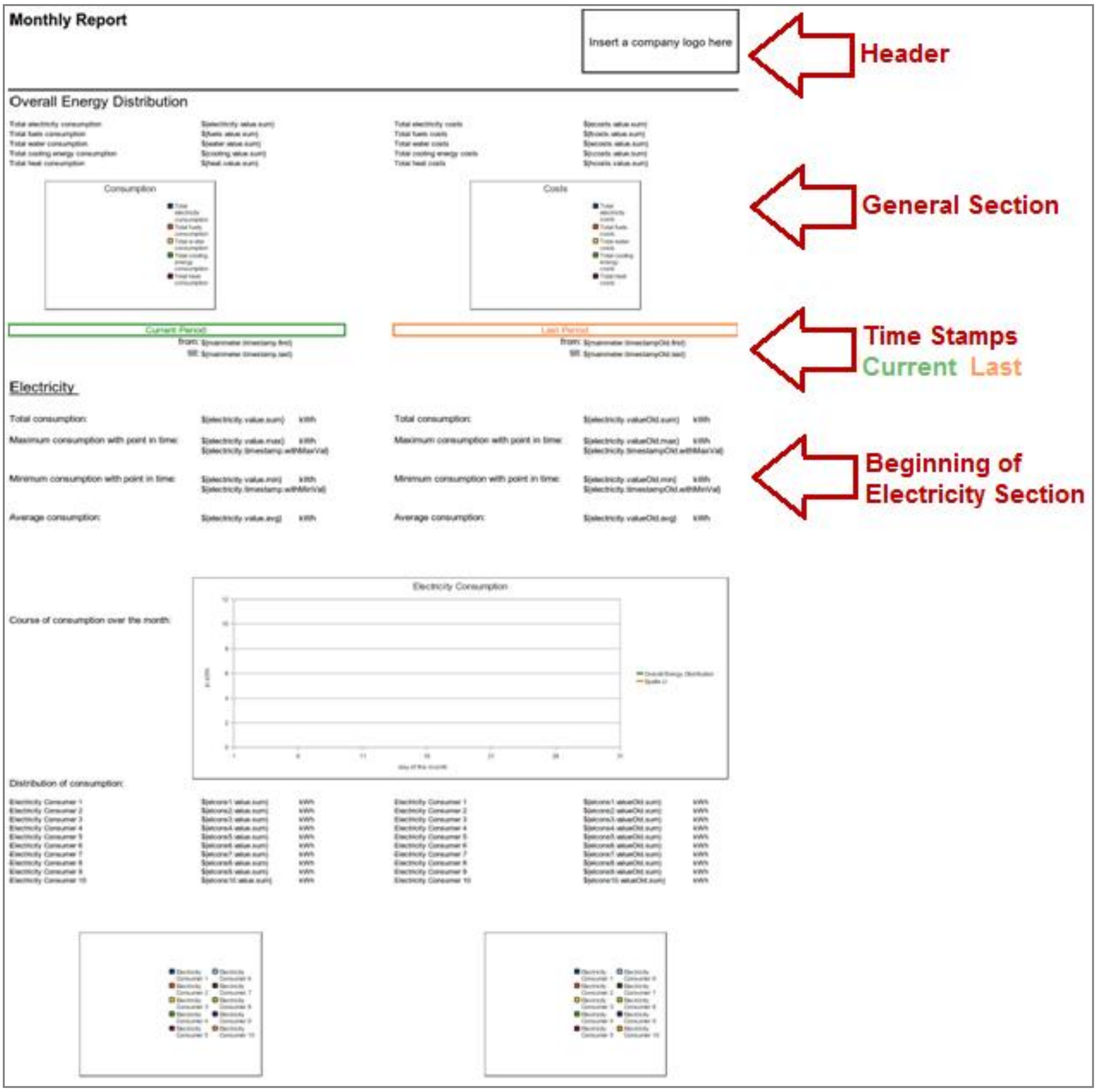


Figure 29: Spreadsheet document: Monthly Report

8.2 JEVis

The JEVis system can support the implementation and operation of monitoring systems. As a result, the development process of this thesis is backed up by the JEVis system's features. The process of how measured values are processed in the JEVis system before they reach the user is visualized in Figure 30.

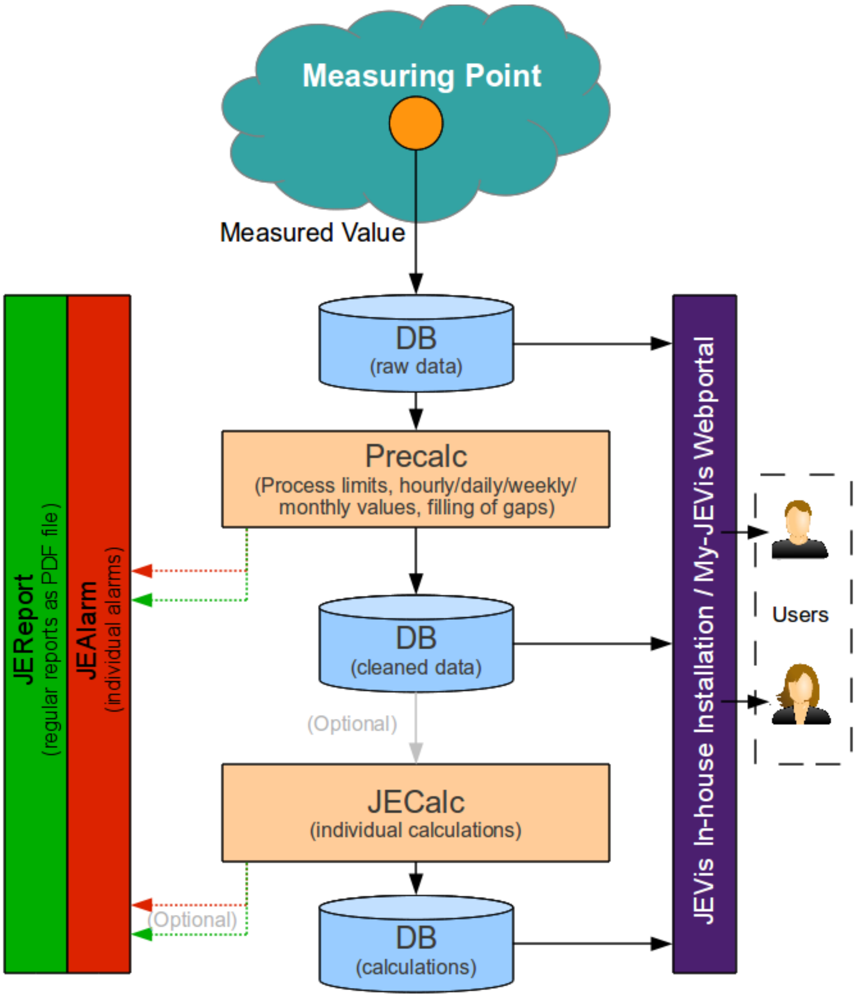


Figure 30: JEVis workflow; based on: [20, p. 4]

For a functioning energy and operating data monitoring system the measuring points identified by the selection process and the communication system for data transmission have to be installed physically. Afterwards, the measuring points are set up in the JEConfig, where the settings for the automated data fetching are regulated. Necessary settings are the ID of the corresponding data gateway, the fetch rate and the properties of the data source for example. The raw data information coming from the measurement system is parsed into a list of samples and stored in a database (JEDB). [60, pp. 19-21] The so called Precalc checks the incoming data on their plausibility. Furthermore, the accumulation to hourly data, for instance, is done before the now cleaned data are stored in the JEDB as well. Optionally, the user has the possibility to process further individual calculations, using the so called JECalc. For this purpose, any kind of mathematical model can be applied. Of course, all calculations and their respective results are also taken to the JEDB. The user can retrieve stored data from the JEDB via the JEVis system at any time. The visualization and analysis is done using the system component JEGraph. Here the definition of critical thresholds and benchmarks is possible. The preparation of reports and alarms happens with the configuration component JEConfig. The settings for individual, irregular alarms and the definition of key figures also have to be made within JEConfig. This includes the definition of limits for the single data points according to the description in 7.2 Alarming. For reports the standardized or individually altered template must be uploaded within JEConfig. There, it is filled with data retrieved from the database. To secure faultless functionality, the two report templates from the existing file should be saved as two separate Excel documents. Unused functions should be deleted from the standardized template file. Additionally, the name of variables within JEConfig must be identical with the ones in the template. Otherwise, the JEVis system cannot allocate the data. Moreover, it is necessary to define the periodicity and the email address of whom the report is sent to. The periodicity is important to distinguish the monthly report from the yearly report. By indicating an email address responsibilities are assigned. The number of possible reports is unlimited so that customers are able to design additional report templates individually.

9 Practical System Verification

Up to now, the idea of a systematized approach for the implementation of energy and operating data monitoring systems has just been described in theory. Although the previous chapter already has outlined how the developed strategy has been realized with software tools, the system's feasibility and the reasonability of generated results have not been proven yet. In order to verify the plausibility of the output generated by the spreadsheet program tool developed in the course of this thesis, it is applied to an actual exemplary project.

9.1 Small-Scale Testing

For testing the general functionality on a small scale basis beforehand, the system has first been applied to the office of the Envidatec GmbH. Despite the fact that the office of a service company is clearly no industrial organization, this testing environment was chosen, however, because all data relevant for a first test run were available on short call. This mainly includes the consumption data which are documented within the JEVis system. The attribution of costs bases on energy bills. Another advantage of this test was the staff of the Envidatec GmbH. Their reliable knowledge of the consumers helped to categorize them after their importance when it comes to energy intensity. These clarifications simplified the evaluation of the results. As this small-scale application only serves the function of a pre-test, it is not necessary to include too many details in the conduction. Therefore, only the data already available through the JEVis system were used instead of also including all unmonitored consumers like office lighting or computers.

The office has consumers using electricity, heat or water. An analysis of how these energy sources are distributed among the monitored consumers is depicted in Figure 31. This figure shows the consumption over a period of three weeks in early 2013 and is rather supposed to visualize the relative amounts of energy than the absolute total consumption over a whole year. The diagram on top shows the electricity consumption, the one in the middle shows the heat load and the bottom graph visualizes the water usage. Whereas heat and water are only acquired with single main meters, the electricity consumption splits into six measurements. To distinguish their shares of the total electricity consumption, a 100% display mode has been chosen. The brown part is of the coffee machine, the three green curves display the three server racks, the blue section is the air handling unit in the server room and the light pink division stands for the remaining electricity not separately acquired.

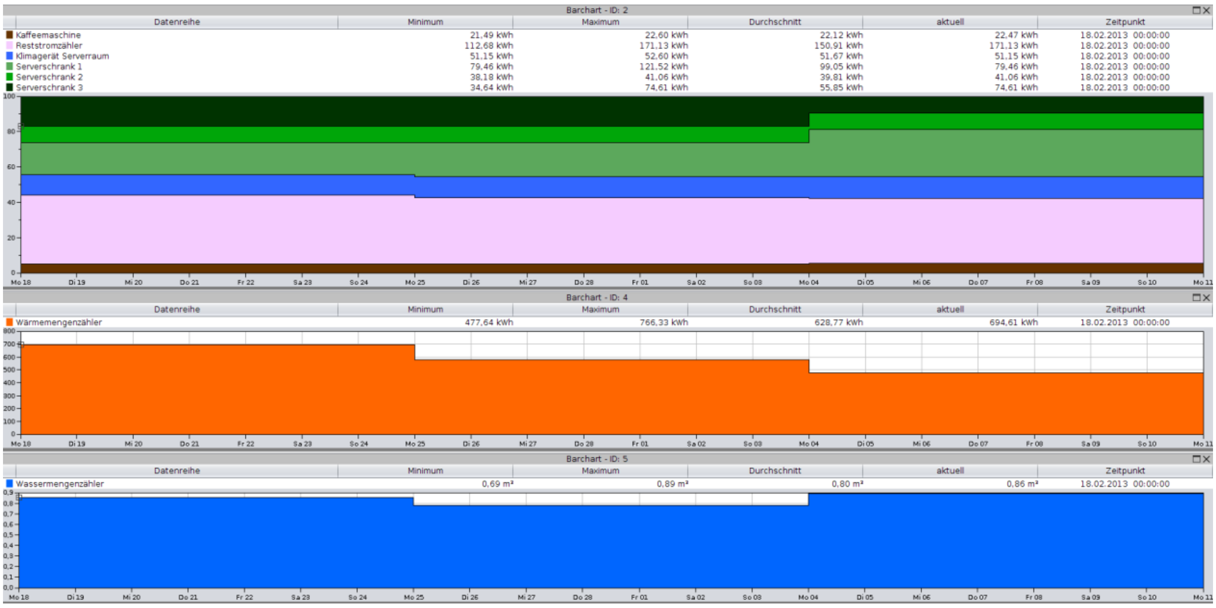


Figure 31: Energy distribution of the Envidatec office

The total consumption values for the period of a whole year have been extracted from a data export out of the JEConfig. The price per kWh electricity is 0.18 €/kWh. The water price of 3.81 €/m³ includes the costs for waste water as well and has been taken from the web site of the regional water supplier of the city Hamburg [61]. The price for the heat is based on heating bills. For this test only commodity prices without basic charges were regarded. The multiplication of these prices by the identified consumption values lead to the total costs of energy. An energy balance of the office can be seen in Figure 32. Divided into the three types of energy all consumers are listed. Still, for the analysis some of the consumers are only listed but not regarded in particular. The attributed single consumption values have been extracted from the JEConfig again so that the shares of total consumption and total costs could be calculated. These results are also included in Figure 32.

Envidatec Office

			Conversion to kWh		Price per Unit	Costs	
Total **Electricity** Consumption	21378,22	kWh	21378,22	kWh	0,18 €/kWh	3848,08	€
Total **Water** Consumption	33,38	m³	11169,94	kWh	3.81 €/m³	127,19	€
Total **Heat** Consumption	13251,52	kWh	13251,52	kWh	0.09467 €/kWh	1254,52	€
Total Energy Consumption			45799,68	kWh	**Total Energy Costs**	5229,79	€

List of Consumers			Share of Electricity	Share of Total Energy Consumption		Share of Total Energy Costs
Main Water:	11169,94	kWh		0,244		0,024
Toilets						
Restroom Sinks						
Kitchen Sink						
Coffee Maker						
Dishwasher						
Main Heat	13251,52	kWh		0,289		0,240
Coffee Maker	962,97	kWh	0,05	0,021	173,33	0,033
Server Room AHU	2814,11	kWh	0,13	0,061	506,54	0,097
Server Rack 1	3657,69	kWh	0,17	0,080	658,38	0,126
Server Rack 2	2254,42	kWh	0,11	0,049	405,80	0,078
Server Rack 3	4160,16	kWh	0,19	0,091	748,83	0,143
Remaining Electricity:	7528,88	kWh	0,35	0,164	1355,20	0,259
Lighting Total (amount?)						
Computer Total (amount?)						
Projector						
Fridge						
Printer 1 & 2						
Geysers (amount?)						
Various Kitchen Appliances						
Miscellaneous (e.g. phone charger)						

(microwave, kettle, little coffee machine, extractor hood, stove, dishwasher)

Figure 32: Energy balance of the Envidatec office

The values have been transferred to the spreadsheet document for the actual testing. The input sheet provides the first outcome, which is the definition of the theoretical monitoring budget. Calculating 5% of the total energy costs results in an amount of 261.49 €. Applying both selection processes to the list of consumers leads to the final decision as depicted in Figure 33.

Decision

Main Energy Consumers	Ranking of Measuring Points	Already Monitored?	Remaining Measuring Points
Main Heat	Remaining Electricity	no	Remaining Electricity
Remaining Electricity	Server Rack 1	yes	
Server Rack 3	Server Room AHU	yes	
Server Rack 1	Main Heat	yes	
Server Room AHU	Server Rack 3	yes	

Figure 33: Monitoring recommendation: Envidatec office

The main water consumption, the coffee machine and one of the three server racks were already sorted out after the first selection process so that only five main energy consumers remained. After the second selection process the aggregation of still unmonitored electrical consumers is on top of the ranking list. Since this is per initially defined setting the only consumer which is not monitored yet, it is recommended to monitor the composition of this consumer group more detailed.

In comparison with Figure 31 this result was expected as the remaining electricity makes up for around one third of the total electricity consumption. Thus, the general functionality of the developed analyzing system could be proven.

9.2 Verification on Real Terms

After the feasibility has been proven, the system was applied to an actual project of the Envidatec GmbH. The company chosen for this verification process is a regional enterprise in the building chemistry branch. The main production focuses on construction materials. The reason why this company was selected is its participation in a Learning Energy Efficiency Network (LEEN). The Envidatec GmbH prepared an energy efficiency consulting report for the company based on data gathered from audits and questionnaires according to certified LEEN standards. [62] The results of these surveys allowed for a solid data base for the aspired practical verification. It is assumed, that most of the values refer to the year 2009 although this is not clearly indicated at all times. Nevertheless, the data are precisely enough for a practical system verification. However, since there are comprehensive values for one year only, this test can just prove the application to one period instead of the development over two or more application cycles.

With 70 employees the company produces about 50,000 t of the described building and construction chemicals every year and generates a turnover of 32,000,000 €. The production costs of the company are not available. [62, p. 2] As can be seen in Figure 34 the total costs of energy are composed of costs for the consumption of electricity, natural gas and water. Due to the lack of more detailed information, for this verification it has been neglected that in the year 2009 the company partly still used light fuel oil instead of natural gas. To compensate for the neglected amount of fuel oil, the natural gas consumption and costs have been extrapolated to the year's total heat demand. The total costs of energy define the budget for monitoring investments of 14,280 €. To include the water into the total consumption, for the time of water purchase an average water temperature of 10°C is assumed. Individual target values for the reduction of energy costs or consumption are unknown.

Input

			Annotations
Company Related Data			
Name of the Company:	Anonymous		
Address:	North East of Hamburg		
Contact Information:			
Branch of Industry/Business:	Construction Chemistry		
Number of Employees:	70		
Total Area:	15.500	m²	
- Production Area:	6.030	m²	
- Heated Area:	6.250	m²	
Economic Data			
Production Costs:	n.a.	€	
Production Output:	50.000	PU	Production unit = t
Turnover:	32.000.000	€	
Energy Related Data			
Total Costs of Energy:	285.600	€	
- Total Costs Electricity	266.583	€	
- Total Costs Fuels	12.984	€	natural gas
- Total Costs Water	6.033	€	
- Total Costs Cooling Energy	0	€	
- Total Costs Heat	0	€	
Total Consumption of Energy:	2.579.957	kWh	
- Total Consumption Electricity	1.799.948	kWh	
- Total Consumption Fuels	302.525	kWh	natural gas
- Total Consumption Water	477.484	kWh	1453m³ average temperature 10°C
- Total Consumption Cooling Energy	0	kWh	
- Total Consumption Heat	0	kWh	
Predefined Individual Targets			
Yearly Reduction of Energy Costs	n.a.	%	
Yearly Reduction of Energy Consumption	n.a.	%	
Approximate Budget (5% of Energy Cost	14.280	€	

Figure 34: Input sheet: Exemplary Company

After the general values have been filled into the input sheet as depicted in Figure 34, the known consumers were listed on the next sheet. Altogether, 39 consumers respectively consumer groups could be identified. Heating demand is covered by three electric night storage heating systems and one natural gas condensing boiler. Six main pumps in the heating system are responsible for the distribution of the heat into the different company sections. The next consumer group is for the provision of compressed air including two compressor stations and one compressed air dryer. For the production several drives are needed. There is one aspiration drive, 35 drives for metering screws and four drives for blenders. The drives were aggregated into five groups of identical drives distinguished by their application, age and nominal power. The grouping of lighting facilities has been adopted from the LEEN consulting report. There the lighting is aggregated into certain building and production sections as within separate sections technically comparable luminaries are used. Further consumers are IT facilities like computers, monitors, servers and copiers for the production area and the administrative building. Shares of the water consumption used for production processes and for water in sanitary facilities are not available. The total water consumption is therefore registered as one dummy consumer. The assignment of values for the three categories of the first selection process can be seen in Figure 35.

Selection Process 1

Consumer Index	Name of Consumer	Nominal Power in kW	Operating Hours per a	Type of Energy	CO2-Emission (Value A)	Costs in €	Share of Total Costs of Energy in %	Value B	Consumption in kWh	Share of Total Consumption in %	Value C	Final Value
1	Storage Heating 1			electricity (mix)	2	12.537,20	4,39	2	100.842,00	3,91	2	12
2	Storage Heating 2			electricity (mix)	2	12.537,20	4,39	2	100.842,00	3,91	2	12
3	Storage Heating 3			electricity (mix)	2	12.537,20	4,39	2	100.842,00	3,91	2	12
4	Boiler Heating			natural gas	3	12.984,00	4,55	2	302.525,00	11,73	4	17
5	Pump Air Heating Office			electricity (mix)	2	289,70	0,10	1	2.190,00	0,08	1	7
6	Pump Air Heating GEA			electricity (mix)	2	214,40	0,08	1	1.620,60	0,06	1	7
7	Pump Heating Social/Lab			electricity (mix)	2	69,50	0,02	1	525,60	0,02	1	7
8	Pump Heating Storage			electricity (mix)	2	214,40	0,08	1	1.620,60	0,06	1	7
9	Pump Heating Social			electricity (mix)	2	69,50	0,02	1	525,60	0,02	1	7
10	Pump Heating Production			electricity (mix)	2	289,70	0,10	1	2.190,00	0,08	1	7
11	Refrigerating Machine			electricity (mix)	2	752,30	0,26	1	5.687,00	0,22	1	7
12	Compressor 1			electricity (mix)	2	20.556,80	7,20	3	155.400,00	6,02	3	17
13	Compressor 2			electricity (mix)	2	5.340,00	1,87	2	40.368,00	1,56	2	12
14	Compressed Air Dryer			electricity (mix)	2	1.495,60	0,52	1	11.304,70	0,44	1	7
15	M1 Aspiration	22	4000	electricity (mix)	2	11.639,80	4,08	2	88.000,00	3,41	2	12
16	M2 Metering Screw 1-13	52	200	electricity (mix)	2	1.372,80	0,48	1	10.400,00	0,40	1	7
17	M3 Metering Screw 1-22	33	50	electricity (mix)	2	217,80	0,08	1	1.650,00	0,06	1	7
18	M4 Blender 1-2	110	600	electricity (mix)	2	8.712,00	3,05	2	66.000,00	2,56	2	12
19	M5 Blender 1-2	220	800	electricity (mix)	2	23.232,00	8,13	3	176.000,00	6,82	3	17
20	Light Filling L1/L3 1-18	1,278	4208	electricity (mix)	2	711,32	0,25	1	5.377,82	0,21	1	7
21	Light Filling L4/L5 1-37	2,627	4208	electricity (mix)	2	1.462,17	0,51	1	11.054,42	0,43	1	7
22	Light Palletizing 1-78	5,538	4208	electricity (mix)	2	3.082,41	1,08	2	23.303,90	0,90	1	10
23	Light Shipping 1-80	5,68	3156	electricity (mix)	2	2.371,08	0,83	1	17.926,08	0,69	1	7
24	Light Incoming Goods 1-310	18,91	3156	electricity (mix)	2	7.893,87	2,76	2	59.679,96	2,31	2	12
25	Light Wet Hall 1-214	13,054	3156	electricity (mix)	2	5.449,32	1,91	2	41.198,42	1,60	2	12
26	Light Wash Hall 1-19	1,159	3156	electricity (mix)	2	483,82	0,17	1	3.657,80	0,14	1	7
27	Light Commissioning 1-270	16,47	2104	electricity (mix)	2	4.583,54	1,60	2	34.652,88	1,34	2	12
28	Light Silo/Dispensing 1-58	4,118	4208	electricity (mix)	2	2.292,05	0,80	1	17.328,54	0,67	1	7
29	Light Office 1-62	2,79	2104	electricity (mix)	2	776,45	0,27	1	5.870,16	0,23	1	7
30	Light Outside 1-10	0,11	1578	electricity (mix)	2	22,69	0,01	1	173,58	0,01	1	7
31	Light Tower	4	2104	electricity (mix)	2	1.113,18	0,39	1	8.416,00	0,33	1	7
32	Printer Adm. 1-15	0,375	1920	electricity (mix)	2	95,23	0,03	1	720,00	0,03	1	7
33	Monitor Adm. 1-40	1,6	1920	electricity (mix)	2	406,33	0,14	1	3.072,00	0,12	1	7
34	PC Adm. 1-30	4,5	1920	electricity (mix)	2	1.142,81	0,40	1	8.640,00	0,33	1	7
35	Server Adm. 1-2	0,3	8760	electricity (mix)	2	347,61	0,12	1	2.628,00	0,10	1	7
36	Copier Adm. 1-5	0,75	1920	electricity (mix)	2	190,47	0,07	1	1.440,00	0,06	1	7
37	Monitor Prod. 1-10	0,4	3889	electricity (mix)	2	205,76	0,07	1	1.555,60	0,06	1	7
38	PC Prod. 1-10	1,5	3889	electricity (mix)	2	771,60	0,27	1	5.833,50	0,23	1	7
39	Water Usage			water	1	6.033,00	2,11	2	477.484,00	18,51	4	15

Figure 35: First selection process: Exemplary Company

As described in the chapters before, the final values in the last column of Figure 35 are still unsorted. This leads to the ranking process. It is apparent that many consumers have the same final value which is why the final value is not sufficient as exclusive ranking criterion. The consumers are sorted after their share of the total costs with second priority and after their share of consumption in case, that the share of costs is also identical. The sum of the shares of consumption in the penultimate column shows, that the identified consumers only cover for about 73.6% of the total consumption. This discrepancy is partly attributed to the fact, that some consumption values are only rough estimations based on operating hours and nominal power. Nevertheless, it cannot be excluded, that not all consumers were registered during the assessment period, potentially because they have been forgotten or because they were considered as unimportant. Still, since the total sum does not exceed the limit of 80% all consumers are selected for the following process.

Ranking

Final Value	Index	Name	Share of Costs	Share of Consumption	Sum	Decision
17	19	M5 Blender 1-2	8,13	6,82	6,8218	SELECT
17	12	Compressor 1	7,20	6,02	12,8452	SELECT
17	4	Boiler Heating	4,55	11,73	24,5712	SELECT
15	39	Water Usage	2,11	18,51	43,0786	SELECT
12	1	Storage Heating 1	4,39	3,91	46,9873	SELECT
12	2	Storage Heating 2	4,39	3,91	50,8959	SELECT
12	3	Storage Heating 3	4,39	3,91	54,8046	SELECT
12	15	M1 Aspiration	4,08	3,41	58,2155	SELECT
12	18	M4 Blender 1-2	3,05	2,56	60,7737	SELECT
12	24	Light Incoming Goods 1-310	2,76	2,31	63,0869	SELECT
12	25	Light Wet Hall 1-214	1,91	1,60	64,6838	SELECT
12	13	Compressor 2	1,87	1,56	66,2485	SELECT
12	27	Light Commissioning 1-270	1,60	1,34	67,5916	SELECT
10	22	Light Palletizing 1-78	1,08	0,90	68,4949	SELECT
7	23	Light Shipping 1-80	0,83	0,69	69,1897	SELECT
7	28	Light Silo/Dispensing 1-58	0,80	0,67	69,8614	SELECT
7	14	Compressed Air Dryer	0,52	0,44	70,2995	SELECT
7	21	Light Filling L4/L5 1-37	0,51	0,43	70,7280	SELECT
7	16	M2 Metering Screw 1-13	0,48	0,40	71,1311	SELECT
7	34	PC Adm. 1-30	0,40	0,33	71,4660	SELECT
7	31	Light Tower	0,39	0,33	71,7922	SELECT
7	29	Light Office 1-62	0,27	0,23	72,0197	SELECT
7	38	PC Prod. 1-10	0,27	0,23	72,2459	SELECT
7	11	Refrigerating Machine	0,26	0,22	72,4663	SELECT
7	20	Light Filling L1/L3 1-18	0,25	0,21	72,6747	SELECT
7	26	Light Wash Hall 1-19	0,17	0,14	72,8165	SELECT
7	33	Monitor Adm. 1-40	0,14	0,12	72,9356	SELECT
7	35	Server Adm. 1-2	0,12	0,10	73,0374	SELECT
7	5	Pump Air Heating Office	0,10	0,08	73,1223	SELECT
7	10	Pump Heating Production	0,10	0,08	73,2072	SELECT
7	17	M3 Metering Screw 1-22	0,08	0,06	73,2712	SELECT
7	6	Pump Air Heating GEA	0,08	0,06	73,3340	SELECT
7	8	Pump Heating Storage	0,08	0,06	73,3968	SELECT
7	37	Monitor Prod. 1-10	0,07	0,06	73,4571	SELECT
7	36	Copier Adm. 1-5	0,07	0,06	73,5129	SELECT
7	32	Printer Adm. 1-15	0,03	0,03	73,5408	SELECT
7	7	Pump Heating Social/Lab	0,02	0,02	73,5612	SELECT
7	9	Pump Heating Social	0,02	0,02	73,5816	SELECT
7	30	Light Outside 1-10	0,01	0,01	73,5883	SELECT

Figure 36: Ranking main consumers: Exemplary Company

The three consumers with the highest final values on top of the list are two old drives of blenders, the bigger of two compressors and the gas-fuelled boiler heating. In accordance with the ranking, the whole list of consumers is transferred to the second selection process. How they have been evaluated in the different categories can be seen in Figure 37.

Selection Process 2

Consumer	Name	Energy Application	Saving Potential (Value A)	Energy Prices	Value B	Process Dynamics	Value C	Measuring Target	Measuring Effort (Value D)	Operating Hours / a	Value E	Age in a	Value F	Final Value
19	M5 Blender 1-2	2	2	electricity	4	unstable	2	Electricity (power/energy)	1	800	2	19	5	25
12	Compressor 1	3	3	electricity	4	unstable	2	Electricity (power/energy)	1	2444	3	4	3	27
4	Boiler Heating	1	1	fuels	2	unstable	2	Heat (energy)	2		No Value	3	2	15
39	Water Usage	2	2	water	1	stable	1	Water (volume flow)	3		No Value		No Value	15
1	Storage Heating 1	Heat Supply	2	electricity	4	stable	1	Heat (energy)	2		No Value	31	5	24
2	Storage Heating 2	Heat Supply	2	electricity	4	stable	1	Heat (energy)	2		No Value	31	5	24
3	Storage Heating 3	Heat Supply	2	electricity	4	stable	1	Heat (energy)	2		No Value	31	5	24
15	M1 Aspiration	Drive	3	electricity	4	unstable	2	Electricity (power/energy)	1	4000	4	32	5	30
18	M4 Blender 1-2	1	1	electricity	4	unstable	2	Electricity (power/energy)	1	600	2	10	4	21
24	Light Incoming Goods 1-310	3	3	electricity	4	stable	1	Electricity (power/energy)	1	3156	3		No Value	23
25	Light Wet Hall 1-214	3	3	electricity	4	stable	1	Electricity (power/energy)	1	3156	3		No Value	23
13	Compressor 2	Compressed Air	4	electricity	4	unstable	2	Compressed Air (energy)	5	1837	3	4	3	38
27	Light Commissioning 1-270	2	2	electricity	4	stable	1	Electricity (power/energy)	1	2104	3		No Value	20
22	Light Palletizing 1-78	4	4	electricity	4	stable	1	Electricity (power/energy)	1	4208	4		No Value	27
23	Light Shipping 1-80	Lighting	5	electricity	4	stable	1	Electricity (power/energy)	1	3156	3		No Value	29
28	Light Silo/Dispensing 1-58	Lighting	5	electricity	4	stable	1	Electricity (power/energy)	1	4208	4		No Value	30
14	Compressed Air Dryer	2	2	electricity	4	unstable	2	Compressed Air (energy)	5	2659	3	4	3	32
21	Light Filling L4/L5 1-37	Lighting	5	electricity	4	stable	1	Electricity (power/energy)	1	4208	4		No Value	30
16	M2 Metering Screw 1-13	Drive	3	electricity	4	unstable	2	Electricity (power/energy)	1	200	1	31	5	27
34	PC Adm. 1-30	IT	1	electricity	4	stable	1	Electricity (power/energy)	1	1920	3		No Value	17
31	Light Tower	3	3	electricity	4	stable	1	Electricity (power/energy)	1	2104	3		No Value	23
29	Light Office 1-62	4	4	electricity	4	stable	1	Electricity (power/energy)	1	2104	3		No Value	26
38	PC Prod. 1-10	IT	1	electricity	4	stable	1	Electricity (power/energy)	1	3889	3		No Value	17
11	Refrigerating Machine	Cooling System	2	electricity	4	unstable	2	Cooling Energy (energy)	2	1153	3		No Value	23
20	Light Filling L1/L3 1-18	Lighting	5	electricity	4	stable	1	Electricity (power/energy)	1	4208	4		No Value	30
26	Light Wash Hall 1-19	4	4	electricity	4	stable	1	Electricity (power/energy)	1	3156	3		No Value	26
33	Monitor Adm. 1-40	IT	1	electricity	4	stable	1	Electricity (power/energy)	1	1920	3		No Value	17
35	Server Adm. 1-2	IT	1	electricity	4	stable	1	Electricity (power/energy)	1	8760	6		No Value	20
5	Pump Air Heating Office	Drive	3	electricity	4	stable	1	Electricity (power/energy)	1	8760	6		No Value	26
10	Pump Heating Production	Drive	3	electricity	4	stable	1	Electricity (power/energy)	1	8760	6		No Value	26
17	M3 Metering Screw 1-22	2	2	electricity	4	unstable	2	Electricity (power/energy)	1	50	1	17	5	24
6	Pump Air Heating GEA	Drive	3	electricity	4	stable	1	Electricity (power/energy)	1	8760	6		No Value	26
8	Pump Heating Storage	Drive	3	electricity	4	stable	1	Electricity (power/energy)	1	8760	6		No Value	26
37	Monitor Prod. 1-10	IT	1	electricity	4	stable	1	Electricity (power/energy)	1	3889	3		No Value	17
36	Copier Adm. 1-5	IT	1	electricity	4	stable	1	Electricity (power/energy)	1	1920	3		No Value	17
32	Printer Adm. 1-15	IT	1	electricity	4	stable	1	Electricity (power/energy)	1	1920	3		No Value	17
7	Pump Heating Social/Lab	Drive	3	electricity	4	stable	1	Electricity (power/energy)	1	8760	6		No Value	26
9	Pump Heating Social	Drive	3	electricity	4	stable	1	Electricity (power/energy)	1	8760	6		No Value	26
30	Light Outside 1-10	2	2	electricity	4	stable	1	Electricity (power/energy)	1	1578	3		No Value	20

Figure 37: Second selection process: Exemplary Company

Indicated by "No Value" in some of the cells it is apparent, that for some consumers in certain categories it was not possible to assign a value. The least information was available in the category "Age". As already described, the omission of values does not lead to the exclusion of affected consumers because the final values can still be calculated but missing values principally lead to lower final values. The resulting final values in sorted order are depicted in Figure 38. Compared to the first selection process, the occurring final values are more diverse. Still, the saving potential and the measuring effort are needed as supporting decision criteria.

Ranking

Final Value	Index	Name	Saving Potential	Measuring Effort
38	13	Compressor 2	4	5
32	14	Compressed Air Dryer	2	5
30	28	Light Silo/Dispensing 1-58	5	1
30	21	Light Filling L4/L5 1-37	5	1
30	20	Light Filling L1/L3 1-18	5	1
30	15	M1 Aspiration	3	1
29	23	Light Shipping 1-80	5	1
27	22	Light Palletizing 1-78	4	1
27	12	Compressor 1	3	1
27	16	M2 Metering Screw 1-13	3	1
26	29	Light Office 1-62	4	1
26	26	Light Wash Hall 1-19	4	1
26	5	Pump Air Heating Office	3	1
26	10	Pump Heating Production	3	1
26	6	Pump Air Heating GEA	3	1
26	8	Pump Heating Storage	3	1
26	7	Pump Heating Social/Lab	3	1
26	9	Pump Heating Social	3	1
25	19	M5 Blender 1-2	2	1
24	1	Storage Heating 1	2	2
24	2	Storage Heating 2	2	2
24	3	Storage Heating 3	2	2
24	17	M3 Metering Screw 1-22	2	1
23	24	Light Incoming Goods 1-310	3	1
23	25	Light Wet Hall 1-214	3	1
23	31	Light Tower	3	1
23	11	Refrigerating Machine	2	2
21	18	M4 Blender 1-2	1	1
20	27	Light Commissioning 1-270	2	1
20	30	Light Outside 1-10	2	1
20	35	Server Adm. 1-2	1	1
17	34	PC Adm. 1-30	1	1
17	38	PC Prod. 1-10	1	1
17	33	Monitor Adm. 1-40	1	1
17	37	Monitor Prod. 1-10	1	1
17	36	Copier Adm. 1-5	1	1
17	32	Printer Adm. 1-15	1	1
15	39	Water Usage	2	3
15	4	Boiler Heating	1	2

Figure 38: Final ranking: Exemplary Company

The next Figure 39 now shows the final listing of consumers. The first column shows the consumers that were selected as main consumers after the first selection process. How these consumers have been rearranged after the second selection process can be seen in the second column. For these it has been indicated whether they are monitored already or not. The last column therefore only shows the remaining unmonitored consumers. According to their position further up the list, it is recommended to install measuring technology beginning on top of the list. Consequently, it is most recommendable to monitor the compressed air dryer followed by three lighting appliances and the aspiration drive. In comparison to the findings of the LEEN consulting report, similar results were attained. Compressed air applications are always important to observe, as they cause substantial costs and are prone to high losses in general. As the two compressor stations themselves are monitored already, the associated compressed air dryer remains. The three groups of lighting are the ones with the most obsolete technology such as conventional ballast and without reflectors. The aspiration drive is also in the consulting report identified as the least efficient of all drives. Moreover, the results on the decision sheet show that the IT appliances as well as the water usage are least interesting when it comes to monitoring. This result is also in compliance with the consulting report which does not see much potential for improving the operation of the IT. A comparison to the findings concerning the water usage cannot be made as this has not been investigated in the consulting report.

Decision

Main Energy Consumers	Ranking of Measuring Points	Already Monitored?	Remaining Measuring Points
M5 Blender 1-2	Compressor 2	yes	
Compressor 1	Compressed Air Dryer	no	Compressed Air Dryer
Boiler Heating	Light Silo/Dispensing 1-58	no	Light Silo/Dispensing 1-58
Water Usage	Light Filling L4/L5 1-37	no	Light Filling L4/L5 1-37
Storage Heating 1	Light Filling L1/L3 1-18	no	Light Filling L1/L3 1-18
Storage Heating 2	M1 Aspiration	no	M1 Aspiration
Storage Heating 3	Light Shipping 1-80	no	Light Shipping 1-80
M1 Aspiration	Light Palletizing 1-78	no	Light Palletizing 1-78
M4 Blender 1-2	Compressor 1	yes	
Light Incoming Goods 1-310	M2 Metering Screw 1-13	no	M2 Metering Screw 1-13
Light Wet Hall 1-214	Light Office 1-62	no	Light Office 1-62
Compressor 2	Light Wash Hall 1-19	no	Light Wash Hall 1-19
Light Commissioning 1-270	Pump Air Heating Office	yes	
Light Palletizing 1-78	Pump Heating Production	yes	
Light Shipping 1-80	Pump Air Heating GEA	yes	
Light Silo/Dispensing 1-58	Pump Heating Storage	yes	
Compressed Air Dryer	Pump Heating Social/Lab	yes	
Light Filling L4/L5 1-37	Pump Heating Social	yes	
M2 Metering Screw 1-13	M5 Blender 1-2	no	M5 Blender 1-2
PC Adm. 1-30	Storage Heating 1	yes	
Light Tower	Storage Heating 2	yes	
Light Office 1-62	Storage Heating 3	yes	
PC Prod. 1-10	M3 Metering Screw 1-22	no	M3 Metering Screw 1-22
Refrigerating Machine	Light Incoming Goods 1-310	no	Light Incoming Goods 1-310
Light Filling L1/L3 1-18	Light Wet Hall 1-214	no	Light Wet Hall 1-214
Light Wash Hall 1-19	Light Tower	no	Light Tower
Monitor Adm. 1-40	Refrigerating Machine	yes	
Server Adm. 1-2	M4 Blender 1-2	no	M4 Blender 1-2
Pump Air Heating Office	Light Commissioning 1-270	no	Light Commissioning 1-270
Pump Heating Production	Light Outside 1-10	no	Light Outside 1-10
M3 Metering Screw 1-22	Server Adm. 1-2	no	Server Adm. 1-2
Pump Air Heating GEA	PC Adm. 1-30	no	PC Adm. 1-30
Pump Heating Storage	PC Prod. 1-10	no	PC Prod. 1-10
Monitor Prod. 1-10	Monitor Adm. 1-40	no	Monitor Adm. 1-40
Copier Adm. 1-5	Monitor Prod. 1-10	no	Monitor Prod. 1-10
Printer Adm. 1-15	Copier Adm. 1-5	no	Copier Adm. 1-5
Pump Heating Social/Lab	Printer Adm. 1-15	no	Printer Adm. 1-15
Pump Heating Social	Water Usage	no	Water Usage
Light Outside 1-10	Boiler Heating	yes	

Figure 39: Remaining measuring points: Exemplary Company

Costs for the installation of measuring technology have not been assigned. Therefore, it is not possible to compare these costs with the theoretical budget of 14,280 €. The reason for leaving out this last step is that at least some of the consumers identified as highly recommended were exchanged or modernized subsequent to the delivery of the consulting report. Hence, the input for the monitoring system is completed.

This leaves the parts considered as output of the monitoring system. Only the calculation of EnPIs could be included completely in the practical system verification.

Energy Performance Indicators

Specific Energy Consumption	$\frac{Total\ Energy\ Consumption}{Production\ Output}$	51,60	$\frac{kWh}{PU}$
Industry-Typical EnPI	$\frac{Total\ Energy\ Consumption}{Turnover}$	0,08	$\frac{kWh}{€}$
Share of Electricity	$\frac{Consumption\ per\ Energy\ Source}{Total\ Energy\ Consumption}$	69,77	%
Specific Costs of Electricity	$\frac{Electricity\ Costs}{Electricity\ Consumption}$	0,15	$\frac{€}{kWh}$
Share of Fuels	$\frac{Consumption\ per\ Energy\ Source}{Total\ Energy\ Consumption}$	11,73	%
Specific Costs of Fuels	$\frac{Fuel\ Costs}{Fuel\ Consumption}$	0,04	$\frac{€}{kWh}$
Share of Water	$\frac{Consumption\ per\ Energy\ Source}{Total\ Energy\ Consumption}$	18,51	%
Specific Costs of Water	$\frac{Water\ Costs}{Water\ Consumption}$	0,01	$\frac{€}{kWh}$

Figure 40: Energy performance indicators: Exemplary Company

The performance indicators which appear in the original template but are irrelevant for the exemplary company have been deleted from the file. The remaining energy performance indicators are listed in Figure 40. The specific energy consumption states that the production of one ton of construction material requires an average energy consumption of 51.6 kWh. In relation to the company's turnover the energy consumption with 0.08 kWh/€ only has a small impact. Regarding the respective shares of electricity, fuels and water, it is evident that electricity is responsible for almost 70% of the total energy consumption. This is true at least for the identified and registered consumers. The indicators dealing with the specific costs per energy source confirm the initial consumption of chapter 6.4.1.2 Energy Prices that out of these three energy sources electricity is the most expensive type of energy whereas water can allocated with the lowest price per kWh. The actual significance of these EnPIs could only be evaluated in comparison to other year's results, which are not available.

The monthly and the yearly report are the second systematized output. As already indicated, the automated generation of reports according to the designed templates cannot be displayed completely. This is because the company data are not imported to the JEVis system and therefore the template cannot be filled with stored or automatically acquired data. However, an extract of what part of the yearly report could look like, if it is filled with data, can be seen in Figure 41.

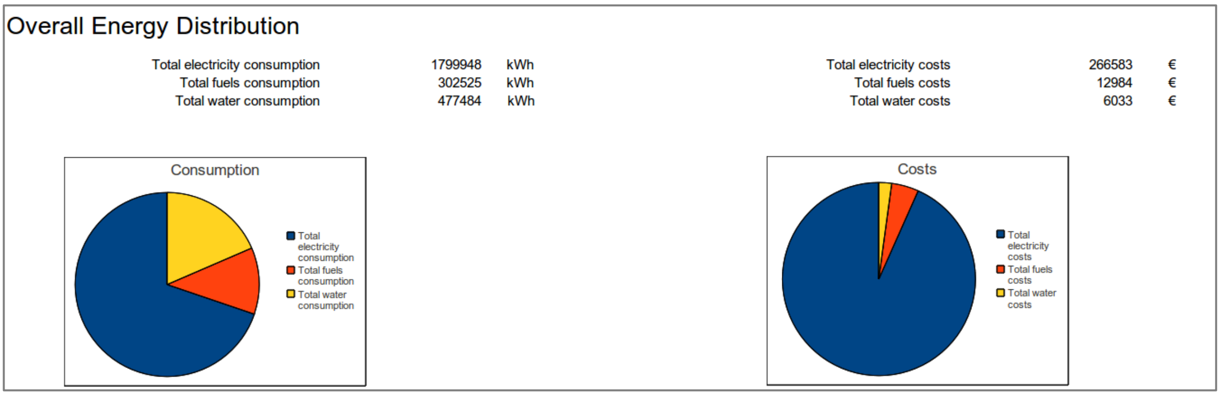


Figure 41: Report extract: Exemplary Company

The overall energy distribution from the beginning of the report has been chosen for the exemplification. The yearly values for consumption and costs per available energy source are compared with each other. The pie chart on the left side depicts the consumption distribution and the pie chart on the right side contains the corresponding costs. The report visualizes what has already been detected before. Electricity (blue) has the greatest share of both, consumption and costs. Moreover, although the amount of consumed water (yellow) exceeds the fuels (orange) consumption, the lower price per kWh leads to a smaller share of costs for water compared to the share for fuels. With this finding, the verification of the regarded output of the monitoring system is also completed.

10 Conclusion

This last chapter provides a final summary of the results of this assignment. Besides a general evaluation of the scope, especially the findings concerning the verification process are critically assessed. In addition, it is outlined which adaptations or improvements are recommended together with expectations for future developments.

10.1 System Review

The objective of this thesis has been the development of a systematized tool for integrating energy and operating data monitoring systems in industrial organizations. This aim is motivated by the increase in energy efficiency, which is realizable through the monitoring of energy flows. The application of the developed scheme to a real company in practice verified the general functionality as well as the reasonability of the results.

The recommendations of the system were comparable with the findings of a consulting report which has been drawn up prior to the system test. This implies that the system design operates in accordance with established energy consulting working methods. As consequence, the found solution is able to serve the purpose of simplifying the implementation of energy monitoring systems. The results generated through the selection processes are not only a recommendation for a monitoring system. What is more, they represent a well substantiated line of argumentation for the decision of which consumers need a more in depth analysis when it comes to increasing their energy efficiency. It is therefore a good starting point for further analyses. Taken together, the result in addition to monitoring might be the exchange or modernization of a consumer.

Moreover, the work during the development phase demonstrated which information about consumers has to be collected in order to evaluate their energetic situation properly. The Envidatec GmbH can use this outcome for future projects as it suggests aspects that should be paid particular attention to during audits. In addition, such audits can be approached more systematically which reduces the individual project-related handling time. This is a benefit for both Envidatec and its customers.

On the other hand, the critical assessment of the verification process also disclosed some limitations and drawbacks of the system. Due to the need of comprehensive information, the application requires preparation time for data collection. As proven during the practical verification, the system also works, if not all information is at hand. The significance of the results, however, increases with data availability.

Another aspect applies to the grouping of consumers. It has been found that the consumer assessment partly depends on how they are aggregated. For example, the drives which were added up to one consumer would have been evaluated differently if they would have been listed one by one. Thus, the combined consumption leads to a greater share of the total, just to name one reason. The fact that the one drive which has been listed separately in the end appeared further up the list than the aggregated drives might be a hint, that although the grouping has an effect on the evaluation, this does not prevent the identification of really inefficient consumers.

Lastly, adaptations that had to be made in order to fit the chosen company confirmed the impossibility of developing a completely standardized procedure applicable to all industrial branches. The differences between various industrial organizations will always require individual adaptations. The positive aspect of this revelation is the constant advancement of the system, because during the applications more and more aspects might unveil, which are true for other companies and branches as well.

In conclusion, the system might still have some unavoidable drawbacks but this does not affect its functionality in any way. The development can be regarded as effective support of project handling and in consequence meets the requirements that have been defined with the scope of this thesis.

10.2 Future Prospects

This final paragraph aims at future developments. Regarding the developed process itself, some aspects have been mentioned already. There are the assessment criteria which require careful revision and reevaluation for correctness in regular intervals as they might change over the years. This applies to the classifications rather than the weighting factors. Especially affected by adjustments might be the relation of energy prices. Furthermore, there is the fact, that some parts of the system are not fully automated yet which offers room for improvement. It needs further evaluation whether this could be changed by transferring the system from the spreadsheet program to a new plug-in for the JEVis system as the programming effort might exceed the resulting benefit.

In the course of assessing the system structure, it is advisable to evaluate further extensions of the system. One possible addition could be the combination with standard monitoring system solutions. These include more detailed information on which measuring technology can be used with which data loggers. The connection with the JEVis system is defined as well.

The realization would be possible through further inquiries subsequent to or alongside the existing system process. The combination with this information would increase the level of standardization and further reduce the individual project handling time.

Last but not least, considering the marketing options of the developed procedure, getting certification for the process of being in compliance with ISO 50001 standard would be an advantage. Therefore, it is planned to present the system at the international certification institute DQS. By using a monitoring system the user is aware of the energetic condition of its consumers at all times and is able to follow up on the development of energy targets and performance indicators. Main argument for the compliance, however, is the continuous improvement process which can be realized through periodical application of the developed scheme. This is because the resulting monitoring system will expand constantly which increases the transparency and finally leads to a more sensible use of energy.

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Erklärung zur selbstständigen Bearbeitung

Hiermit versichere ich, Katharina Dill, dass ich die vorliegende Masterarbeit mit dem Thema:

Systematization of Energy and Operating Data Monitoring Systems as Standardized Measure to Increase Energy Efficiency in Industry

ohne fremde Hilfe selbstständig verfasst und nur die angegebenen Quellen und Hilfsmittel benutzt habe. Wörtlich oder dem Sinn nach aus anderen Werken entnommene Stellen sind unter Angabe der Quellen kenntlich gemacht.

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