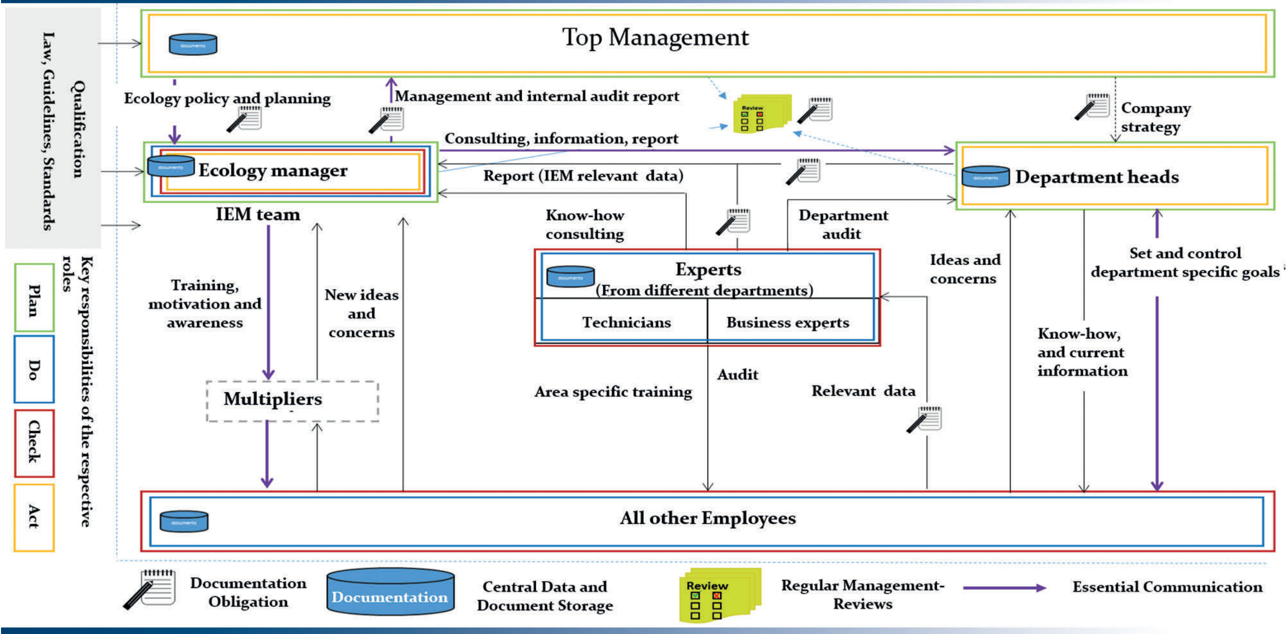

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Tallal Javied

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Prof. Dr.-Ing. Jörg Franke

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Totally Integrated Ecology Management for Resource Efficient and Eco-Friendly Production

Ganzheitliches Ökologiemanagement für eine ressourceneffiziente und umweltschonende Produktion

Der Technischen Fakultät
der Friedrich-Alexander-Universität
Erlangen-Nürnberg

zur
Erlangung des Doktorgrades Dr.-Ing.

vorgelegt von

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Preface

This dissertation was written during my work as a research assistant at the Institute for Factory Automation and Production Systems (FAPS) at the Friedrich-Alexander University Erlangen-Nuremberg.

I would like to thank Professor Jörg Franke for his support during my time under his supervision at his institute. I appreciate more than just his qualities as a doctoral supervisor. I am thankful for his many suggestions, which are of advantage to me in my professional, but also in my private life.

My sincere thanks go to many colleagues and alumni, including David Meinel, Alireza Esfandyari, Jochen Zeitler, Jonathan Fuchs and Matthias Brossog. Thank you for the pleasant working atmosphere, for many valuable suggestions and constant helpfulness, which contributed substantially to the success of this work. I would also like to thank my students for the good cooperation and for their valuable work.

I am very grateful to Daniela, who motivated me during this work and made sure that I did not lose sight of the goal. The tips and hints she gave me about my writing style, spelling and grammar helped me a lot. I am thankful to Sophia for encouraging me especially in the final phase of my doctoral exam.

I would like to thank my mother Bilqis Javied and my father Javaid Hafeez as well as my siblings Azqa, Fawad and Bilal for their constant support. I would like to thank my longtime friend Fahad for his valuable feedback.

Erlangen, in December 2020

Tallal Javied, Master of Business Engineering

Table of Contents

List of abbreviations

AJAX	Asynchronous JavaScript And XML
AMQP	Advanced Message Queuing Protocol
BAFA	Bundesamt für Wirtschaft und Ausfuhrkontrolle (federal office of economics and export control)
BMWi	Bundesministerium für Wirtschaft und Energie (federal ministry of economics and energy)
CH_4	Methane
CHP	Combined Heat and Power
CIP	Continuous Improvement Program
CO_2	Carbon dioxide
CSR	Corporate Social Responsibility
CSS	Cascading Style Sheets
Dena	Deutsche Energie-Agentur (German energy agency)
DIN	Deutsches Institut für Normung (German Institute for Standardization)
DMAIC	Define-Measure-Analyze-Improve-Control
ECI	Electricity Cost Intensity
EDL-G	Gesetz über Energiedienstleistungen und andere Energieeffizienzmaßnahmen (German energy services act)
EDP	Electronic Data Processing
EED	Energy Efficiency Directive
EEG	Erneuerbare-Energien-Gesetz (German renewable energy act)
EEV	Energy Efficiency Value

EMAS	Eco Management and Audit Scheme
EMn	Ecology Manager
EMS	Environmental Management System
EnB	Energy Baseline
EnMS	Energy Management System
EnPIs	Energy Performance Indicators
EPIA	Ecology Performance Improvement Actions
ERP	Enterprise Resource Planning
GRI	Global Reporting Initiative
GVA	Gross Value Added
HTTP	Hyper Text Transfer Protocol
IEKP	Integrated Energy and Climate Program
IEM	Industrial Ecology Management
IHK	Industrie- und Handelskammer (chamber of commerce and industry)
ISO	International Organization for Standardization
JSON	JavaScript Object Notation
KBV	Knowledge Based View
M&V	Measuring and Verifying
MBV	Market Based View
MES	Manufacturing Execution System
N_2O	Nitrous oxide
NAPE	National Action Plan for Energy Efficiency
NEEAP	National Energy Efficiency Action Plan
PDCA	Plan Do Check Act
PHP	Hypertext Preprocessor
PLC	Programmable Logic Controller

QTC	Quality, Time and Costs
QTCS	Quality, Time, Costs and Sustainability
RBV	Resource Based View
SCADA	Supervisory Control And Data Acquisition
SMEs	Small and medium-sized enterprises
SV	Shared Values
TIEM	Totally Integrated Ecology Management
TQM	Total Quality Management
UNFCCC	United Nations Framework Convention on Climate Change
UTC	Coordinated Universal Time

List of figures

List of tables

1 Introduction

The presented work focuses on the development of an integrative model to support business organizations methodologically and technically in the implementation and application of holistic industrial ecology management. In this context, motivation, objectives and approach of the work are explained in more detail below.

1.1 Motivation and goals

The scarcity of resources, volatile energy availability, prices in an energy market that are strictly regulated by laws and the importance of the preservation of environment mean that a resource efficient production is increasingly becoming a priority for companies. This is particularly important for Small and Medium-sized Enterprises (SMEs). However, it is not only the reduction of energy costs or compliance with laws and standards that make active ecology management attractive. Since the climate conference in Kyoto in 1997, or at least, since the UN climate conference in Paris in 2015, climate protection has moved into the global consciousness. The main aim of Paris agreement is to take strong actions against global warming by limiting the rise of global temperature to below two degrees by the end of 21st century [1]. The social relevance of resources such as energy and water along with waste management as a factor has thus steadily increased in recent decades. It has the critical view of the legitimacy of corporate management to act. Manufacturing plants account for a major proportion of environmental pollution. Figure 1 illustrates some environmental impacts of production sites.

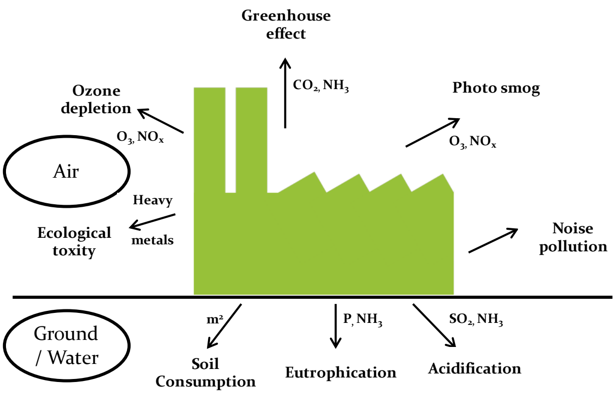

Figure 1: Environmental impact of factories [2].

This demonstrates the need to make industrial production more resource efficient and sustainable to minimize its negative impact on the environment.

Due to the increased environmental awareness of society, the auditing and certification of the energy and eco-friendly performance of a company has become an urgent necessity for organizations to survive in international competition. The current situation is further exacerbated by developments in environmental legislation, such as the shutdown of German nuclear power plants by the year 2022 [3] and phasing out coal based power plants by the year 2038 [4]. Germany has set itself ambitious goals to protect climate. The German climate protection plan 2050 demonstrates the German government's determination to counter climate change. The climate protection plan 2050 shows how Germany intends to implement the Paris agreement. The plan is based on Germany's largely greenhouse gas-neutral approach up to the year 2050 [5].

Thus, in the future, ecology management will play an increasingly important role within the corporate policy, which not only aims at reducing energy costs, but also at the sustainable and efficient management of resource and wastes.

Although there are many incentives for companies to implement energy management systems. Nevertheless, acceptance in companies has so far been low. According to a survey conducted by the German energy agency (Dena) in December 2012, only 14% of German companies made effective use of the benefits offered by energy management [6]. Whereas industrial ecology management as a further step is completely absent since there exists no standard framework for ecology management.

About 55% of Germany's economic output is generated by small and medium-sized enterprises [7]. Thus, one of the goals of this work is to show especially these economically important companies, methods to sustainably deal with energy. The main aim of this work is to develop a totally integrated ecology management model that enables companies to easily integrate ecology management into their systems and structure. This includes the development of an ecology management methodology and an ecology management software to support companies in every step of the plan, do, check and act cycle.

In this work first, the necessity of an active ecology management and means by which companies can profit from it will be examined in a comprehensive analysis of the legal and ecology-related political framework conditions.

The first step here is to identify the reasons for the lack of implementation of ecology management and complications that the companies face in its implementation. The goal of the solution approach is to overcome these challenges by developing a framework for industrial ecology management that encompasses energy management and environmental management holistically.

1.2 Outline of the dissertation

This dissertation is divided into six chapters.

The first chapter discusses the motivation and objectives of this work. It also describes the outline of this dissertation.

Chapter two explains the fundamentals of energy and environment management. The purpose here is to develop a common understanding by proposing definitions of the terms used in this work. Subsequently the important norms and standards related to energy and environment management are described, since these norms build the foundation of ecology management.

In chapter three the initial situation of the energy market in Germany is examined. Here the importance of reliability of energy supply for the companies, the impact of energy conversion on the environment by means of non-renewable resources and the economic impact of increasing energy prices on businesses, especially manufacturing companies is elaborated. Furthermore, in this chapter, the complications that companies face in the implementation of industrial ecology management are identified. Thereby, the 5Ms of cause-effect diagram are used as the base for this analysis. Through this analysis the gaps are identified and need for action as well as requirements on a solution approach are derived.

Chapter four focuses on the development of the solution approach, which is designed using the 7S model. The solution approach is called totally integrated ecology management (TIEM). It is a framework for industrial ecology management that delivers tools and methodologies for its operations. This approach addresses all the areas of an organization.

The TIEM software solution is presented in chapter 5 along with the cloud infrastructure developed for platform and location independent ecology management system. This chapter concludes with a prototypical implementation and evaluation of this web-based software solution using an industry 4.0 compatible demonstrator.

In the sixth chapter, the present work concludes with a summary and an outlook on future research approaches in the field of ecology management.

2 Fundamentals of energy and environment management

Energy management and sustainability are the focus of the research in this work. In this chapter the fundamentals of sustainability and energy management as well as the definition of the terms used in this work are explained. The norms and standards relevant to the topic of energy management and sustainability are elaborated here as well.

Energy, which means efficiency originated from the Greek word Energeia. It represents the amount of work a physical system can do. It can neither be created nor destroyed. It can be converted and has the ability to produce external effects [8]. From a business point of view, energy is a production factor that causes costs for the company, which are referred to as energy costs [9]. Therefore, the colloquial term "energy consumption" is also used in the further course of this work to illustrate the associated energy costs of a company [10].

2.1 Definitions

Definitions of the terms “energy management and sustainability”, are proposed in this subchapter to establish a common understanding.

2.1.1 Energy management

The scientific literature contains many definitions of the term energy management. Over the years, the term itself has been extended primarily from the focus on efficient energy supply to the objectives of reliability, sustainability, transparency and motivation [2]. Table 1 shows a list of most significant existing different definitions of energy management.

Definition	Source
Energy management is the foresighted, organized and systematized coordination of procurement, conversion, distribution and use of energy to meet the requirements, while considering ecological and economic objectives.	VDI [11]

Energy management comprises the sum of all measures that are planned and implemented in order to ensure minimum energy consumption at the required output.	BMU [10]
Energy management influences organizational and technical processes and behavior in order to reduce the total energy consumption (including the energy required for production) and the consumption of raw materials and additives in order to continuously improve energy efficiency of the company from an economic point of view.	BMWi [12]
Combination of interrelated or interacting elements to implement an energy policy and strategic energy objectives, as well as processes and procedures to achieve these strategic objectives.	DIN EN ISO 50001 [13]

Table 1: Various definitions of the term energy management

The one common feature in these definitions is the focus on the implementation of energy-efficient technologies. Since there is therefore no internationally valid, uniform definition, the following explanation of term shall apply for this dissertation work:

Energy management is the targeted deployment of methods and measures for energy related objectives. It includes implementing energy efficiency improvement programs in companies while keeping the costs and uninterrupted energy supply in consideration. An energy management system comprises of definition, implementation, monitoring and controlling of energy policy and strategic energy goals. Thereby, the approach is transparent, systematic, sustainable, economical and continuous [14].

This definition of energy management covers both the economic perspective of companies and the environmental aspects that are important for the society. It shows that energy management is the application of a consistent and continuous implementation of various methods and measures necessary for sustainability.

2.1.2 Sustainability

The topic of sustainability has been the subject of much discussion in recent years. The first international reference to the concept of sustainability was made in the Brundtland Report of 1987. This presented a concept that for the first time placed the issues of conservation of natural resources and environmental pollution in the context of a global policy. The report published the following definition of sustainability that still applies today.

Sustainable development is a development that meets the needs of present generations without compromising the ability of future generations to meet their own needs [15].

The German Federal Parliament (Bundestag) developed the "three pillar model" (see Figure 2) of sustainability in 1995, which gave the concept of sustainability, its interdisciplinary character.

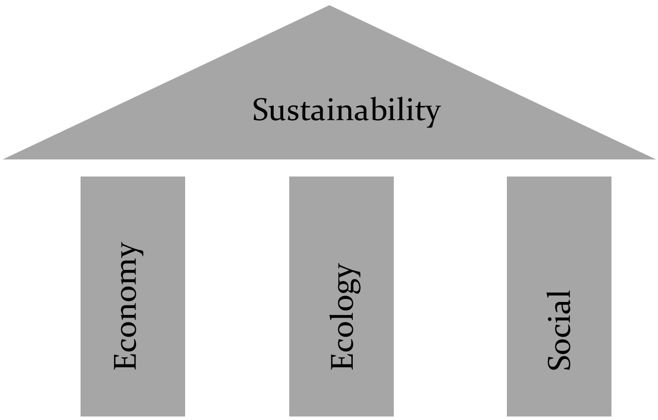

Figure 2: The three pillars of sustainability [16]

The ecology pillar

The ecological objectives include the conservation of natural resources, environmentally compatible production along with mobility and the consideration of natural regeneration cycles.

Under the ecology aspect companies focus on reducing their carbon footprint and overall waste of natural resources. It is evident that conscious handling of resources not only have environmental benefits but also have economic benefits for the companies. For instance, reducing the amount of material used for packaging results in reducing the procurement costs.

The social pillar

The most relevant issues for society are health and demographic change. The social pillar of sustainability describes the way a business should treat its stakeholders such as employees and the society where it operates. Taking care of the local environment by treating wastes and disposing them safely is considered essential by the society.

On a global scale, corporations need to be aware of the working environment of their suppliers. The significant benefit to the environment can only be achieved if the whole supply chain is focused on sustainability.

The economy pillar

Many organizations consider the economic pillar of sustainability as the most important one. One of the main objectives of businesses is to be profitable; however, profit by harming the other two pillars is not acceptable especially in the modern market environment, where the consumers demand products that are manufactured using environmentally friendly production processes. Therefore, the economy pillar of sustainability puts focus on environmental and energy management efforts of a company.

2.1.3 Industrial ecology

There are many definitions of industrial ecology in the literature. However, they all focus on similar elements. Since there is no unique internationally valid, uniform definition , the following, definition of this term adapted from [17] shall apply to this work.

“Industrial ecology aims to inform decision-making about the environmental impacts of industrial production processes by tracking and analyzing the usage of resources and flows of industrial products, consumer products, and wastes. Quantifying the patterns of use of materials and energy in businesses” [17].

The objective of industrial ecology is to integrate the environmental concerns of the society into the economic activities of businesses. This requires the introduction of industrial ecology management (IEM) in businesses.

“IEM encompasses all activities of energy management and environment management”.

The reduction of the impact of industry on the environment through innovation, efficient use of resources and sustainable growth is the aim of industrial ecology. This field of study acknowledges the fact that industry will continue to grow as it is important for the global economy and wellbeing of societies and thus supports industry that is environmentally friendly and cause no burden on the planet. Industrial ecology views industry as a part of the ecology and not as a solitary entity.

Industrial ecology as proposed in this work covers holistically, the industrial management of sustainability concepts such as energy management and environmental management. It also encompasses tools such as energy and material flow analysis, environmentally sensible technologies, design for disassembly and dematerialization.

The principles of industrial ecology are [18]:

- Impact of business on the environment - Improve the carbon footprint of the business. Balance the use of resources with the natural recovery capacity. Increase awareness of the impact of waste on the environment and develop programs to reduce waste.
- Efficient use of material – use less material by increasing efficiency, reducing and reusing waste material and substituting material with more environmentally friendly material.
- Improve processes – redesign process and products to achieve ecology goals.
- Use of energy – Improve energy efficiency and incorporate energy management in business. Use environmentally friendly energy sources.
- Industrial ecology as integral part of business – Develop policies that align with industrial ecology. Integrate energy management and environment management into the corporate strategy and structure. Promote ecology management with the organization by introducing programs that involve all stakeholders.

Methodologies and concepts for the implementation and management of industrial ecology would be referred to as ecology and ecology management in the further course of this work.

2.2 Norms and standards

To fully comprehend energy management and sustainable production. It is important to analyze and develop a comprehensive understanding of the use and requirements of the national DIN (Deutsches Institut für Normung – German Institute for Standardization) and international ISO (International Organization for Standardization) norms regarding resource efficient and environmentally friendly production. The most significant norms in this area are described in the following.

2.2.1 International energy management standard DIN EN ISO 50001

According to the European Energy Efficiency Directive (EED) and the German energy services act (EDL-G), all German companies have an obligation to contribute to energy efficiency. This also affects, for example, non-energy-intensive companies such as, banks, insurances, supermarkets, food and beverage producers, furniture, hotel chains, etc. The current legal requirements point to the introduction of DIN EN ISO 50001 standard.

The DIN EN ISO 50001 is a globally valid standard that aims to support organizations and companies in setting up a systematic energy management system. The European Committee for Standardization has worked out the standard for energy management and published it in 2009 as EN 16001:2009 [19]. In 2012, this norm was replaced by DIN EN ISO 50001. Consequently, the existing 16001 certificates lost their validity and had to be renewed as a part of an audit. This was not an obstacle for companies that were already certified since the contents of the two standards are essentially the same. Certification is particularly important for energy-intensive companies [20]. Because they can benefit from a compensation scheme in the Renewable Energy Act (EEG in German). Since 2013, companies can similarly be exempt from the energy tax known as electricity peaks tax compensation if they fulfill the requirements of DIN EN 16247-1 or DIN EN ISO 50001. In 2016, however, only about 9,000 organizations were certified. Considering that the total number of medium-sized and large companies is about 75,000, the certification rate is only about 12% in Germany [21].

The principles of DIN EN ISO 50001 are essentially based on a quantitative and qualitative assessment of the energy flows within a company, i.e., the energy sources, distributors and sinks. Their evaluation and development of optimizations measures are within the framework of this norm. Resulting optimization measures may be of a technical, economical or organizational nature.

The task of the bodies responsible for energy management is to create a suitable documentation management system and an appropriate process organization. The overall objective of all these measures is to optimize the company's energy efficiency and to make a positive contribution to the climate policy targets. An energy management system can also make an effective contribution in reducing costs, through optimization of the production and business processes regardless of their energy consumption.

The structure of the DIN EN ISO 50001 is based on the Deming's PDCA cycle as illustrated in Figure 3 and thus resembles other management systems such as DIN EN ISO 9000 and DIN EN ISO 14001.

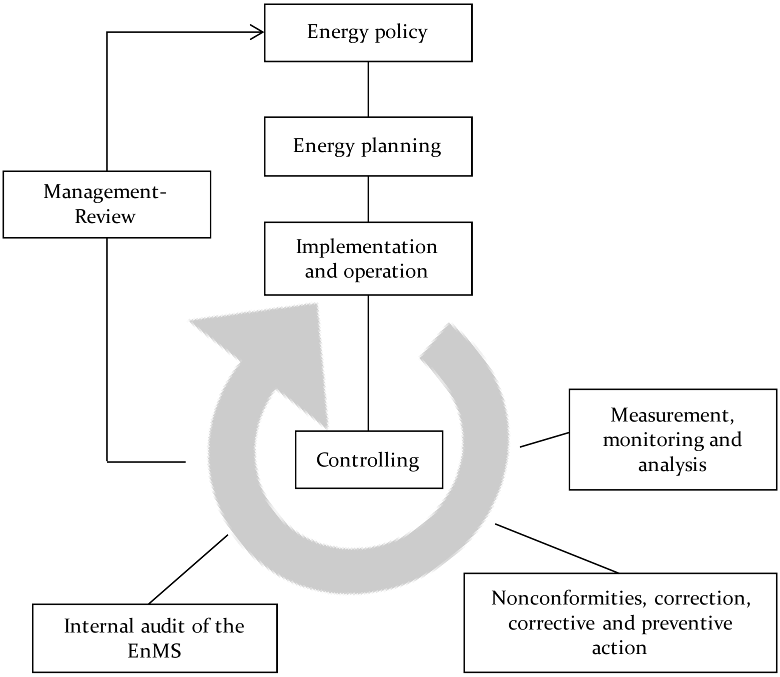

Figure 3: PDCA cycle according to DIN EN ISO 50001 [13]

Plan: setting targets and appropriate measures, responsibilities and procedures.

Do: implementing the optimization measures and procedures.

Check: verification of the responsibilities and procedures as well as the measures regarding the energy targets and energy policy of the organization.

Act: adaptation of responsibilities, procedures, measures and where appropriate the objectives and guidelines

Due to their similarity, DIN EN ISO 50001 can easily be integrated into the other management systems. This standard provides companies with a set of requirements regarding:

- Energy policy
- Objectives to achieve a consistent energy efficiency
- Energy measurements to achieve energy transparency

- Energy data usage and energy monitoring
- Management reviews
- Continuous improvement processes [13]

The structure of the PDCA cycle is found in the composition of the norm. The basis for this are the "General Requirements" that essentially state that the system boundaries of the energy system should be defined and that EnMS must be documented, implemented, maintained and improved. The EnMS is intended to define the energy target in the sense of a continuous improvement process. It is the responsibility of the management to appoint a representative for the implementation and application of EnMS.

Energy policy sets the commitment of the organization to achieve improvements in its energy performance. The policy forms the basis for the strategic and operational objectives. In energy planning, the processing of legal regulations and energy assessment based on an initial energy consumption baseline along with suitable EnPIs are considered. Determination of the requirements for operational and strategic energy targets as well as action plans are based on energy assessment.

Documentation and communication are essential elements of an EnMS. A suitable documentation structure and process organization guarantees control and traceability.

Organizations are required to show a Continuous Improvement Program (CIP) to obtain DIN EN ISO 50001 certification. In order to show continuous improvement, a comparison between the achieved and not achieved energy targets is essential. Therefore, it is necessary to setup an energy measurement and monitoring system, as a part of EnMS, for the analysis of the optimization measures and their results. Furthermore, organizations are required to review, in a yearly management review, the continued suitability, appropriateness and effectiveness of the EnMS.

Since the publication of DIN EN ISO 50001 further extensions of this standard has been developed. These standards complement the DIN EN ISO 50001.

DIN EN ISO 50003 describes the requirements for auditing and certifying bodies of EnMS. This International Standard is intended for the use in conjunction with ISO/IEC 17021-1 [22]. The DIN EN ISO 50003 standard specifies additional requirements that reflect the specific technical area of EnMS and are necessary to ensure the effectiveness of the audit and certification. In particular, the planning of the audit process, the initial certification audit, the implementation of the on-site audit, the auditor's competence, the duration of EnMS audits and random checks at several of the facilities are the essential parts of this.

DIN EN ISO 50004 is a systematic approach to the continuous improvement of an energy management system [23]. It serves as a practical guide and should help make the EnMS as simple as possible while meeting the requirements of DIN EN ISO 50001 at the same time. For example, the standard recommends the sensible definition of system boundaries, energy influencing factors (such as material properties, process parameters or operating hours) as well as the assessment of legal requirements. Thus, DIN EN ISO 50004 specifies the requirements of DIN EN ISO 50001 in concrete terms, contains various examples and suggestions including about energy policy, internal audits, management reviews, organization and so on.

DIN EN ISO 50006 provides a practical guide to the development, use and adaptation of EnPIs and Energy Baseline (EnB) which is also referred to as energy consumption baseline or energy starting point [24]. Figure 4 shows the correlation between EnPIs and EnB. EnPIs are values or measures that quantify results in terms of energy efficiency, energy use, and energy consumption in systems and processes such as electricity consumption per employee per year. The EnB provides a reference point for quantifying the success of the EnMS. This means that changes can be viewed over a selected period of time. Together, they form the key elements of DIN EN ISO 50001 and enable an exact measurement and analysis of the energy-related performance of an organization. The following diagram illustrates the relationships between EnPIs and EnB.

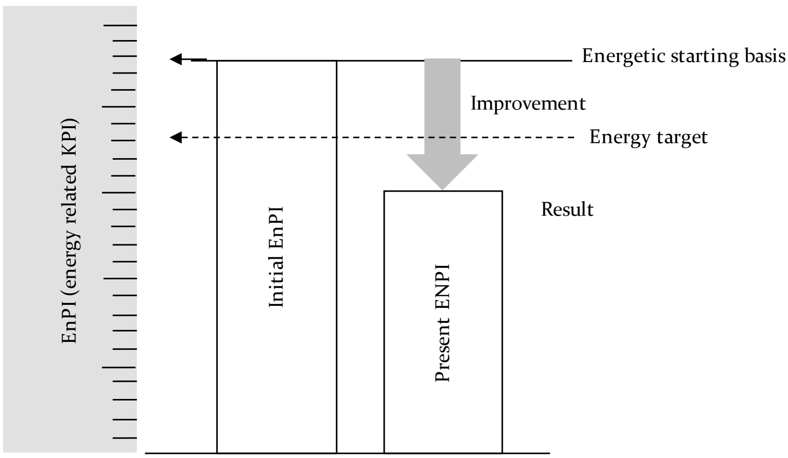

Figure 4: Correlation between EnPIs und EnB according to DIN EN ISO 50006 [24]

DIN EN ISO 50015 establishes a common framework for Measuring and Verifying (M&V) energy efficiency and improving the organization's energy-related performance [25]. This does not apply uniform calculation methods; nevertheless, provides a uniform understanding of M&V and how M&V could be applied to different calculation methods. The focus here is on the creation of uniform M&V principles, the preparation of the M&V plan and its implementation including analysis and reporting. In this process, DIN EN ISO 50015 relies largely on DIN EN ISO 50006. For comprehensive energy measurement, the following six steps are necessary:

1. Drawing up and documenting the measurement plan
2. Data collection
3. Implementation of Energy Performance Improvement Actions (EPIAs)
4. Perform analysis
5. Reporting results and documentation
6. Checking whether results are valid or whether measurement must be repeated

2.2.2 Environmental management system

In addition to EnMS the environmental management system (EMS) is necessary for sustainable production. DIN EN ISO 14001 is the norm for EMS that is applied worldwide. It was published in 1996 and was last updated in 2015. By implementing, the suggestions laid down in EMS, companies can improve their environmental performance, fulfil (legal) obligations and achieve their environmental goals [26]. It is worth mentioning that DIN EN ISO 14001 does not lay down any absolute requirements. Thus, two companies with similar structures and setups can achieve different environmental goals but still get certified similarly. It applies to organizations of all types and sizes, with various geographical, cultural, social and environmental conditions. DIN EN ISO 14001 is essentially based on the PDCA cycle and its structural layout is very similar to many other norms.

In addition to DIN EN ISO 14001, the following standards are available:

- DIN EN ISO 14004- Environmental management systems: General guidelines for implementation.
- DIN EN ISO 14005 - Guidelines for the phased introduction of an environmental management system - including environmental performance assessment.

DIN EN ISO 14005 additionally includes an approach to assess the maturity of an environmental management system [27, 28].

Eco management and audit scheme

Apart from EMS, Eco Management and Audit Scheme (EMAS) is also an instrument for optimizing the environmental performance of organizations. It was developed in 1993 in a joint EU project. The current legal basis is the regulation (EC) No 1221/2009. EMAS goes beyond a pure management system. The standard EMAS cycle as shown in Figure 5 consists of ten focus areas.

The basis for successful EMAS certification is the creation of an environmental declaration by means of which the operational data is measured and evaluated. These include, for example, source of energy supply, energy consumption, emissions and wastes. It requires an evidence of compliance with legal environmental regulations.

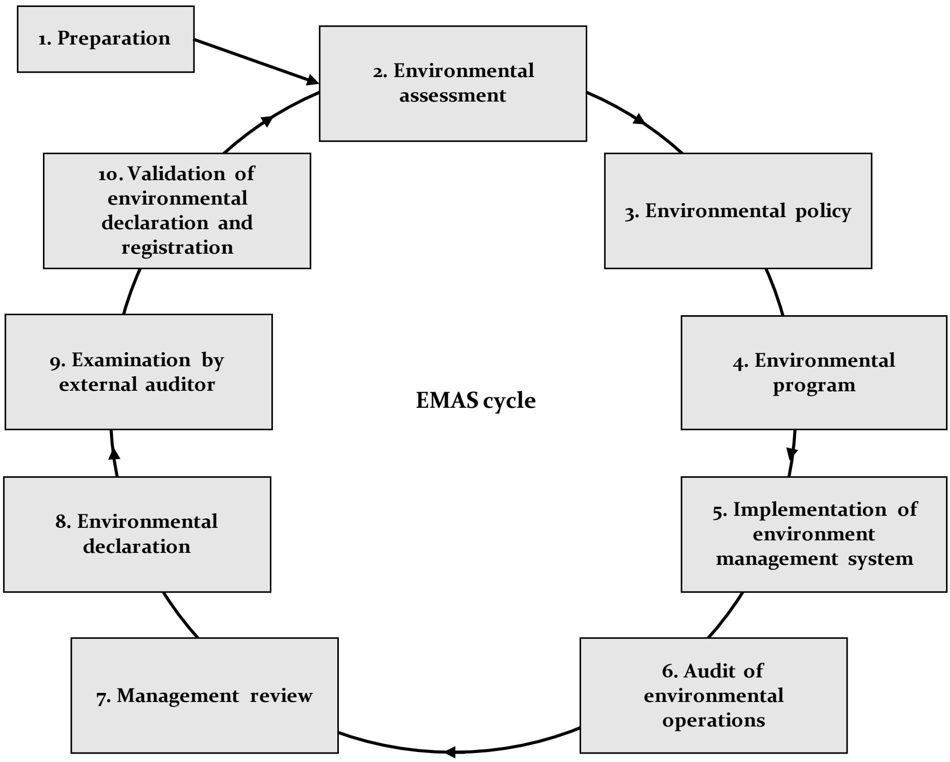

Figure 5: EMAS cycle, according to [29]

EMAS certification is generally considered to be of a higher quality than DIN EN ISO 14001 certification and continues to be considered increasingly in public tenders. EMAS certified organizations, can acquire with low additional effort and cost the DIN EN ISO 14001 certification.

After an initial internal assessment of the environmental performance (environmental audit), EMAS requires that once every year the internal audit is carried out to evaluate the environmental performance of the organization. An external audit by an independent, state-approved environmental auditor is required every three years. For companies with fewer than 250 employees, upon request may carry out an internal environmental audit every two years and an external audit every 4 years [29]. Upon successful EMAS certification, the organizations are listed in the EMAS register.

Organization in that list can use the EMAS logo for marketing purposes. The main difference to DIN EN ISO 14001 is that EMAS is results-oriented. This means that a continuous improvement in environmental performance is a requirement, such as reducing emissions of pollutants and reducing waste. It is necessary to provide not only a declaration but also proof of the management's compliance with environmental regulations. Table 2 lists the main differences between DIN EN ISO 14001 and EMAS.

	EMAS	**DIN EN ISO 14001**
State	Legal bases in the EU-law Nr.1221/2009	No legal bases
Environmental policy	Commitment by the organization to continuous improvement of environmental performance	No commitment required, only system performance is considered
Internal initial test	Required	Recommended
Environmental aspect	Identification and evaluation of environmental aspects, establishing criteria for evaluation	Necessary since 2015
Consideration of environmental regulations	Evidence required by compliance audit	Declaration of intent

External communication	Dialog with the public	No dialog with the public, just with relevant external partners
Continuous improvement	Annual increase in performance required	Improvement is required. However, a time period iso not clearly defined
Management review	By performance audit	Environmental performance is required in management review; however, performance audit is not required
Contractual partners and suppliers	Influence on the contractual partners and suppliers is required	Communication of information of relevant processes
Inclusion of employees	Yes	No
Internal auditing	• System audit • Performance audit • Environmental Compliance audit	System audit
Auditor	Independent external auditor is required (certified environmental expert)	Independent external auditor is recommended but not required (accredited by DAkkS)

Table 2: Difference between DIN EN ISO 14001 and EMAS, based on [26, 29]

2.2.3 Energy audit

The standard procedure for auditing management systems is specified in DIN EN ISO 19011. It is based on the PDCA cycle with the aim of continuous improvement. The intent of this audit is to enable companies to focus on key areas and processes and make significant contributions to the success of business. Figure 6 illustrates the procedure of an audit according to the norm:

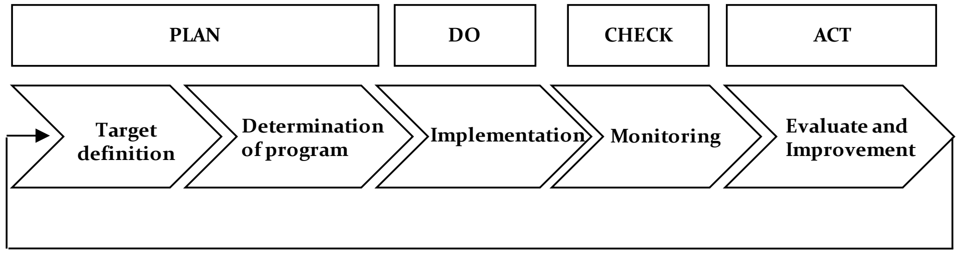

Figure 6: Audit procedure according to DIN EN ISO 19011 [30]

To meet the special requirements of energy audits, a separate standard, the DIN EN 16247-1, was published in 2012 and subsequently enhanced in 2014 to include the special requirements of buildings, processes, transport and the competence of energy auditors. Since December 2015, companies that are not SMEs, according to the EU definition of SME, are required by law to carry out energy audit according to the DIN EN 16247-1. Companies that already operate a certified EnMS or EMAS are exempt from this regulation.

The execution of an energy audit according to DIN EN 16247-1 is a means for organizations to meet the requirements of the German electricity and energy tax act for peak compensation. An energy audit is a methodological process that is implemented to optimize the energy efficiency in companies and organizations of all sizes. This process is shown in Figure 7

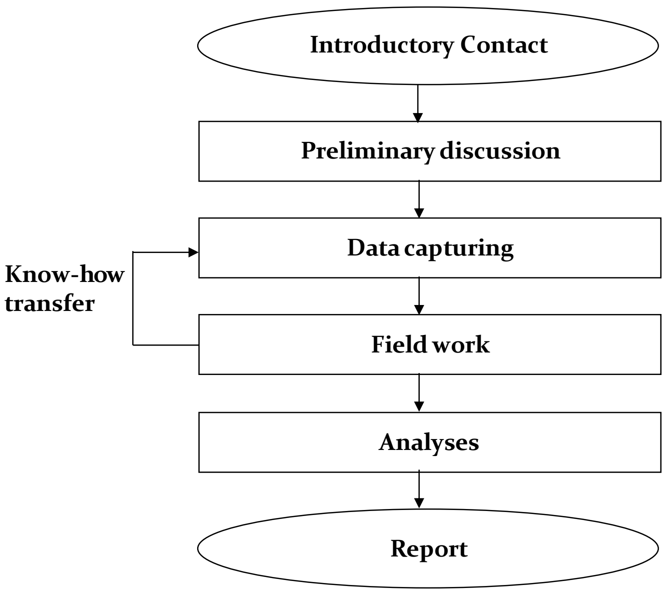

Figure 7: Procedure of energy audit according to EN 16247-1 [31]

The energy audit is considered as the first step towards energy transparency and the first stage of the implementation of an EnMS in organizations [32]. It involves systematically measuring the energy input and consumption of a system. DIN EN 162471 consists of the scope of application, normative references and definitions of terms. It explains the quality requirements for the auditor and the audit process.

During the process of energy audit, first, in an introductory contact, the objectives, requirements, expectations, system boundaries, the implementation period, the degree of thoroughness and evaluation criteria are outlined and documented. In a subsequent discussion, specific details such as personnel details and areas of responsibility, as well as agreements regarding data security, access rights and operating resources are documented. This is followed by data collection and measurement of energy consumption of the production plants.

Based on the data collected, the main energy consumers are identified and optimization measures for them are developed. These optimization measures are documented in an energy audit report according to their importance along with their economic and ecological impact. An energy audit report is prepared after the completion of the audit process. This report forms the basis for further energy-related performance optimization. Basic contents of this report are:

- A summary of energy efficiency improvement potential
- General information on the background of the company and the audit
- Methodology, auditor, objects and standards.
- Areas of application of energy audit
- Energy key figures and information on their acquisition
- Analysis of energy consumption and optimization approaches
- Conclusions and next steps

3 Situation, challenges and need for action

This chapter provides an overview of the initial situation in Germany and the impact that energy conversion and consumption have on environment and economy. Furthermore, this chapter provides an outline of the complications that companies face in the implementation and application of ecology management system.

3.1 Initial situation

In recent years, the importance of sustainable management has become increasingly important for German companies, as society in particular places increasing importance on clean environment and on the sustainability aspects. Despite the high acceptance and demand for clean energy by the society, Figure 8 shows that only a small share of about 29% of the total consumption of electrical energy is generated by using renewable and clean resources.

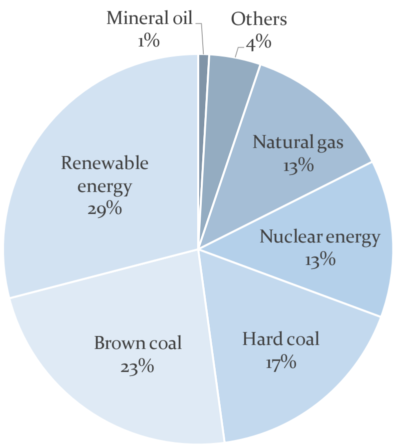

Figure 8: Share of various resources in the generation of electricity [33]

As a first step towards cleaner, safer energy resources, the German government has set for itself a goal to shut down all the nuclear power plants by the year 2022 [3] and phase out coal based power plants by the year 2038

[4]. This planned phasing out of nuclear and coal power, however, will create as a result an energy supply gap. The aim is to minimize this gap by reducing the overall energy consumption through increasing energy efficiency, especially in the industrial sector and close the remaining energy supply gap ideally by renewable energy resources. Nevertheless, the shift towards environmentally friendly resources must in no way jeopardize the reliability of energy supply.

3.1.1 Reliability of energy supply

The competitive advantage and strength of German industry is based on products with high quality standards. This competitive advantage is achieved through a high degree of automation in German industry. Therefore, an unhindered supply of energy is necessary for German industry to remain competitive in the global market. Thus, energy supply is a critical factor for economic competitiveness. A survey of 266 companies confirms the high priority given to a failure-free energy supply, in particular to the supply of electricity [34]. Only about 28% of the total energy requirement of Germany is met by inland energy generation as shown in Figure 9.

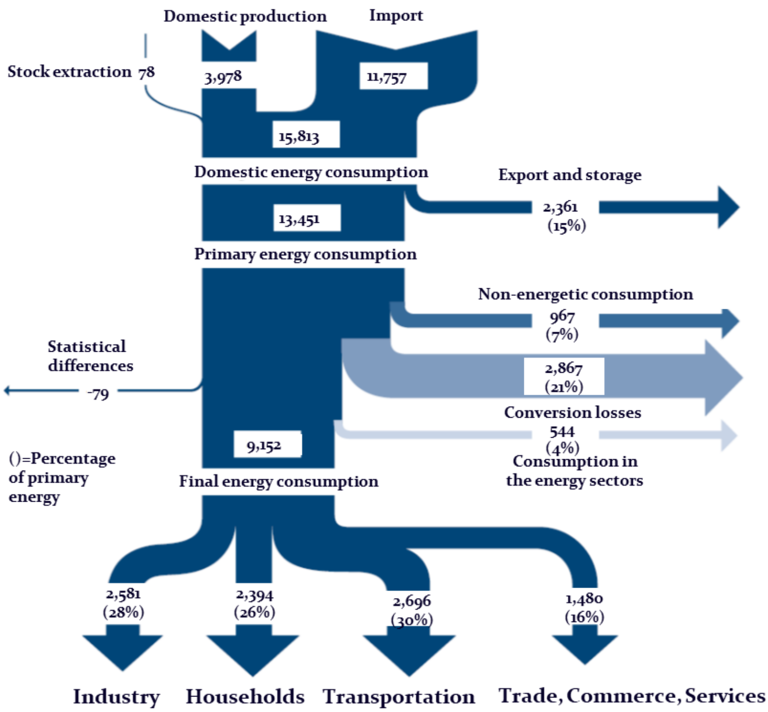

Figure 9: Energy Flowchart for Germany in 2016 in PJ [35]

Due to a high share of energy imports of about 72%, the German national economy is additionally exposed to fluctuating prices on the global market and to a supply risk [9].

Figure 9 shows in an energy flow chart, that industry at 30% has the second highest share of final energy consumption in Germany. In terms of electricity consumption, this share is even bigger, with a consumption of 233 TWh, it amounts to around 44% [36]. In addition to the political policies in place that are responsible for the attractiveness of Germany as a market location, the industry itself must therefore become active to remain attractive in the global market. Strategic energy management is therefore necessary for the industry to produce energy efficiently.

3.1.2 Economic impact

Another aggravating factor is that the proportion of energy costs to the total costs in German industry has doubled in the last ten years (see Figure 10). In industries like paper, the share of energy costs to the total cost is already almost 15% [37]. To remain competitive in the global market, efficient use of energy and resources had to become one of the top priorities for businesses, especially for manufacturing industry. The focus here should not only be on the use of renewable resources, but also on saving energy and the responsible use of other natural resources.

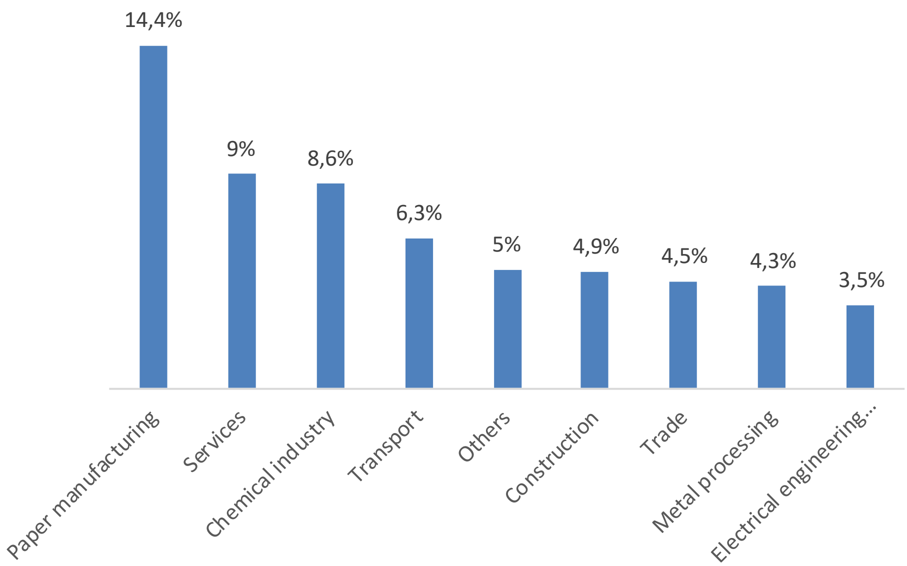

Figure 10: The share of energy costs in total enterprise costs continues to rise [37]

The energy costs in Germany, as shown in Figure 11, are high in comparison to international standard for the industry. Compared to other European countries, electricity prices for German industry are around 14% higher than most of its competitors [14].

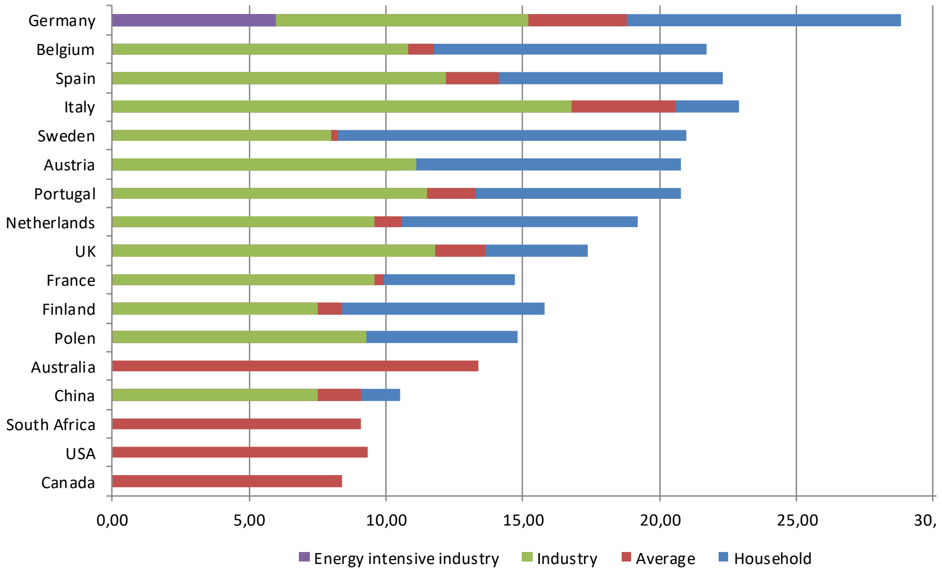

Figure 11: International energy price comparison (€ct/kWh) [38, 39]

Through the planned expansion of renewable energies, an additional increase in energy costs is predicted which in return places enormous stress on manufacturing companies [13].

According to the German renewable energy act (EEG), the share of renewable energies in electricity supply should be increased from 29% in 2018 to at least 35% in 2020 [40]. In addition, the share of renewable energies in total gross energy consumption should be increased to at least 18% by 2020 [41]. Since regenerative energy sources are intended to gradually replace not only nuclear energy, but also other fossil fuels that are detrimental to the environment, this increase in share of renewable energy resources alone is not enough to fulfill energy requirement of the country. Thus, industry in particular will have to make a major contribution to the energy transition through energy savings [42]. Energy efficiency is therefore another pillar of the desired energy transition. A market-economy solution that creates incentives to increase energy efficiency is therefore of utmost importance [12].

To find out why the energy costs are much higher in Germany in comparison to its competitors, the first step is to analyze the composition of the electricity price. In simplified terms, the electricity price here consists of the following three main components:

- Costs of electricity generation and distribution
- Costs for the use of the grids
- Taxes and duties

The cost of electricity generation, transport and distribution are not higher here than the international standard. Figure 12 shows that in Germany, the largest share, and thus almost half of the costs are accounted for by the "Taxes and duties" and thus represents the decisive difference compared to other countries.

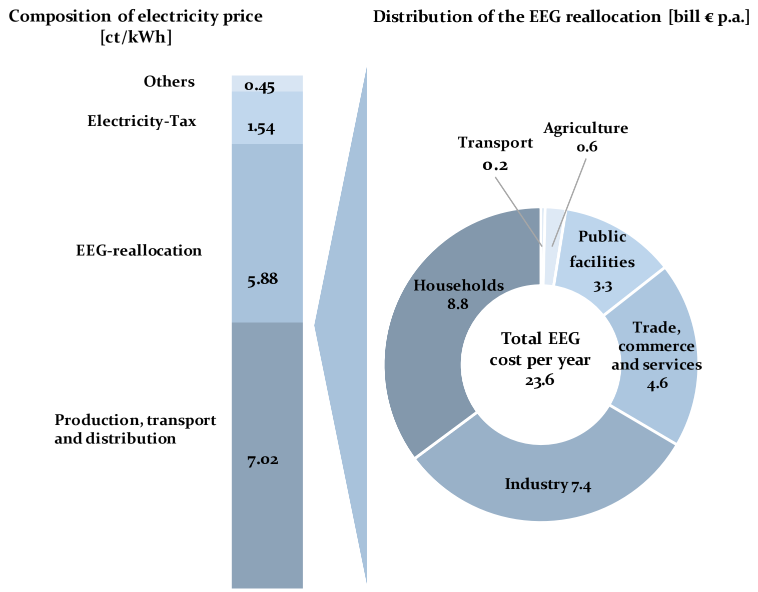

Figure 12: Composition of electricity price and EEG tax burden [39]

Electricity tax and the EEG surcharge, introduced as part of the planned energy transition, are particularly noteworthy here. These additional costs, which are added to the price, represent a considerable competitive disadvantage for Germany as a production location, since these costs either do not exist at all or are considerably lower elsewhere in the world. The total

EEG surcharge sums up to around 23 billion euros in the year 2018. These funds are used to finance the development and expansion of renewable energies in Germany. The EEG surcharge costs the industry around seven billion euros per year. Although this is an extra burden on the industry, these costs can be reduced enormously by implementing the DIN EN ISO 50001 energy management system. The EEG is considered as an incentive for the industry to push them to implement energy management system and reduce their overall energy consumption.

A special compensation scheme under the EEG applies to companies that consume more than one GWh of electricity per year. For example, the EEG stipulates in accordance with German energy law, that a reduction of the EEG surcharge is only possible “if a certification has been carried out by means of which the energy consumption and the potentials for reducing energy consumption have been identified and evaluated" [43, 44]. Furthermore, companies seeking EEG reduction are obligated to show, in a yearly energy audit, the implementation of a continuous improvement program that complies with the Plan Do Check Act (PDCA) cycle as proposed in the DIN EN ISO 50001 norm. An auditing and certification body carries out this audit [41]. Certification according to this norm is mandatory for companies that have an energy consumption of 5 GWh or more.

Tax relief for companies in the manufacturing industry is granted according to both §55 of the energy tax act and §10 of the electricity tax act only if the operation of an energy management system that meets the requirements of ISO 50001, is proven [45, 46]. Companies with lower energy consumption may have themselves certified according to an alternative system, usually DIN EN 16247-1. By setting up EnMS, companies are entitled to the reduction or reimbursement of the EEG surcharge if they fulfill the following requirement:

- Energy consumption > 1 GWh
- Share of energy costs in gross costs of at least 14-20% (depending on industry)
- Certified EnMS or Environmental Management System (EMS or EMAS)

The exact limits are complex and depend on the industry, Electricity Cost Intensity (ECI) as well as product and Gross Value Added (GVA) of the company. Table 3 provides a brief overview of the amount of the EEG surcharge for companies with high electricity costs in accordance with §64 EEG [43].

Energy consumption	Amount of the EEG surcharge	Limitations
Less than 1 GWh	Non-refundable	-
More than 1 GWh	15-20% (depending on industry, product and electricity cost intensity)	• Maximum EEG surcharge: • 0.5% of GVA if ECI > 20% • 4% of GVA if ECI <20% • Minimum EEG surcharge: • 0.05 Cent/kWh (production and processing of aluminum, lead, zinc, tin, copper) • 0.1 Cent/kWh (other points of sale)

Table 3: Refundable EEG surcharge according to [43].

The efforts in this area not only pay off with a better, greener image for these companies, but also have significantly good financial impact. These measures can mitigate part of the competitive disadvantage by reducing energy costs considerably. The use of such systems is therefore very important for German industry to stay competitive in the international market.

3.1.3 Environmental impact

Environmental compatibility is an important objective of ecology policy. Due to the worldwide increase in energy demand and the associated utilization of fossil fuels, the emission of harmful greenhouse gases increased drastically. Greenhouse gases include carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). CO_2 accounts for the largest share of greenhouse gas emissions and accounts for more than 80% of the total share of greenhouse gases. Increasing temperature and thus droughts and floods that are caused by melting icecaps, are among the consequences of the climate change, which are associated with rising greenhouse gas concentration [47].

A global problem such as global warming can only be tackled effectively through global actions. In the early 1990s, 166 countries signed and continuously revised the United Nations Framework Convention on Climate Change (UNFCCC). At present, 196 states are bound by this treaty. The secretariat of this convention is currently based in Bonn. They have recommended national regulations and laws [48]. For example, the German government has set a goal of quantitative reduction in greenhouse gas emissions by 2020 with the "Integrated Energy and Climate Program" (IEKP) in 2007 and 2008 [49, 50]. The intent is to reduce emissions to a level which is 40% below 1990's level [51]. In further guidelines and action programs, the German government last committed itself in 2016 to achieve its climate goals by the year 2050 [5].

In addition, European directives extend the area of action in climate protection and bind the member states of the European Union to further measures for achieving the climate protection goals. For example, Article 8 of Directive 2012/27/EU Energy Efficiency Directive requires regular energy audits for companies that are not SMEs[1] [52]. These must be carried out cost-effectively and independently by qualified and accredited experts. The quality criteria of which is monitored by independent authorities in accordance with the national law. This directive defines energy audits as "a systematic procedure for obtaining sufficient information on the existing energy consumption profile, of an industrial process or industrial or commercial installation in industry or trade, to identify and quantify the possibilities for cost-effective energy savings and to document the results in a report" [52]. Furthermore, energy audits must be conducted according European and international standard by means of EN 16247-1 norm. Companies that have a certified EnMS are exempted from this energy audit obligation, since EnMS certification process already includes a yearly audit. The aim is to motivate SMEs to implement EnMS through incentive systems and support schemes.

In Germany, the generation of electricity has by far the largest share of CO_2 emission [23]. In 2015 as part of the climate conference in Paris, a pledge was made by most countries of the world to limit global warming to a maximum of 2°C, by reducing CO_2 emissions. To achieve this goal, the German government under the burden-sharing agreement plans to reduce its emissions in areas subject to non-emission trading by 14% until 2020 as compared to 2005 [53].

Reduction of greenhouse gas emissions can be achieved by reducing energy consumption. The share of CO_2 emissions of the manufacturing sector, as

[1] SME: small and medium-sized enterprises as defined in Title I of the Annex to Commission Recommendation 2003/361/EC of 6 May 2003 are enterprises employing fewer than 250 persons and having either an annual turnover not exceeding EUR 50 million or an annual balance sheet total not exceeding EUR 43 million.

shown in Figure 13, at 21% is small in comparison to the energy sector. However, a reduction in energy consumption in the manufacturing industry would lead to a reduction in energy demand, which in return would reduce the amount of greenhouse gas emissions in the energy sector [12]. Therefore, a reduction of energy consumption through appropriate ecology management in industry is also important for the protection of the environment from an environmental point of view. Worldwide though, around 36% of energy-related CO_2 emissions are caused by the manufacturing industry [54].

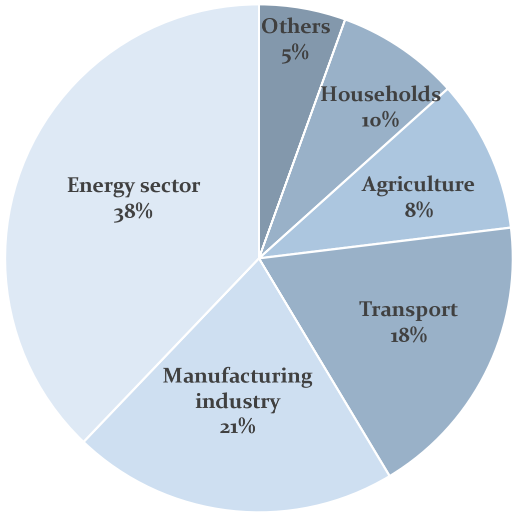

Figure 13: Energy-related CO2 emissions in Germany by sector in 2016 [54]

Social changes lead to a general increase in awareness of environmental and energy-related issues [55]. Stakeholders, such as environmental associations, actively promote the environmental sensitization and thus indirectly ensure greater transparency. They therefore influence consumer behavior and in some cases even call for boycotts [2]. All existing and potential customers thus have a strong influence on the behavior of companies regarding their environmental impact. The image of both the company and the product plays a decisive role. Organizations that are perceived by its customers as ecologically responsible and sustainable, enjoy often a socially positive image. This in turn has a direct influence on sales figures. Since, according to a study, 89% of customers in Germany want to know how companies fulfil their corporate social responsibility [56].

CO_2 emissions correlate with energy consumption. Certifications such as EMAS or DIN EN ISO 50001 can thus be used to demonstrate that a company assumes its corporate social responsibility. Differentiation from the competitors is possible through the development and marketing of innovative solutions in the field of energy efficiency [55].

3.2 Challenges in the implementation of ecology management

Parts of the corresponding requirements in Germany of the above-mentioned European directive is found in the National Action Plan for Energy Efficiency (NAPE) of 2014, which describes the energy efficiency targets of the German government and refers to funding programs. The promotion of energy management systems by the federal office of economics and export control (BAFA) is mentioned as an example. Based on a corresponding guideline of the federal ministry of economics and energy (BMWi), the introduction of an energy management system or the initial certification of an energy management system according to DIN EN ISO 50001 can be subsidized [57].

It is therefore undeniable that both the Federal Government and the European Union regard energy management systems as meaningful tools whose dissemination and application can contribute to increase energy efficiency and ultimately to a better and cleaner environment. Nevertheless, acceptance in companies has so far been low.

In industry, 91% of companies either have implemented or are planning to implement some measures to increase their energy efficiency [58]. Concrete energy efficiency measures are however, implemented to a very low degree. For example, only 12% of the motors installed in Germany are controlled by variable frequency drives [59] and only 32% of manufacturing companies use technologies to recover and use waste energy. The size of the company has an influence on the use of energy efficient technologies. The smaller the companies, the smaller the share [60].

According to a December 2012 survey by the German Energy Agency (Dena), only 14% of German companies benefited from the opportunities offered by energy management [6]. In the successor to NAPE, the National Energy Efficiency Action Plan (NEEAP), the share of companies operating predominantly locally or nationwide using an energy management system is stated at 27% [61].

By means of a thorough assessment of the situation, it can be derived that implementation of a systematic energy management would make a decisive contribution to the optimization of energy consumption making the production system of a company environmentally friendly, economically competitive and sustainable.

Although the solution to the energy problem is identified, it is however, inevitable that the question arises as to why only a few companies have so far been certified according to DIN EN ISO 50001.

Although there exists some framework for energy management, there is no standard framework for ecology management. Merely dealing only with energy is not enough to achieve the climate goals. Therefore, industrial ecology management framework is deemed necessary.

Nevertheless, there are many obstacles in developing and implementing industrial ecology management as shown in Figure 14 in an Ishikawa diagram. These obstacles are for instance, lack of transparency, organizational structure, corporate strategy, know-how and lack of ecology management framework. Depending on the significance and severity of the individual barriers, there is a dependency on company specific factors such as size, sector, energy cost share, corporate culture and external factors such as current energy prices and regional environmental laws [36].

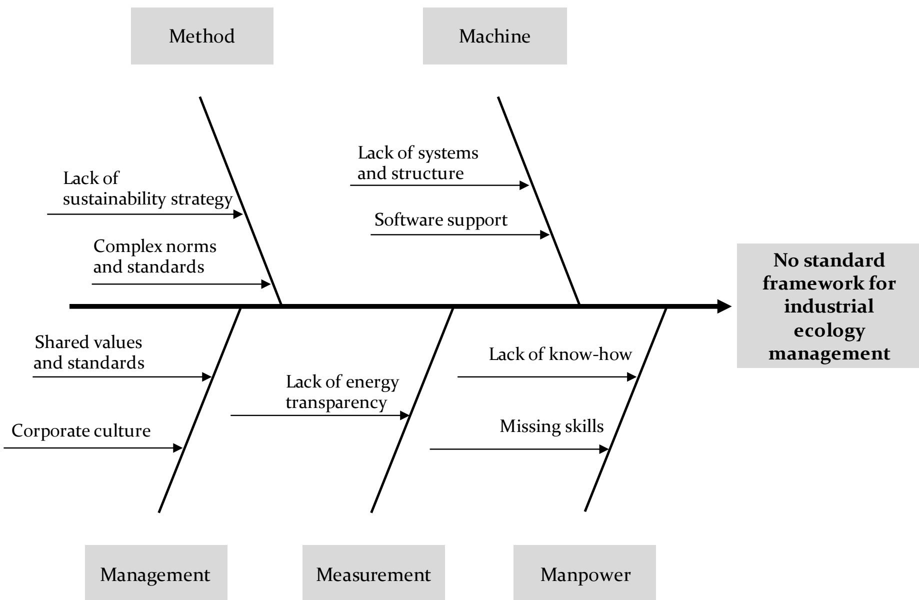

Figure 14: 5M analysis of the complications regarding ecology management

Lack of transparency and awareness

There is often a lack of awareness about the optimization potentials available in an organization, as these are only accessible through measurements, subsequent analysis and interpretation of the obtained complex information. Thus, the resource savings potentials in companies are not assessed adequately.

Missing or incorrect information, for example on energy consumption and costs, are a barrier to the application of energy management [62]. Inappropriate preparation of available data leads to lack of transparency and the lack awareness about the importance and necessity of the implementation of ecology management. Consequently, many companies are unaware of their optimization potential and therefore do not take advantage of industrial ecology management.

A lack of a cause-related allocation of energy costs also obscures potential savings [63]. In companies, it is often assumed that the search for and preparation of information is associated with too high costs and therefore this search is not carried out [64].

Lack of know-how and skills

Even when organizations desire the implementation of ecology management and are motivated to use associated methods and implement measures, a lack of know-how poses a further obstacle, since there exists no standard framework for ecology management and environmental agenda of businesses [18]. This includes not only a lack of technical knowledge but also insufficient knowledge about the processes and workflows necessary for the implementation and practice of a successful industrial ecology management.

Due to the lack of know-how, wrong use of inappropriate economic evaluation criteria and tools may lead to wrong assessment of the benefits of EnMS and industrial ecology management. This may discourage companies from implementing energy and ecology management system [36].

Although the foundations for effective energy management are with DIN EN ISO standards 50001, 50003, 50006 and 50015 well prepared, these are not enough for the introduction of an effective ecology management since it is more than just energy management. These standards describe only generally applicable requirements for energy policy, energy audits, Energy Performance Indicators (EnPIs) and energy baseline without any concrete recommendations for action [65]. There is an extremely wide scope for interpretation, particularly in the development of strategy, resource planning and energy and ecology policy.

In the literature, many different definitions of ecology management are found and therefore there is no common understanding of ecology management and the tasks related to it in the industry.

Lack of sustainability strategy

To increase profit, organizations strive to produce goods or services with the best quality, with the minimum possible production costs and with minimum time to delivery. This relationship is shown in the QTC diagram in Figure 15. Addressing QTC triangle is an integral part of a company's strategy.

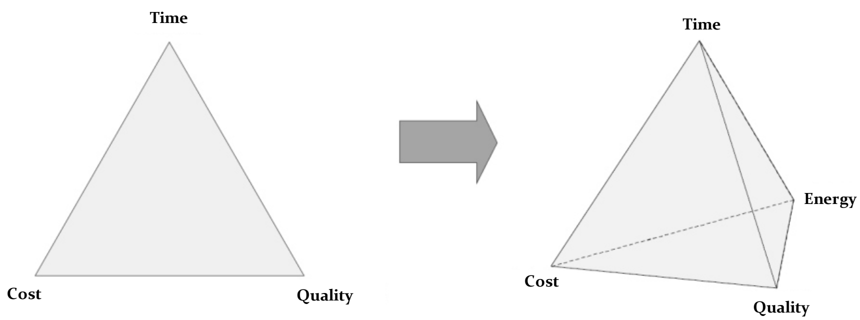

Figure 15: Expansion of Quality, Time, Cost triangle with the dimension energy [66]

The expansion of QTC triangle with a new dimension of energy to a tetrahedron, has introduced energy as a new field for the controlling of a business [66]. However, sustainable and environmentally friendly production that aims to implement industrial ecology management is thereby not a part of this new expanded version. Therefore, lack of an appropriate ecology strategy is one of the reasons behind the lack of implementation of IEM in organizations.

The energy management and the environment management standards define several requirements. Companies that aim to operate EnMS or go even further and implement the IEM, pursue the goal of enhancing their energy and ecology performance to improve their competitiveness as well as their impact on the environment. Therefore, the reduction of energy costs, greenhouse gas emissions and other environmental impacts are elements that needs to be addressed as a part of the industrial ecology strategy.

Sustainable development can only be achieved if the three pillars of sustainability are in harmony with the QTC triangle. The application of the sustainable production standards presupposes that companies strive to manage their environmental responsibilities in a systematic manner that contributes to the ecological pillar of sustainability.

Comparing the standards and guidelines of lean production with sustainable production, shows that many of the requirements overlap in both standards. For example, the application of the PDCA cycle and risk-based thinking are already a part of the quality management standard under the aspect of "process-oriented approach". Risk-based thinking is an integral part of sustainable production and is explicitly mentioned in EMAS, prescribing the determination of opportunities and risks as well as measures for dealing with them. The demand for continuous improvement process exists in both systems. However, the strategy for improving sustainability and energy efficiency is not a part of a solely lean based production system.

The introduction of IEM not only requires adapting existing elements of strategy, but also defining new ones. It is therefore particularly important that the elements of "improving energy-related performance" and "improving environmental performance" are integrated into the business strategy.

The current process of strategy planning has large gaps regarding sustainability. For instance, the energy evaluation as well as the development of the EnPIs, which are necessary for the determination of the energy baseline, are missing. The least energy usage method has proposed a solution to optimize energy usage for the production of a product [65]. Nevertheless, the definition of environmental aspects and industrial ecology are not considered. EnPIs and environmental aspects are important prerequisites for setting up ecology targets. They are important for pursuing the strategy of fact-based decision-making.

In order to achieve the ecology targets, IEM requires the introduction of ecology improvement action plans (EPIA), which are not mandatory in the current production systems. The aim is to document the responsibilities, means, timeframes for achieving the objectives and the methods for reviewing and verifying the improvement of the ecology-related performance. The challenge is to integrate the new objectives in harmony with the existing objectives of "high quality" and "customer orientation". Negligence of these will result is deterioration of quality and customer satisfaction making the competitive advantages of sustainable development meaningless.

Lack of appropriate structure and systems required for sustainable production

Often structural errors within a management system are found. The most crucial of them is the lack of transparency, which is very important for uncovering the potential for optimization. Although there exits methods for energy controlling like Keah* [66] and least energy allocation [65]. A framework which offers these methods to be integrated into the business process of a company are widely missing.

Ecology management is a continuous improvement process that requires the implementation of the PDCA cycle. This in addition requires a set of rules regarding information flow, setting up of goals, implementation of action plans, assessment of the achieved results using EnPIs and complete documentation of every step including management reviews. Energy planning process according to DIN EN ISO 50001, as shown in Figure 16, alone is a very complex task that requires resources and input from all hierarchical levels of an organization.

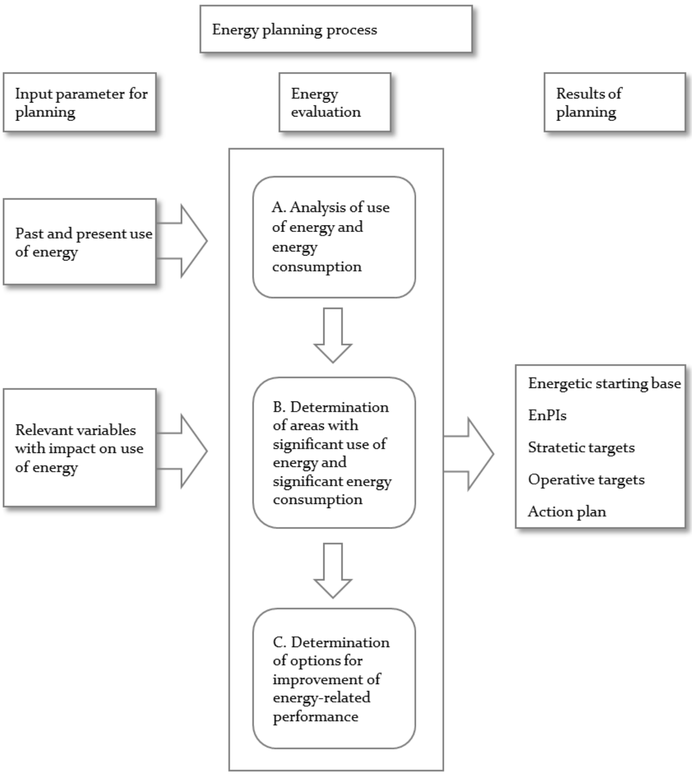

Figure 16: Energy planning process according to [13]

Lack of a structure for the ecology workflow and dedicated decision-making hierarchies is a cause of poor ecology performance and poor implementation of IEM. The lack of appropriate resource monitoring and benchmarking system as well as incomplete controlling concepts results in additional waste of resource.

Lack of sustainability focused corporate culture

A lack of interest on the part of management leads to low prioritization of sustainability goals [64]. Since top management is the role model, failure on their side result in the negligence of ecology management throughout the company as a consequence [63].

Lack of recognition of the staff that is actively involved in resource-saving measures and lack of incentives to encourage activities that improve the ecology performance of an organization leads to a poor acknowledgement of IEM by the staff in an organization. In addition, from a behavioral point of view, it is important for companies to recognize that changing existing behavioral patterns is essential. Often processes in an organization are regarded as fixed or hardly changeable entities. The motivation for changing them is often absent. In many cases, even resistance to changes are detected [62]. Overall, the lack of awareness of resource efficiency and the lack of its integration into the corporate culture is a barrier that hinders the implementation of ecology management. An ecology management organizational structure that is anchored in the company configuration offers a remedy for behavioral and motivational barriers. This combined with suitable information and motivational measures that aims to create a shared value of sustainable production can eliminate the resistance to change.

Lack of ecology management framework

One of the pillars of sustainability is ecology (see 2.1.2). Although companies and businesses opt to reduce resource consumption in order to reduce their energy costs, the ecological aspects are only considered if extra effort is not involved in achieving the ecological goals.

As shown in figure 1, the impact of business is significant on the environment and recognized methodologies to integrate industrial ecology management in companies does not exist [18].

To overcome these challenges a technical as well as an organizational approach, on a global scale, is necessary.

The environmental and sustainability policies of companies today are often determined by an individual issues that they face, as there is no established framework for implementing comprehensive programs.

Currently the environmental policy of companies usually includes objectives such as encouraging recycling, increasing energy efficiency and reducing waste. These actions merely treat the effects of the environmental pollution and are not sufficient to transform current businesses into environmentally friendly establishments, since strategic ecology and efficient resource management is not an integral part of corporations today.

Climate change was long regarded as a phenomenon of the 20th and 21st centuries. Researchers have now discovered that climate change began with the beginning of the industrial revolution as early as 1830 [67].

Yet very little is known about the various long term of effects of industrialization on the environment. Nevertheless, it can be stated that the key driver of environmental stress on the planet is the ongoing industrialization [18]. This means that in order to eliminate the root cause of environmental crises, significant changes in the industry must be made. The implementation of these changes needs to begin as soon as possible and therefore development of systematic solution approaches is more important now than ever.

Environmental concern is no longer a marginal condition but is now widely recognized and supported by society. State environmental legislations are increasingly becoming strict, forcing companies to act. As a result, large companies are beginning to respond. This in turn has created the need for developing solutions to align strategy, structure, systems and corporate values with the ecological and environmentally conscious resource management practices.

"The challenge now is to engineer industrial infrastructures that are good ecological citizens, so that the international demand for industrialization can be met" [18].

Missing software support

The lack of acceptance of energy management systems in companies is attributed to many different factors, which differ from case to case. This includes the lack of functionality of the software systems currently available in the market. An analysis of the EnMS market matrix of the Energy agency NRW illustrates the deficits in the current standard portfolio of energy management software systems [68].

The EnMS market matrix is intended as an aid for companies to search suitable solutions for their specific requirements via a comprehensive analysis of energy management software available in the market. However, none of the software systems listed in their database covers all the DIN EN ISO 50001 requirements and only one in five systems surveyed (see Table 13 - Appendix) meet the following minimum requirements that are necessary for comprehensive ecology management:

- The hosting concept is a local installation at the customer's site:

The company has full data control. Especially sensitive/strictly confidential data does not leave the infrastructure of the company.

- Access to data via internet/intranet (also administrative):

Networking is an important prerequisite for Industry 4.0. In addition, this type of access is essential for modern working methods with mobile devices.

- A list of possible cost-saving measures can be maintained and documented in the system:

Without the crystallization and processing of optimization measures, a system is limited to pure monitoring and does not bring about any active improvement in terms of ecology management.

- Document management is integrated in the system:

Missing document management system can result in data conflicts.

- Meter structures can be arranged in any number of hierarchy levels:

Full flexibility in data acquisition without restrictions is guaranteed. Only in this way it is possible to acquire data in high resolution.

- Displaying of measured values within the program interface is possible as a time-load curve:

The visualization of data directly in the system avoids the necessity of exporting data to an external system for subsequent graphical representation.

- User-defined key figures and their graphical evaluation can be generated:

Key figures serve as an indicator of the success of the implemented measures and it must be possible to appropriately define them.

Although many energy management software offer wide scope of energy measurement and monitoring solutions, none of these software offers an automatic operation of the required PDCA cycle [68].

3.3 Need for action

Since environmental protection has become important for society, customers increasingly demand a continuous improvement in the environmental performance of companies.

On one hand, companies that have high energy costs can benefit by carry out energy audits or by implementing DIN EN ISO 50001. Companies can benefit from the introduction of an ecology management system in many ways such as energy cost savings, energy and electricity tax reductions and at the same time compliance with the applicable laws. However, only about 12% of the companies are DIN EN ISO 50001 certified, even though the foundations for effective energy management with DIN EN ISO standards 50001, 50003, 50006 and 50015 are available. Therefore, it is safe to conclude that companies are either unaware of the large savings potential, such as the reimbursement of the EEG surcharge as well as the reduction of energy consumption, or they have difficulties in setting up an appropriate EnMS in practice. The introduction of an effective EnMS based solely on standards is difficult. Organizations often do not have the necessary capacities and capabilities to deal explicitly with the development of EnMS.

On the other hand, there is a complete lack of industrial ecology management. Ecology management is a concept that is not an integral part of organizations. Questions such as the type of ecology strategies, the required structure, the systems for a successful operation and its relevance for the company are very hard for the organizations to answer.

Development of a concept framework that would provide companies guidelines to overcome these issues and implement a holistic ecology management system that encompass energy and environment management system in it, is essential.

If only a few of the companies decide and set up an ecology management system, this would not only have extremely positive effects on the environment, but also on the competitiveness of German industry. Simultaneously, Germany as an oil and gas importing state would become less dependent on external suppliers and achieve the energy transition goals without having to face energy supply gaps. These complications and the outcome caused by them are shown in Table 4.

Complications
No common understanding of ecology management
Lack of awareness
Lack of know-how and skills
Lack transparency
Lack of structure and systems
Missing energy monitoring, controlling and management concepts
Lack of DIN EN ISO 50001 based automated software solutions
Lack of ecology management

Outcome
Only 12 % of the production sites in Germany are DIN EN ISO 50001 certified.
Unknown / not utilized cost and energy optimization potential
No established framework for ecology management

Table 4: Summary of the complications in the implementation of IEM

3.4 Requirements for a solution

As shown in chapter 3,2 and 3,3, ecology management is not only a technical task but also an organizational and strategic undertaking. Nevertheless, the existing energy management systems only offers software support for energy monitoring and neglect all the organizational aspects which are necessary for a successful day to day practice of energy management. Whereas a thorough ecology management system is vastly absent in organizations. For this reason, a comprehensive modular system consisting of procedures and tools for the complex ecology management methods needs to be developed.

The requirements for a comprehensive concept for effective management of resources were aggregated based on the deficits formulated in Chapter 3.2 and 3,3 along with expert interviews. The resulting requirements are described in detail in the following:

- The continuous improvement of the ecological footprint and resource efficiency must be defined as a strategic goal of the company.

Due to the high importance of natural resources for companies and the resulting importance of improving resource efficiency, this solution approach therefore must include a long-term strategic concept. A key prerequisite for this is the active support of the management. To achieve this, sufficient financial and personnel resources are necessary.

- The resource and ecology management (solution approach) must actively focus on the continuous optimization and implementation of PDCA cycle.

The concept should therefore consider the possibility of actively focusing on all key areas of organizations.

- An ecology management system (solution approach) must integrate all available experts.

It is important to note that this is solely a matter of setting guidelines and that there is therefore room for maneuver regarding the precise content. These liberties are intended to facilitate the decentralized integration of the ecology experts and thus enable valuable experience to be considered in the improvement process. At the same time, intensive bottom-up integration boosts the acceptance of developed solutions.

A corresponding approach is therefore also important for ecology management. Strategic guidelines must be set top-down, while at the same time expert knowledge must be integrated bottom-up based on a broad user network. At the same time, however, scope must be created so that the knowledge and experience bearers of the company can initiate the development and implementation of improvement measures themselves.

Furthermore, additional tools must be provided which support the implementation of improvement measures or are necessary for the ongoing methodological work. Tools for measuring success must be established for the regular monitoring of activities and for ensuring a continuous improvement process.

- For the support of the optimization process, simple applicable tools must be developed.

For ecology management, this means the availability of application-specific tools for analyzing companies' activities and identifying improvement approaches. At the same time, it must be ensured that relevant stakeholders are involved in the ecology performance improvement actions (EPIAs) at a very early stage. The corresponding optimization support tool must therefore be easy to use by all involved stakeholders. Furthermore, this tool should automatically take care of ecology management tasks which are prone to human error such as correct information flow and documentation.

- The tools and procedures of an ecology management system must be actively integrated into the management and the operative work process.

To increase the acceptance of an ecology management, it is important that the new activities should not be seen as additional tasks to the actual operational work. The concept should therefore show ways in which the necessary tools and procedures for improving energy consumption and environmental impact can be integrated as optimally as possible into the management and work process.

- The development and operation of an ecology management system must be supported by a comprehensive set of methods and tools to fill the competency gaps.

It is necessary to develop suitable analysis, training and evaluation methods to implement a cultural change in the company.

These requirements are divided into two categories namely, organizational aspects and technical aspects. These are summarized in the table 5.

Technical aspects	**Organizational aspects**
Resource transparency and measurement	Ecology policy
Resource monitoring	Strategy and structure
Resource controlling	Staff and stakeholder awareness
Benchmarking and EnPIs	Knowledge management and skills
Data management system	Sustainable corporate culture
Various ecology-optimization measures	Energy and environmental regulations
Audit report generation per mouse click	Implementation of automated PDCA cycle
Software assisted Management review	Continuous improvement process
Automation of tasks and workflows that do not require critical thinking	

Table 5: Required necessary elements of TIEM

4 Development of Totally Integrated Ecology Management along the 7S model

As explained in Chapter 3, there is a need to develop a concept and methodologies to support a comprehensive ecology management. The main goal of this approach is the establishment of an ecology management system with the goal of sustainable implementation of improvement measures in the company.

In the following sections, the concept is first conceived. The underlying structure of this concept and related methodologies are described using the 7S model.

Conception of the solution approach

A suitable reference structure is required to design a comprehensive ecology management system that is deeply anchored in the company. The solution concept is a framework and a combination of tools and methodologies for industrial ecology management.

This concept will be referred to as totally integrated ecology management (TIEM) in the further course of this work. TIEM covers all the requirements of EnMS, EMS and EMAS.

The social pillar of sustainability that focuses on corporate social responsibility is not an ample part of the scope of TIEM since there exist many solutions for efficient CSR in the literature.

7S model as reference

The 7S model provides a comprehensive and flexibly applicable framework for designing a holistic ecology management system.

The application of the model ensures that all relevant design dimensions are considered. Figure 17 shows the model consisting of seven interconnected key variables.

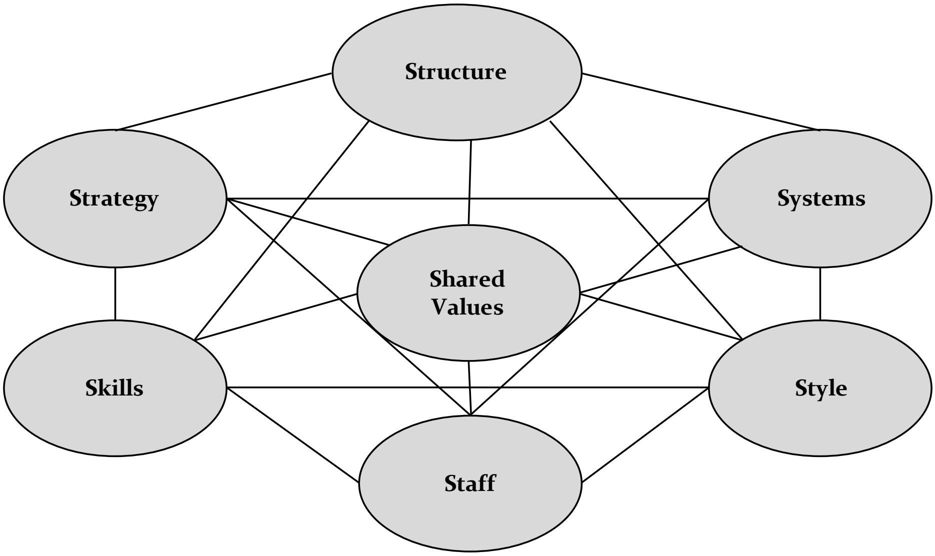

Figure 17. McKinsey 7-S model [69]

Background of the model

McKinsey's 7S management tool provides an excellent framework for this. Tom Peters and Robert Waterman first published this in the article „Structure is Not Organization" and „The Art of Japanese Management ".

This framework is divided into seven so-called core variables, which are regarded as essential for the design of a company and therefore represent suitable starting points for the further development of a company. The model thus makes it clear that the individual variables must not only be considered in isolation, but also as a function of the other variables.

The underlying fact is the understanding that an organization is more than just the sum of its structures and systems. Rather, it is characterized by an interplay of all these variables. The 7S tool provides an answer to the questions as to why companies that are similar in structure, strategy and systems differ in their market success.

This model is very well suited as an orientation for the design of TIEM. The large scope of the 7 variables ensures that all essential influencing factors are taken into consideration.

Explanation of the contents and description of the variables

The seven variables are clearly distinguished from each other and must be considered equally while examining change management or optimization measures within an organization. The variables of the 7S model are divided into the so-called "soft" and "hard" variables.

The hard variables (strategy, structure and systems) are "tangible and clearly defined within the company". These are, for example, a specific strategy, a documented organizational structure or the implemented Information Management systems. [69].

On the contrary to hard variables, the other four so-called soft variables (Skills, staff, style and shared values) are intangible. The skills and staff for example are variables that changes with time. The shared values and style of a company evolve continuously.

The 7 variables are described as follows:

- Strategy defines the company's behavior and the actions it plans to take in response to environmental change and to achieve a sustainable competitive advantage.
- Structure represents organizational and operational framework, which considers the formation of departments and workflows, responsibilities and delegation rights.
- Systems encompasses all (in)formal processes that determine the efficiency of the organization such as controlling, information systems, manufacturing execution systems and so on.
- Staff is the term that describes the organization of human resources, employee involvement and the demographics of the company.
- Style is the corporate culture which is defined by management and it evolves continuously.
- Skills are the characteristic abilities that an organization master.
- Shared Values expresses the principles that gives organizations their unique identity.

Integration into a comprehensive concept

For each of the seven variables, comprehensive methods and tools specific to ecology management are developed. The interplay of all these core variables and the overall concept is the totally integrated ecology management system (TIEM).

Figure 18 shows an overview of the TIEM framework. It shows the addressed business areas, the focus corresponding to these specific business areas along with the tools and concepts that are developed in this work.

TIEM framework			
Business element	**Focus on**	**Developed concepts and tools**	
Strategy	Strategy development	Vision and mission statement	Ecology policy
Structure	Operational structure of the organization	Design of process organization	Concept for integrating ecology management in various structures
Staff	Involvement of employees in ecology management	Concept for roles and functions along with incentives for motivating employees	Definition of roles and responsibilities for ecology management
Skills	Knowledge management	Model for knowledge management system	
	Acquisition of the required skills	Requirement profile for ecology managers	Training concepts
Style	Creating a culture of sustainability	Concept for culture audit	Model for management reviews
Shared values	Ecology management as an identifying corporate value	Measures that create sustainability as a shared value in the organization	
Systems	Functional software for ecology management and communication system	EPIA management, fully automated operation and documentation of each phase of PDCA cycle	
		Resource controlling and monitoring including condition monitoring	EnPIs and benchmarking system
			User management

Figure 18: Organization of TIEM in the 7S-model

The element strategy focusses on the development of strategy and contains tools and procedures for the development of an ecology-specific vision and mission.

In the area of structure, the focus is on the development of an organizational structure and the concept to integrate it in various types of organizational frameworks.

In the area of Staff, the emphasis is on stakeholder analysis and on the development of employee motivation concepts.

The element style is focused on creating sustainability centered corporate culture and enhancing employee motivation towards environmentally friendly operations.

The soft element skills focus on maintaining the current and acquiring new knowledge by developing a reference model for knowledge management. Furthermore, it covers, the development of the knowledge profile for ecology managers and training methodologies.

Whereas in shared values the focus is on developing sustainable production as a desired goal of the organization and a core principle for creating partnerships with external entities.

In the area of system, the focus is on developing a comprehensive ecology management software. This is explained in detail separately in chapter 5 since it addresses various essential systems and hence require a comprehensive description.

4.1 Strategy

Strategy management is a comparatively new discipline in business administration. It was first discussed in a conference at the University of Pittsburgh in 1977 with a focus on "Business Policy and Planning. The State-of-the-Art ". The articles were subsequently published in an anthology entitled "Strategic Management". A central component of strategic management is the attainment of a sustainable competitive advantage over competitors through a corporate strategy geared for success. [70] The development stages of a strategy are shown in the Figure 19.

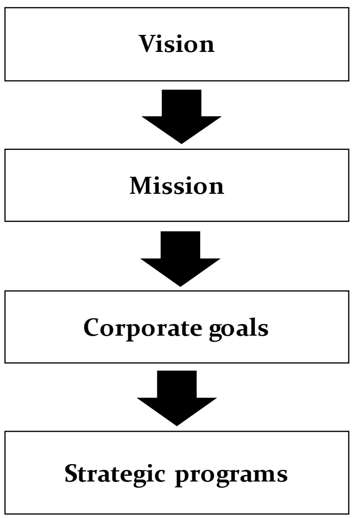

Figure 19: Development stages of strategy [71]

This include the formulation of the corporate vision from which, the mission is derived. The corporate objectives are derived from mission that determines the strategic orientation of the company. The strategy is designed for gradual implementation [71].

According to Porter, strategic management deals with three main objectives namely: strategy, structure and systems, which are reflected in McKinsey's 7-S analysis as well. Strategic management is applied at both corporate and business division level [72]. In order to explain the sustained corporate success of some companies, three explanatory approaches have emerged, which are explained below.

Market-Based-View

The Market Based View (MBV) is focused on achieving a sustainable competitive advantage for a company in the market. There are two basic competitive strategies: cost leadership and differentiation [73]. This means that a competitive advantage can only be achieved by offering specific added value to the customer. It can either be achieved by low prices or by a unique product that is different from the competition. Therefore, the value chain of the company is aligned with the goal of cost leadership or differentiation.

The Porter value chain is shown in Figure 20. It portraits corporate activities systematically.

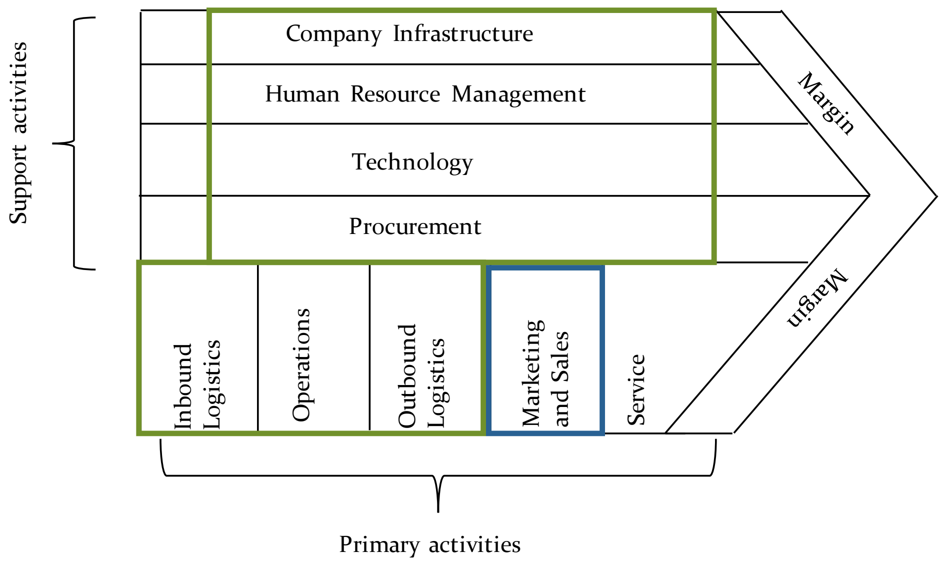

Figure 20:Value chain according to Porter [73]

It combines business analysis with strategy development, whereby the relative strengths and weaknesses in the value chain form the basis for the determination of core competencies that enable organizations to formulate competitive strategies.

Ecology management considers mainly the fields that are outlined in green on Figure 20. Blue marked are the soft consideration such as positive effect of sustainable production on marketing of products. IEM is well suited for both cost leadership strategies and differentiation strategies, since some products tend to cost more if produced sustainably; nevertheless, they find more acceptance by the customers due to high awareness about environmental impact of sustainable production.

Resource based view

The Resource Based View (RBV) neglects the market environment. It rather uses the heterogeneous resource endowment of companies as an explanatory approach for empirically observable differences in the success of companies. Strategic resources here include physical resources such as. tools, buildings and machinery. Human capital-related resources include. knowledge, experience and skills of employees. Organizational resources include the control and planning systems along with company's structure [74]. The conceptual framework of the RBV is based on the following four theorems:

Heterogeneity of resources

This theorem assumes that resources are not equally distributed in the market. The base for heterogeneity is the non-imitability of a resource (e.g. technology) through innovation.

Imperfect mobility

Resources that are important for the sustainable success of a company should be as immobile as possible, i.e. tradable only to a limited extent on the market. Examples of this are company-specific resources such as production technologies specially tailored to the company, corporate culture, specific distribution channels and so on.

Ex-ante restriction of competition

The ex-ante view refers to the time before the provision of services. It is assumed that the purchase of a resource in a perfect market is equivalent to its actual value and therefore no profit is possible. In order to gain a competitive advantage, an imperfect market must exist. This means that the resource must either be of greater value to the company than its actual worth or the buyer acquires an undervalued resource. This is possible if the buyer has an information advantage over the seller.

Ex-post restriction of competition

In order to maintain a permanent heterogeneity of resources during the competitive process, resources may only be substituted and imitated to a limited extent. Since products can be copied, the resources used in the production process and in the organization are of particular importance.

Knowledge based view

The Knowledge Based View (KBV) is a recent development. It is based on RBV. This approach highlights the knowledge of companies as the most important resource. The competitive advantage is derived from the implicit and explicit knowledge of an organization combined with its ability to acquire and transfer new knowledge [74]. Active knowledge management, such as setting up online training courses or work instructions that are available online are some possible measures. Various types of strategies can be identified that gain relevance from the perspective of the knowledge-based approach such as co-operation strategies, acquisition strategies, outsourcing and exit strategies [75].

Conclusion derived from the three approaches

An active ecology management system strengthens the strategic competitiveness of a company in all three approaches. However, the most benefits are mainly found in MBV and RBV. With an active ecology management, the impact of companies on environment is reduced through better use of resources and energy. This subsequently has a positive effect on the company's cost structure. Additionally, active ecology management is an important differentiating feature since sustainability has become increasingly important to the customers [48]. Certification such as DIN EN ISO 14001, EMAS and DIN EN ISO 50001 that can be obtained by implementing TIEM thus make it easier for industrial organizations to differentiate themselves from their competitors. Totally integrated ecology management as a necessary element of company strategy streamlines the company through enhancing the lean production approach by closing the gaps regarding sustainable production. This as a result helps companies to increase their innovative capacity. KBV suggests that active knowledge management is an integral part of resource efficient production because it has a positive effect on existing optimization approaches within the company. It shortens the learning process and reduces the dependency on individuals and their experiences. Therefore, TIEM vision and mission as explained in the following chapter considers all elements of these three approaches.

4.1.1 TIEM vision and mission

The first step towards building a new strategy is the development and communication of vision and mission statement to all the stakeholders of the company.

Vision statement

The vision statement formulates, in a short sentence, the goals of the organization that it would like to achieve in the mid-term or long-term future. The TIEM vision is formulated as follows:

*The "**TIEM vision** is to implement sustainability programs to ensure the ecological and economical production of goods and services with which the organization succeeds in completely satisfying their customers. The aim is to achieve CO2 neutral business operation, with 100% recyclable products that are produced by least energy usage method."*

This statement contains the most important elements from the lean and sustainable production view such as customer satisfaction and environmentally friendly production. The focus on ecology management is clearly identified in the statement.

Mission statement

The mission statement is in line with the company's vision. This is defined as the formal self-definition of an organization in terms of its goals, purpose and principles of action. It should be formulated in a concise manner and include the mandate, the strategic objectives and an orientation for the way in which they should be implemented. The TIEM mission is formulated as follows:

*The "**TIEM mission** is to provide a holistic approach towards a sustainable production by fully integrating all the relevant systems in one automated PDCA cycle and provide users a holistic solution for strategic ecology management."*

The mission statement above describes the objective to make business processes value adding and resource efficient in order to achieve the goal of an ecologically sustainable production. The implementation of which is done by understanding the environment and efficient structures. This particularly appeals to management style, teamwork and supporting framework structure.

4.1.2 TIEM ecology policy

Ecology policy in TIEM is a living document that must be reviewed regularly and updated as necessary using the TIEM software. It is the company's ecology principle. It forms the basis for all activities that are carried out within the framework of ecology management.

Ecology policy of TIEM contains the following three aspects:

- A commitment to continuous improvement of environment related performance. This means setting up yearly goals to reduce carbon footprint, reduce total resource consumption and so on.
- An obligation to ensure the availability of information and the resources necessary to achieve the strategic and operational ecology objectives. This refers to setting up regular EPIAs in TIEM and allocating personnel and monitory resources required for them.
- An obligation to comply with all applicable legal and social requirements regarding resource consumption, resource efficiency and waste management. This includes certification according to ISO 50001, ISO 14001 and EMAS.

TIEM goals

Ecology policy is the framework that is used for setting and controlling ecology goals. This is divided into two main categories as shown in Figure 21.

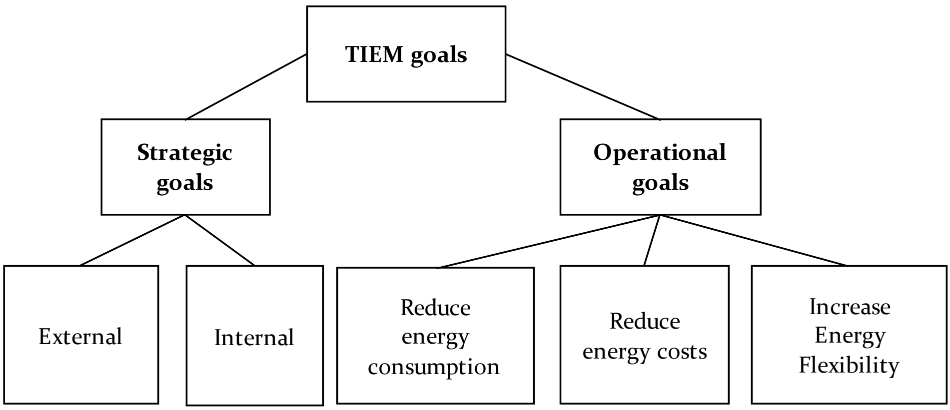

Figure 21: Industrial ecology goals [76]

Communication of ecology policy and the availability of information to all the stakeholders is established in TIEM through software support (see chapter 5). A definition of the ecology goals is compulsory to formulate EPIAs. These, as shown in Figure 21, form the basis for the development of an ecology strategy. The strategic and operational ecology goals are specified as follows:

- **Strategic ecology goals** describe the aim of improving the impact of business on the environment. Strategic goals of TIEM include external and internal objectives. External objectives include market competitiveness, site-specific conditions and social acceptance. Whereas internal objectives include, compliance, transparency and awareness [13].
    - External goals of TIEM include building Eco partnerships with other businesses for waste treatment, where waste of one business is used as raw material for other businesses. The analogy to this is found in natural ecological systems where waste of animals such as CO_2 is used as feedstock for plants. Further important external goal of TIEM include working only with suppliers that have certified sustainability management programs implemented in their organization.
    - Internal goals of TIEM includes involving all employees in sustainability culture. Implementation of the principle of reduce reuse and recycle to achieve Zero waste through continuous improvement program. This all can be achieved through integrating dedicated roles and position for ecology management in company structure (see 4.2).
- **Operational ecology goals** describe detailed requirements for achieving the strategic goals. Reducing resource consumption and costs in addition to implementing measures to use energy flexibly through demand side management are operational goals of TIEM. Furthermore operational goals of TIEM include usage of new technology such as TIEM software for monitoring, controlling and optimizing the consumption of resources along with the implementation of regular EPIAs, introduction of Keah* [66] and least energy usage methodology [65].

Individual divisions and regions may have different priorities in their ecology goals. For example, a production facility of a company in one location may prioritize energy flexibility and another factory of the same company in another location may prioritize a reduction in the energy costs as a decisive target. Hence, depending on the region and division, operational goals of a company may differ; nevertheless, strategy of sustainable production stays the same for the organization.

Conclusion

Ecology management is reflected both in the cost structure of a company and in the perception of the customer from outside. A sustainable competitive advantage is derived from MBV and RBV. The vision and mission statements and TIEM goals described here provides a starting point for companies struggling to integrate ecology management in their corporate strategy. The major requirements that companies need to fulfill in order to create a norm compatible ecology policy is described in this chapter along with the formulation of strategic and operational goals.

Through implementing this proposed continuous improvement ecology policy, companies will improve their environmental impact and reduce costs through better efficiency. In addition, TIEM will generate a unique selling proposition through improving sustainability in production and through better environmental performance.

4.2 Structure

The company's organizational structure is divided into functions also referred to as job positions or roles and departments that regulate management, staff and communication [77]. This is classified according to functions, objects, rank, phase and purpose relationships to make a distinction between single lines and multi-line systems. Roles and position creation is based on task analysis and task synthesis. Depending on the specifications of an organization, ecology management is integrated in an organization in either central or decentral manner. The most common types of organization structure are the one-line organization and the staff line organization. However, in large multinational corporations, there is an extension of organizational structure concepts to include divisional organization, matrix organization and tensor organization [78].

The organizational assignment of the roles and position is necessary for ecology management. For example, SMEs may only assign few employees as representative of the core ecology management team. However, larger companies, on the other hand, establish a separate dedicated ecology management department. In both cases however, it is important to establish an ecology management system with comprehensive, organization wide responsibilities and authority.

The structure of totally integrated ecology management is designed with a modular approach to ensure its integration in any type of organizational structure while retaining that existing structure as much as possible. The first step of this process is the definition of roles and functions required to establish the energy and environmental Norm compliant ecology management processes and workflows.

Core Roles and positions of TIEM

The role of management, also referred to as top management, is responsible for ensuring the overall coordination of ecology-related tasks. Within the framework of the organizational structure, introduction of either external service providers or internal dedicated position is essential. Internal role within the company can be supported by external know-how. However, to ensure sustainable progress, the core TIEM operational responsibilities must remain a company internal task.

Ecology management requires the introduction of a management representative, referred to as ecology management representative. In the course of this work, this role is mentioned as the Ecology Manager (EMn).

The EMn is an advisory, initiating and monitoring function. This role is the driver for ecology management issues. Therefore, access to the top management level is necessary for the EMn. This allows the actions of the EMn to be legitimized and empowered. It is important that the EMn is given the necessary freedom for decision-making and the required resources. Relevance of TIEM can only be ensured through appropriate support and empowerment of EMn.

The energy and ecology management team mentioned in the ISO standard consists of one or more persons responsible for the effective implementation of the EnMS, which is encompassed in IEM and for achieving improvements in ecology-related performance [13]. The TIEM structure establish an ecology management core team, as shown in Figure 22, that is responsible for taking on these tasks and consult experts for technical questions. Depending on task specification, this core team can be extended by introducing technical experts or external consultants to form the extended IEM team. Figure 22 outlines the structure of various teams.

The ecology manager thus represents a decisive, central role in the context of ecology management. Depending on the company size and task complexity, this role may either require a solely dedicated employee or it may be exercised as part of another position. For larger companies, several full-time dedicated ecology managers working under an ecology management head is necessary.

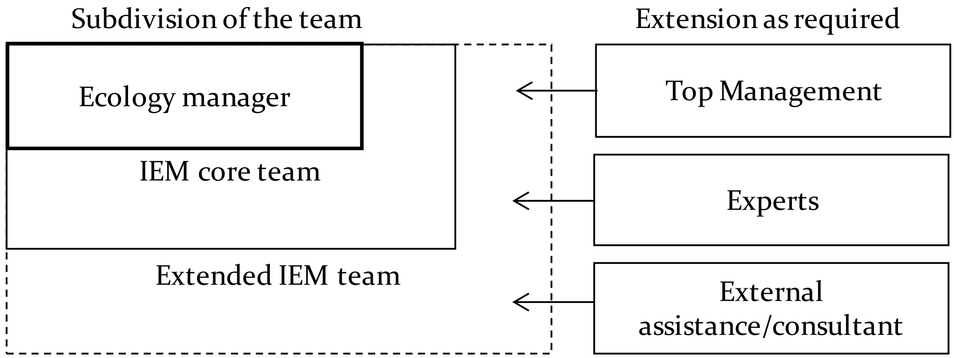

Figure 22: Classification of the ecology management team [S4]

In many companies, however, employees in addition to their existing tasks may take the tasks of ecology management. In smaller companies, this is a benefit since it additionally facilitates the integration of IEM into the existing organization and prevents excessive number of interfaces [79].

4.2.1 TIEM Process organization

The process organization controls the process flow between departments, positions and materials based on the organizational structure. This refers to the process of task fulfilment considering factual, logical, personnel and sequential aspects. This allows the representation, analysis and optimization of work-time relationships [80]. The aim here, is to reduce throughput time with maximum capacity utilization.

Operation synthesis is based on the determined operational elements such as operating sequences and stages of operation which, defines the actual workflow and represents the process organization [81].

The representation of the process organization (shown in Figure 23) is based on the PDCA cycle which is essential to ensure a continuous improvement process. This is the core structure of TIEM.

The integration of ecology management into operational processes is necessary for the implementation of a conscious use of resource. An effective organization makes optimal use of limited resources and it demonstrates an efficient information flow.

Therefore, the integration of ecology management into the organizational and operational structure of the company needs to be implemented systematically as proposed in Figure 23.

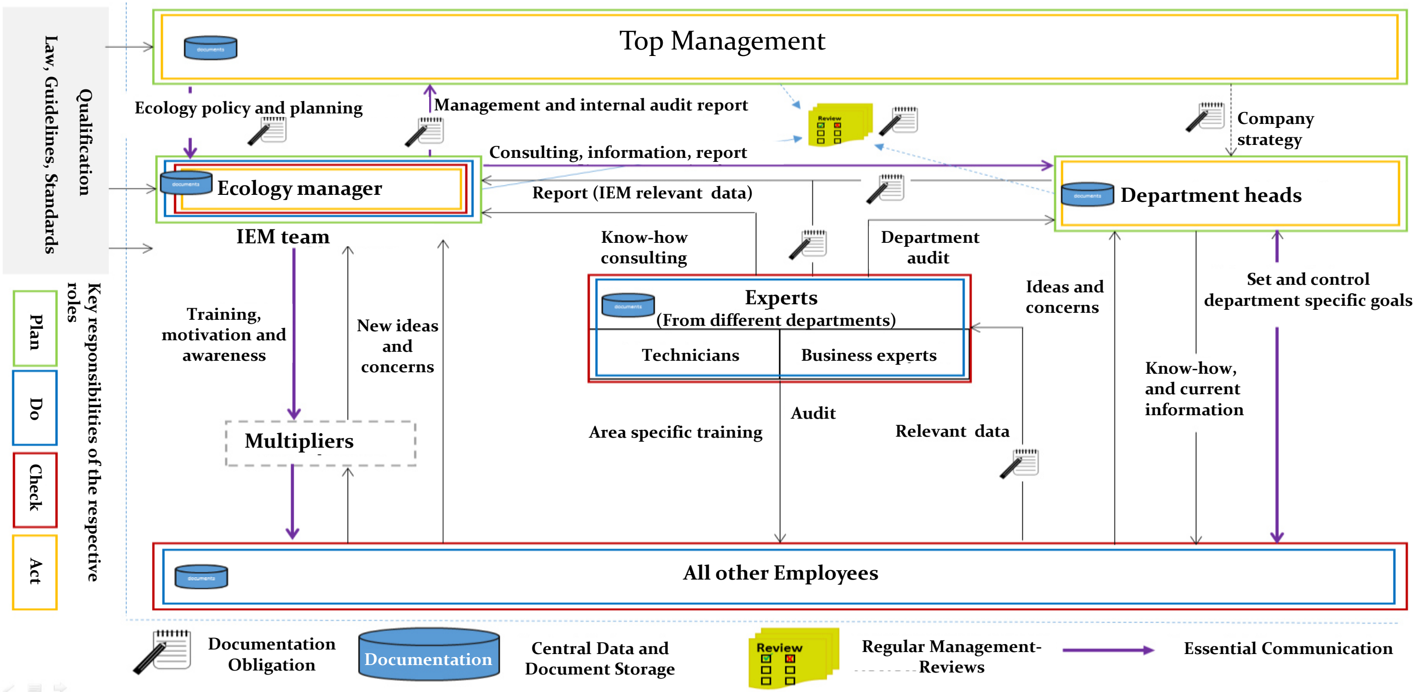

Figure 23: TIEM structure and organization based on relevant ISO norms [82]

In addition to the role of ecology manager and the ecology management team, it is necessary to include the entire organization in TIEM process organization.

TIEM structure is a framework for the establishment of the ecology organization in operational processes. Here, an ecology management team is set up, which is responsible for processing, acquisition of information, development and subsequent implementation of EPIAs. Thereby, a dedicated ecology manager reports to the top management and is responsible for establishing EnPIs and ecology performance indicators. These EnPIs and KPIs facilitate ecology and energy performance controlling and benchmarking. The top management is responsible for making updates, controlling the ecology policy (see 4.1.2) and providing the necessary resources. The entire structure of the organization is geared to the PDCA cycle as required by the energy and environment relevant norms. Each position assumes a part of the responsibilities and a single person, depending on their qualification, can assume multiple roles [82].

This model is generally applicable to all companies regardless of their size since single person or complete departments can assume the roles necessary for TIEM. The definition of these roles and their interaction is the core of TIEM structure. The interactions of these dedicated roles with each other are shown in Figure 23.The responsibilities of these roles are described in Table 7 (See 4.3.3).

4.2.2 Integration of TIEM structure into the operational process organization

The process organization for industrial ecology management is company-specific, nevertheless it should always represent the PDCA cycle. It essentially means that the operational organization is broken down into planning, executing, controlling and reacting units. The integration of TIEM structure in different type of organizational framework is described as follows:

Integration of TIEM structure as staff function

The organization of ecology management in a staff function is a solution if ecology efficiency is a high priority in a company. According to the PDCA cycle, the tasks are distributed in the organization as illustrated in the Figure 24. The ecology management tasks are handled separately in a dedicated department. This department is integrated hierarchically either under the top management or under the first management level. The ecology management department has a high delegation power and guiding authority. The coordination effort is rather high in big companies and in companies where ecology management tasks are decentralized.

To establish a fixed point of contact between ecology management team and the top management, a permanent ecology committee of one or more top managers needs to be appointed.

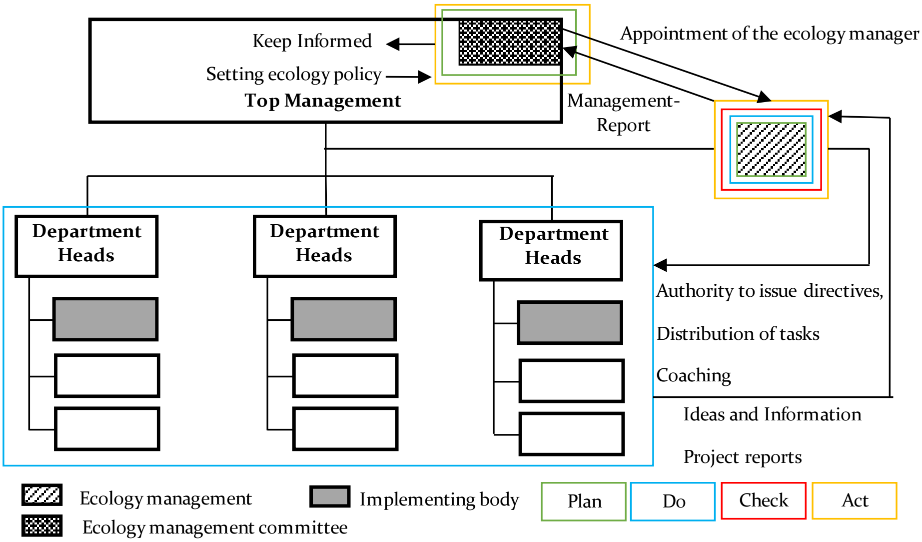

Figure 24: Staff organization of ecology management, based on [83, 14, 84]

The ecology management department reports to this dedicated committee. The ecology management committee receives from the board of directors the specific company targets which they then adapt to the ecology targets and pass on to the ecology management department for further processing. This committee is responsible for the staffing of the head of the ecology management department. They are involved in the “plan” and the “act” stage of the PDCA cycle. They are responsible for providing the necessary support and resources required for ecology related tasks. The EPIAs are implemented in the “do” phase of PDCA by the individual departments.

The ecology management department is responsible for following up the EPIAs and reviewing them for success.

Integration of TIEM structure as line organization

Companies that have power generation plants such as Combined Heat and Power (CHP) plants may integrate ecology management as a line (single or multi) organization (see Figure 25). Thereby, the operational tasks of the

CHPs are handled effectively in a separate department, if necessary, with its own subdivisions. The coordination effort for ecology management is still high, but less than the staff organization due to the higher centralization of it. The establishment of an ecology committee is nevertheless necessary for the coordination with other business line areas and for the implementation of overarching EPIAs.

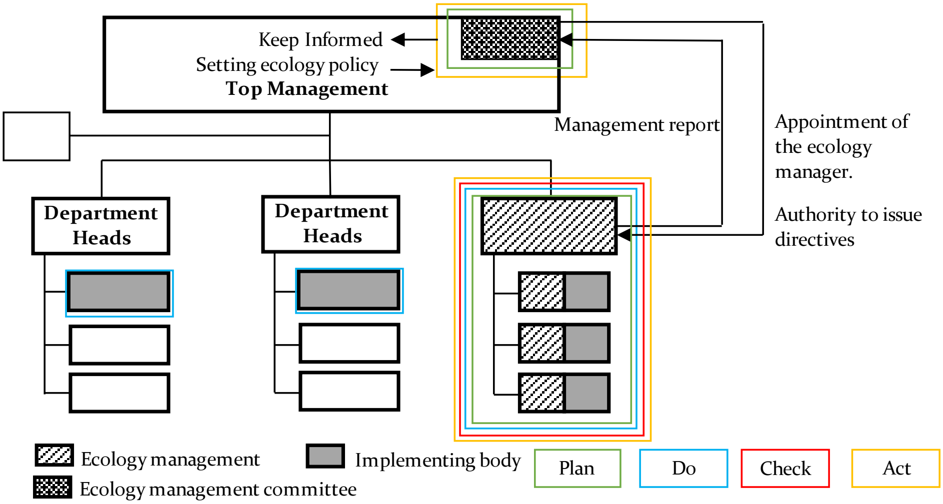

Figure 25: Divisional integration, based on [83, 14, 84]

With regards to process organization, the entire PDCA cycle is carried out by the ecology management department and therefore all tasks are planned, performed, verified and reviewed for further improvement within this department. To support the processing of ecology issues, the ecology management team can rely to some extent on input and task execution from other departments, for example programming of the control systems in plants, etc.

Integration of TIEM structure as integral organization

Smaller companies usually have less work separation. As a result, ecology management, as shown in Figure 26, is integrated directly into the established corporate organization structure. Here, a separate ecology department only makes sense if internal power generation is a factor, which generally is an exception. Due to the smaller size, the coordination effort is less. Nevertheless, personnel coordination here plays an increasingly important role.

Given the high attractiveness of energy as a resource and since it is required by the DIN EN ISO 50001 standards, the involvement of top management (ecology committee) is indispensable. Along with other tasks, the role of ecology manager can be assumed by qualified employee of a department such as quality manager or environment manager. A role dedicated only to ecology management is not required as per task necessity or regulations.

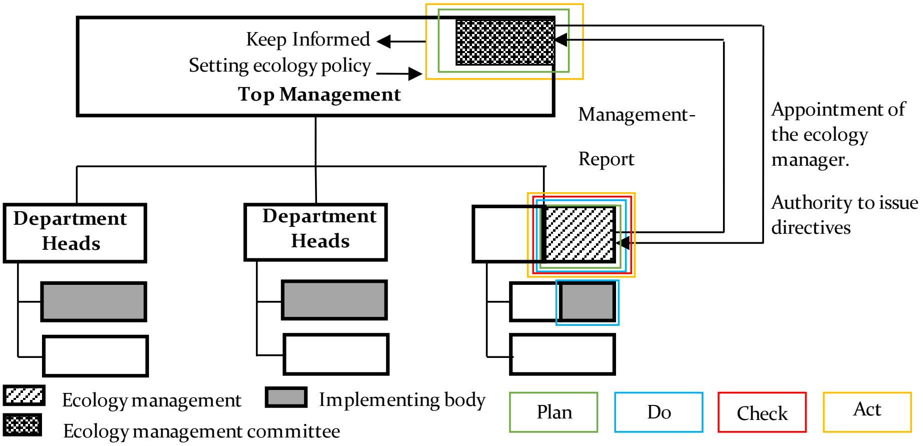

Figure 26: Integral organization structure, based on [83, 14, 84]

Integration of TIEM minimum organization

Organizations in business areas where coats of resources (raw material, energy, etc..) and the impact of their waste material on the environment are not significant, tend to ignore their eco performance. Nevertheless, due to the demand and pressure from the customers to operate sustainably, organizations regardless of their size must strive now for a greener image of their brand and take actions to be environmentally friendly in their operations. Thereby, ecology management is not a dedicated task, rather, the top management expects the employees to act in the spirit of "good housekeeping" and take the necessary precautions to maintain the corporate social responsibility. Here the TIEM process organization is uncoordinated. Each department as shown in Figure 27 carries out the PDCA tasks independently to improve ecology performance. Companies which are not required by law to implement EnMS may decide to audit their energy performance according to DIN EN 16247-1 standard. Through energy audit the energy optimization potential of a company can be identified. It also provides a possibility to market the brand with greener image. Where the implementation of IEM is not the primary goal, there is no need for an ecology committee. The aim of the ecology management system here is to minimize the waste of resources and reduce carbon footprint as much as possible.

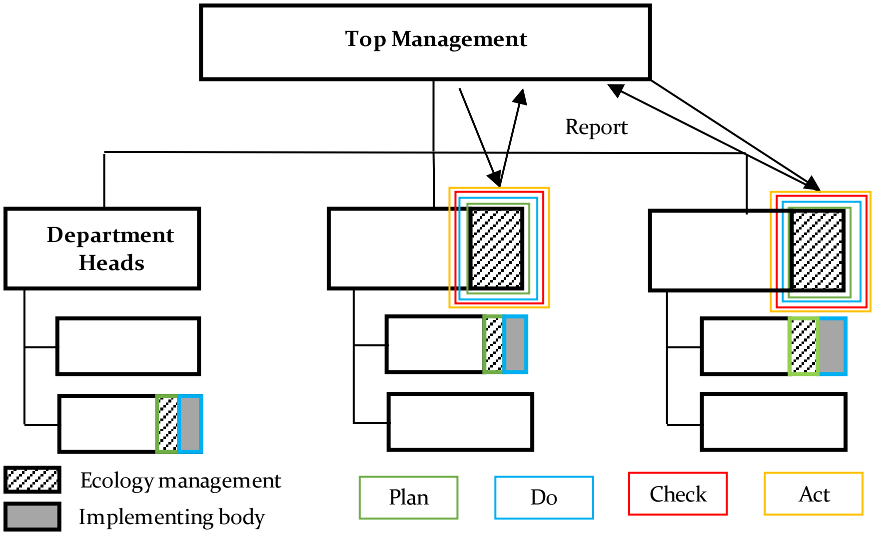

Figure 27: IEM minimum organization, based on [83, 14, 84]

4.3 Staff

The staff of a company play a decisive role in ecology management and can make a significant contribution to resource savings and improving the environmental performance of their organization. Therefore, it is necessary to raise the awareness of all employees of a company regarding IEM.

4.3.1 Measures to improve the motivation of employees

In a survey by German chamber of commerce and industry (IHK), it was found that 76% of the companies that were surveyed, actively inform and qualify their employees on energy-related topics [58]. Energy savings of about 5% to 15% can be achieved alone through behavioral measures at the workplace, which often requires only little or no investment [85]. This has consequently a positive effect on the environment.

It is therefore essential to make employees aware about ecology issues in their working environment so that they can contribute to increasing resource efficiency and reducing wastes of their organization. The main elements that must be addressed to initiate a change in behavioral pattern of the employee at workplace are:

- Awareness about sustainability
- Motivation and incentive system
- Employee training and qualification

Information and awareness

Only employees who are aware of the influence of their actions on resource consumption and the potential for saving resources can act accordingly. Therefore, awareness building is the first step in the continuous employee-related resources efficiency measures. In addition to providing information, for example about seminars and events, idea competitions (see 5.5) can promote interest of employees in ecology topics [86]. Suggestions and tips for the private sector strengthens the ecology awareness of employees as a whole, which also have a positive effect on operational ecology management [87]. A clear and understandable internal communication of the ecology strategy and ecology policy to employees along with planned optimization measures and the success of completed measures, ensures the recognition of the importance of sustainable production. Overall, the transparency of communication makes a significant contribution in improving the total ecology performance of an organization.

University of Freiburg carried out an experiment to see if increasing employee awareness about energy makes any significant improvement in overall energy consumption. In this project comprehensive information with recommendations for possible actions were developed to encourage employees to participate in energy saving. The result of this experiment showed that about 14% of energy consumption was reduced only through behavior and awareness about energy [88]. This experiment showed that the stakeholder motivation is particularly important in ecology management.

Employee motivation

Classical motivational theory approaches are divided into content and process theories. The content theories of motivation classify and specify the existing motives and goals and deal with the question of what exactly generates motivation. Well-known examples of this are the widely recognized need pyramid of Maslow or the two-factor theory of Herzberg. Process theories deal with cognitive processes and the question of how motivation influences action and how can people be influenced in a targeted manner.

Adams (equal weight theory) and Vroom (valence instrumentality expectation theory) represent process theories. Thus far, it has been assumed that the human beings are rational thinking beings, who try to increase their own benefit, who are concerned about profit and act according to their own interests.

However, the behavioral economist Richard Thaler empirically proved that most people do not act completely rationally. He proposed for instance, that people would prefer small instant rewards over larger future rewards and forego profits if that involves effort [89]. Thaler suggested that people need the so-called nudges to push them softly in order to motivate them for a specific task. For this insight, he was awarded the Nobel Prize in 2017. The theory of soft pushing or nudging as proposed by Thaler is be applied thoroughly to ecology management.

The employees must actively be encouraged to save resources and reduce waste. It is not enough just to compensate employees with bonuses for achieved goals. Information signs on machines for example, can remove the uncertainty in decision making, such as shutting down a plant at a given time.

Information boards for each production line about the cumulative resource consumption of the work shift put the employees unconsciously in a "competition" with their colleagues. This encourages each shift to try and achieve a higher resource efficiency than the other. Motion detectors for light eliminates the decision and effort involved in operating the switches.

Even small measures such as requests to close doors, pre-set energy-saving modes on the computer or a brief discussion with colleagues about the required office or hall temperature (usually 1 °C saves about 6 % of energy) bring a measurable success.

Training courses, especially information about what has been achieved, create a common ecology awareness. Particularly important ecology-related positions are required to be devoted to improving resource efficiency. This should be a part of the performance bonuses in the target agreements of such employees. The energy cost share in the company can serve as an indication of the magnitude of the energy-dependent performance bonus. Ideas for increasing resource efficiency should be awarded with a monetary prize and recognition through mentioning it in the intranet and newsletters of the company.

Table 6 shows the list of developed nudges and their implementation in ecology management systems.

Nudges	**Examples**
Default rules (Standards)	Preset energy saving modes on computers, systems, printers (e.g., double-sided printing as default setting) etc.
Streamlining measures / Simplification	Structured document management system Defined behaviors of installations Forms and applications with a simple structure Clear points of contact for energy issues
Social standards	Anchoring ecology management in the company's mission statements
Increased convenience and simplicity	Door closing system Motion detector for lighting
Disclosure	Labelling energy consumption of power-intensive systems
Strategies of Self-Commitment	Reward system for ideas aimed at ecology optimization and for achievement of ecology targets
Warnings	Warning by e-mail to plant operator or ecology manager if critical thresholds are exceeded
Reminders	Remind the importance of the environment and energy efficiency in the company's communication channels time and again
Increase willingness to implement (Through the repeated questions about intentions for action, people tend to actually act.)	Publishing EPIAs and their successes on the intranet or the notice board Hold regular production meetings to discuss how resource efficiency can be increased and wastes decreased
Information on consequences of previous decisions	Making the impact of energy costs on company results clear

Table 6: Nudges in ecology management [90]

Training and qualification

Overall, know-how about the risks and opportunities in the field of ecology management is necessary. This in addition to the general information is acquired through special courses, further education and training [91].

Employees are trained specifically and according to their individual development needs by means of coordinated further education programs that are integrated into personnel development process. The training courses should convey a common basic understanding of how to use the resources responsibly. This is done, for example, by means of a basic training module that is obligatory for all employees. With the increasing specialization of the training contents, external offers are used, which enable a professional focus and exchange of experience. The group dynamics of employee training courses contributes to increasing ecology efficiency in the company as a whole [92].

Ecology management is often understood as purely a technical discipline. However, training courses should also consider non-technical aspects, since economic and legal issues are becoming increasingly important for decision-making processes. In addition, due to the large number of interrelationships in ecology management, the social and methodological competence should not be neglected [91].

4.3.2 Stakeholders

Companies thrive on the excellence of their stakeholders. Without the involvement of all parties in the company in an optimal way, a company cannot succeed in the market. It has been observed that only shareholder value-driven business models often lead to suboptimal results. Which consequently leads to lower returns for shareholders, but also for the company and its employees. Stakeholder approaches involve all parties involved in the company and align the organization with a common goal to increase value creation for shareholders, stakeholders and society as a whole [93]. Therefore, development of concepts and measures for the industrial ecology management on a stakeholder basis are essential.

Three environments model for TIEM

The three environments model proposed by Stapleton is useful in identifying and visualizing the stakeholders of an organization. This model divides the environment of an organization into three areas.

- Internal environment: the internal environment is subject to management control. It encompasses all processes, skills and positions for task competence. In the framework of TIEM, the internal environment is influenced by the ecology manager, the top management and the employees of the business.
- External environment: the external environment cannot be controlled; however, it can be influenced. It encompasses the market competition, customers and suppliers. Most of the marketing activities are focused on this environment. In TIEM framework, influence is projected by the business on the external environment through prerequisites such as allowing strategic partnership only with suppliers that are certified according to energy and environment management norms.
- Distant environment: the distant environment can neither be influenced nor controlled. It provides the legal framework. Since ecology management fulfills the requirements of the sustainability norms, legal requirements are fulfilled in TIEM framework.

Illustrated in Figure 28 is the application of the three-environments model in terms of ecology management.

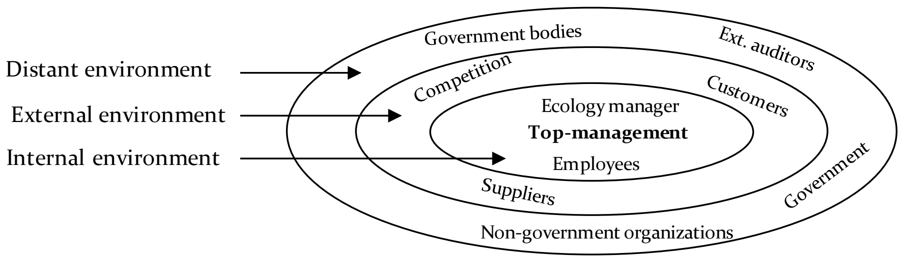

Figure 28: Three environments model in terms of ecology management [93, 78]

Stakeholder analysis

The stakeholder analysis is carried out based on ecology management. As far as the key players are concerned, the members of the organizational structure and process organization were considered as primary stakeholders. Results of stake holder analysis according to Müller-Stewens is shown Figure 29).This approach distinguishes between four basic types of stakeholders [94, 93]. These different types are described as follows:

The "playmaker group" has a high degree of influence and plays a decisive role in determining the company's fortunes. However, this group has a high influential power. Ecology manager and IEM team are the core members of this group in TIEM structure.

The "Joker group" has a high degree of influence but can itself hardly be influenced. The power thus clearly resides with this group. The aim of interaction with them is to bind this groups closely to the ecology management process in order to profit from their influence (see 4.2.1).

The "Rules group", have low impact on the company policy. However, interaction with them plays a vital role, as they are influenced by the policies of the company and their acceptance of these policies is essential for a successful business.

The "fringe group" is hardly affected by the company and does not have any means of power at its disposal. Regular information is sufficient here and it should not be neglected.

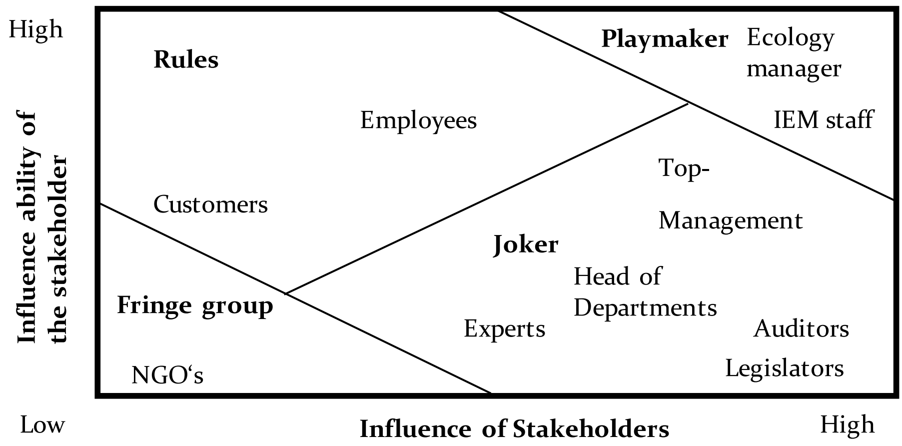

Figure 29: Result of the Müller/Stewens analysis [94]

Not surprising is the high power and influence of the ecology manager on IEM. It is therefore important to ensure that the ecology manager has comprehensive qualification which is required for the ecology management tasks. Since ecology management is not only a technical task, rather it is an interface system. Therefore, the ecology manager should have both technical know-how and management skills as well as the ability to lead employees.

Successful ecology management depends on the integration and involvement of all the employees in the IEM since they have a high influence on the organization. This group probably has little interest in the subject, but it needs to be particularly made aware of the fact that the energy-intensive activities are carried out by them. Here, methods of personnel management are used to motivate employees regarding IEM (see4.3.1).

4.3.3 Roles and positions concept in TIEM

A concept for functions that are required for ecology management and their task description is developed using the results of the stakeholder analysis. The result is shown in Table 7 in a top-down hierarchical distribution.

Hierarchy	Roles and positions	Task description	Workload
Top	Top management	▪ Defining the goals ▪ Controlling the accomplishment of goals	▪ Management review ▪ Meetings with ecology manager
	Ecology manager	▪ Development of EPIA ▪ Coordination and leadership of the ecology team ▪ Determination of milestones and work packages ▪ Budget responsibility and controlling	
	Ecology team	▪ Identification of optimization potentials ▪ Development of solutions proposals ▪ Implementation of the EPIA ▪ Documentation	▪ Weekly team meetings ▪ Work on projects
	Ecology staff		
	External experts		▪ Additional services when required for complex and costly projects
	Heads of Department	▪ Procurement of characteristic values and information ▪ Support during implementation ▪ Informing subordinate employees	▪ Periodic regular meetings with the ecology manager/team
Down	Employees	▪ Complying with the developed procedures ▪ Internalizing the "Ecology Vision" ▪ Creating ecology awareness	▪ Attendance at training courses

Table 7: Assignment of roles of TIEM [84]

4.4 Skills and knowledge management

Skills are understood as knowledge possessed by an organization. Knowledge management deals with the acquisition, development, transfer, storage and use of knowledge. Under no circumstances may knowledge be mixed with data and information. This often results in knowledge management being reduced to IT solutions. It is rather the aggregation of data into information using an appropriate syntax. The information that is set in a certain context produces knowledge. Therefore, information without context is of little value [95]. Knowledge is a key competitive advantage for Germany as a business location. Even in the manufacturing industry, human capital and the knowledge tied to it are regarded as the most important raw material, far ahead of material resources [96]. Thus, it is important to transfer and store both explicit and implicit knowledge from the individual to the organization.

4.4.1 Reference models for knowledge management systems

There are several reference models for knowledge management. One of the best-known models is the SECI (socialization, externalization, combination, internalization) model according to Nonaka and Takeuchi. This divides knowledge into implicit and explicit knowledge [97]. While implicit (e.g., empirical knowledge or experience-based knowledge) knowledge is difficult to transfer, the explicit knowledge (e.g., theoretical knowledge) can be stored easily. The transformation of explicit and implicit knowledge into each other takes place continuously. Four forms of the transformation of knowledge are represented as follows:

- Socialization: acquisition of implicit knowledge through the exchange of experiences
- Externalization: converting implicit knowledge gained through socialization into explicit knowledge (e.g., through reports)
- Combination: combine existing explicit knowledge to create new explicit knowledge (e.g., using existing technologies for new fields of application)
- Internalization: explicit knowledge is converted into implicit knowledge (e.g., internalization through repetition)

Another important model in knowledge management is the methodology of knowledge building blocks [98]. This methodology includes eight building blocks that provide a framework for the development of knowledge management as shown in Figure 30. The six core components form the inner cycle and the two other forms the outer cycle. Usually, the building blocks are processed in order based on the knowledge objectives. Strong dependencies exist among them.

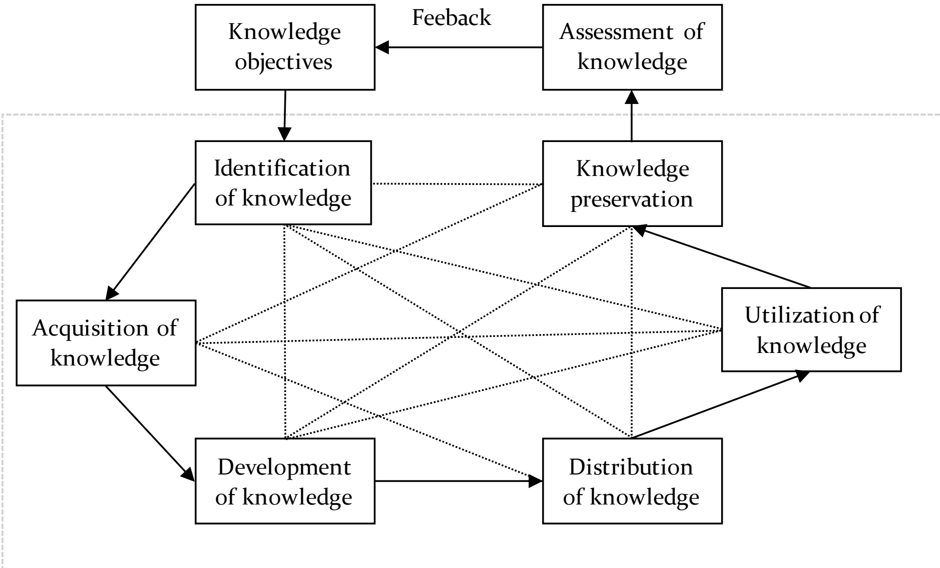

Figure 30: Methodology of the knowledge building blocks [98]

While preserving and saving knowledge is no longer a big challenge, there are still deficits, especially regarding efficient access methods. The use of ontology-based knowledge management systems would make the search for information more efficient and focused, thus enabling even non-experts to gain access to information available in ecology management systems. Thereby an attempt to obtain relevant information from the knowledge management system by means of databases and controlled queries is developed.

This means that roles are first defined (e. g. production planners) to be able to determine the knowledge background of the users in the IEM area. By means of a decision tree, information that the users require, is specifically prepared for them in order to optimize the search result.

On completion of the process, the user provides feedback. This is taken into account during the next query and thus improving results continuously [99].

4.4.2 Acquisition of the knowledge status quo

In organizations, the financial and human resources are limited. It is therefore necessary to assess the status quo of the company in dealing with knowledge in order to introduce concrete measures to eliminate weaknesses. The knowledge audit is a widespread methodology for determining the current status of knowledge management in the company. Table 8 shows the knowledge audit scheme.

The strengths/weaknesses profile of the company is quantitatively assessed in a survey of employees and/or qualitatively in workshops. In the employee survey, the skills required to carry out specific tasks is determined. These are then compared with the availability of knowledge. The evaluation of this can based on the Likert scale. In contrast to binary questions, which always have only two answer options (e.g., yes or no), the Likert scale allows a deeper feedback on the assessed views and opinions. The aim is to achieve a precise set of ideas, which is the basis for a valid result regarding the investigated questions. The higher the difference between knowledge requirements and knowledge availability, the greater the need for action. For example, it is important for the ecology management department to be aware of current norms and legal regulations.

Audit phase	Activities
Preparation	Selection of target group and questions as well as adaptation to the organization Planning of communication and coordination with the workers council
Execution	Invitation of participants, data collection and follow-up action
Evaluation	Analysis and preparation of data along with identification of fields of action
Feedback	Evaluation of results, definition of new goals and communication of results to stakeholders
Implementation	Planning and implementation of the identified measures

Table 8: Knowledge audit scheme [100]

Lack of knowledge database calls for a clear need for action. A knowledge pool, in TIEM contains among others the legal provisions and relevant standards in the shared content management system (see 5.5). At the same time, knowledge is generated, stored, distributed and applied based on the core activities. This is then used to evaluate the methodological approach in the respective business areas. For example, an assessment is made to determine whether the knowledge is predominantly bound to individuals or exists in documents. Personnel-bound knowledge must be externalized to make it available for the entire organization. The willingness and the way in which knowledge is exchanged can as well be quantified in particular, through knowledge audit described in Table 8. The quality of the existing formal methods is evaluated to derive improvement measures.

Requirement profile of ecology managers in TIEM

In order to define the requirements for knowledge management as well as training methods, it is important to know the requirement profile for ecology managers. Ecology management has an impact on technical, organizational and economic processes of an organization that aims to reduce its energy consumption and carbon footprint. Hence, the requirement profile for ecology managers is very complex. An ecology manager should have both technical and business management skills. In addition to these classical skills, leadership and social competence cannot be neglected. Figure 31 illustrates the requirement profile for ecology manager and ecology management team.

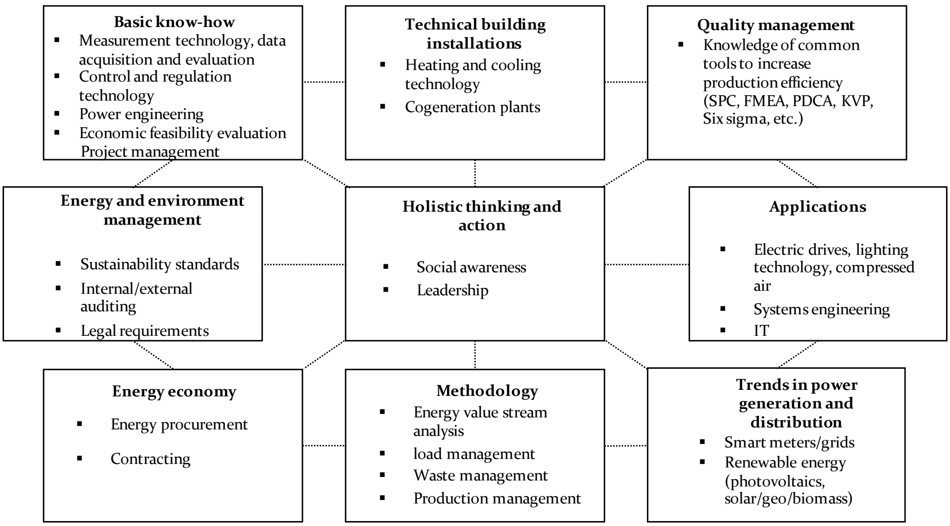

Figure 31: Requirement profile of an ecology management team [98]

4.4.3 Training concept for acquisition of knowledge

Personnel development involves the transfer, expansion, consolidation and implementation of specialist knowledge, skills as well as attitude in behavior of the employees [101]. In order to ensure the suitability of both the ecology manager and the team members, an appropriate personnel policy and training methodology is therefore required. Human resources development in the field of ecology management involves planning and implementation of training and further education measures with a focus on ecology-related topics.

The goals of personnel development include, among others, improving the following [102, 103]:

- Competitiveness
- Efficiency and effectiveness of the organization and its members
- Job satisfaction
- Qualification and flexibility
- Public perception
- Satisfying individual and educational needs

Regarding ecology management, there are special requirements concerning the content of the training courses. These are shown in Table 9.

Knowledge sharing	Knowledge and skills about: ▪ Ecology balance/key energy performance indicators of the company ▪ "Energy guzzler" of the company ▪ Operation and maintenance of IEM components (measuring systems, software, etc.)
Skills enhancement	▪ Methodology (e.g., method of value stream analysis and implementation of ecology guidelines) ▪ Analytics (energy value stream analysis, waste management) ▪ Social (ability to communicate, motivate and lead in groups)

Creation of new configurations	▪ Respect, acceptance and openness to new processes, technology and change ▪ Continuous learning ▪ Understanding the need for sustainability

Table 9: Contents of training and further education, based on [101], complemented by ecology management elements

There is no one standard methods for teaching the contents of IEM to the involved employees. Important are the qualification measures as they are used, for example, by quality cycles or in project work [101].

The specialist knowledge, skills and attitudes required for ecology management must be communicated efficiently and effectively. The different approaches to describe the development of training processes are as follows:

- Function cycle of the corporate education system
- DIN EN ISO 29990:2010 " Learning services for non-formal education and training - Basic requirements for service providers" [104].

These models essentially describe the basic steps of requirements analysis, preparation, implementation and evaluation.

Depending on the model, they go into detail in some areas, but barely cover all components completely. This often leaves a wide spectrum for interpretation and hinders an effective development process.

To eliminate these weaknesses, a dedicated training process, based on the

- Define
- Measure
- Analyze
- Improve
- Control

which is known as the DMAIC cycle is developed for ecology managers and all involved employees. Illustrated in the Figure 32, this methodology covers multiple topics in various areas in depth.

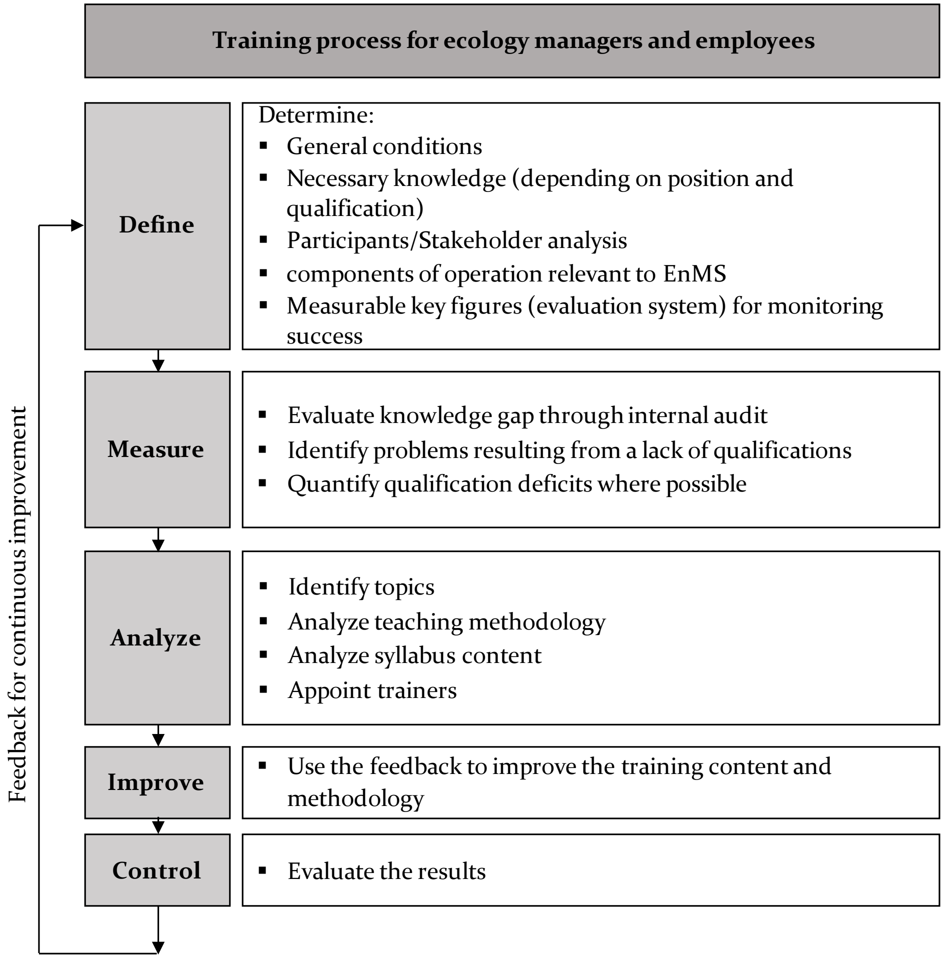

Figure 32: DMAIC cycle for conceptual design of training courses [84]

4.5 Style

The style of a company is synonymous to corporate culture and consists of the following two components:

- The dominant values and norms of the organization that develop over time and become very stable elements of the company.
- The management culture or leadership style which is reflected more through actions of the management rather than what it says.

A sustainable corporate culture is part of every company's philosophy and legacy. The strategic orientation of the company and the environment is based on the company's vision, expressed in the mission statement. Thus, it describes the way in which the company acts. The most important functions of a corporate culture are:

- External adaptation, which include raising awareness about changes and trends in the corporate environment coupled with differentiation from competitors.
- Internal integration is the creation of an identity to strengthen the feeling of belonging also known as corporate identity. It is the guidance for reducing the daily decision-making effort, controlling through common objectives and effective collaboration through shared goals and values.

The goals and values of organizations are usually summarized as mission statements in the company's annual reports. The set of values usually consists of positively correlating but exchangeable terms. The individual terms in the vision and mission statement are tailored specifically to the industry. For example, many car manufacturers advertise with a technological lead especially in the context of the increasing demand for environmentally friendly vehicles. A bank puts the customer first, while a medicine manufacturing company promises the safety of their chemical products.

In the study of corporate culture and performance, the role of corporate culture in the economic success of companies was empirically and quantitatively investigated. Based on an index of "cultural strength", the economic performance indicators were compared with the corporate culture. Companies with a weak or not clearly established corporate culture were able to increase their earnings in the period under review by 166%, while companies with a clearly established corporate culture were able to increase their earnings by 682% [105]. Other studies also suggest a connection between company culture and success. Companies with a corporate culture adapted to sustainability are not only geared for more financial success, they in addition also benefit from the positive reputation in the marketplace. The market share of people who make purchasing decisions for products based on sustainability and environmental impact of the production of these goods is estimated to be at around 30% of the total consumers [106].

4.5.1 Cultural change for sustainability

The implementation of a sustainable corporate culture requires absolute motivation, willingness to change and persistence. The change process comes with costs and effort. Therefore, the commitment from all the employees and top management is essential here. In addition, it is important to consult the workers union and establish initial communication with employees to fulfil the information obligations, regarding the change process.

The culture change is a gradual process; however, a systematical approach as proposed below removes unnecessary costs and effort:

- Beginning with the definition and communication of long-term goals
- Development of sustainability strategy and EnPIs (see 4.1)
- Definition of roles and responsibilities (see 4.3.3)
- Introduction of sustainable controlling, measuring, monitoring and documenting energy and material flow using the TIEM software (see 5.1).
- Commitment of management at strategic level (ecology policy, vision and mission statements)
- Scheduling regular eco-auditing (EMAS, DIN EN ISO 50001/14001)
- Carbon footprint and life cycle assessment to determine the environmental impact of the organization.
- Leadership by objectives with sustainability goals

The conception of the future corporate culture is based on the analysis of the current situation. The first step is to designate a project team. A steering committee should be set up to control the content of the overall project. It consists of the members of top management, experts and a project manager to ensure sufficient communication with all stakeholders. The project team is responsible for the practical implementation of the overall project. Managers, experts and employees from the company's key divisions may form the board to exchange ideas and opinions and give feedback to the project team on their achievements [107].

Change process is primarily an internal organizational task. However, the involvement of external experts can offer advantages such as reduction of workload and knowledge transfer. Nevertheless, the drawbacks of consulting external experts such as lack of trust, lack of cultural expertise and costs should be taken into consideration. Figure 33 shows the process of culture analysis.

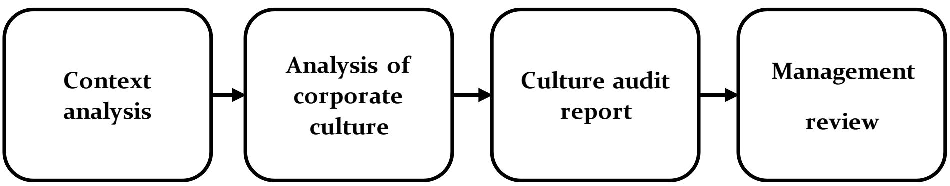

Figure 33: Workflow chart of culture analysis [107]

Context analysis

The context analysis is the study of the business environment. In the context of ecology management, this includes the following issues:

- Climate change
- Importance of sustainability for customers
- Market trends
- Developments at suppliers
- Legal framework

The available information is used to anticipate future developments in the corporate environment to establish focal points for the analysis of the corporate culture.

Analysis of corporate culture

The analysis of the corporate culture is based on a preparatory selection of topics and a subsequent qualitative and quantitative data collection. Through interviews and/or questionnaires, the values, attitudes and behavior of employees is surveyed. Often these provide valuable information on the future cultural orientation of an organization. It is important to involve all stakeholders to define thematic areas. To make the survey representative, it is important to collect data from the employees of each business unit. The following key aspects of ecology management are particularly important in the corporate culture:

- Significance of sustainability for employees
- Personal initiatives regarding resource saving
- Feedback from supervisors and leadership behavior
- Potentials of sustainable production
- Incentive systems
- Compliance with the company's vision and mission statements

Through data analysis, it is possible to determine the extent to which ecology consciousness is anchored in the behavior of employees. Based on this, a catalogue of measures is developed such as "the idea management system" designed in TIEM software that offer employees a platform to communicate potential optimization measures to the top management (see 5.5).

Culture audit report

A crucial aspect of a culture audit report is the preparation of a gap analysis. Thereby, the external aspects such as industry development, customer requirements and trends are compared with internal factors to draw conclusions for the change process.

The Culture audit report is a summary of the results of the culture analysis. It includes:

- The methodology of data collection and the results
- Strengths and weaknesses in the context of the environment
- Identification of problems, barriers and their countermeasures
- Roadmap for future development and milestones

Management-Review

According to DIN EN ISO 9001 and DIN EN ISO 50001, the management review (See 5.4) includes the assessment of the measures regarding the suitability, appropriateness, effectiveness and their alignment with the strategic orientation of the organization [13, 108]. The planning of the further procedure, the staffing and the allocation of resources are particularly important here.

4.5.2 Conceptual design

Most companies have a quality management and lean production thinking anchored in their corporate culture. Therefore, a fundamental change in culture is not necessary. However, integration of sustainable production philosophy into the corporate culture is essential. This requires adapting to the new processes and improving the understanding of the employees regarding sustainability. Since, sustainable production is a demand of the society, customers and shareholders, it is necessary to make the changes in corporate culture and advertise them. For instance, by using external certifications for advertising on contracts, websites and so forth. Essential input for the conceptual design comes from the above-mentioned culture analysis. To integrate ecology management in the corporate culture the change concept should include:

- Definition of communication tools
- Creation of a roadmap with milestones
- Persuasion of employees

Rollout

The rollout of a change process requires the involvement of all employees. The change process is a top-down process. The process flow of a culture rollout as shown in Figure 34 begins with an event to inform all the employees about the upcoming changes. The other phases include offering workshops to employees in small groups in order to facilitate in depth discussion and transfer of knowledge. Offering seminars to come together and reflect on the achievements. Offering refreshing course to solidify the new corporate culture.

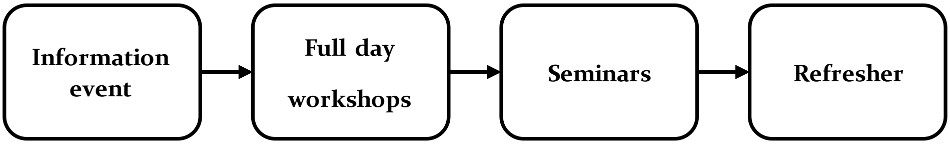

Figure 34: Procedure for a culture rollout [107]

With the change process itself, the cultural change is by no means complete. Rather, it requires tools to prevent relapse into old habits [90]. Often people fall back into old patterns and everyday routine takes over. Therefore, change management must take these psychological effects seriously and use suitable measures to counter them. These are divided into short-term, medium-term and long-term counter measures according to their effective time horizon. In order to maintain the culture of sustainability in the short term, common measures such as action plans, workshops or the communication of quick wins on the company's communication channels are used. Goal agreements or a sustainable balanced scorecard is particularly suitable in the medium term. Training managers and staff in operations of IEM can help maintain a long-term corporate culture.

Internal communication is essential in the event of a cultural change. On the one hand, the works constitution act establishes strict limits on the extent to which the employer must inform employees about operational processes. On the other hand, cultural change takes place in the minds of employees. Early information on planned projects is therefore essential to promote and motivate employees to accept the new corporate culture [109].

4.6 Shared values and corporate social responsibility

Shared Values (SV) and Corporate Social Responsibility (CSR) is a broadly interpretable guiding principle of management. A uniform definition does not exist. Essentially, it means that companies make a voluntary contribution to sustainable development that goes beyond the legal requirements. The ten principles of corporate sustainability have been defined by the UN. This includes standards in the areas of human rights, working conditions, environment and anti-corruption. The traditional understanding of CSR assumes that environmental or social problems are external problems that do not cost the company anything. It is therefore only through legal pressure that companies are forced to share their profits with society.

The shared value concept, on the other hand, starts with a different worldview. This assumes that a proactive approach is the one that best serves the interests of the company and can lead to a profit maximization. Hence, it is used to derive a competitive advantage in the market [110].

Companies can create shared value in three ways [111]:

- Understanding new products and markets

By satisfying societal needs, companies can open new markets and develop products or innovations that are oriented towards a common benefit. For example, more than one-third of the world's population suffers from a shortage of essential nutrients. A company can analyze the signs of deficiency and adapt its products regionally to meet local needs and differentiate itself additionally from competitors.

- Revaluation of value-added productivity

By optimizing product quality, quantity and costs, companies can improve their production and logistics processes while staying committed to sustainability at the same time. For example, packaging is cost-intensive, innovative solution to reduce material used for it can reduce costs and it can benefit the environment at the same time.

- Setting up local clusters

A strong and competitive business environment consisting of regional suppliers, qualified employees and infrastructure help strengthen the ability of an organization to innovate and succeed in the competitive environment.

By creating clusters based on defined criteria, such as technology, a company can enable each of its regional suppliers to concentrate only on their strengths, which in turn benefits the entire value chain.

Implementation of the shared value approach in companies

Shared value integration requires internal awareness building, which results in tasks for employees. These are classified according to the hierarchy level as shown in Figure 35.

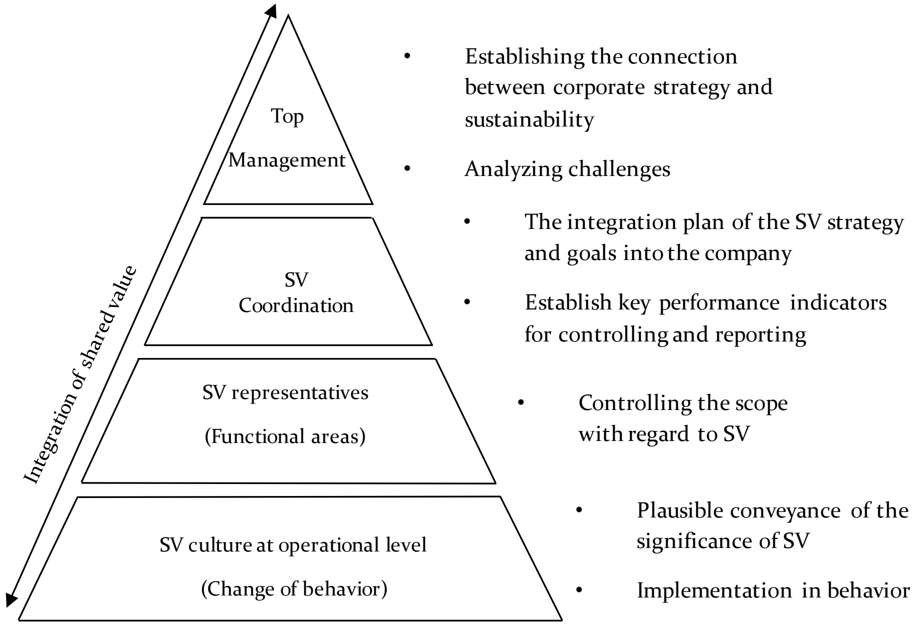

Figure 35: Structuring and integration of SV into the organizational culture [112]

Through proactive sustainability communication, potential investors and customers can be attracted which otherwise may deter by the lack of communication. Many companies therefore compile a corporate social responsibility report on a voluntary basis, which also covers non-financial aspects. An international recommendation for the contents of the reports is the Global Reporting Initiative's (GRI), which contains guidelines for the basic principles of truth, essence, clarity, consistency and comparability of the CSR reports.

Sustainable production as shared value

According to Porter, companies would benefit from a sustainable competitive advantage through shared values with respect to the revaluation of value-added productivity. Reducing emissions and energy consumption pays off in many ways. For example, buying less expensive emission certificates and reduction of costs through reduced energy consumption.

Internal and external stakeholders have a high level of interest in the sustainability performance of a company.

In order to optimize the value chain, all suppliers must be involved in the process of increasing energy efficiency and reducing the carbon footprint of the supply chain. The cumulated energy consumption (KEA) according to VDI 4600 is used as reference value. This value indicates the primary energy consumption of a product during its manufacturing, usage and disposal [113].

However, the value of the manufacturing process KEAH is determined by means of pre-analyzed data sets and therefore does not represent a company specific situation. This should be determined on a company specific basis. This new value KEAH* is intended to serve as a real benchmark for companies in terms of energy efficiency [66].

KEAH* value can be used for marketing and communication purposes of the SV approach. Certification according to EMAS or DIN EN ISO 50001 are also important components for a successful differentiation of competitors. Table 10 shows the methods that are developed to achieve a sustainable competitive advantage through shared value in the field of ecology management.

Shared value approach	**Measures**
A new understanding of products and markets	▪ Green Production/ Logistics ▪ CO_2-neutral production using renewable energies ▪ Advertise with KEAH*, EMAS, ISO certifications
Revaluation of value creation in terms of productivity	▪ Integration of suppliers, customers and service providers to reduce the cross-company KEAH* value ▪ Energy optimized redistribution of production processes ▪ Shorter logistics chain ▪ Shorter value creation stages ▪ Orientation of the value chain towards resource efficiency
Build local clusters	▪ Establishing contacts with local universities

Table 10: Implementation of the SV concept in ecology management systems

4.7 Systems

In order to implement energy management, it is necessary to establish functional and operational systems in companies. These systems are required to process information and support service processes in the organizations. They are also referred to as socio-technical systems and consist of software, hardware and users [7, 114, 115].

A modular software system is developed for industrial ecology management. This system supports organizations in all the 'S' elements of the TIEM framework. This software is further referred to as TIEM software (TIEMS) in this work. TIEMS is the functional system with the ability to identify problems and to support the implementation of EPIAs. The system automatically takes care of the work and information flow and ensures a thorough practice of PDCA cycle and eliminate human error through intelligent algorithms. Data collection and its statistical evaluation necessary for this purpose is largely managed within the framework of this functional system, which include:

- Energy data management and monitoring system
- Controlling and benchmarking system
- Online analytical processing systems

Energy data management and monitoring system

Energy data management encompasses the storage and processing of the collected data. This is accompanied by the processing, analysis, output and archiving of energy-related data [116, 117]. It covers all installations used for the generation, conversion, distribution and storage of energy in accordance with [118, 119].

"If you can't measure it, you can't manage it." [120]

Data collection is thus essential for a functioning industrial ecology management system [120, 121]. This includes people, departments and processes that have an influence on the respective aspects of resource, especially energy-related issues in the organization [122, 123].

Energy controlling

Controlling is described as a support function for corporate management. It includes planning, information flow, control, rationality and coordination functions. Industrial ecology controlling system in TIEM is designed in accordance with VDI 4602 [11]. Particularly controlling in the TIEM software is based on the methodology of Keah* [66] and least energy usage concept [65]. The transparency of the production achieved through the TIEM data acquisition and management system opened the doors for effective cost allocation, according to [124], to the single processes by means of energy value stream mapping.

Online analytical processing systems

This module of TIEM encompasses condition monitoring. Based on the defined threshold values of a process, TIEM software is able to generate triggers to start pre-defined responses such as sending warning message to the operators with detailed information about the reason that caused the error.

In addition to functional system, the TIEM software also has the following functionalities:

- Communication system
- knowledge management system.

These systems support tasks such as sharing of information, collaboration and preservation of knowledge. They are intended to simplify group-oriented work and represent a building block for knowledge management.

TIEMS is explained in detail separately in chapter 5 since it addresses various areas of an organization and hence require a comprehensive description.

5 Development of TIEM software

As described in chapter 3.2, one of the reasons hindering companies in implementing IEM is the missing functionalities of the currently available energy management software in the market. Furthermore, there is no software support available in the market for ecology management since this a very new topic and companies are starting to accept this as a necessary element of their operations. Therefore, the goal is to develop a completely automated totally integrated ecology management software using a modular approach that allows the integration of all the elements mentioned in Table 5. The software is designed to complement all the elements (i.e., the other 6 S) of TIEM. The software can provide interface to other systems such as quality management system and facilitate cooperation between the various integrated modules by creating common standards. In order to make ecology management easy for the companies, TIEM software offers fully automated solution allowing the user to concentrate solely on the development of strategical and technical ecology optimization measures and their implementation in the organization leaving all the non-technical task as listed in Table 11, to the software.

Additional features required in TIEMS
Completely automated PDCA-Cycle
DIN EN ISO 50001 conform work and information flows
Automated report generation for the audit
Automated DIN EN ISO 50001 conform documentation

Table 11: Non-technical essential ecology management tasks.

The intention is to provide companies the necessary infrastructure required to fulfill all the DIN EN ISO 50001 tasks.

General properties of TIEM software

The core objective of TIEMS is the application of ecology management to improve resource efficiency, resource use and resource consumption as well as reduction of greenhouse gas emissions, environmental impact and energy costs. In accordance with the standard norms of energy management, environment management and EMAS, TIEMS is designed to integrate continuous improvement processes, based on PDCA cycle, into day-to-day business of organizations. In this procedure, improvement measures are planned (plan), implemented (do), their effects assessed (check), new measures for further improvements derived using available information and initiated (act). TIEMS is a tool that implements PDCA automatically, guides the user in the execution of it in every phase and documents every required detail at the same time.

To ensure maximum flexibility, TIEM software is designed as a platform-independent web tool. This gives it several positive characteristics. The concept as a web tool initially reduces the administration effort of the system, because on the user side there is no need for a local installation that involves additional administrative tasks for each user terminal. A web browser is sufficient to run the web tool. Web browsers are administered as part of modern business IT infrastructure in any case and therefore do not represent any additional administrative effort, on the user side, to enable the execution of TIEMS. The same applies to network connections of the end-user devices. Only the administration of the web server, on which TIEMS is hosted within the intranet of the organization causes additional effort. Compared to the installation of software on each user terminal, the administration effort of web-based system is significantly lower. This difference becomes especially noticeable with an increasing number of terminals. TIEMS is platform independent. It uses the standardized protocols and scripting languages such as HTML, JavaScript and CSS. These standards are implemented by various browsers of all common operating systems. In combination with responsive design techniques, TIEMS can be operated easily both on high-resolution desktop PCs with powerful operating systems as well as on mobile devices. This greatly increases the application potential of the software.

The TIEMS server uses a Debian operating system version 9 "Stretch". This is a free operating system under the GNU general public license. This web application is based on the Symfony PHP framework that is why PHP 7 is used on the TIEMS server to generate the dynamic web pages. An Apache web server is used to host them on the default port for Hype Text Transfer Protocol (HTTP). In addition to responsive design techniques, which adapt the visual representation of TIEMS to the given boundary conditions of the user device. TIEMS can display contents in several languages and thus adapts to the user on a further level.

Modules and functions of TIEM

Figure 36 shows the modular structure of TIEMS that integrate different sub functions necessary for ecology management creating thereby, a holistic software solution. The segments with green solid color are the core elements of the TIEMS and the elements with a green outline represent the add-on features.

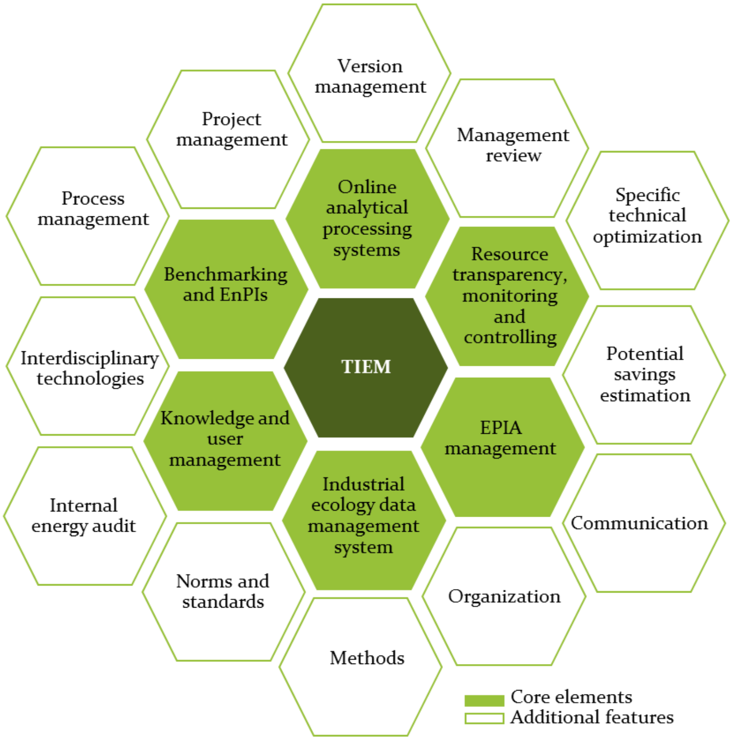

Figure 36: Modular structure of TIEM software

This modular structure is made possible by the use of the widespread Symfony framework [125]. It is based on several standards and provides a comprehensive basic framework that is extendable to an individual product via a large selection of available modules. Conceptually, a Symfony project consists of several bundles, which are intended as reusable packages that add functionality to a web application. Based on this concept, various function packages are structured into bundles in TIEM software. They can theoretically be deactivated or used identically in other applications and thus give TIEMS the stated modularity. To link all the bundles to each other, a main bundle as an obligatory node was defined, which is called MainBundle in this application. All TIEMS functions are combined in this bundle.

The MainBundle generates a dashboard (see Figure 37) that contains overviews of various modules.

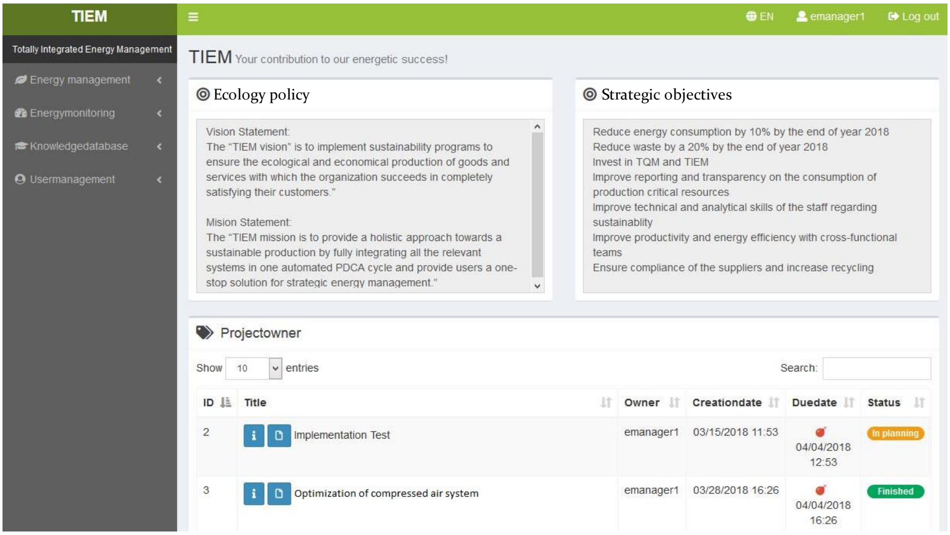

Figure 37: The TIEM homepage

The MainBundle also defines the navigation bar on the left-hand side of the website, which allows the user to call up individual functions of the various bundles via their menu items. The functionality of TIEMS is divided into five areas, which are described in more detail in the following sections.

In addition to the primary broker function of the MainBundle, which is carried out according to the Symfony guidelines via routing files [126]. The schematic structure of all web pages is defined in the MainBundle via several templates. Each bundle derives its own representation from these templates, which guarantees a uniform structure in all areas of the web application. TIEMS uses elements of the bootstrap design AdminLTE [127]. This is a collection of harmonized representations of common standard components of modern web pages, defined using tools such as HTML5 and CSS3.

Bootstrap in combination with the AdminLTE design gives each component and thus the entire TIEM application a responsive design. As a result, all web pages of the application are able to adapt their layout to the display device of the user, for example by arranging several elements in columns on high-resolution devices, which are otherwise displayed line by line on smaller screens.

5.1 Resource monitoring in TIEMS

Data on resource consumption, also referred to as “resource data” in this work, such as use of energy, water and gas, is a central component of ecology management and it is therefore very important for TIEMS. However, TIEMS is not limited to the analysis of acquired resource data from the past. Rather, TIEMS embodies a deeper approach that includes the collection and simultaneous monitoring of resource data, thereby demonstrating approaches that link Industry 4.0 standards with ecology management.

5.1.1 Cloud infrastructure for data collection and monitoring

To ensure a continuous improvement, complete transparency of the production plants is necessary. Therefore, resource monitoring regarding the consumption of those plants and their components needs to be improved significantly.

Particularly in the industry, the resource consumption of a plant is measured as a solitary value without having any information about the resource consumption of the individual processes during production.

Hence continuous monitoring of the production plants and the individual processes is the goal. Modern Industry 4.0 compatible plants offer this functionality. In doing so however they generate bulks of data. In order to efficiently acquire, analyze, process and save this data, while retaining the approach of keeping the communication and networking independent of location and platform, a cloud infrastructure is developed. It serves a database module of TIEM software.

To ensure communication, various signals are brought together at the field level. Digital signals are generated via suitable data loggers, which in turn enable the connection to other software-supported systems.

Furthermore, a low susceptibility to malfunctions is ensured, which enabled the reliable collection of ecology-relevant data. Intelligent communication protocols and bus systems are used in this approach to support the collection of data from meters [128].

Figure 38 shows that the path of resource consumption data, from its acquisition to its analysis, includes four major stations.

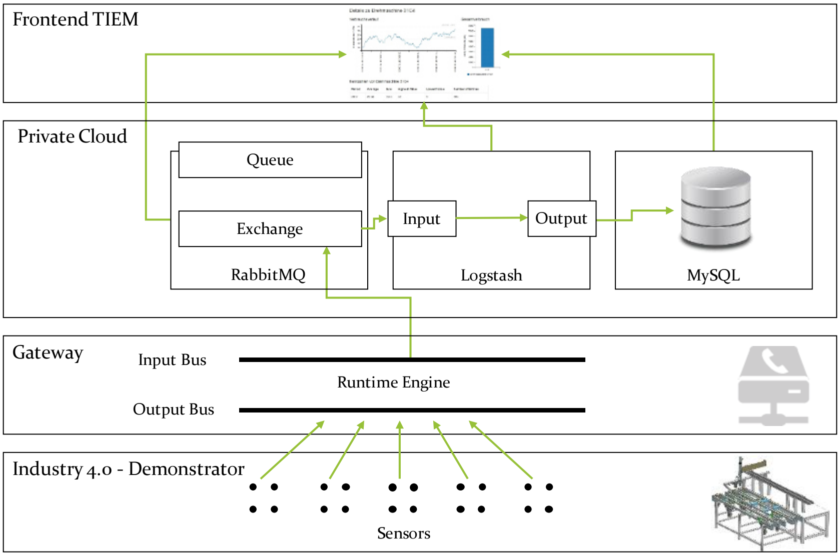

Figure 38: Data flow from sensors to frontend [129]

Gateway for the data

An internet of things (IOT) gateway called “Open Access – Gateway” was developed to serve as an interface between the plants and the cloud platform. This gateway is an edge-computing device that collects, filters, aggregate and forwards raw and preprocessed data of the production plant to the cloud platform. The modular design of this gateway (see Figure 39) allows further integration of plants and systems to the cloud platform easily [129].

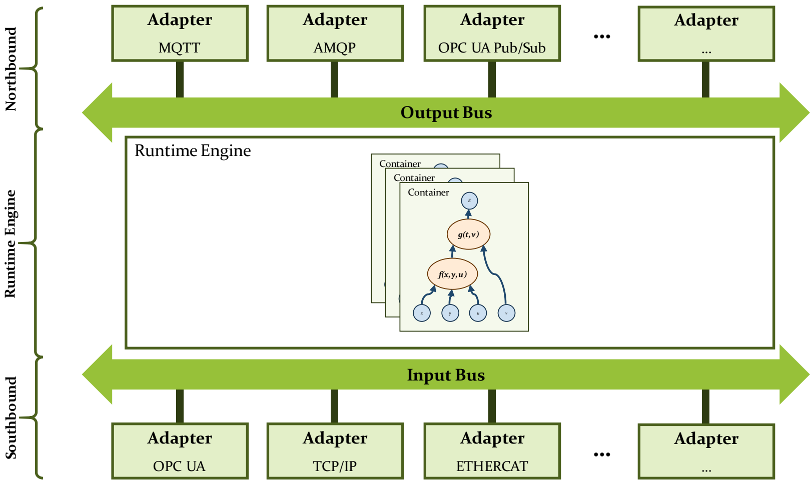

Figure 39: Architecture of the Open Access – Gateway [129]

This gateway was designed exclusively using open-source software and it is implemented in Node.JS. The three main components of this gateway are:

- Input Bus: The function of the input bus, the so called southbound, is to establish a connection with the sensors of the production system. Different adapters can be used to support various communication protocols.
- Runtime Engine: The runtime engine is responsible for pre-processing incoming raw data. Such as reducing the data by removing waste.
- Output Bus: The output bus, also called northbound, enables the flow of data out of the gateway via common communication protocols.

The gateway is installed in the network and has a Linux-based operating system, which is programmed with different high-level languages that enables it to use almost any communication protocol such as TCP/IP, OPC UA, Modbus or Profinet [S1].

Message broker

The first point of contact of the transmitted data via the Open Access Gateway to the cloud is a message broker server. RabbitMQ is an open-source message broker solution that is implemented for the management of incoming messages (See Figure 40). Although RabbitMQ offers a bi-directional communication possibility, for simplicity it is programmed in TIEMS to work only in uni-direction. This message broker uses the Advanced Message Queuing Protocol (AMQP) to securely and reliably distribute the aggregated resource data to all the micro services forming the private cloud [129].

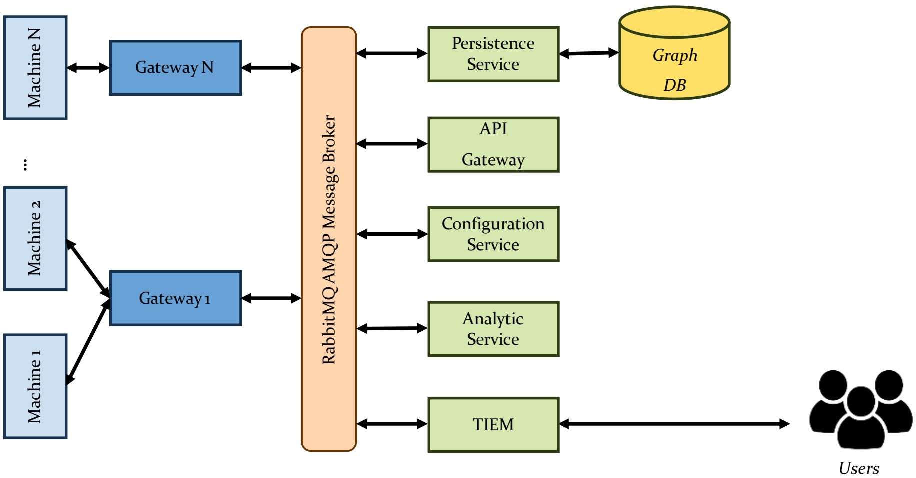

Figure 40: Architecture of message broker

The messages received by the exchange server are queued according to the exchange configuration and remain there until they are processed by a consumer. For the permanent storage of the measured values of the production systems, a database is set up on a server as shown in Figure 40.

The AMQP is used because it bidirectionally confirms any transfer of messages, repeats it if necessary and thus minimizes data loss due to transmission errors. In addition, RabbitMQ is highly scalable. If the current RabbitMQ configuration reaches its capacity limit, for example due to increasing data throughput caused by the integration of further production plants, further RabbitMQ server instances can be integrated into the system to increase the capacity limit to fulfill the new requirements. A migration to another system is hence not necessary.

In TIEMS all resource data is sent from the Gateway to a single exchange. This queue each message in two separate strings so that both queues contain the same resource data. One of the two queues is used to archive the data, the other for direct retrieval for real-time monitoring. From the archiving queue, the data is retrieved, processed and archived by a consumer which runs on the TIEMS server.

5.1.2 Data management

In addition to measuring and transmitting the resource data, archiving is also one of the necessary processes that takes place before an evaluation based on the available data can be done. Resource data must therefore be stored after acquisition so that it is possible to compare it at a later point in time together with the actual data. In TIEMS structure, a MySQL database has been set up to archive the collected data. This database is set up on the TIEMS server as a MySQL server instance and contains all relevant database tables of the web application TIEMS. The database tables are divided into two sub-databases that separate resource monitoring and resource management. By separating the contents of the tables at this level, it is possible to physically store them on different servers at any time. All that is required in TIEMS is adjusting the communication settings. It is not necessary to change the application itself. The same applies if one of the databases needs to be moved to a more powerful system.

Structure of the database

The structure of the TIEMS database for monitoring is shown in Figure 41. It is also used to store resource data.

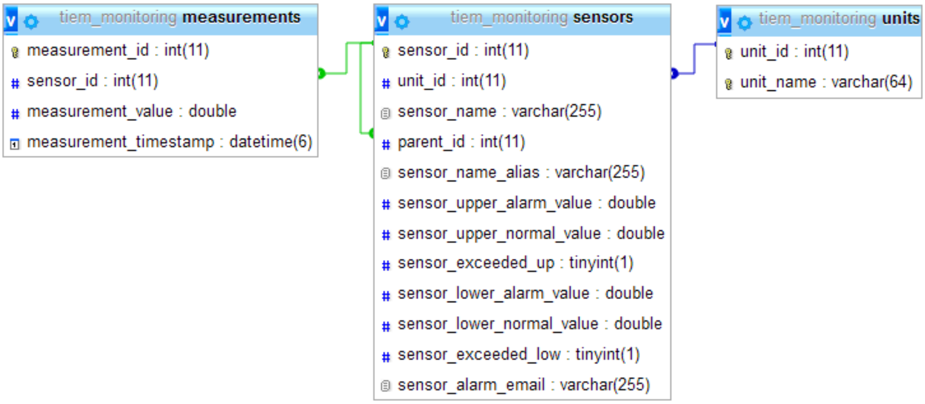

Figure 41: Database Structure for TIEMS monitoring

Three main information elements describe a data point of the resource data. Namely, time of measurement, identity of the measuring sensor, and measured value. The database table for storing the measured values is simple. In addition to a unique ID, which is automatically assigned to each data point, an entry in the table consists of the above mentioned three values.

The time of the measurement is recorded and specified with an accuracy of up to six decimal places in the millisecond range, whereby theoretically one million measurement points per second can be distinguished. The time stamp is recorded in UNIX format in the time zone UTC, so TIEMS can be used in several time zones without time conflicts.

The numerical value of the measurement is stored as a floating-point number. With a standard size of eight bytes. The accuracy of floating-point numbers of the data type double is almost 16 valid digits. The data type Float occupies only half of the memory space with four bytes and can therefore only accept floating point numbers with an accuracy of up to eight valid digits. Measured values of precise sensors cannot be stored with this low accuracy, which is why the data type Double is used for recording the measured resource data in TIEMS.

The identity of the measuring point is recorded as sensor_id. Detailed information on the measurement point is recorded in a separate table to keep the database table as lean as possible. Only a reference to a detailed data set of the sensors is logged. The relevant sensors are uniquely assigned via these.

Sensors are described in the sensors table. The digital image of a sensor is limited to the following main information elements:

- The designation (sensor_name), which the gateway uses to name it.
- An alias that the user can utilization to identify the sensor.
- The unit ID for interpreting the measured values.

The unit of measurement is encrypted via a separate database table. This allows sensors that measure in the same unit to use the same data model. This dependency allows the data model of the units to be extended by complex conversion factors. It is possible to use concepts that can convert simple powers of standard units such as mV, V, kV into each other so that data series of different units can be compared correctly in a graph. In addition, different standard units can be used to enable complex evaluations with correlations of different measuring points or media. To map dependencies of sensors, data sets are used to refer to other data sets. In concrete terms, a higher-level sensor is assigned to each point. In this way it is possible to reproduce hierarchical structures. These structures are managed using the application TIEMS. There it is possible to define the alias name and unit of the sensors.

The remaining columns of the sensors table shown in Figure 41 enable condition monitoring, which is described in more detail in section 5.2.

This structure of the database tiem_monitoring allows resource data to be archived efficiently. The storage space required for the measurements table is estimated easily. A total of 24 bytes are required to record a data set. These sets consist of four bytes for each column. The required storage space per time interval is calculated using the following formula:

$$Storage\ Capacity = 24\ Byte * \frac{time\ interval}{measurement\ interval} * number\ of\ sensors \tag{5}$$

In contrast to the measurements table, the contents of the respective tables for sensors and units does not grow continuously. Compared to the number of data records in the table for measurements, the storage space required for the two tables for sensors and units is therefore extremely small and can be neglected.

An AMQP consumer is used to feed the database structure as described in the previous section. The consumer links the RabbitMQ server queue to the MySQL database for archiving resource data. It is executed as a PHP program on the TIEMS server and executes the process shown in Figure 42 in a continuous loop.

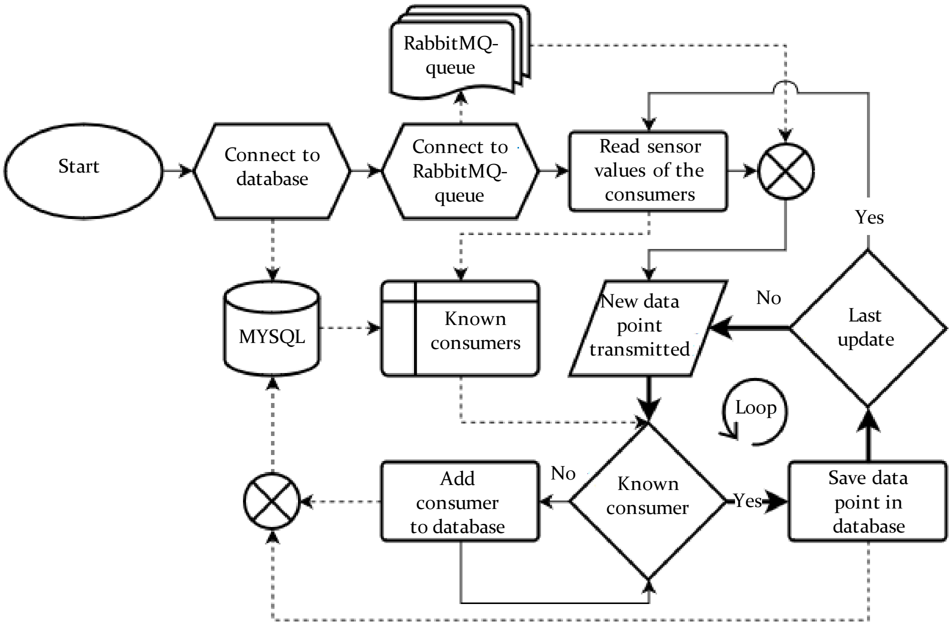

Figure 42: The consumer process for archiving resource data [137]

The first step of the process is to establish a connection between the source (RabbitMQ queues of the resource data) and the target (MySQL database). Thereafter, all consumers already stored in the database are retrieved and stored as an internal list for further use within the process. Subsequently, continuous processing of the loop begins, which immediately recognizes new messages in the queue and processes them individually. For the assignment of the measured values to the correct sensor, the sensor ID designation transmitted in the AMQP message is compared with the list of all registered sensors in the database. If there is a match, the measured value is linked to the corresponding data set of the sensors and supplemented to the table of measurements as a new entry. If the consumer is not yet listed in the database, a new data record for the unknown consumer is first stored in the database and the updated complete list of all known consumers is retrieved from the database again. The measured value is then stored in the database. This procedure allows new plants or sensors to be connected to the system in a quick and easy manner. Therefore, changing the transmission process of the resource data is not required. Only the system control requires adaptation so that it sends measured values of the new consumer to the gateway via the OPC UA protocol. The AMQP server generates the messages without changing the configuration and sends them to the RabbitMQ exchange server, where they are queued. After the messages have been retrieved, if the consumer process described above recognizes that no digital copy of the sensor is stored in the database for the transferred message, it generates it in this case automatically. Thus, all interfaces between system and frontend are configured automatically. The digital image of the consumer can be edited from the web application. TIEMS independently configures the database, assigns keys and routes the data packages for the user itself.

The final step in the consumer process ensures that the list of known consumers is queried from the database at regular intervals. This procedure is necessary because changes to the data records of known receivers can be made at any time via the TIEMS application. Regular updating of the internal storage of the consumer means that these changes are also considered in the consumer process. These changes have a particular influence on condition monitoring.

Visualization of the archived resource data

TIEMS allow users to analyze any system that is connected to the software using the archived data. The user can load resource data of selected consumers over a freely selectable period. This is done according to the procedure shown in Figure 43.

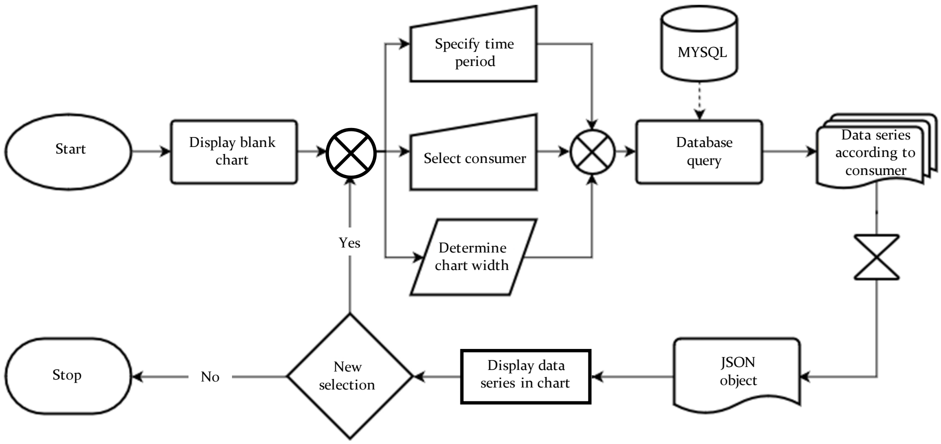

Figure 43: The process of data retrieval to visualize achieved resource data

The two selection criteria namely, consumer and time, must be set using the input masks. Individual consumers or entire consumer groups can be selected using checkboxes. Sensors are represented by the alias name stored in the database. If this is not defined, the name of the sensor that the gateway uses to identify the component is displayed.

An intuitive drop-down menu allows the user to specify the time interval. The time from the beginning and end of the query is defined via drop-down lists or text input with an accuracy of up to 1 second. The selection dialog is multilingual and supports country-specific date formats. Before a time is visualized, it is converted into the corresponding time zone of the user, so that the users receive a representation of the time that is familiar to them.

In addition to defining the time interval and consumer settings, TIEMS uses another internal control variable that influences the result of the query. It analyzes the display area of the device where the desired graphs should be displayed. The maximum width of the graph limits the number of data points that can be displayed on the time axis. Even if more data points are available in the selected time interval, they are not visualized. Hence, to avoid unnecessary data transfer and computing power for processing data that a specific device cannot display, the database query averages all values of the entire time interval in such a way that no more data points are processed than what can be displayed in the diagram by the device of the user (see Figure 44).

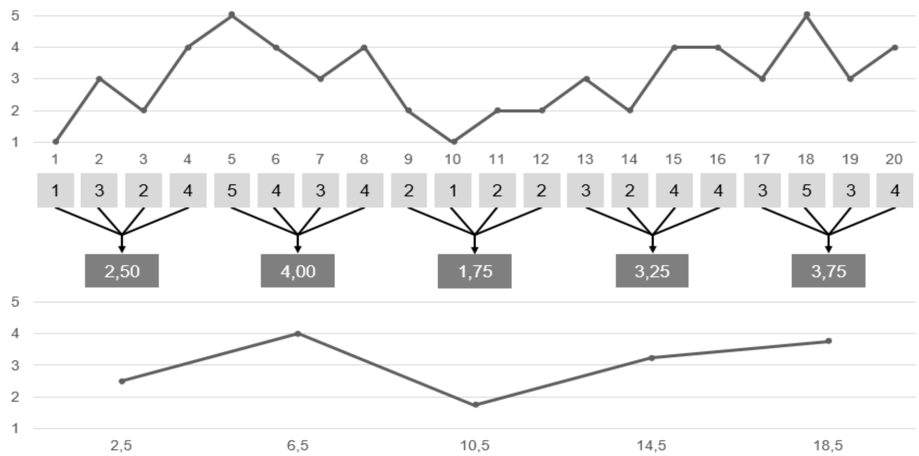

Figure 44: Schematic representation of averaging data point to avoid unnecessary data transfer

TIEM utilizes the widely used Highcharts diagram library to display the result of the query. It enables the creation of interactive diagrams in which, for example, dynamic tooltips for data points that are selected with the mouse pointer is displayed. A special feature of the diagram library is the possibility to load data asynchronously via AJAX requests. This function is useful for evaluating large time intervals. Highcharts offers possibilities to select a part of the displayed time interval by drag-selection. As a result, the displayed diagram is zoomed in on the selected. For example, it is possible to zoom directly into a single month from the display of a year (see Figure 45). The data point boundary described in the above means that zooming in an area limited by the number of data points again provides space for additional data. Therefore, when the view is zoomed-in, a subsequent database query is immediately initiated, which provides a more detailed data set for the new selection of the time interval which is limited to the maximum width of the diagram.

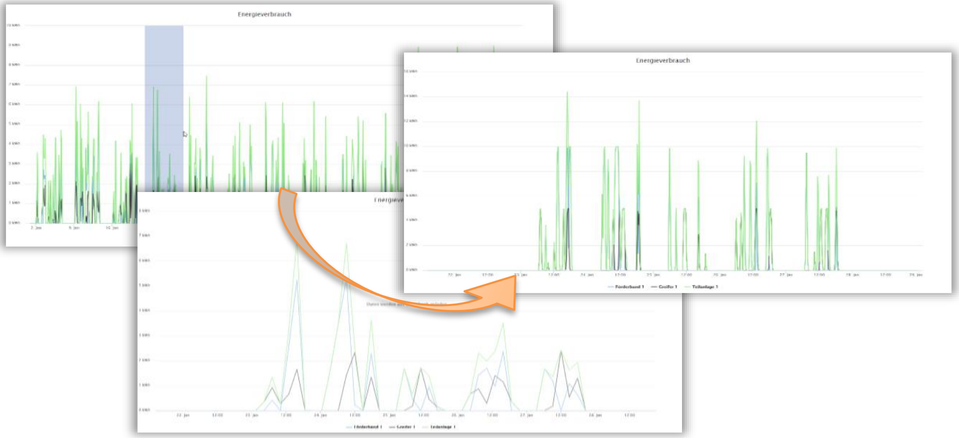

Figure 45: Zoom-In directly in the resource data diagram to display more detail

Visualization of real time resource data

TIEMS can display current real time values of the consumers. Similar to the analysis using the historic resource data, the user can restrict or change the selection of consumers. It is not possible to limit the period since actual live resource data is continuously added to the diagram. The diagram is configured to remove values older than 60 seconds so that the number of data points does not exceed a maximum threshold.

The data flow of real-time monitoring is summarized in Figure 58 (Appendix). Unlike the procedure for displaying historical resource data, real-time monitoring does not retrieve data from the database. Instead, this monitoring variant accesses relevant data directly from the RabbitMQ data stream. As already mentioned, to enable this without affecting the described data archiving process, the RabbitMQ server exchange writes incoming data in two queues. Data archiving retrieves resource data from the first queue, whereas real-time monitoring uses the second queue. In this way, both queues and consequently both monitoring methods contain the complete resource data. Similar to the procedure for archiving data, a consumer is linked to the queue, which process all incoming messages in the queue but does not feed the messages into a database. It instead publishes them as a JavaScript Object Notation (JSON) in a Socket.IO server, which is hosted on the same machine. Socket.IO is a JavaScript framework that enables bi-directional communication in real time. Socket.IO uses different communication protocols depending on the possibilities of the two communication partners. For example, WebSockets or Long Polling are supported. Depending on the operating conditions or capabilities of the communication partners, Socket.IO automatically uses the most suitable communication protocol, which makes the development of powerful web applications immensely easier. However, this property is not the reason for using this framework. The possibility of bidirectional connection is decisive. Unidirectional communication, as used in HTTP, cannot be used for real-time monitoring. In this case, the server takes a passive approach and only offers its services on request. For real-time monitoring, client and server must at least partially exchange roles. Here, the server initially waits passively for incoming connection requests and acts only upon request, similar to the conventional communication protocols. The client actively opens a connection to the server, however from this point on it plays a passive role in the communication.

The server confirms the connection and switch to an active role by continuously sending new data to the client, which is then visually displayed to the user. The connection is retained until one of the two communication partners disconnects. A predefined end of the connection, for example by complete transmission of a document, is not allowed. In TIEMS structure, the JSON objects are permanently sent from the Socket.IO server to all connected Socket.IO clients. Socket.IO clients are code fragments of the Socket.IO framework library that are executed by the user via web browser when the real-time monitoring web page within the TIEMS web application is launched.

The web browser initiates a new connection to the Socket.IO server by displaying the real-time monitoring web page. It is continuously supplied with current resource data. AJAX-Calls subsequently change the displayed Highcharts diagram without disconnecting from the Socket.IO-Server or reloading the web page.

5.2 Condition monitoring

Another function in the field of monitoring which is also realized in TIEMS is condition monitoring. All relevant data is taken into consideration as suggested by [130]. By coupling sensors with TIEM software, critical entities such as the load is continuously monitored. Warning at threshold values can thus enable early intervention [131]. Notifications are sent as soon as consumers exceed the defined threshold values. The basic procedure is shown in Figure 46 and is described in more detail below.

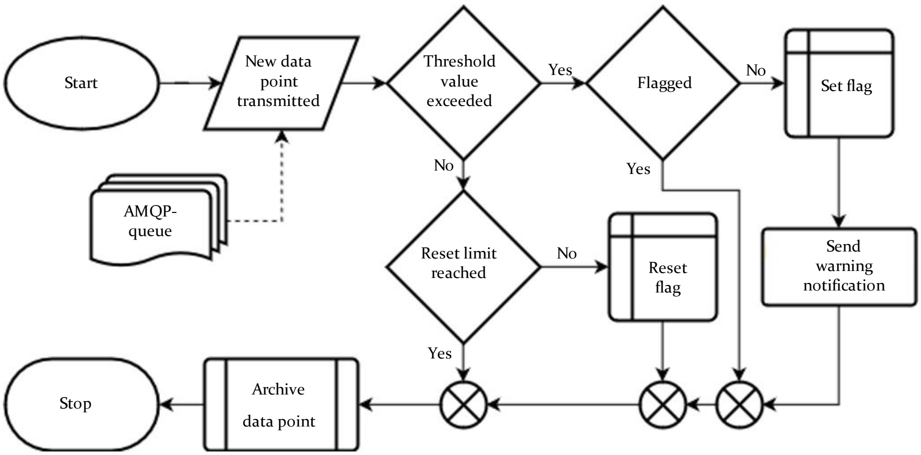

Figure 46: Condition monitoring flowchart [137]

Visualizations of data according to the procedures illustrated in Figure 43 is only generated by the server on request of the clients and represent passive service, which can be used at any time. In contrast, condition monitoring is continuously and actively executed independently of client requests. Resource data such as energy consumption is monitored by the system and threshold value violations are automatically reported immediately. Condition monitoring is not bound to a client or user interaction with the frontend of TIEMS. The concept shown in Figure 46 is therefore implemented on the TIEMS server as part of the consumer data archiving process. This process ensures that the service runs continuously. Furthermore, it is ensured that data archiving and condition monitoring work with the same data base, which guarantees the consistency of both functions. In contrast, the implementation of a separate data stream for condition monitoring could lead to a contradiction in the archived and monitored resource data.

The monitoring of data is implemented as an extension data archiving procedure shown in Figure 42. Incoming data in the form of a message from the AMQP therefore first goes through the consumer process and is assigned to the digital image of the consumer. Finally, defined threshold values are derived from this assignment and stored in the database.

TIEMS determines whether a notification needs to be sent by comparing the current value received from the AMQP message with the defined threshold value. The decision is based on the operating principle of a two-step controller to avoid multiple notifications being sent within a short time.

The system uses internal flag variables for each threshold value and consumer. These are set as soon as a threshold value is exceeded, triggering a notification for the first time. Any further incoming AMQP message, which also represents a violation of the threshold value of the same consumer, does not lead to a new notification as long as the flag is set.

If the actual value of the consumer falls below the reset limit, the flag is reset again. Therefore, an event where the threshold value is violated again would lead to another immediate notification. This principle is used to intercept the non-ideal, fluctuating values of the consumers.

Using this method, two independent threshold values can be defined for each consumer so that the system can detect an upper and a lower threshold. The schematic procedure shown in Figure 46, runs separately for each threshold value.

The notification is limited to basic information about the set threshold value namely, the affected load and the type of violation (lower/upper threshold value). Notifications are sent via e-mail, however other notification methods, such as SMS or push services via a mobile application can be easily integrated in TIEMS.

Threshold values and reset limits as well as the recipient address can be changed with special authorization in the TIEMS frontend. Together with the current resource data, upper and lower threshold limits are displayed graphically as shown in Figure 47.

With its implementation, condition monitoring is used to enhance further functionality of TIEMS. For example, condition monitoring is used to monitor environmental conditions relevant to production.

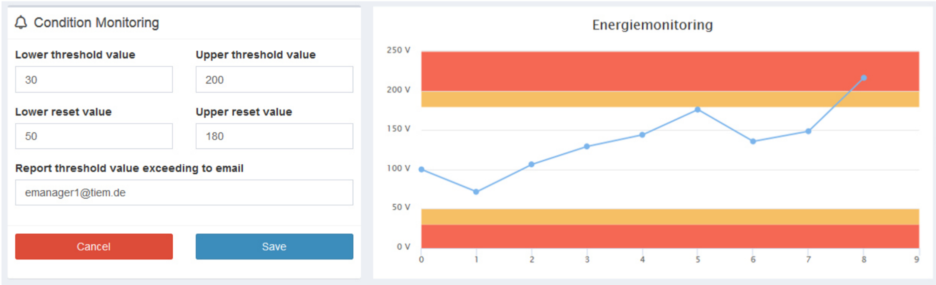

Figure 47: Condition monitoring in TIEM using threshold values

Threshold value can be used to bring a process to a standstill to prevent any damages to the production plants and to production losses due to defective products. Similarly, condition monitoring combined with flexible production planning stabilizes resource consumption. Analogous to known load management strategies for the optimization of plant capacities, condition monitoring serves as a basis for load management, where the main focus is on constant energy load. Such an approach avoids load peaks and fluctuations for which companies pay higher prices to energy suppliers. Condition monitoring is also used for predictive maintenance. Predictive maintenance is one of the key elements of Industry 4.0. This concerns the expected service life of a plant or component. Based on data, conclusions are drawn, for instance, about wear or insufficient lubrication of electric drives or mechanical components of the drive unit. An increase in load profile of a system can serve as an indicator for necessary maintenance before the machine breakdowns causes unplanned downtimes. This maintenance concept differs significantly from conventional concepts based on replacement, which only replace or improve machine components in a reactive manner. Traditional concepts are therefore associated with unplanned downtime and waste of resources. Constant condition monitoring allows proactive actions at the right time and thus offers potential for cost and time saving.

5.3 Benchmarking & controlling in TIEM software

Energy benchmarking is an essential function of ecology management. It is a "comparison of the energy efficiency of processes or companies using energy performance indicators (EnPI)" [132]. The benchmark is the target value that the process or company aim to achieve with best possible performance [122]. Framework conditions and influencing factors, such as climatic conditions or plant-specific parameters are taken into account when comparing key figures [11].

For the compilation of specific key performance indicators (KPI), energy consumption and waste production figures are set in relation to known company data such as turnover or employees. Monetary reference values are not suitable as sole reference values for benchmarking, since there is a strong dependency on time and regional aspects [133]. The number of employees is considered as a supplementary indicator [134].

Benchmarking and controlling module is developed to extend the capabilities of TIEMS. This module is designed in conformity with the relevant energy and environment standards and norms [119, 135]. The control system technology of TIEM software helps diagnose faults and malfunctions. It allows controlling and regulation of the connected systems with limited user influence. It is the interface between man and machine. Apart from preventing operating errors, the control system also help reduce resource consumption through simple means such as by setting up independent control values for heating and cooling processes [136].

Different categories of energy performance indicators are created for the benchmarking and controlling system. These are divided into the areas of security of supply, economic efficiency and environmental risk [83]. These indicators are implemented to provide transparency on the status of the system and operations. They are used to derive, set up, monitor and evaluate measures to improve the overall performance and environmental impact of the organization. EPIAs in TIEM are therefore evaluated using EnPIs (see Figure 48).

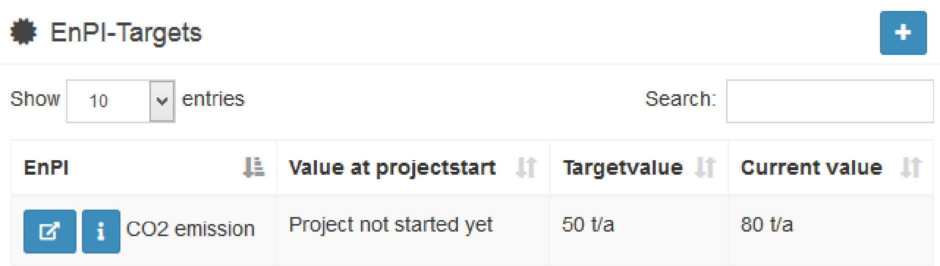

Figure 48: Tracking of EnPIs

All available EnPIs are listed in TIEMS using the interactive table. The EnPIs can be sorted and filtered according to various criteria to quickly find the desired indicator. Selecting an EnPI from the table leads to a more detailed view of it (see Figure 49). Here it is possible to adjust the title and description of the EnPI. In addition, a unit can be assigned to the numerical values of the indicator. New values are archived together with the definition of the EnPI in the database. The values of the EnPI of the past twelve months are retrieved from the database and visualized in a graphical representation as shown in Figure 49.

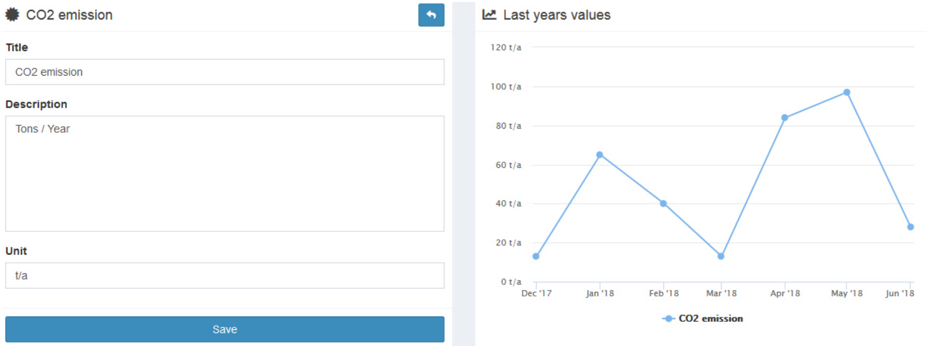

Figure 49: Course of a specific EnPI over a period of twelve months

As shown in Figure 50, EnPI targets can only be defined in the planning phase. At the start of the project, current values of EnPIs are determined to allow a comparison of the target and achieved values to determine the success of the project.

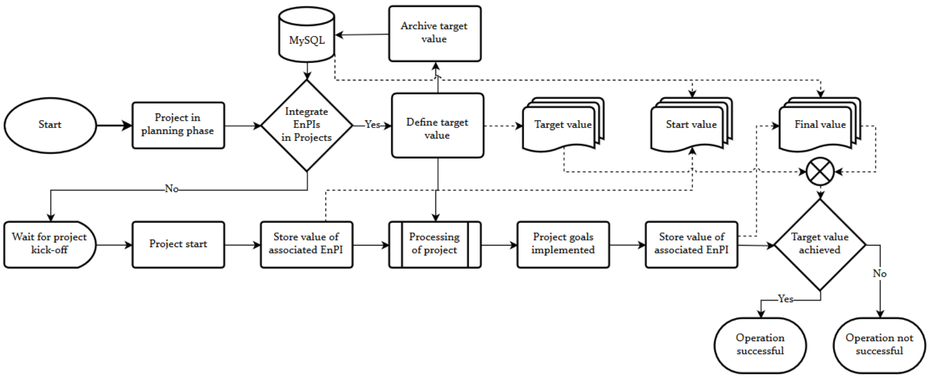

Figure 50: Integration of EnPIs into the overall process

5.4 Automated resource management in TIEMS

Resource management in TIEMS is based on standard norms as discussed in chapter 2.2 and the PDCA cycle as shown in Figure 3. One of the main objectives of the TIEM software is to support the planning and monitoring of EPIAs and the related tasks. The software is designed to prevent user errors in the organization, documentation and flow of information in these projects by automatically implementing the required PDCA cycle. This way the user is only required to concentrate on the implementation of EPIAs and TIEM software takes care of the rest of the process and guides users systematically through each phase of the PDCA. TIEM guides user also in the documentation of the EPIAs as required by the energy and environment norms.

Ecology policy and strategic goals

Ecology policy and strategic goals are essential components of TIEM (see 4.1.2) and therefore appear on the start page of every user (See Figure 37).

Ecology policy and strategic goals represent guidelines that reflect a company's overriding intentions and define a framework for improvement measures. These guidelines are stored in a database, which contains information on the person who wrote or changed them together with the time of the modification. This creates transparency and traceability on the development of the values of the company over time.

EPIA process

Implementing EPIAs is the core objective of ecology management. Their implementation is monitored, controlled and documented automatically via the software itself using intelligent algorithms. This ensures a work and information flow according to the PDCA cycle. EPIA, also called as TIEM-projects, represent a large part of the model (shown in Figure 3). They are intended to optimize the company's ecology situation. These projects are divided into several phases and are implemented according to the PDCA cycle. This requires the cooperation of different departments with each other in interdisciplinary teams.

TIEMS guides users individually according to their tasks and function and ensure an error free execution and documentation of the EPIAs. Selecting an existing EPIA or creating a new one leads the user to a detailed project overview. In this form-based view, all relevant information about the EPIA is visualized. Users with sufficient authorization levels can make changes to the EPIA by editing the input fields available in the user form. User groups are assigned authorizations, in the form of roles, that are required for their function. These roles are assigned via a hierarchical role model (see 4.3.3).

The signature concept

Improvement measures in TIEM are defined and implemented in a multi-stage process with several participants (see Figure 59- Appendix). This inevitably results in several issues and the work progress must be saved and forwarded to other users for further processing. It is therefore essential for the successful implementation of such processes that the progress of the EPIAs is documented automatically. This problem is solved by developing a digital signature concept in TIEMS. A digital signature is assigned to every user action automatically. Signatures are stored in a database table as datasets. A dataset comprises information that describe who carried out what and when. These are therefore independent data records describing only one single action.

Signatures are independent of EPIAs; thus, it is possible to use the same data model to digitally sign other objects. For instance, tracking of resource access and assignment. Mapping tables are used to maintain the relationship between signatures and the corresponding objects. These tables link the data record to projects and signatures (see Figure 51).

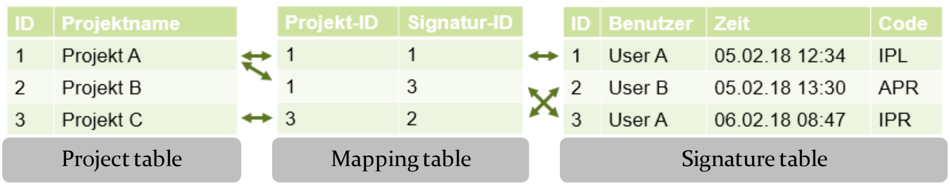

Figure 51: Schematic representation of the mapping between signatures and projects

The project history can be extracted easily via the combination of signatures and projects. Icon for "current project status" in the header data of the detailed project view opens a dialog box that shows the project progress (see Figure 52).

Signatures ×

#	Date	Signer	Key	Description
1	03/28/2018 16:26:47	emanager1	INI	Initiated
2	03/28/2018 16:26:47	emanager1	ASO	Owner assigned
3	03/28/2018 16:26:47	emanager1	ASR	Responsibility assigned
4	03/28/2018 16:26:47	emanager1	CDD	Set duedate

Figure 52: Representation of the project history based on the archived signatures

Figure 52 shows that actions are carried out in chronological order within an EPIA. There are activities that automatically lead to follow-up actions. For example, signatures one to five are posted with identical time stamps as seen in the Figure 52. They result through the initiation of the EPIA, during which mandatory information is filled automatically. Entry six in the signature list shows that signatures are linked to further information. The status is encoded as a sequence of letters with three characters to enable multilingualism and to occupy only a small space in the database storage. Only the signature code is stored in the database which is converted to plain text for visualization as soon as it is required in the web application. Further signature codes from TIEM are listed in Table 12.

Code	Description	Code	Description
APR	Approved	IPR	In progress
ASR	Responsibility assigned	NAP	Not approved
ASO	Owner assigned	NON	No status
CAN	Cancelled	RCA	Requested to cancel
CDD	Set due date	RDP	Requested to finish planning
FIN	Finished	RDD	Requested to finish project
IMP	Implemented	RPS	Project start requested
INI	Initiated	REQ	Requested
IPL	In planning	WPS	Waiting for project start

Table 12: TIEM signature codes

Initialization of TIEM-projects

The EPIAs in TIEM always starts with the initialization of the planning phase. Initialization is a sequence of automated signatures that assigns default values to the EPIA. First, an initial signature is set which logs the time of EPIA initialization and the EPIA initiator. A minimum of two mandatory users are assigned to each project. These users are called project owner and project responsible. They are assigned the signature codes ASO and ASR. Project owners provide administrative support. Whereas project responsible is the employee who is accountable for the actual execution and implementation of the EPIA. TIEMS create two mapping tables to manage these two functional positions separately. The combination of the archived signatures with the archived assignments makes it possible to display the assignment history in the signature log of the project. The deadlines are likewise stored in a separate database table and linked to EPIAs via a mapping table. These are used to log any changes in the EPIA or accomplishments transparently. Finally, the TIEMS signs the project progress with the signature code IPL. The five initialization signatures mentioned above are generated automatically within a very short time and therefore seem to receive the same time stamp. However, the time stamps can differ.

Resources

For implementing any kind of improvement measures, resources are required. These can be requested from top management according to the process shown in Figure 53.

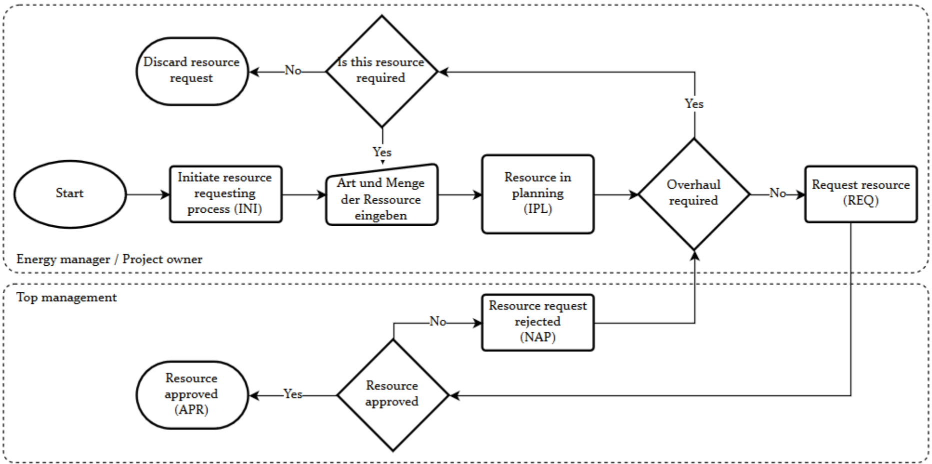

Figure 53: The process of applying for project resources

Similar to EPIAs, resources are treated as signable objects in the database structure, so that decisions can be traced back at any time. TIEMS allows the visualization of the history of the requested and used resources. Similar to EPIAs this starts with an initialization signature INI, which creates a resource entry in the database. Saving the values in the database sets the status of the resource in consideration to IPL. In this status, the quantity or type of the resource requested can be changed. Once the user is satisfied with the information, it is possible to sign the request (REQ) and thus formally submit it to top management.

A user with the role assignment top manager must decide on the request approval or rejection and confirm the decision by signature. Rejected requests can be revised and reapplied. Approved resources are signed with

APR and can no longer be edited by project responsible. This concept thus implements an iterative process based on the principles of the PDCA cycle. The process is continuously logged, so it is possible to track and view it at any time via the history of the database entries.

Command functions

In the second block of the project form, various command buttons are available to the users. These have a direct influence on the status of the EPIA. These functions help in controlling the progress of the EPIA. These are generated dynamically based on the authorization level of users. Users can see only specific buttons that correspond to their function in the project. Furthermore, only buttons relevant to the current status are displayed. This eliminates the chance of human errors in the organization and documentation of EPIAs. This representation is based on the flowchart shown in Figure 54.

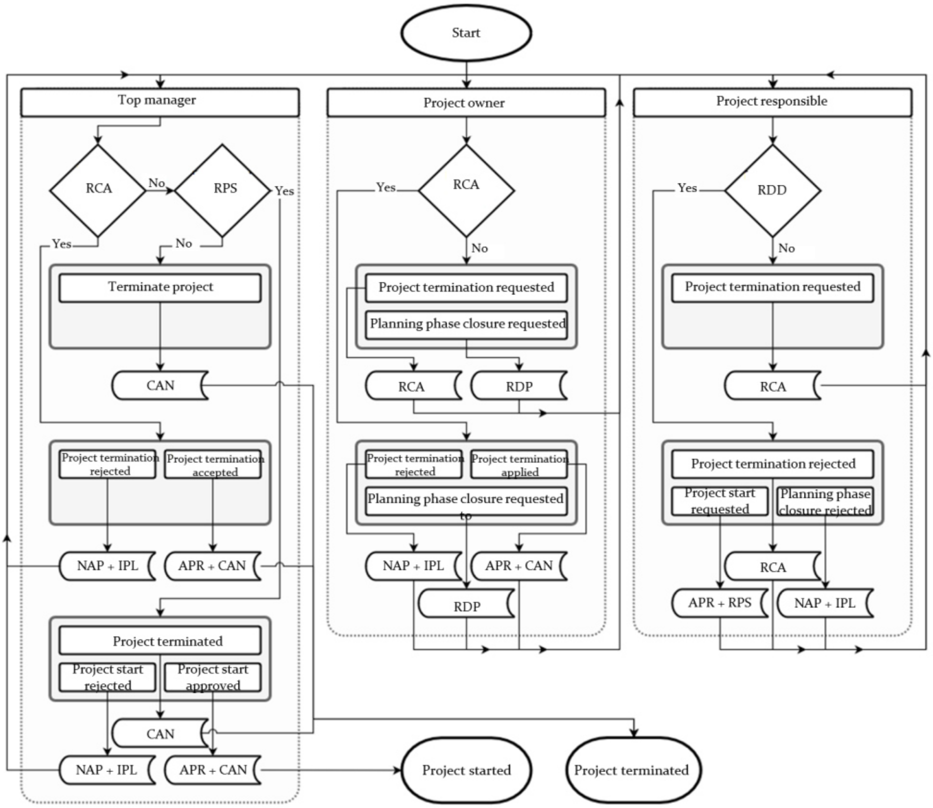

Figure 54: Schematic representation of the dynamic control buttons in the planning phase

The various possible combinations of commands are displayed in the planning phase. The displayed buttons are generated dynamically depending on the authorization level of user and depending on the current status of the EPIA. Each user action in project is archived by one or more signatures. Figure 54 shows a simplified representation of the respective signature codes that are triggered by the respective commands. Signature codes are described in Table 12

Implementation phase

After the completion of the planning phase the TIEM-project automatically advances to the implementation phase. Several runs may be necessary before an EPIA completes the planning phase. The same applies to the approval process of the EPIA. Since top management must approve the EPIA, several attempts may also be necessary before the EPIA enters the implementation phase. Thereby, a continuous improvement processes in the planning of EPIAs is realized. In addition, it prevents errors by validating data within a project before it is documented. Furthermore, it prevents transferring of an EPIA into the implementation phase prematurely. It informs the user about the inaccuracies and points out the causes of the error.

The implementation thus begins in conformity with the nomenclature of the respective phases. This transfer makes another input field visible in the header data of the project form. It is used for logging the implementation report and can only be edited by the project manager. Planned work packages are also transferred to the implementation phase with the start of the EPIA. This phase includes an input field for specifying an implementation report for each work step, which can only be edited by the employee responsible for that specific task (see Figure 60 - Appendix).

The successful implementation of the EPIA initiates the evaluation phase. Similar to the end of the planning phase, validation steps are executed in TIEMS to prevent errors at the end of the implementation phase. Specifically, TIEMS only allow the completion of an EPIA if all assigned work packages have been digitally signed as completed or cancelled.

TIEM does not allow any user to close an EPIA project, until it is signed by the controlling authority. It displays a warning message if a user attempts to close a project despite incomplete work packages. In addition, it is not possible to conclude a project without formulating a specific implementation report in the system.

Evaluation phase

In the final step of PDCA cycle, the EPIA is evaluated as required by the norm. Here, the current values of the EnPIs at the time of completion of the implementation phase is logged automatically for each relevant EnPI. In addition, an input field becomes available in which the project owner may enter an evaluation report. Changes to other project properties are no longer possible. The results of the evaluation are used to define follow-up actions. In this way, a continuous improvement process is implemented with TIEM software that supplements the TIEM methodology.

Management reviews

These are prepared in accordance with the requirements of the DIN EN ISO 50001 standard. TIEMS supports the user with predefined questions and validates the input of users. Thus, incorrect entries are eliminated and valid reviews are created. For this purpose, reviews are managed in an extensive database structure. These are interwoven with the database of the TIEM EnPIs. They thus, are used in the reviews and audit reports. Management reviews are stored in an archive and can be accessed for review again at any time.

Since the whole PDCA cycle is managed and documented by the TIEM software, preparing audit reports for the yearly energy audit is merely a task of minutes that does not require any effort. Audit reports are compiled in TIEMS with a few mouse clicks.

5.5 Knowledge management

Alongside resource monitoring and management as well as benchmarking and controlling, knowledge management function is a part of TIEM portfolio. Under the category knowledge database in the navigation bar, every user, according to their authorization, have access to company knowledge, so that transparency is guaranteed for all employee groups.

Best Practices

Successful examples should serve as a model for solving new problems. TIEMS ensures that knowledge from the execution of past EPIAs is not lost. Instead, the completed projects are documented in a predefined manner and can be used at any time to for review. For example, the user can search for EPIAs that are similar to a new challenge and apply successful project structures or procedures and best practices to overcome this new challenge. At the same time, less successful EPIAs in the database are used for learning purposes. This way lessons learned are documented in the system. A systematic evaluation of EPIAs can also shed light on general deficits in guidelines or processes in a company for implementing EPIAs. The availability and access to best practices in TIEMS therefore represents a promising opportunity to achieve continuous improvement through knowledge documentation and transfer. TIEMS ensure that the knowledge is not personnel dependent, but it is documented and stored in the system. It can be accessed at any time by authorized employees of an organization.

Idea pool

The transfer of knowledge is a significant problem in hierarchical corporate structures. Transferring existing knowledge from the grassroots to the management levels often fail because of a lack of communication. TIEMS therefore implements a further approach to enable a better communication and structure the transition of subject related knowledge by creating an idea pool of optimization measures.

This function intends to create a hierarchy independent communication platform through which employees of all hierarchical levels can act on an equal basis. The idea pool (see Figure 55) provides a ticket system by which every employee can suggest improvement measures regardless of their role or profile. This way, employees who are involved directly in the production processes and are confronted with the challenges during their work regularly, can take part in the process of defining improvement measures for the respective systems. Their experience in the regular handling of plants and processes enables them to quickly identify concrete areas for improvement. Otherwise only through a classic "top-down" approach, i.e., initiated by an ecology manager who does not work directly on the plants may cause missing many optimization possibilities.

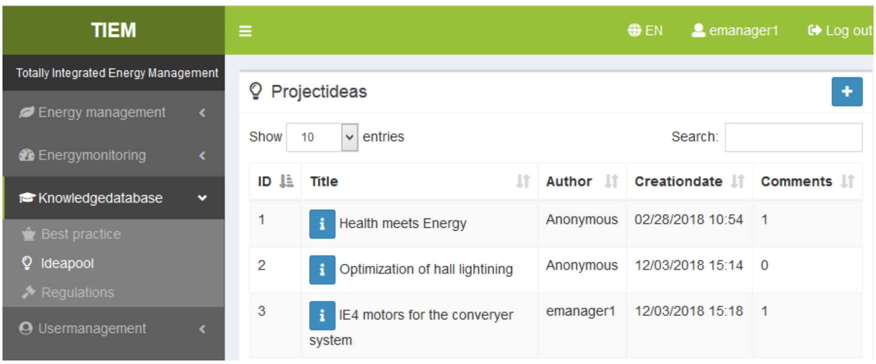

Figure 55: Accessible ideal pool for all employees

TIEMS offer all employees the opportunity to communicate potential improvement measures to the controlling authorities. They are encouraged to show commitment. Positive feedback through the acceptance of the proposal and the implementation of the measure also promotes the self-esteem of the employees and may offer an additional incentive to propose further optimization measures. As a result, the overall system can benefit and foster the development of a continuous improvement culture within the company.

The yield of such a pool of ideas is further increased by allowing employees to anonymously suggest improvement measures. It is conceivable that employees in comparatively lower hierarchical position feel neglected. Feelings of inferiority due to the position in the company can constitute obstacles that make employees reluctant to contribute their meaningful and valuable ideas. The possibility of anonymous submission enables such employees to overcome these obstacles. Anonymity as an option can motivate employees to share their suggestions. TIEMS therefore offers every employee the opportunity to publish their idea without mentioning their personal details (see Figure 55). However, the pool of ideas can also be misused under the guise of anonymity. Camouflaged by unfamiliarity, writing insults, or spreading confidential information can take place. To avoid misuse, super-administrators are setup to scan the information and only allow the ideas which comply with the corporate guidelines. Published ideas are used and serve as templates for new EPIAs. Since only users with the ecology manager role are entitled to initiate EPIA, it is possible for ecology managers to use these ideas as a template for a new EPIA.

Rules and regulation

TIEMS offers enterprise policy management as another classic knowledge management solution. In the application, all users can find a tabular list of the regulations, rules and guidelines stored in the system that currently apply. Older regulations that have been applied at an earlier point in time in the company are also archived in the system.

The knowledge transfer is uncomplicated since every user has reading access to the regulations stored in the system without exception. It is therefore possible to look up detailed information that may apply to different circumstances at any time. Furthermore, it is possible to assign experts to each entry in this category. Only ecology managers have writing privileges thus new policies and changes to regulations can only be introduced into the system by users with the ecology manager role.

Like all other elements of the TIEMS, guidelines are designed as database objects. These are kept very simple to show the possibilities of such a system. The system allows administrators to activate specific policies and make them binding for all employees of the company. For a more practical solution in the corporate environment, file storage systems are conceivable as add-ons so that external documents can be archived in the system as well.

Comment sections

Another tool used in TIEMS is the ability to write comments in dedicated fields. It is an intuitive tool for recording and documenting information. Due to the wide distribution of social media and messenger services, commentary fields are widely known, so that their use is not a problem for users. This are therefore suitable as a tool for TIEMS. However, TIEMS does not use comment fields as a platform for exchanging private messages. The focus of this functionality is on the documentation of business communication. Especially regarding the sound documentation of EPIAs, the collection of data and archiving of relevant information. Comment fields provide an easy way to close these gaps. Comment fields in TIEMS is used during the whole PDCA process. The system ensures that all the obligatory information during each phase is entered in the system properly by the respective task owners. As a component of many ecology management data objects, comment fields are used to record facts on specific topics in direct reference to the data model. Comments are managed in the same way as signatures in a database table and are assigned to the respective database objects. Messages that are entered into the system in the form of a comments always contain three items of information: The message itself, the time of entry and the name of the author. This makes it possible to reproduce the history of archived communication at any time via database query. This enables companies to pinpoint specific challenges faced during the implementation of EPIAs and the measures taken to overcome the said challenges. This way best practices are established and documented for future references.

5.6 User management

TIEMS offers individual content and functionality to users depending on their authorization level. This is made possible through the flexible user administration feature, which is one of the core modules of this application (See Figure 36).

Access authorization

The access authorization in TIEMS is based on the administration of user identities. The real identities of the users are mapped in digital accounts and stored in a database. An account is essentially defined by a username, an e-mail address and an access password, which is required to view the content of the TIEMS. Each session is personalized and is uniquely assigned to the logged in user. Depending on the authorization of users, TIEMS determines the content that the user can view or edit.

Authorizations in TIEMS are granted to users by assigning roles to them. Roles are linked to certain functions and are firmly anchored in the source code of the application according to the system requirements. In TIEM, a hierarchical structure between different roles is implemented to facilitate the assignment of authorizations (see Figure 56).

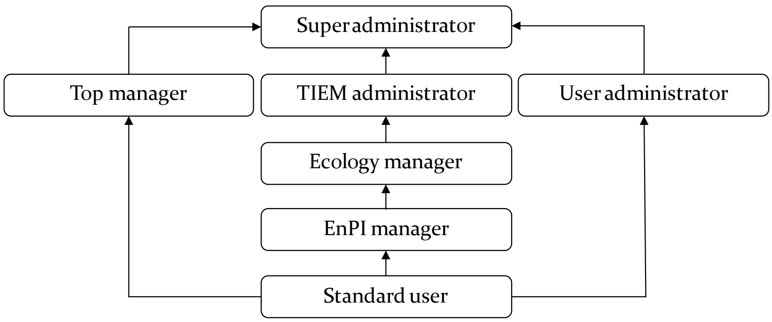

Figure 56: Hierarchy Model of the Implemented User Roles in TIEM [137]

The roles displayed in Figure 56 inherit their functions in the direction of the arrow. The assignment of the Super administrator role profile corresponds to the highest level of authorization in TIEMS. A standard user only receives basic authorization. All actions that a standard user can perform can also be performed by a super administrator. With the focus on ecology management, the role profiles are most prominent in this field. However, additional roles in other areas are conceivable and can be integrated into the application with little additional effort. In the field of ecology management, the three roles EnPI manager, ecology manager and ecology administrator are essential. Assigning the role "EnPI manager" allows the corresponding user to manage EnPIs. Users with the ecology manager role profile are also able to manage EnPIs because they inherit the authorizations of the EnPI manager profile.

The TIEM administrator role profile is used to introduce an additional hierarchy level among the ecology managers. This role authorizes the project owner of EPIA projects. TIEM administrators are managers of ecology and extended ecology teams.

The role profile top manager is part of a secondary strand of the role hierarchy that is independent of operational ecology management. Top managers cannot change the content of EPIAs or the EnPIs. They are only able to approve resources and EPIA initiation. They, therefore, have decision making power over financial aspects of ecology management. Users with the role profile "Top manager" are, for instance, members of a management committee.

A user can be assigned several role profiles simultaneously. Role profiles are associated with the tasks of a functional unit in the company. This means that a suitable user account is created for a user who is both a member of the management committee and an ecology manager in the company. The profiles, "Top manager" and "Ecology manager" are enabled for this account allowing the user to take responsibility of tasks that are designated for both said roles. Allocations of roles and their administration require an additional role profile, namely the User administrator. This profile is responsible for the supervision of the user accounts stored in the system.

The "Super administrator" role profile exists especially for the system administrators. This profile combines all other profiles and authorizes the corresponding user access to all possible functions of this application. Therefore, the allocation of this profile ought to be strictly regulated and only take place in justified exceptional cases.

Organization of users in groups

Since TIEMS requires individual accounts for each user, the number of users can quickly grow large. To facilitate the administration of user data, TIEMS allows the user administrators to group users in categories (see Figure 57). These categories can be based on the function or hierarchy level of respective users.

Unlike roles in the system, groups can be created or removed as per demand. User administrators can choose descriptive titles of the groups that they create in TIEMS.

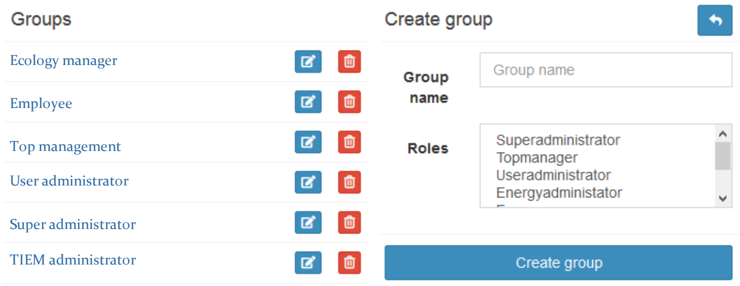

Figure 57: Configuration of groups in TIEM

The user administrators can assign any number of roles from the available roles to each group. User profiles are configured by the user administrators. One use can be a part of multiple groups simultaneously. The use of groups allows the user administrators to manage the role assignments of several users at the same time. In addition, groups can be used to bundle department specific roles, which simplifies user management in a company.

6 Summary

Energy and environment management is becoming increasingly important for the companies, and for the whole society. Increasing energy prices and the climate change are the main drivers behind this phenomenon. Industrial Ecology Management (IEM) is concerned with the core objectives of security of energy supply, economic efficiency, sustainability and environmental protection.

The implementation of an ecology management system ensures energy and environmental management as well as EMAS certification. In Germany companies that obtain DIN EN ISO 50001 certificate have the right to get EEG surcharge (partially) reimbursed upon application, if they meet all the requirements. Here an essential basis, however, is the conscious assessment of the energy situation in the companies. For this purpose, various series norms offer valuable support. Therefore, implementation of these norms, as an integral part of a comprehensive industrial ecology management system, is the intended goal (IEM).

To implement and operate an IEM, technological, organizational and business obligations must be satisfied. There are various reasons for corporation to apply ecology management methodologies and implement associated measures to establish an ecology management system. Through the implementation of IEM, a sustainable competitive advantage is achieved by means of cost reduction and increased customer acceptance. However, companies face many complications in the implementation of IEM. Although there exists norms and standards to provide some guidelines for implementing ecology management in organizations, they do not provide complete approaches to reach the targets specified by the regulations. Therefore, a totally integrated ecology management system (TIEM) is developed to overcome these challenges and help organizations implement ecology management. TIEM model is a combination of a comprehensive methodology and a supporting software for the implementation and operation of IEM. This is a holistic approach to industrial ecology management.

The McKinsey 7S framework is used to develop the TIEM methodology. The 7S model comprises of the so called three hard elements and four soft elements. The hard elements include strategy, structure and systems. Whereas the soft elements are staff, skill, style and shared values. By using this model all relevant areas of organization are addressed in this work.

TIEM software a platform-independent, cloud-based web application that implements industrial ecology management in a standardized and user-friendly way. It demonstrates how ecology management in the age of Industry 4.0 can be harmonized with the current legislation.

For demonstration purpose, a real handling and assembly plant is operated via TIEM software as part of a networked production system. Various hardware and software components are networked by means of modern communication protocols in such a way that a cloud based, database supported overall system is created. This system is capable of measuring, storing and processing various types of operational data. Various monitoring variants such as real time monitoring and condition monitoring are some of the features of this system. These in combination with energy performance indicators serve as the foundation for integrated resource planning and for the definition, implementation and controlling of EPIAs.

With the focus on ecology management, this application demonstrates processes for the sustainable documentation of standard compliant improvement measures for continuous optimization. The multi-user system implements iterative processes according to the PDAC cycle and directs users of different function groups automatically to their respective tasks. The planning and implementation of EPIAs includes the definition, administration and documentation of the identified challenges, detail improvement action plans, required resources and milestones as well as implementation report of each phase of the PDCA.

One of the main features of TIEM software is the automated ecology management PDCA process. The system takes care of the information flow by following the strictly designed algorithms that intelligently drive the process as required by the relevant energy and environment norms. The benefit of this is reduced effort on part of the employees, elimination of human errors and effortless preparation for the regular energy audits.

knowledge management functions are a part of the TIEM portfolio. Knowledge transfer with the goal of continuous improvement forms a central aspect of the entire application.

TIEM has core functions that enable ecology management according to current guidelines and standards through a practical lean solution.

Future work can build upon TIEM, particularly, in the area of condition monitoring. Introduction of ontology based artificial intelligence to the current condition monitoring functionality can enhance the system by adding intelligent pattern recognition features. These features can be used for enhanced predictive maintenance. Furthermore, extensions of the existing system to allow the inclusion of external documents can be beneficial, especially for knowledge management.

TIEM support industry 4.0 approaches by making use of modern production planning and communication methods under ecology aspects. However, support for older communication procedures and protocols is also necessary to create an innovative holistic approach. TIEMS as a modular, platform independent application offers a framework for all such efforts, thereby offering a complete solution for industrial ecology management.

7 Zusammenfassung

Energie- und Umweltmanagement wird immer wichtiger, nicht nur für die Unternehmen, sondern auch für die Gesellschaft insgesamt. Steigende Energiepreise und der Klimawandel sind die Hauptgründe für dieses Phänomen. Dabei befasst sich das IEM insbesondere mit den Kernzielen Energieversorgungssicherheit, Wirtschaftlichkeit, Nachhaltigkeit und Umweltschutz.

Mit der Einführung eines IEM Systems wird die Energie- und Umweltmanagement sowie die EMAS-Zertifizierung sichergestellt. In Deutschland können Unternehmen, die nach DIN EN ISO 50001 zertifiziert sind und alle Anforderungen erfüllen, die EEG-Umlage (teilweise) erstattet bekommen. Eine wesentliche Grundlage dafür ist jedoch die bewusste Bewertung der Energiesituation in den Unternehmen. Hierfür bieten verschiedene Normen wertvolle Unterstützung. Daher ist die Umsetzung dieser Normen, als integraler Bestandteil eines umfassenden IEM, das angestrebte Ziel.

Um ein IEM einzuführen und zu betreiben, müssen technologische, organisatorische und betriebswirtschaftliche Verpflichtungen erfüllt werden. Es gibt verschiedene Gründe für Unternehmen, Methoden des Ökologiemanagements anzuwenden und entsprechende Maßnahmen zum Aufbau eines Ökologiemanagementsystems umzusetzen. Durch die Implementierung von IEM kann ein nachhaltiger Wettbewerbsvorteil mittels Kostensenkung und erhöhter Kundenakzeptanz erreicht werden, doch gleichzeitig stehen Unternehmen bei der Implementierung von IEM vor vielen Komplikationen. Es gibt zwar Normen und Standards, die einen gewissen Leitfaden für die Implementierung von IEM in Organisationen bieten, aber keine vollständigen Ansätze, um die in den Vorschriften festgelegten Ziele zu erreichen. Daher wurde ein vollständig integriertes IEM-Modell entwickelt (TIEM), um diese Herausforderungen zu bewältigen und Organisationen bei der Implementierung von Ökologiemanagement zu unterstützen. Das TIEM-Modell ist eine Kombination aus einer umfassenden Methodik und einer unterstützenden Software für die Implementierung und den Betrieb von IEM. Es handelt sich um einen ganzheitlichen Ansatz für das industrielle Ökologiemanagement.

Das McKinsey 7S Framework wird zur Entwicklung der TIEM-Methodologie verwendet. Das 7S-Modell besteht aus den so genannten drei harten Elementen und vier weichen Elementen. Zu den harten Elementen gehören

Strategie, Struktur und Systeme. Die weichen Elemente sind dagegen Mitarbeiter, Fertigkeiten, Stil und gemeinsame Werte. Durch die Verwendung dieses Modells werden in dieser Arbeit alle relevanten Organisationsbereiche berücksichtigt.

Die TIEM-Software ist eine plattformunabhängige, cloudbasierte Webanwendung, die das IEM standardisiert und benutzerfreundlich umsetzt. Sie zeigt, wie IEM im Zeitalter von Industrie 4.0 mit der aktuellen Gesetzgebung in Einklang gebracht werden kann.

Zu Demonstrationszwecken wird eine reale Handhabungs- und Montageanlage über die TIEM-Software als Teil eines vernetzten Produktionssystems betrieben. Verschiedene Hard- und Softwarekomponenten werden mittels moderner Kommunikationsprotokolle so vernetzt, dass ein cloudbasiertes, datenbankgestütztes Gesamtsystem entsteht. Dieses System ist in der Lage verschiedene Arten von Betriebsdaten zu messen, zu speichern und zu verarbeiten. Verschiedene Überwachungsvarianten wie Echtzeitüberwachung und Zustandsüberwachung gehören zu den Merkmalen dieses Systems. Diese dienen, in Kombination mit Energieeffizienzkennzahlen, als Grundlage für eine integrierte Ressourcenplanung sowie für die Definition, Implementierung und Kontrolle von EPIAs.

Mit dem Schwerpunkt IEM zeigt diese Anwendung Prozesse zur nachhaltigen Dokumentation von normgerechten Verbesserungsmaßnahmen zur kontinuierlichen Optimierung auf. Das Multi-Benutzersystem setzt iterative Prozesse nach dem PDAC-Zyklus um und führt Anwender unterschiedlicher Funktionsgruppen automatisch zu ihren jeweiligen Aufgaben. Die Planung und Umsetzung von EPIAs umfasst die Definition, Verwaltung und Dokumentation der identifizierten Herausforderungen, detaillierte Verbesserungsmaßnahmenpläne, benötigte Ressourcen und Meilensteine sowie den Umsetzungsbericht jeder Phase des PDCA.

Eines der Hauptmerkmale der TIEM-Software ist der automatisierte IEM-PDCA-Prozess. Das System kümmert sich um den Informationsfluss, indem es den entwickelten Algorithmen folgt, die den Prozess intelligent steuern, wie es die relevanten Energie- und Umweltnormen verlangen. Der Vorteil dabei ist ein reduzierter Aufwand für die Mitarbeiter, die Eliminierung menschlicher Fehler und eine mühelose Vorbereitung auf die regelmäßigen Energieaudits.

Wissensmanagementfunktionen sind Teil des Portfolios der TIEM Anwendung. Ein zentraler Aspekt, der sich durch die gesamte Anwendung erstreckt, ist der Wissenstransfer mit dem Ziel der kontinuierlichen Verbesserung. Damit verfügt TIEM über wichtige Kernfunktionen, die ein IEM nach aktuellen Richtlinien und Standards durch eine praxisnahe Lean-Lösung ermöglichen.

Zukünftige Arbeiten können auf TIEM aufbauen, insbesondere im Bereich der Zustandsüberwachung. Durch die Einführung ontologiebasierter künstlicher Intelligenz in die aktuelle Zustandsüberwachungsfunktionalität kann das System durch Hinzufügen intelligenter Mustererkennungsfunktionen verbessert werden. Diese Funktionen können für eine verbesserte, vorausschauende (Predictive Maintenance) Wartung genutzt werden. Darüber hinaus können Erweiterungen des bestehenden Systems, die die Einbeziehung externer Dokumente ermöglichen, vor allem für das Wissensmanagement von Vorteil sein.

TIEM unterstützt Industrie 4.0-Ansätze durch die Nutzung moderner Produktions-, Planungs- und Kommunikationsverfahren unter ökologischen Gesichtspunkten. Aber auch die Unterstützung älterer Kommunikationsverfahren und -protokolle ist notwendig, um einen innovativen, ganzheitlichen Ansatz zu schaffen. TIEMS, als modulare, plattformunabhängige Anwendung, bietet einen Rahmen für all diese Bestrebungen und damit eine Komplettlösung für das industrielle Ökologiemanagement.

Appendix

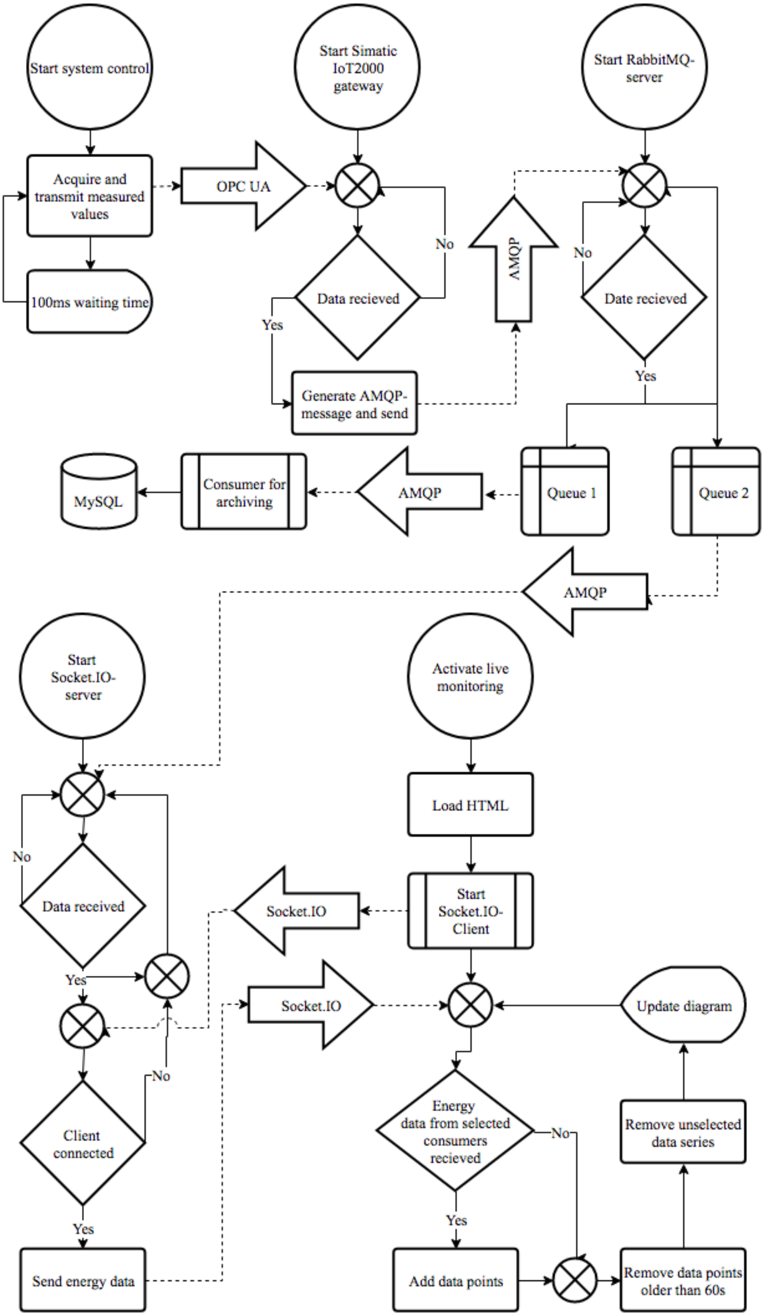

Figure 58: Real time energy monitoring

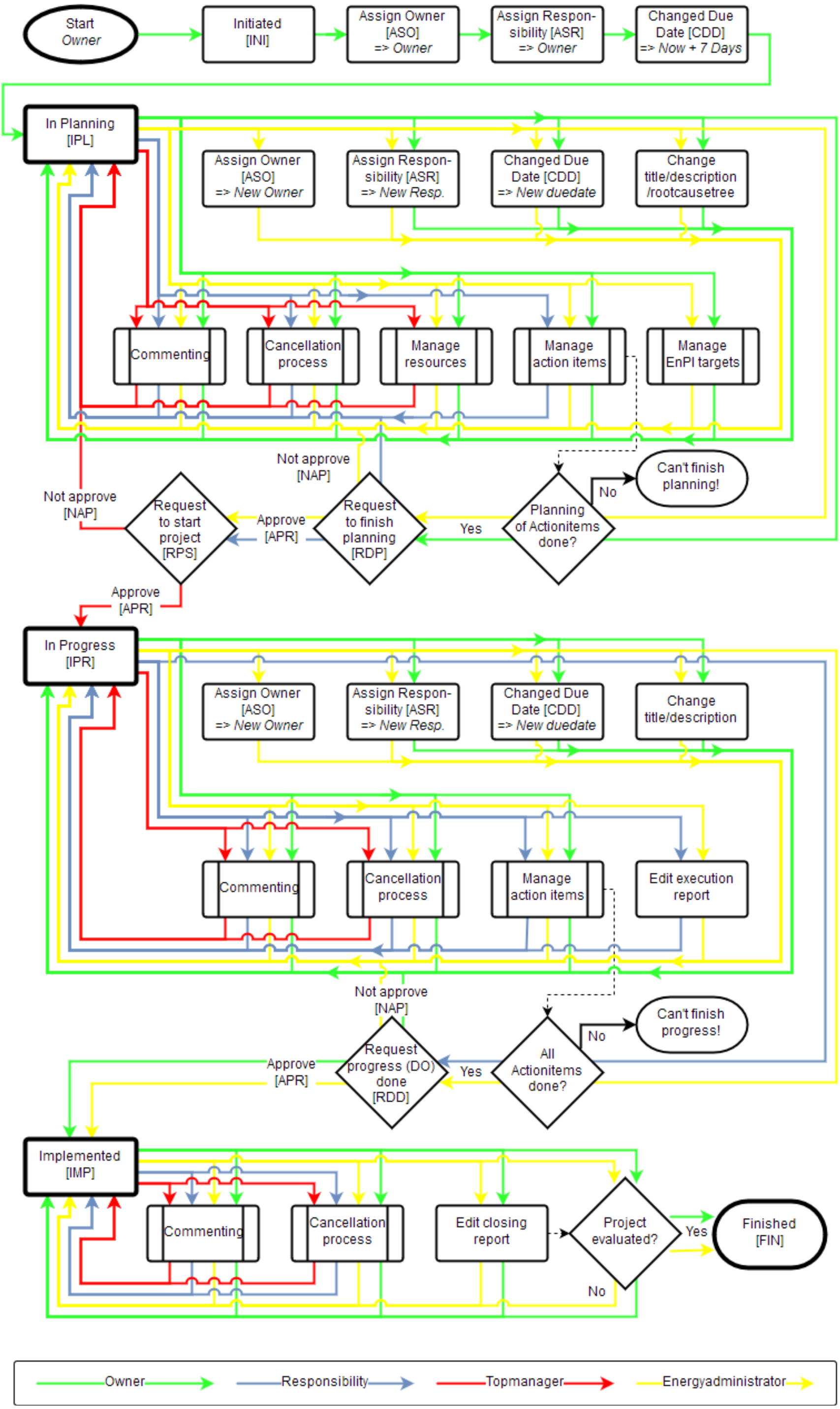

Figure 59: EPIA organization process

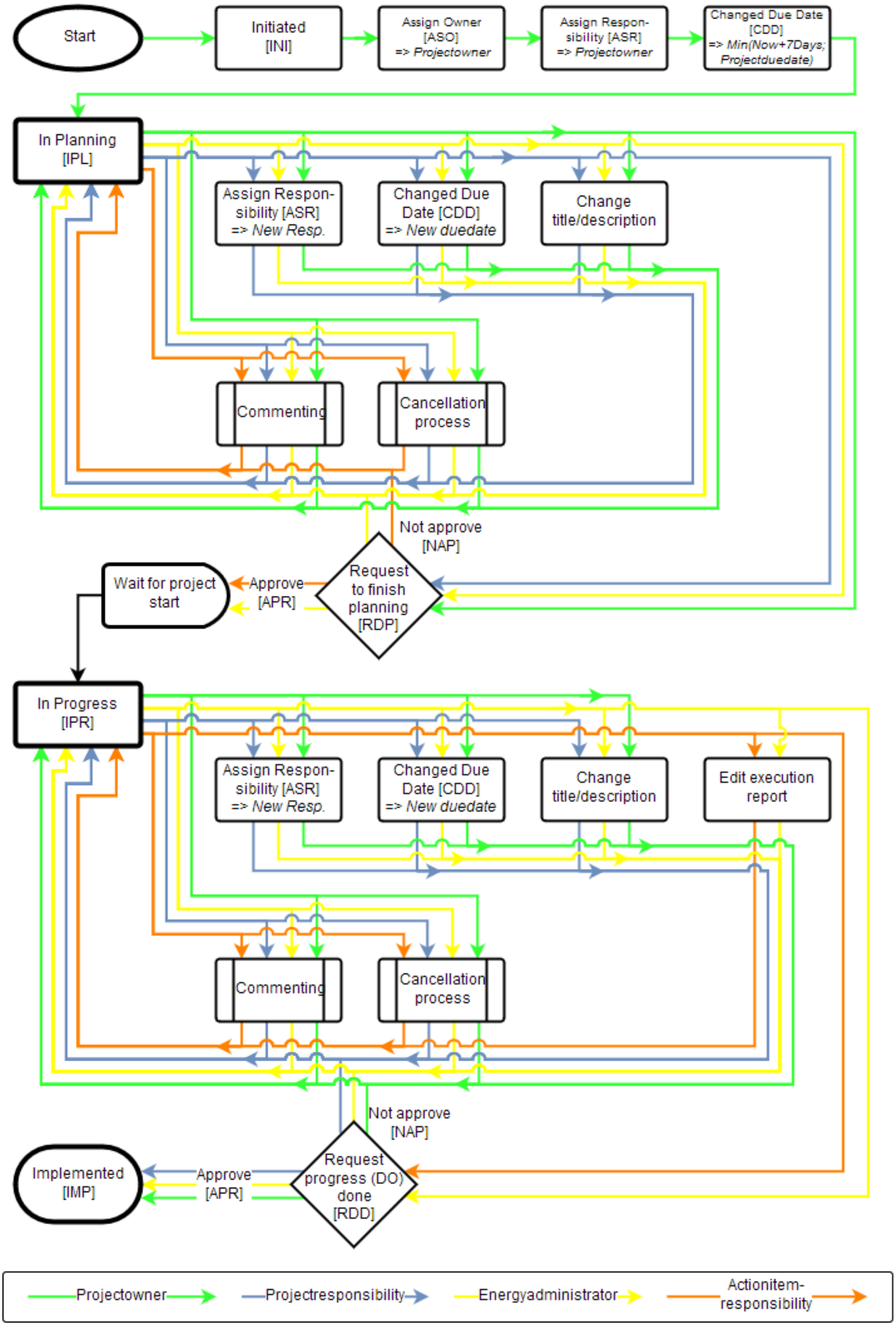

Figure 60: Workflow for action items

Name	Das Hosting Konzept ist eine lokale Installation beim Kunden	Zugriff auf Daten ist via Inter-/Intranet möglich (auch administrativ)	Beliebig viele Hierarchiestufen von Zählern	Automatisch Meldung/ Warnung bei Grenzwertüberschreitun	Darstellung Von Messwerten innerhalb des Grenz--wertes	Grenzwert je Zählstelle
123 SmartBusiness	1	1	0	1	1	1
ABB cpmPlus Energy Manager 4.2	1	1	1	1	1	1
ACOS ECS	1	1	1	1	1	1
ACRON 8.3	1	0	1	1	1	1
AENEA BOSS-System V3.09	1	1	0	1	1	1
AKROPOLIS	1	0	1	1	0	0
AKTIFdataService 4.0	1	1	0	1	1	1
APROL EnMon	1	1	1	1	1	1
Arkadon eco Smart Monitor 1.1	1	1	1	1	1	1
ATHION ALPHA	1	1	1	1	1	1
Axxerion Revision 1944	0	1	1	0	0	0
CMA32-OPC 10.3	1	0	1	0	1	1
deZemVis 3.19.7	1	1	1	1	1	1
E-Controller 1.00.15	1	1	1	1	1	1
e-Gem 6.1	1	1	1	1	1	1
e.Manager	0	1	1	1	1	1
E.ON Energy Management SV2 1.17.1	0	1	0	1	1	1
é.VISOR Web 3.7	1	1	1	1	1	1
E3CON, Das Energie-Transparenz-System 2.3	1	0	0	1	1	1
e3m 3.5	1	1	1	1	1	1
E58-SolarDATA Energiemanagement 3.6.11	1	1	1	1	1	1

Es können eigene Kennzahlen definiert werden	Kennzahlen können grafisch ausgewertet werden	Es existiert ein interner Report-Generator	Im System kann eine Maßnahmen-Liste erstellt werden	Dokumenten-management ist im System integriert	Betriebszustände/ Maßnahmen sind dokumentierbar	Alle Kriterien erfüllt
1	1	1	1	1	0	0
1	1	1	1	1	1	**1**
1	1	1	0	1	1	0
1	1	1	0	0	1	0
1	1	1	0	0	0	0
1	1	0	1	0	0	0
0	1	0	0	0	1	0
1	1	1	0	1	1	0
1	1	1	1	1	1	**1**
1	1	1	1	0	1	0
1	1	1	1	1	1	0
1	1	0	1	0	1	0
1	1	1	1	1	1	**1**
1	1	1	0	1	1	0
1	1	1	0	0	1	0
1	1	1	1	1	1	0
1	1	1	0	0	0	0
1	1	1	1	1	1	**1**
1	1	0	0	0	0	0
1	1	1	1	1	1	**1**
1	1	1	1	0	1	0

Table 13: EnMS market analysis (1/5)

Name	Das Hosting Konzept ist eine lokale Installation beim Kunden	Zugriff auf Daten ist via Inter-/Intranet möglich (auch administrativ)	Beliebig viele Hierarchiestufen von Zählern	Automatisch Meldung/ Warnung bei Grenzwertüberschreitun	Darstellung Von Messwerten innerhalb des Grenzwertes	Grenzwert je Zählstelle
econ app 2.5	1	1	1	1	1	1
EDL EM 3.0	0	1	0	1	1	1
EFFICEUS 1.3	0	1	0	0	1	0
Efficio Version 1.10	1	1	0	1	1	1
EIQ	1	1	1	0	1	0
Ekomm 4.5	1	1	0	1	0	0
EM-Control 5.2.0	1	1	0	1	1	1
EMPURON EVE	1	1	0	1	1	1
emson 3.4	1	1	1	1	1	1
EnEffCo® 3.0	1	1	1	1	1	1
enerchart 1.21	1	1	1	1	1	1
Energie Management System (EMS)	1	1	1	1	1	1
Energie-Management-System	1	1	0	1	1	1
EnergieDatenManagement EDM V 4.5	1	0	1	1	1	1
Energiekonto 4.0	0	1	1	1	1	1
Energiemonitoring Software 2011	1	1	1	1	1	1
Energinet	1	1	0	1	1	1
ENerGO+ 1.3.0	1	1	0	1	1	1
ENerGO+ Version 1.5	1	1	1	1	1	1
EnergyControllingSystem 2.0.2	1	0	1	1	1	1
EnergyManager 1.08	1	1	1	1	1	1
EnergyWeb	1	1	1	1	1	1

Es können eigene Kennzahlen definiert werden	Kennzahlen können grafisch ausgewertet werden	Es existiert ein interner Report-Generator	Im System kann eine Maßnahmen-Liste erstellt werden	Dokumenten-management ist im System integriert	Betriebszustände/ Maßnahmen sind dokumentierbar	Alle Kriterien erfüllt
1	1	1	1	0	1	0
1	1	1	1	1	1	0
0	0	1	1	1	1	0
1	1	1	1	1	1	0
0	1	1	0	0	0	0
1	1	1	1	1	1	0
1	1	1	1	1	1	0
1	1	1	1	1	1	0
1	1	1	1	1	1	**1**
1	1	1	1	1	1	**1**
1	1	1	1	0	1	0
1	1	0	1	0	0	0
1	0	0	0	0	0	0
1	1	1	0	0	0	0
1	1	0	1	1	1	0
1	1	1	0	0	1	0
1	1	1	1	1	1	0
1	1	1	1	0	1	0
1	1	0	1	1	1	0
1	1	1	1	0	1	0
1	1	0	0	0	1	0
1	1	1	1	1	1	**1**

Table 13: EnMS market analysis (2/5)

Name	Das Hosting Konzept ist eine lokale Installation beim Kunden	Zugriff auf Daten ist via Inter-/Intranet möglich (auch administrativ)	Beliebig viele Hierarchiestufen von Zählern	Automatisch Meldung/ Warnung bei Grenzwertüberschreitun	Darstellung Von Messwerten innerhalb des Grenzwertes	Grenzwert je Zählstelle
ennovatis controlling 6.0	1	1	1	1	1	1
EPOS 2.2	1	1	0	1	1	1
eSight 2012.1	1	1	1	1	1	1
eSight 2016.2	1	1	1	1	1	1
FirstMeter 6.2	1	1	1	1	1	1
FirstNet 6.2	1	1	1	1	1	1
FIS# Energy 2.5	1	1	1	1	1	1
FM-Tools 5.70	1	1	0	1	0	1
GEBman 5.0	0	1	0	1	1	1
GILDEMEISTER energy monitor	1	1	1	0	1	0
GridVis 5.0.0	1	1	1	1	1	1
IngSoft InterWatt	1	1	1	1	1	1
INSCONTROL	1	1	1	1	1	1
ITC PowerCommerce EnMS Professional 5	1	1	0	1	1	1
Logit V6.0	1	1	1	1	1	1
Manage Energy 2.1	1	1	1	1	1	1
MESSDAS Version 2016	1	1	0	0	1	0
My JEVis 2.1	1	1	1	1	1	1
my-energiemanagement.eu V7.8	1	1	1	1	1	1
narz EMS 8.8	1	0	1	1	1	1
Navigator powered by Sinalytics(TM)	0	1	1	1	1	1
OPENenergy 2.2.2	1	1	1	1	1	1

Es können eigene Kennzahlen definiert werden	Kennzahlen können grafisch ausgewertet werden	Es existiert ein interner Report-Generator	Im System kann eine Maßnahmen-Liste erstellt werden	Dokumenten-management ist im System integriert	Betriebszustände/ Maßnahmen sind dokumentierbar	Alle Kriterien erfüllt
1	1	1	0	0	1	0
1	1	0	1	1	1	0
1	1	1	0	0	1	0
1	1	0	0	0	1	0
1	1	1	1	1	1	**1**
1	1	1	1	1	1	**1**
1	1	0	0	0	0	0
1	1	1	1	1	1	0
1	1	1	1	0	1	0
1	1	1	0	0	1	0
1	1	1	0	0	0	0
1	1	1	1	1	1	**1**
1	1	1	1	0	1	0
1	1	1	1	1	0	0
1	1	1	0	0	0	0
0	1	0	0	0	1	0
1	1	0	1	1	1	0
1	1	1	1	1	1	**1**
1	1	1	1	1	1	**1**
1	1	1	0	0	1	0
1	1	1	1	0	1	0
1	1	1	1	0	1	0

Table 13: EnMS market analysis (3/5)

Name	Das Hosting Konzept ist eine lokale Installation beim Kunden	Zugriff auf Daten ist via Inter-/Intranet möglich (auch administrativ)	Beliebig viele Hierarchiestufen von Zählern	Automatisch Meldung/ Warnung bei Grenzwertüberschreitun	Darstellung Von Messwerten innerhalb des Grenzwertes	Grenzwert je Zählstelle
ProOffice 5.0	0	1	0	1	1	1
ResMa	1	1	1	1	1	1
robotron i*EDM Release 5	1	1	1	1	1	1
SAUER Vision Center 5.2	1	1	1	1	1	1
SAUTER EMS 3.4.6	1	1	1	1	1	1
SEKS (Stuttgarter EnergieKontrollSystem) Version 2.1	1	0	0	1	0	1
SENTRON Powermanager V3.0	1	1	1	1	1	1
SIMATIC Energy Manager PRO V7.0	1	1	1	1	1	1
SIMATIC powerrate (Option für SIMATIC WinCC) 4.0 SP3	1	1	1	1	1	1
skems	1	1	1	1	1	1
SMARTVISUAL / SMARTANALYTICS	0	0	0	1	0	1
SOL.Connect Energy Manager	0	0	0	0	0	0
StruxureWare Energy Operation Informationsanalysemodul Energy Operation 2.4	0	1	1	1	1	1
StruxureWare Power Monitoring Expert v8.1	1	1	1	1	1	1
SWK Energie Controlling Online (ECO) 1.13	0	1	1	1	1	1
SynergyVision (Energy Edition) 1.0	1	1	0	1	0	1

Es können eigene Kennzahlen definiert werden	Kennzahlen können grafisch ausgewertet werden	Es existiert ein interner Report-Generator	Im System kann eine Maßnahmen-Liste erstellt werden	Dokumenten-management ist im System integriert	Betriebszustände/ Maßnahmen sind dokumentierbar	Alle Kriterien erfüllt
1	1	1	1	0	1	0
1	1	1	1	1	1	**1**
1	1	1	1	1	0	0
1	1	1	0	1	1	0
1	1	1	1	1	1	**1**
0	1	0	1	1	0	0
1	1	0	0	0	0	0
1	1	1	1	1	1	**1**
1	1	1	1	1	1	**1**
1	1	0	0	0	0	0
1	1	1	1	1	1	0
0	0	0	0	0	0	0
1	1	1	1	0	0	0
1	1	1	0	0	0	0
1	1	1	1	1	1	0
0	1	0	1	1	1	0

Table 13: EnMS market analysis (4/5)

Name	Das Hosting Konzept ist eine lokale Installation beim Kunden	Zugriff auf Daten ist via Inter- /Intranet möglich (auch administrativ)	Beliebig viele Hierarchiestufen von Zählern	Automatisch Meldung/ Warnung bei Grenzwertüberschreitun	Darstellung Von Messwerten innerhalb des Grenzwertes	Grenzwert je Zählstelle
TeBIS 2.6	1	0	0	1	1	1
TIPLUX auf CD	1	0	0	0	0	0
VADEV 5.1.7.0	1	0	1	0	1	0
visual energy 4	1	1	1	1	1	1
Vitricon V5	1	1	1	1	1	1
WA-EM04 und Watch16Com	0	1	0	0	0	0
WEBENCON 4.3 (Stand 01/2016)	1	1	0	1	1	1
WEBfactory i4Energy 5.4	1	1	1	1	1	1
Wilken ENER:GY und Wilken ERP 4.x	1	0	0	1	0	1
WiriTec Energiemanagement	1	1	1	1	1	1
Wonderware InTouch & Wonderware System Platform 10.1 bzw. 3.1	1	1	1	1	1	1
zenon 7.20	1	0	1	1	1	1

Es können eigene Kennzahlen definiert werden	Kennzahlen können grafisch ausgewertet werden	Es existiert ein interner Report-Generator	Im System kann eine Maßnahmen-Liste erstellt werden	Dokumentenmanagement ist im System integriert	Betriebszustände/ Maßnahmen sind dokumentierbar	Alle Kriterien erfüllt
1	1	1	1	0	1	0
1	1	1	1	1	1	0
0	0	0	0	0	0	0
1	1	0	0	0	0	0
1	1	1	1	1	1	**1**
0	0	0	0	0	0	0
1	1	1	1	0	1	0
1	1	1	1	0	1	0
1	1	1	1	1	1	0
1	1	1	1	1	1	**1**
1	1	1	1	0	1	0
1	1	1	0	0	1	0

Table 13: EnMS market analysis (5/5)

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List of student projects related to this work

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Kurzzusammenfassung

Energie- und Umweltmanagement wird für die Unternehmen und die gesamte Gesellschaft immer wichtiger. Steigende Energiepreise und der Klimawandel sind die Haupttreiber für dieses Phänomen. Das Industrial Ecology Management (IEM) befasst sich mit den Kernzielen Energieversorgungssicherheit, Wirtschaftlichkeit, Nachhaltigkeit und Umweltschutz.

Unternehmen müssen sich zunehmend ihren Fokus auf Werte wie Energieeffizienz und Ökologiebewusstsein legen und diese verbessern, um Akzeptanz bei den Kunden zu erreichen und durch den nachhaltigen und effizienten Einsatz von Ressourcen einen Wettbewerbsvorteil auf dem Markt zu erzielen. Um ein IEM zu implementieren und zu betreiben, müssen jedoch technologische, organisatorische und geschäftliche Verpflichtungen erfüllt werden.

In dieser Arbeit wird ein vollständig integriertes industrielles Ökologiemanagementsystem (TIEM) vorgestellt, das entwickelt wurde, um diese Herausforderungen zu bewältigen und Organisationen bei der Implementierung des industriellen Ökologiemanagements zu unterstützen. TIEM ist eine Kombination aus einer umfassenden Methodik und einer unterstützenden Software, die einen ganzheitlichen Ansatz für das Management industrieller Ökologie bietet.

Die vollständige Integration und Ganzheitlichkeit von TIEM wird durch die Entwicklung entlang des 7-S-Modells erreicht. Mit diesem Modell werden alle relevanten Organisationsbereiche angesprochen. Dies umfasst Strategie, Struktur, Systeme, Fähigkeiten, Mitarbeiter, Stil und gemeinsame Werte. In dieser Arbeit werden speziell entwickelte Methoden, Tools und Prozesse zur Unterstützung der Implementierung von IEM in einem Unternehmen vorgestellt.

Energy and environment management is becoming increasingly important for the companies, and for the whole society. Increasing energy prices and the climate change are the main drivers behind this phenomenon. Industrial Ecology Management (IEM) is concerned with the core objectives of security of energy supply, economic efficiency, sustainability and environmental protection.

Organizations are increasingly required to put focus on and enhance values such as energy efficiency and ecology awareness, to achieve acceptance by customers and to achieve a competitive advantage in the market through the sustainable and efficient use of resources. However, to implement and operate an IEM, technological, organizational and business obligations must be satisfied.

This work presents a Totally Integrated Ecology Management system (TIEM) that is developed to overcome these challenges and help organizations implement industrial ecology management. TIEM is a combination of a comprehensive methodology and a supporting software that offers a holistic approach for IEM.

The full integration and completeness of TIEM is achieved through the development along the 7-S model. By using this model all relevant areas of organization are addressed. This includes strategy, structure, systems, skills, staff, style and shared values. Specifically developed methodologies, tools and processes to support the implementation of IEM in a company are presented in this work.

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