A Systematic Approach to Adopt Sustainability and Efficiency Practices in Energy-Intensive Industries

Karin Tschiggerl and Milan Topić

Abstract

The foundry industry is counted among the energy- and resource-intensive industries, and thus an important contributor to impacts on climate change. On a global level, the production of casting parts is expected to increase, with China, USA and India as the main cast producers, and the automotive sector as the main purchaser. While the production of castings is one of the oldest production processes in human history, there are still weaknesses regarding sustainable operations, amongst others due to the asset intensity and different energy cost situations on global level. Political and legislative actions were taken to force sustainable practices in Europe, which means a challenge and a responsibility for foundries at the same time, to adapt their processes, and to adopt sustainability and efficiency management. This paper describes a systematic model approach combining a synthesis of top-down and bottom-up analyses and establishing sustainable practices in foundries. The approach follows the Plan–Do–Check–Act cycle and allows to identify and capture energy and resource efficiency potential while considering life cycle aspects within a highly specific and complex industry. The paper also highlights the importance of transdisciplinary collaboration regarding the realization of sector-specific energy efficiency and integrated into value chain networks. The benefit of the approach is its application on different sustainability maturity levels, and its potential to be adopted in different energy- and resource-intensive industries.

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Energy-intensive industries · Energy efficiency · Foundries · Life cycle aspects · Transdisciplinarity

1 Introduction

The foundry industry is counted among the energy- and resource-intensive industries, and thus an important contributor to impacts on climate change. Foundries are represented in nearly every country in the world, the annual production of casting parts mounts up to more than 100 million tons. On a global level, the production of casting parts is expected to increase, with China, USA, and India as the main cast producers, and the automotive sector as the main purchaser. An interesting fact to be pointed out is the nonlinearity between production output and efficiency of production. Looking at the top 10 cast producing countries, the number one in amounts is the last one regarding efficiency (Turner 2015).

While the production of castings is one of the oldest production processes in human history, there are still weaknesses regarding sustainable operations, amongst others due to the asset intensity and different energy cost situations on global level.

Political and legislative actions were taken to force sustainable practices in Europe, which means a challenge and a responsibility for foundries at the same time, to adapt their processes, and to adopt sustainability and efficiency management. Globally, restrictions seem to refer rather to guidelines and voluntary initiatives than obligatory actions. One of the newly formed actions is the so-called Paris Agreement dealing with the mitigation of greenhouse gas emissions, adaptation, and finance, which will only be started in 2020 (UN 2015a).

1.1 The Sustainable Development Goals and Their Implications for Energy-Intensive Industries

The United Nations General Assembly adopted the Sustainable Development Goals in 2015, comprising 169 targets under 17 goals (UN 2015b). They are related to issues like poverty, education, and environment. Addressing all countries worldwide, on a micro-level also individual organizations are demanded to make a contribution. Regarding this and the focus of the underlying paper, two out of the 17 goals can be pointed out: Goal 9 "Industry, Innovation and Infrastructure", and Goal 12 "Responsible Consumption and Production". Taking a closer look at the targets, the following shall be considered (UN 2015b):

- By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities

- By 2030, achieve the sustainable management and efficient use of natural resources
- By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment
- By 2030, substantially reduce waste generation through prevention, reduction, recycling, and reuse
- Encourage companies, especially large and transnational companies, to adopt sustainable practices and to integrate sustainability information into their reporting cycle

With regards to this representative targets, and the questions of "How to?" and "Where are we now?" the search for adequate solutions has to start. It seems clear that a one-sided disciplinary viewpoint won't be able to resolve the problem. As a first step, however, the problem has to be analyzed and evaluated, which leads to the so-called "energy efficiency gap" (Hirst and Brown 1990).

1.2 Addressing the "Energy Efficiency Gap"

Energy-intensive industries are challenged more than other industries in finding adequate solutions to capture the energy concerning targets on the Agenda for Sustainable Development. This leads to the question why there are still weaknesses in the implementation of energy conservation measures. A number of studies deal with barriers hindering energy efficiency in foundries (CFA 2003; Davies 2012; Eronen et al. 2013; Helber and Steinhäuser 2011; Trianni et al. 2013). The self-assessment of foundries considering a potential cut-down of 15% in energy consumption leads to the so-called "energy efficiency gap", which was studied by several researchers (Hirst and Brown 1990; Jaffe and Stavins 1994; Rohdin et al. 2007; Thollander and Ottosson 2008). According to Schmid (2004) the disproportion between the techno-economic possible and the actual realization can be explained through the following aspects (Fig. 1):

- Insufficient rating of economic potential: Internal hidden costs (i.e., costs for information or the implementation) are mainly not considered in the calculation of the economic potential. This leads to an overestimation of the economic potential (Jaffe and Stavins 1994). In practice, the risk assessment of investments is stricter than assumed in models and analyses. Especially in small and medium sized enterprises (SMEs), a lack of capital lead hinders the implementation of effective measures, and thus a lower application of cross-sectional technologies because of the heterogeneity of the industry.

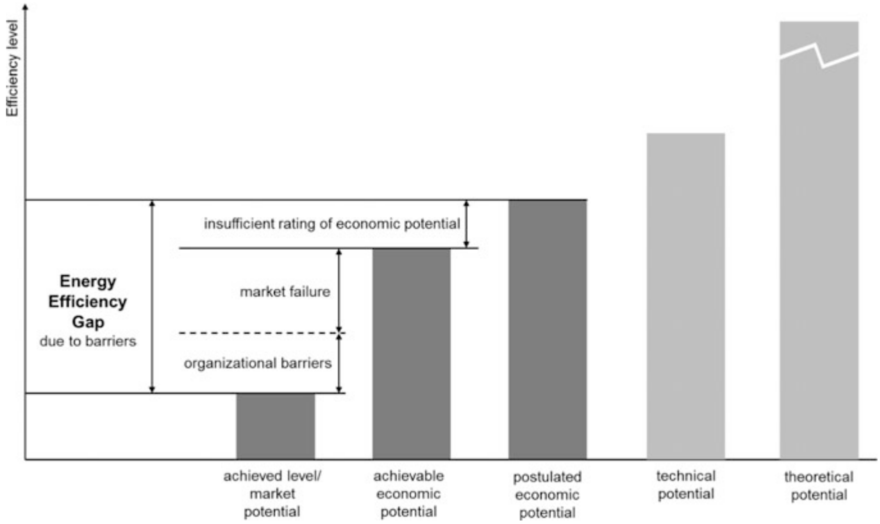

Fig. 1 Levels of energy efficiency and the "energy efficiency gap". *Source* Posch (2011) based on Schmid (2004)

- Market failure: This barrier appears when the mechanism of supply and demand does not allocate goods to the actors giving most value to them. This in turn can be attributed to externalities, market structures, insufficient provision of information, and asymmetric information (Sorrel et al. 2004). Externalities are costs or benefits that are not reflected in the market prizes of energy-efficient products, but transferred to the public in the form of external or social costs (i.e., environmental costs or subsidies). Together with biased competition (i.e., monopolistic or oligarchic markets) they have strong influence on the pricing of energy and thus the profitability of energy-saving measures. Imperfect information is a result of the incomplete information that is provided by market actors to generate profits. This means costs for a purchaser aiming at adequate and comprehensive information regarding energy consumption characteristics of a good. Asymmetric information on the other hand is explained by an unequal share of information: problems of adverse selection, where lower qualities become accepted in the market, and the investor-user-dilemma, where the investor cannot gain the economic benefit of a measure.
- Organizational barriers can be reduced to split incentives in companies, principal-agent-problems, and conflicts between individual and corporate targets. Split incentives may occur if different departments are responsible for the planning and the calculation of an investment. Principal-agent-problems typically happen between the management, that rates energy efficiency as an important topic ("top-down" decisions), but on operative level measures are not implemented due to "alibi"-reasons. Least, the bounded rationality in decision taking allows subjective preferences in the selection of projects (Sorell et al. 2004).

At the same time, it has to be distinguished between different levels of energy efficiency that can be defined by various determining factors. Therefore saving potential can be differentiated by stages, as shown in Fig. 1 (Posch 2011):

1. Theoretical potential: described as the difference between the actual and an ideal process. In practice, the theoretical thermodynamic potential is not realizable.
2. Technical potential: can be unlocked through the implementation of the existing most energy-efficient technologies. It does not take into account economic considerations.
3. Economic potential: is generally based on idealized framework conditions from the neoclassical theory. The estimate of the economic potential results from the implementation of the most energy-efficient technologies (for replace, upgrading, and new investments) within a certain time frame, which are cost-efficient under the given market prizes.
4. Market potential: also called anticipated potential and result of the energy efficiency gap. It can be seen as the potential that is captured without changes of the macroeconomic and internal framework conditions. A forecast of the economic potential is difficult as the share of barriers to the energy efficiency gap is not certain.

To identify the energy efficiency potential, methodical conditions have to be considered, besides the defined energy efficiency level. According to Posch (2011), the possible savings depend, amongst others, significantly from considered technologies (for example, cross-sectional vs. sector-specific technologies), defined criteria regarding profitability, and reference values for energy (i.e., values for a reference year or trend scenarios).

Practical experiences complete these findings, as the combination and interdependence of barriers implicate increasing complexity (Coss et al. 2015), and therefore complicate the implementation of energy and resource efficiency in organizations. On the other hand, the evaluation of critical values and data sources becomes crucial for the identification of energy efficiency potential. They have fundamental impact on findings, thus the precision of analyses is the basis for the deduction of measures. As an integrated approach can reach complex dimensions, imprecisions in the assessment of potential might occur.

2 Methodological Framework

The methodological framework for the development of a model approach includes basic theories regarding Industrial Ecology and transdisciplinarity, recognizing the importance of a systems viewpoint and the integration of economic, ecologic, and technical aspects. This aims at making use of existing energy efficiency potential and to overcome implementation barriers.

2.1 Industrial Ecology

Dealing with industrial settings broaching the issue of sustainability requires the adoption of a systems perspective. Thinking in systems enables problem solving by identifying a system's structure that explains behavioral patterns in various situations. As well, systems thinking demands a shift from linear to circular causality, considering relations, interactions, and feedbacks within and crossing the system (Chai and Yeo 2012). In face of urging sustainability problems in material, energetic, and technological fields, a dynamic sampling and the development of strategies for managing complex systems are central. After all, a better understanding of complex systems becomes one of the most important challenges of Industrial Ecology (Von Gleich 2008). This can be described as "the study of the flows of materials and energy in industrial and consumer activities; the effects of these flows on the environment; and the influence of economic, political, regulatory, and social factors on the flow, use, and transformation of resources" (White 1994). More detailed, Graedel and Allenby (1995) point out that the concept of Industrial Ecology "requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them. It is a systems view in which one seeks to optimize the total materials cycle from virgin material, to finished material, to component, to product, to obsolete product, and to ultimate disposal. Factors to be optimized include resources, energy and capital." To this effect, topics regarding energy efficiency are typically included within the concept of Industrial Ecology. While sustainable development goes beyond, efficiency strategies can be seen as a needful way within the Industrial Ecology approach with a high starting potential (Jochem 2003).

The complexity within overall sustainable development and Industrial Ecology topics induces approaches that help to overcome the barriers faced by disciplinary boarders which hinder capturing existing efficiency potential and to benefit from adopting a systems view. To this effect, it requires to open the "black-box" of the techno-sphere, to analyze and to design it (Von Gleich 2008).

Regarding the latter argument, the discipline of techno-economics gained importance in the last decades, facing the demand in sustaining the innovative capacity in industry. To generate practical sustainable answers, that cannot be solved on a disciplinary level but very well depend on the expert knowledge and the methodological accuracy of different professions, the combination and synergies resulted in the development of this quite young discipline. Therefore, techno-economics refer to an alliance of technology (respectively science and engineering), economy (in the sense of micro-economics), and sociology.

2.2 Transdisciplinarity

Regarding the complexity and uncertainty of human–environment systems and to address issues of sustainable development, transdisciplinary research processes turned out to be adequate (Düspohl et al. 2012) and lead to a broad adoption in this

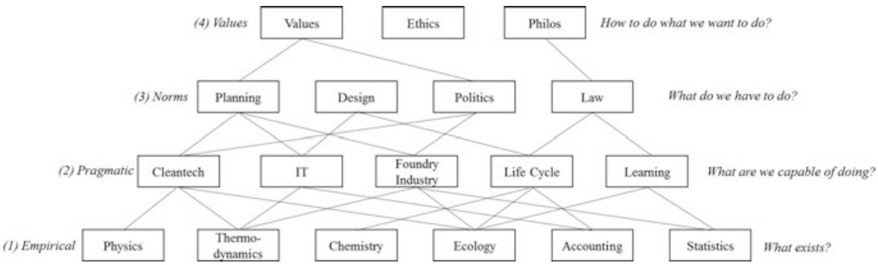

Fig. 2 Transdisciplinary setting of the addressed problem. *Source* based on Max-Neef (2005)

research field (Schaltegger et al. 2013). As Max-Neef (2005) suggests, research relevant to solve current pressing problems should be transdisciplinary. He developed a matrix composed of four levels (values, norms, pragmatic studies, empirical research), where a transdisciplinary action includes related components from every dimension. Applied to the underlying research issue of sustainable practices and energy efficiency in a specific industrial environment, the transdisciplinary setting illustrates the modular composition adapted to Max-Neef's matrix (Fig. 2), similar as it was used by Spreng (2014) for energy research. The dashed lines show any vertical relation including all four levels and the transdisciplinary actions of the addressed problem.

Important characteristics of transdisciplinary research are reflexivity as a part of knowledge production and the enabling of "mutual learning" between scientific and nonscientific actors (Jahn et al. 2012). As Mittelstrass (1992) stated, a transdisciplinary approach has a dynamic nature, as problem-solving efforts are generated during application. Thus, the diffusion of solutions and results occurs in their generation process which also occurs in participatory action research.

3 Results and Analysis

Motivated by current legal challenges and conditions for the foundry industry the research project "EnEffGiess—Development of a life-cycle oriented approach for the assessment of energy-efficient, sustainable foundry products" was started. The objective was to generate a process and evaluation model that enables to sustain the energy efficiency in foundries. As argued in the methodological framework and given the specific implications for energy-intensive industries, the need for a multi-level approach can be deduced. With the developed model, which is based on technical, economic, and environmental methods, it becomes possible to rate different foundry products regarding their energy consumption. As a result, "hot spots" and potential for measures to increase the energy efficiency can be identified.

3.1 Generation of a Systematic Model Approach

Starting point for the development of the model approach are strategic considerations and targets regarding energy topics. Following the idea of the PDCA cycle (Plan–Do–Check–Act), an analysis regarding the previous implementation of energy-related issues and their controlling shall follow to gain an overview of the actual energy situation of an organization. This demands a viewpoint from a strategic level, declared as the "top-down" approach, which impacts the operative level and at the same time requires production-related information, analyses, and processes. Thus, the model has to be established on different management levels: the top-down approach on the strategic and with interfaces to the operative level, and a bottom-up approach situated on the operative level. Figure 3 abstracts the frame and the compilation for the model design.

The model was developed applying a modular proceeding (Coss et al. 2015). This allows to analyze not only diverse operations but also structural differences of the foundry industry. Operations include the design and production, creation of tooling and prototypes, machining and assembling of casting and components placed in downstream assembly lines (CFA 2003). The modules were defined as main or support modules. This follows a description of the European Commission (2005), which includes, i.e., pattern making, mold and core production, melting, casting, metal treatment, etc. A production site is represented by the composition of used modules. This leads to a hierarchical structure including three levels:

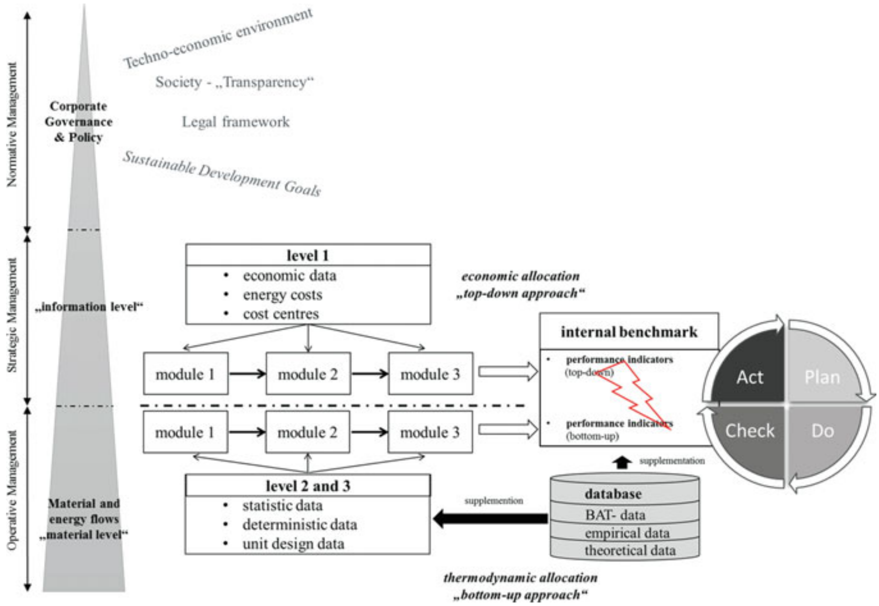

Fig. 3 Systematic model approach following the PDCA method. *Source* based on Coss et al. (2015)

enterprise level (level 1), main and support modules (level 2), and units/aggregates within a module (level 3). In doing so, key processes and key performance indicators can be generated. As well, economic and technical data are deployed to uncover energy efficiency potential. The benefits refer to more lifelike insights, detailed consumption rates on single-product level, and furthermore to the detection of information deficits and hindering mechanisms.

Analyzing data on process and product level helps to identify the most promising energy efficiency potential (Coss et al. 2015). Through the modular compilation it becomes clear that differences may occur when top-down and bottom-up results are compared. This is the reason why such deviations between economic allocations and thermodynamic calculations indicate undepicted energy efficiency potential. The following Fig. 4 illustrates the stepwise proceeding, with step 2 indicating the top-down approach and step 3 the bottom-up approach. The latter refers to a product-oriented view, which enables the identification of best process routes, as well as the comparison with substitutes and further integration of life cycle aspects. This is to say, that a detailed input/output balance generates the basis for the life cycle assessment of a product or product system.

The innovative character of the model is a comprehensive modular approach that generates a novel description and assessment of heterogeneous foundry products. As it considers various data sources and different methodical approaches aiming at different objectives, the role of a high quality, profound data basis, and transparent communication flows gain an importance. The resulting database includes empirical, theoretical and Best-Available-Techniques (BAT) data.

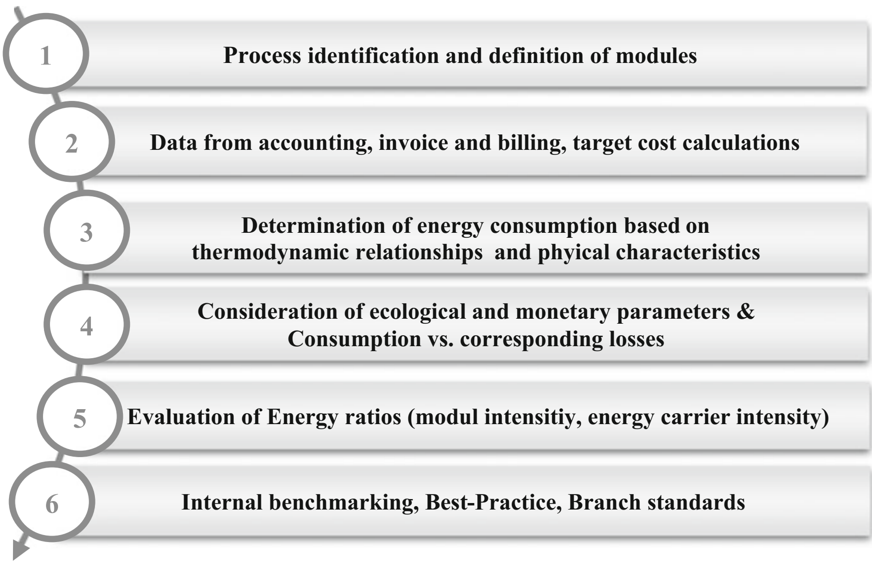

Fig. 4 Proceeding in the model design

During the application of the model in six diverse pilot foundries it turned out, that data were inconsistent or simply not available. Therefore, an iterative proceeding for the data acquisition is advisable (Coss et al. 2015). This means that traditional data collection with checklists and questionnaires should be complemented by a process visualization which is discussed by members from different departments as well as external actors, as, for example, researchers or consultants, technical engineers, etc. Frequent meetings or workshops help to identify input and output parameters on module level, possible losses and potential recycling, as well as they support the verification of data and the improved allocation of resources and costs. Applying such a methodology raises awareness within a company as several team members will be involved, thus it opens a “black box” and follows a participatory, transdisciplinary manner where know-how is generated and diffused during the whole process. Another benefit in the underlying project was that insights into different complex processes and products, as well as deductions for the whole foundry industry could be generated.

Summarizing, the systematic model approach addresses several important aspects: the heterogeneity of the studied industry with diverse products and processes, benchmarking, and a life cycle perspective (Coss et al. 2015), and participatory knowledge-generation and learning processes.

3.2 Integrating Life Cycle Aspects

Analyses considering the whole (product) life cycle gain on importance regarding industrial activities and their affiliated influences on the natural environment and requirements for a sustainable development. Beyond that, the consideration of life cycle aspects supports and gives added value to the identification of (cost-)effectiveness when capturing energy efficiency potential. The standardized method of Life Cycle Assessment (LCA) helps to analyze environmental aspects and potential impacts of product systems over their whole lifetime (“from cradle to grave”; Austrian Standards Institute 2006). LCA shows relevant benefits regarding the improvement of the energy performance and resource intensity on corporate level. Transparency of energy and material flows, and combined with monetary parameters, LCA helps to identify the most auspicious energy efficiency measures on different levels (Coss et al. 2015; Tschiggerl et al. 2016). This refers also to a consideration of the whole value chain, where it becomes even more important to find branch or industry-specific solutions, and to make use of synergies along the value creating process.

4 Conclusion

Networks to support Sustainable Development have been established increasingly after the milestones for our current understanding of the term, namely the Brundtland Report and the Agenda 21. Since then, sustainable development was in fact displayed in its global dimension and became a mainstreaming issue. However, with the rising interest in energy-related issues and a political as well as an economical focus on energy efficiency, energy-intensive industries are challenged more than before in increasing energy efficiency, to reduce the use of primary and raw materials, and to use renewable energy sources (Tschiggerl and Wolf 2012). The question that arises is how individual organizations can implement global policies and goals—as represented with the highly topical Sustainable Development Goals —on a corporate level.

The aspect of complexity and heterogeneity in foundry production and structures may lead to unidimensional assumptions of energy efficiency. For example, a focus only on primary energy demand may risk inhibiting product innovations, which are an important step toward a cumulated energy and material efficiency. However, such energy efficiency strategies from a technical viewpoint are related to the level of efficiency, the process topology, and the component part (Knothe 2013). For the foundry industry, transparency in energy consumption and information about energy flows is fundamental, not only to meet regulatory demands but also to identify useful effects. Corresponding trends may include the increased implementation of energy management systems, energy ratios, and benchmarks, as well as advanced sensor, communication and analyzer systems.

The developed systematic model approach allows a holistic and structured proceeding in the identification of energy efficiency potential. Through combining as well strategic and operative levels not only the efficiency is on the radar but as well aspects beyond a company's boarder that influence decision-making regarding effective measures. Applying a life cycle perspective expands the technical viewpoint to an ecological one and makes use of synergies from the transdisciplinary project setting.

Besides efforts to bridge the energy efficiency gap in the foundry industry, the financial examination in relation to energy efficiency and environmental impacts becomes more important. Energy costs, strongly depending on the volatility of markets and politics, have significant influences on life cycle costs (Rudolph et al. 2010) especially with regards to the asset and investment intensity in this industry. The follow-up costs are relevant to gain meaningful cost information. Foundries need to know about it when they intend to implement new production units or for the assessment of new production processes (Aurich et al. 2009). Operators or users on the other hand are interested in follow-up costs regarding increased degrees of efficiency enabled by cast parts.

These information, respectively, conclusion is valid for energy-intensive industries in general. Therefore, the proposed systematic model approach may be applied to any industry featuring a high level of energy and corresponding resource intensity. To apply the methodology and getting out the most of it, a well-grounded data setting is necessary. As practical experience uncovers this is not the fact, even in well-structured and organized companies. Therefore, data quality based on intensive communication in the sense of an active stakeholder dialogue is essential in realizing solutions and considering life cycle perspectives, and thus capturing the energy efficiency gap and achieving the stated energy targets within the Sustainable Development Goals.

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