2 Energy Usage in Industry

The second chapter illustrates fundamental concepts and underlines the motivation for the research work. At first, relevant terms are explained. Afterwards, drivers and barriers for increasing energy efficiency in industrial enterprises are analyzed with regard to economic, ecological, and political factors. The identification of barriers that hinder the implementation of energy efficiency strategies form a starting point to define requirements for the method.

2.1 Terms and Definitions

Energy E is a state variable of a system that describes its ability to perform work. If a system passes from one state to another one, *work W* appears as a variable to describe this process. Work, heat, and energy are measured by the unit Joule [J], *i.e.*, using the SI units:

$$1\,J = 1\,N \cdot m = 1\,W \cdot s = 1\,\frac{kg \cdot m^2}{s^2}. \tag{2.1}$$

The work of a process related to one period of time is the *power P* measured in Watt [W].

The laws of thermodynamics determine fundamental rules on the transformation of energy. The first law of thermodynamics describes the conservation of energy. It states that the total energy of an isolated system is constant, *i.e.*, energy cannot be created or destroyed. However, energy may be transformed from one form into another one. Energy is composed of exergy, which is usable to perform work, and anergy, which may not be used within the existing surrounding. Although the energy within a system remains constant, it converts exergy into anergy, which is often referred to as energy loss or energy consumption. This direction implies the irreversibility of a process, which is stated by the second law of thermodynamics. Accordingly, heat can never pass from a colder to a warmer body without other changes. Therefore, natural processes take place in a certain direction and are not reversible (*e.g.*, friction). (Windisch, 2014, pp. 70 ff.)

Energy occurs in various *energy forms*, such as mechanical (potential and kinetic), chemical, electrical, thermal, and nuclear (Hesselbach, 2012, p. 18). When considering the physical objects that hold this energy, several *energy carriers* may be identified, such as gas (*e.g.*, natural gas, steam, compressed air), liquids (*e.g.*, oil), and solid materials (*e.g.*, biomass, coal, uranium).

Transformation processes are necessary to make energy carriers useful for any application. The energy conversion chain contains the transformation from raw material until the final application. Energy losses occur on every conversion step. The major phases within this transformation process are explained by the following terms (Müller et al., 2009, pp. 72 ff.): *Primary energy* is the energy content of natural resources prior to any

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transformation (*e.g.*, natural gas, wind). After any transformation, the energy is referred to as *secondary energy* (*e.g.*, diesel). The *end energy* is provided to the final user, for example to a production plant (*e.g.*, electricity). Finally, the energy is directly applied for a specific purpose which is called *use energy* (*e.g.*, lighting).

The objective to increase energy efficiency needs to be discussed with regard to the general ideas of efficiency, effectiveness, and productivity: *Productivity* describes the ratio between an output, such as the amount of products, and the input of production factors, such as time, material, or staff (Nebl, 2011, pp. 18 f.). *Efficiency* is the ratio between useful output and input, whereas *effectiveness* means the ability to produce a desired output (Miller, Colombi & Tvaryanas, 2014, p. 205). A demonstrative definition of the latter two terms is given with efficiency as "doing things right" and effectiveness as "doing the right things" (Drucker, 1974, p. 83).

Energy efficiency can be defined as the ratio between a useful output and the input of energy that is necessary to achieve this output (Müller et al., 2009, p. 2):

$$\text{energy efficiency} = \frac{\text{useful output}}{\text{energy input}}. \tag{2.2}$$

Thus, increasing energy efficiency can be achieved with two strategies: The output can be increased while maintaining a constant energy consumption or the energy consumption needs to be reduced while maintaining the useful output. The usual approach to increase energy efficiency, which is also pursued in this thesis, is to reduce the energy input. Energy effectiveness can hardly be expressed in a quantitative way, but it is used as a concept to question whether the energy provides a useful output. For example, air ventilation in a factory during idle time is an output that would not be considered useful.

Energy productivity is a less common term that is similar to energy efficiency. It expresses the useful output of the energy efficiency definition by means of economic objectives, for example the gross domestic product (Statistisches Bundesamt, 2014, p. 6). Another interpretation is the ratio between value added and energy costs which makes the energy productivity a percentage value (Reinhart et al., 2010, p. 870). The reciprocal of efficiency or productivity objectives represents the energy intensity (Linke et al., 2013, p. 557).

2.2 Driving Concerns for Energy Efficiency

A variety of external factors lead to the necessity to increase energy efficiency for industrial enterprises, such as economic, ecological, and political aspects. As a result, energy efficiency is considered as a relevant competitive factor (Bunse, Vodicka & Schönsleben, 2011, p. 53). A survey by the Fraunhofer Institute for Production Systems and Design Technology among 2,200 industrial companies, points out that 56 % of the participants confirm the importance of energy efficiency (Karcher & Siemer, 2013, p. 17).

When it comes to future development, even more than two third of the respondents expect a growing importance (Karcher & Siemer, 2013, p. 17). Main drivers that foster this development are explained in the following sections.

2.2.1 Ecological Effects of Energy Consumption

The emission of greenhouse gases that is caused by energy consumption considerably influences the global ecological system. Greenhouse gases absorb and emit infrared radiation and, thereby, contribute to global warming. The most important greenhouse gases are carbon dioxide, methane, nitrous oxides, and fluorinated gases (United States Environmental Protection Agency, 2016a).

Usually, ecological effects of these gases are expressed relatively to carbon dioxide (CO_2) since it has the highest share of greenhouse gas emissions. Hence, emissions of any other gas are expressed by carbon dioxide equivalents (CO_2e).

Industry contributes 20 % of the global carbon dioxide emissions and is responsible for an additionally 18 % due to allocated electricity and heat generation, see Figure 3 (International Energy Agency, IEA, 2014, p. 10). Therefore, reducing energy consumption is important in order to minimize global warming.

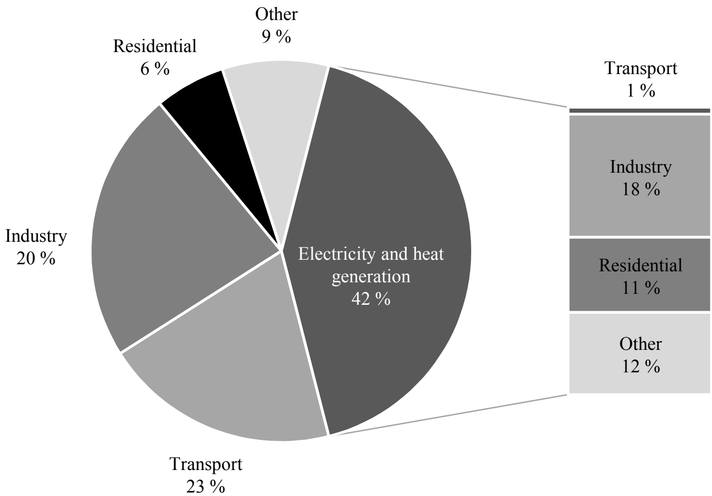

Figure 3: Global carbon dioxide emissions by sector in 2012 (International Energy Agency, IEA, 2014, p. 10)

The development of the global energy demand is decomposed into the following effects (International Energy Agency, IEA, 2012, p. 283): The *efficiency effects* mean to use less energy to provide the same level of service (*e.g.*, energy management in a company). The *fuel and technology switching effects* mean to provide a service with different fuels and technologies (*e.g.*, using natural gas instead of oil for room heating in buildings). The *activity effects* influence the demand for energy services (*e.g.*, economic growth).

According to the International Energy Agency (IEA), energy efficiency provides the highest single share of energy savings of these effects; it accounts for about 70 % in the future projection of the energy demand until 2035 (International Energy Agency, IEA, 2012, p. 282).

2.2.2 Political Conditions for Energy Efficiency

Political and legal conditions are the second group of drivers for industrial enterprises. These contain political strategies, laws, and governmental aids (*e.g.*, through providing financial aids for energy-efficient technologies). An overview with examples within these categories is given in the following paragraphs.

The European Commission concluded the Climate and Energy Framework in 2014 in order to set a European energy efficiency strategy (European Commission, 2016).[1] The key objectives of this framework target greenhouse gas emissions, renewable energy, and energy efficiency. According to the strategy, an increase in energy efficiency by at least 27 % by 2030 is aspired to (European Commission, 2016). A long-term strategy is defined by the Energy Roadmap 2050, which includes an 80-95 % reduction of greenhouse gas emissions by 2050 (European Union, 2012, p. 3).

The German Federal Government decided upon the *National Sustainability Strategy* in 2002 (Die Bundesregierung, 2002). Regarding the topic of energy efficiency, it contains the goal to double energy productivity by 2020 and to reduce primary energy consumption by 20 % by 2020.

The national legislation is influenced by directives and regulations from the European Union (EU). When a directive is passed from the European Commission, the national governments are required to implement these directives into national law.

Examples for EU directives in the context of energy efficiency are the Ecodesign Directive and the Energy Efficiency Directive. The *Ecodesign Directive* provides minimum requirements on the environmental performance of products (European Commission, 2009b), which are implemented through product-specific regulations, such as on the efficiency of electric motors (European Commission, 2014a). The *Energy Efficiency Directive* requires the national governments to define national strategies on energy efficiency and to report their achievements (European Parliament, 2012).

[1] Before, the Climate and Energy Package 2020 was resolved in 2007 and enacted in legislation in 2009 (Council of the European Union, 2007).

The Ecodesign Directive has been implemented by passing the *Energy-Related Products Law* (EVPG). It provides the framework for improving energy efficiency of specific product groups. The implementation of the Energy Efficiency Directive led to the Energy Service Law and to the definition of the National Action Plan on Energy Efficiency. The *Energy Service Law* (EDL-G) requires large companies to perform energy audits. Exceptions are possible for enterprises which have an energy or environmental management system. In 2014, the government passed the *National Action Plan on Energy Efficiency* as a strategy to focus on energy efficiency activities including the cornerstones energy-efficient buildings, establishing energy efficiency as business model, and increasing responsibility for energy efficiency (*e.g.*, sensitization and transparency) (Bundesministerium für Wirtschaft und Technologie, BMWi, 2014, p. 20).

Further important national legislations include the Energy and Electricity Tax Law, the Energy Saving Directive, and the Renewable Energy Heat Law. The *Energy and Electricity Tax Law* (StromStG) regulates the payment of taxes on energy consumption for end consumers. Furthermore, it includes regulations on exemptions and reductions from this tax. For example, industrial enterprises who maintain an energy or environmental management system may apply for a tax reduction. A prerequisite for this reduction is that the entire manufacturing industry achieves a defined goal on increasing energy efficiency every year.

The *Energy Saving Directive* (EnEV) expresses requirements for residential and non-residential buildings. It regulates the heat transmission coefficients and primary energy demand for buildings including building services (*e.g.*, ventilation). The fulfillment of these standards is required in order to receive a building permit for new or refurbished buildings. The *Renewable Energy Heat Law* (EEWärmeG) requires buildings to use a defined share of renewable energies for heat generation (*e.g.*, solar thermal energy for room heating of residential buildings).

2.2.3 Energy Costs in Industry

The consumption of energy comprises an important share of the total production costs for industrial enterprises. Globally, energy costs account for 12.3 % of the total costs, while this share greatly varies between different industrial sectors (United Nations Industrial Development Organization, 2011, p. 69). For example, the highest share can be found in refined petroleum and nuclear fuel industry with 61.6 %, whereas the lowest share is 0.7 % in office and computing machinery industry (United Nations Industrial Development Organization, 2011, p. 69). Furthermore, the share tends to be higher in developing countries. This may be caused by a lower adaptation of efficient technologies in these countries. Figure 4 shows the share of energy costs in different industrial sectors in Germany.

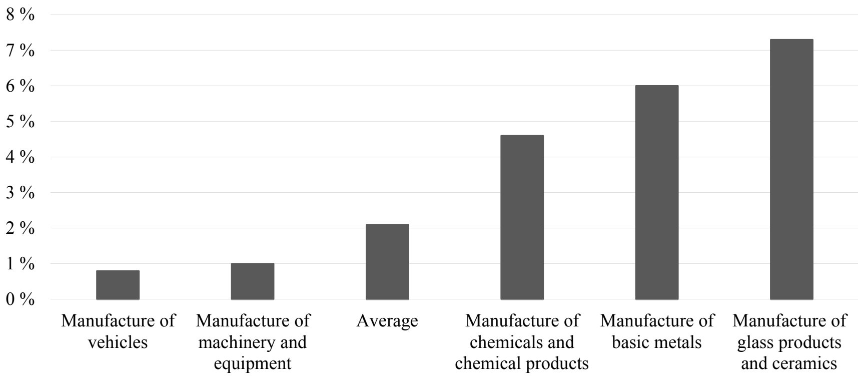

Figure 4: Energy cost's share of total production costs in German industry, divided by sector (data from Statistisches Bundesamt, 2015, pp. 279 ff.)

Although the share of energy costs is low compared to other cost factors (*e.g.*, personnel), it still represents an important lever for increasing profitability of a company. This is especially important when energy prices are presumed to increase in the future. The most commonly used energy carriers in industry are natural gas and electricity (Bundesministerium für Wirtschaft und Technologie, BMWi, 2015). Between 2008 and 2012, energy prices in the European Union annually increased by an average of 1 % for natural gas and 3.5 % for electricity (European Commission, 2014b, p. 5).

The energy price is composed of three elements: The first part reflects the costs of an energy supply company, *i.e.*, for generating energy and delivering it to the grid (energy production). Further costs occur for transmitting energy in an energy network (energy distribution). Finally, taxes and levies are applied according to the governmental policy of a country. For the first element on energy production, prices on wholesale and retail level need to be distinguished: The wholesale price mainly depends on the market structure and may vary several times during the day. The retail costs cover expenses that are required to sell energy to final consumers. While retail energy prices increased as indicated above, the wholesale prices declined by between 35 % and 45 % on the major European wholesale electricity benchmarks during the same period of time. (European Commission, 2014b, p. 6)

The development of electricity retail prices for industry in Germany, separated into production and distribution on the one hand, and taxes and levies on the other hand, is presented in Figure 5. In 2014, energy production costs accounted for approximately 4 to 4.5 Cent and 2 to 2.5 Cent for distribution, while taxes and levies summed up to 8.4 Cent (Bundesverband der Energie- und Wasserwirtschaft, BDEW, 2015, p. 17). The figure shows an increase in the electricity price of 27 % in the past five years between 2010 and 2014.

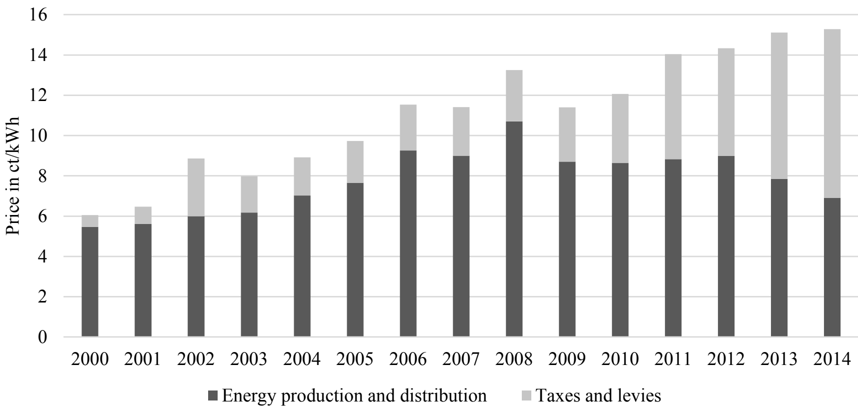

Figure 5: Development of electricity prices in German industry (adapted from Bundesverband der Energie- und Wasserwirtschaft, BDEW, 2015, p. 13)

Taxes and levies contain the following main components: The *electricity tax* is part of the general taxation. The *concession fee* is paid by electricity generating companies to governmental institutions in order to use public area for power lines. The *EEG levy* as part of the Renewable Energy Sources Act (EEG) needs to be paid to operators of energy distribution networks. They use these revenues to pay remunerations to end users that are generating renewable energy (*e.g.*, photovoltaics). The remunerations from the law on renewable energies represent a political incentive for an increasing use of renewable energy. A similar mechanism is pursued by the *combined heat and power levy*, which gives an incentive for the expanded usage of equipment that cogenerates heat and power. (Bundesverband der Energie- und Wasserwirtschaft, BDEW, 2015, p. 13)

The development of electricity prices in the future is mainly driven by the structure of electricity generation and further political decisions. It is expected that electricity prices for industry will rise by 50 % until 2025 due to an increase of EEG levy and wholesale prices (Schlesinger, Lindenberger & Lutz, 2014, p. 227). Therefore, the economic effects of energy consumption pose an important challenge to maintain the competitiveness of industrial enterprises.

2.2.4 Structure of Energy Consumption in Industry

Besides the importance of saving energy, the possibilities to realize these savings need to be considered. Industry causes 28 % of the end energy consumption (Bundesministerium für Wirtschaft und Technologie, BMWi, 2015). This energy is used for several applications (*e.g.*, process heat, mechanical energy).

Figure 6 shows how various applications contribute to the energy consumption in industry. It can be seen that the main usage of energy is for process heat and mechanical energy (*e.g.*, drives), which means that improvement potentials may be especially important in these areas.

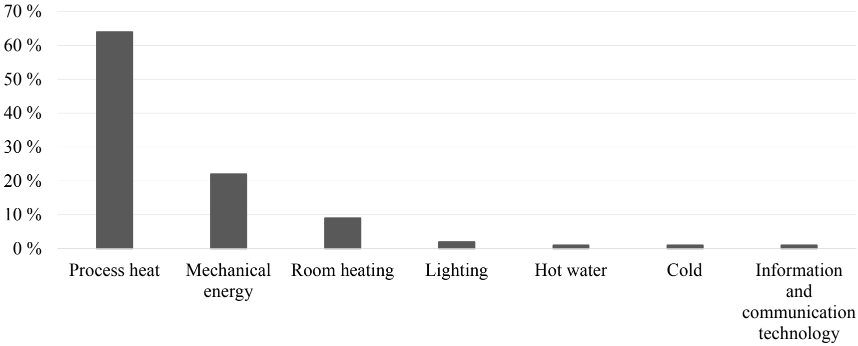

Figure 6: Structure of energy consumption in German industry (data from Bundesministerium für Wirtschaft und Technologie, BMWi, 2015)

It should be noticed that the structure of energy consumption within a factory highly depends on the industrial sector. In general, the *continuous manufacturing industry* is characterized by processing materials and substances, *e.g.*, paper industry, whereas the *discrete manufacturing industry* produces single items, *e.g.*, machinery industry (Chryssolouris, 2006, p. 55). Enterprises in process industries usually have a high energy consumption for generating process heat (*e.g.*, for melting material). The energy consumption of discrete parts manufacturing is as diverse as the products (*e.g.*, automotive, electronic products).

For example, Figure 7 shows the energy consumption structure of the car body shop in an automotive plant. The main process contains manufacturing the car bodies, which requires welding and other production equipment.

Due to the heat generation of welding, the equipment needs to be cooled. Moreover, proper work conditions are maintained, which includes lighting and heating systems. In this example, the heating of the building is realized in combination with the air ventilation system and requires natural gas. Parts of the production equipment need compressed air. Hence, the compressed air is generated with compressors in a centralized supply room and afterwards distributed into the car body shop. The necessary end energy carriers are electricity, water, and natural gas, which need to be purchased.

This example demonstrates the necessity of a holistic consideration in order to increase energy efficiency. For example, a singular improvement measure at the welding system that reduces the electricity consumption in turn effects the heat generation and, hence, the cooling energy demand. Furthermore, the example shows that interdisciplinary action areas need to be considered as part of an energy efficiency project (*e.g.*, manufacturing technology, media supply).

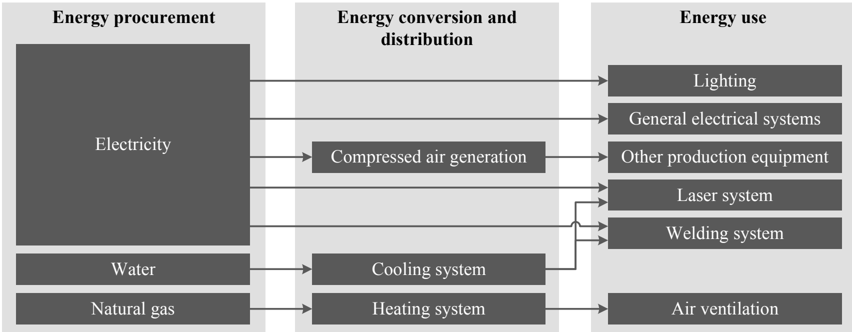

Figure 7: Energy interrelationships in an automotive car body shop (adapted from Engelmann, 2013)

2.2.5 Energy Saving Potentials

The prerequisite to increase energy efficiency are improvement potentials, which can be distinguished into different types: The *theoretical potential* describes possible improvements in contrast to theoretical aspects of physics. It compares, for example, the actual energy consumption of fusion welding with the energy that is theoretically needed to melt the material. The *technical potential* considers technologies that are commercially available. The *economic potential* additionally regards the economic usage of technologies, *i.e.*, it is limited to the cost-effective implementation of a measure. Finally, the *market potential* considers implementation barriers and other market imperfections. The basis of quantifying the market potential is to define a period of time and to estimate a probable scenario including assumptions on which energy efficiency measures are realized. (Schmid et al., 2003, pp. 6 f.)

Several scientific studies analyze the energy efficiency potentials in manufacturing industry. Within these studies, a differentiation is usually made between sector-specific potentials and potentials across several technologies: Whereas sector-specific potentials focus on a branch or specific technology (*e.g.*, paper industry), a high potential can be found in cross-sectional technologies that are applied in a variety of industrial sectors (*e.g.*, drive systems).

In 2008, the Fraunhofer Group for Production conducted a comprehensive study on the potential to increase resource efficiency (Neugebauer et al., 2008). They distinguish improvement potentials according to their realization time into short-term (less than two years), mid-term (two to five years), and long-term (five to ten years) with an increasing intensity of possible changes of a process chain. One result of the study is to quantify the technical potential for manufacturing industry with up to 30 % savings in energy consumption (Neugebauer et al., 2008, p. 344).

BAUERNHANSL ET AL. present a meta study on energy efficiency and include several studies on improvement potentials, of which a few are explained in the following (Bauernhansl et al., 2014). The German Energy Agency (dena) identifies the economic potential of manufacturing industry as 11 % until the year 2020 (Deutsche Energie-Agentur GmbH, dena, 2012, pp. 87 ff.). The technical improvement potential is estimated around 20 % in the long-term (Seefeldt, Berewinkel & Lubetzki, 2009, p. 3). Savings in electrical energy are predominant in cross-sectional technologies and may reach between 80 % and 90 % depending on the scenario (Pehnt et al., 2011, p. 56).

The energy efficiency potential varies between industrial sectors. It is believed that the absolute saving potential is especially high in continuous manufacturing industries, whereas the relative saving potential is higher in discrete manufacturing industries (Bauernhansl et al., 2014, p. 56). This is due to the fact that process industry is rather energy-intensive, which means that energy costs have been focused on earlier. SCHRÖTER ET AL. present a survey to quantify the improvement potential in industrial enterprises (Schröter, Weißfloch & Buschak, 2009, p. 4): Whereas 21 % of the respondents in automotive industry estimate the technical potential above 20 %, this share only accounts for 11 % in the paper industry. A study by the Bavarian Industry Association (vbw) quantifies the economic and technical potential of various discrete manufacturing industries (Table 1).[2]

Table 1: Primary energy saving potentials in different industrial sectors (based on data from Vereinigung der Bayerischen Wirtschaft, vbw, 2012, p. 45)

Sector	Economic potential	Technical potential
Automotive industry	16 %	21 %
Machinery industry	12 %	21 %
Manufacture of basic metals	7 %	11 %
Manufacture of electrical equipment	8 %	22 %

2.3 Barriers for Implementing Energy Efficiency in Industry

Despite the driving concerns and improvement potentials, enterprises face barriers that hinder the implementation of energy efficiency measures. A survey by the Association of German Engineers among 150 industrial enterprises reveals that about 50 % of the respondents have performed an analysis on energy efficiency (Böttger, 2010, p. 46).

[2] It should be noted that this study analyzes savings in primary energy, whereas the aforementioned ones consider end energy.

However, in many cases, no measures are deduced from the analysis. Consequently, there are further barriers for implementing energy efficiency even for sensitized enterprises.

CAGNO ET AL. categorize barriers against energy efficiency into technology-related, information-related, economic, behavioral, organizational, competence-related, and awareness-related (Cagno et al., 2013, pp. 295 ff.). Technology-related barriers describe the unavailability of energy-efficient technologies, *e.g.*, low diffusion of technologies (Cagno et al., 2013, p. 298). A lack of information can be observed when enterprises do not know about energy efficiency measures or additional information, such as costs and benefits of a measure (Cagno et al., 2013, p. 298). An important obstacle is the missing transparency on the energy consumption within a company (Bauernhansl et al., 2014, p. 103). Economic barriers mainly describe the low availability of capital to realize energy efficiency measures (Cagno et al., 2013, p. 297). Another aspect are internal specifications for short pay-back times (Brüggemann, 2005, p. 35). A behavioral barrier depends on the decision-making actions of an enterprise (Cagno et al., 2013, p. 297); for example, when other objectives are interpreted as being more important.

Organizational criteria contain all aspects of the structural and procedural organization, such as lack of human resources, complex decision chains, or no responsible persons for energy efficiency (Cagno et al., 2013, pp. 297 f.). Barriers related to competences comprise lack of specialized know-how (Cagno et al., 2013, p. 298). Finally, aspects on the awareness mean an ignorance towards the topic energy efficiency (Cagno et al., 2013, p. 298).

A survey among 726 small and medium-sized enterprises (SMEs) of the sectors industry, commerce, and construction analyzes existing barriers (Thamling, Seefeld & Glöckner, 2010). According to the results, the main barriers for implementing energy efficiency are lack of capital and too long pay-back times as well as a scarcity of personnel. Figure 8 shows the importance of various barriers and clusters them into economic, organizational, information-related, and behavioral aspects.

Half of the barriers focuses on economic obstacles, which demonstrates the high importance of these issues. The second-most important aspect are information-related reasons, which include the lack of know-how in general and the lack of special knowledge on energy-saving equipment and technologies. The survey results demonstrate the necessity to provide this kind of know-how to industrial enterprises. Additionally, organizational barriers, especially the lack of time to realize energy efficiency, are relevant.

In a more recent survey, BEY ET AL. identify the clusters of information lack and resource allocation (especially of human resources) as the most important barriers for implementing environmental initiatives (Bey, Hauschild & McAloone, 2013, p. 45).

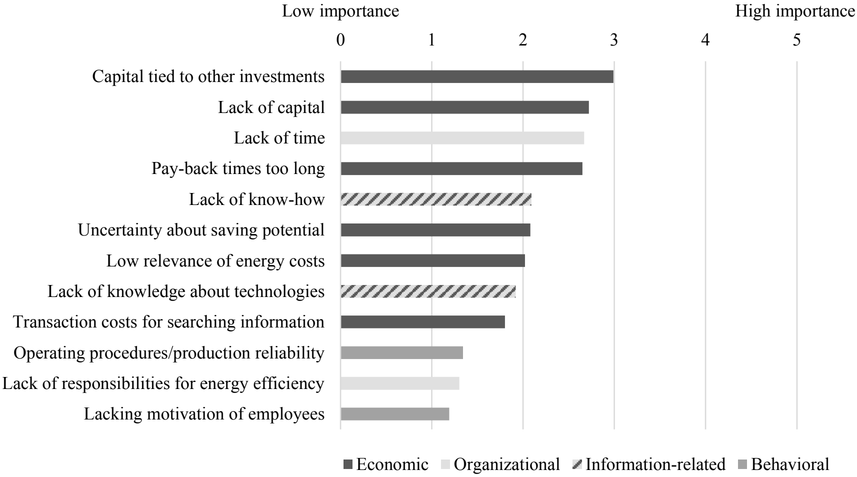

Figure 8: Ranking of barriers towards implementing energy efficiency (Thamling, Seefeld & Glöckner, 2010, p. 27)

The variety of mentioned barriers explains the level of adoption of energy efficiency strategies. Depending on the background of the barriers, different solution approaches are relevant. For example, economic barriers may be addressed by the companies themselves (*e.g.*, availability of capital) or by governmental institutions (*e.g.*, subsidies for energy-efficient technologies).

The development of methods and tools in research especially addresses information-related and organizational barriers. Deduced from the barriers, there is the need to develop methods that provide information on energy efficiency measures (informational aspect) and that can be applied with a manageable effort for finding the relevant information (organizational aspect).

2.4 Interim Conclusion on Energy Usage in Industry

Energy efficiency is an important objective for industrial enterprises. Energy costs represent a significant share of the total production costs, whereof its amount depends on the specific industrial sector. Due to the development of energy prices, especially in terms of increasing taxes and levies, it is assumed that energy costs will increase in the future. Furthermore, energy consumption results in harmful effects on the global ecological system (*e.g.*, carbon dioxide emissions). Against this background, an increasing number of legal requirements obliges industrial enterprises to reduce their energy consumption.

Scientific studies reveal notable potentials to save energy consumption, both within specific industrial sectors and across several sectors. Despite its importance, the topic energy efficiency has not been implemented in depth so far. This is mainly due to economic, organizational, and information-related obstacles regarding the increase of energy efficiency. The empirical results about these barriers point out the need to develop methods and tools that provide information on energy efficiency measures. An important requirement is the handling of these methods and tools without expert knowledge and within a manageable time frame in order to overcome organizational barriers. Since a high number of enterprises estimates that an analysis does not necessarily lead to an improvement, the identification of suitable measures plays an important role.

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