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# What energy management practice can learn from research on energy cultures?

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# What energy management practice can learn from research on energy cultures

## Abstract

**Purpose** – This investigation aims to reframe the sizeable literature on barriers and drivers for energy efficiency measures and the phenomenon of the energy efficiency gap. We identified a gap between academic methods and industrial needs as well as a neglect of the cultural dimension, despite its considerable impact. Based on this insight, the purpose of this paper is to integrate all of the various influences on industrial energy behavior previously identified in the literature in a refined energy cultures framework.

**Design/methodology/approach** – This paper includes a systematic literature review of research in the field of energy management, energy efficiency, and cultural aspects within barriers and drivers of energy behavior. We selected and refined an existing energy cultures framework for the industrial context. To meet industrial needs, we applied an ontology mapping of its core elements onto an international standard common for industrial energy management practice.

**Findings** – First, we present a refined framework for industrial energy cultures incorporating past barriers and drivers as factors. The framework enables an evaluation of attitude and behavioral aspects, underlying technologies, organizational culture and actions related to energy as a system of interdependencies. Second, the factors are ranked based on number of appearances and empirical metadata. Economic aspects such as ‘Purchase, installment, and hidden costs’, ‘General investment and risk behavior’, and ‘Regulatory conditions’ are the highest ranked factors, but ‘Existing knowledge about EEM’, ‘Hierarchy approach: Top down’, and ‘Environmental concerns’ follow closely and represent cultural aspects which are still underrated. Third, while illustrating a successful mapping onto a standardized process of continuous improvement, we also argue for heightened an academia-practice efforts.

**Social implications** – Targeting the energy efficiency gap is an essential part of the sustainable development goals. The refined energy cultures framework allows for a better understanding of the industrial energy behaviors that are responsible for a significant share of a company’s success. The introduction of energy cultures serves as a starting point for future scholarly research within sustainability management accounting.

**Originality/value** – The investigation combines existing research streams, their concepts, and their results about cultural aspects related to energy efficiency for both academics and practitioners. This review is the first to capture all of the various factors analyzed in academic literature using the energy cultures framework as a basis. We add to the theoretical development of that framework with its application to the industrial context. This was identified as a gap. Its refinement helps to holistically understand barriers and drivers of industrial energy efficiency measures in order to support its practical implementation.

**Keywords** – Energy Management, Energy Efficiency, Energy Cultures, Organizational Culture, ISO 50001, Practice Gap

**Paper type** – Literature review

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## 1. Introduction

Increasing energy efficiency is addressed as sustainable development goal (SDG) #7 of the United Nations (UNDSD, 2017) and investments in energy efficiency are key to mitigating climate change (UNFCCC, 2016). They also define a clear business case: the accumulated global energy savings since 1990 amount to almost USD 6 trillion (International Energy Agency, 2015). However, only a third of recommended energy savings are actually realized by companies (Cooremans, 2007), even though ensuring sustainable production is clearly stated in SDG #12 (UNDSD, 2017). Until now, numerous studies have investigated the so-called energy efficiency gap or energy paradox (e.g. Bunse and Vodicka, 2010; de Groot et al., 2001; Trianni et al., 2013). Although that literature stream is broad and well researched, a gap between academic methods and industrial needs still exists (Bunse et al., 2011). Another gap is seen in neglecting the considerable cultural dimension as driver for energy efficiency measures (EEM) (Blass et al., 2014; Cooremans, 2011; Schubert et al., 2015). We close these gaps by applying a systematic literature review based on the so-called energy cultures framework by Stephenson et al. (2010, 2015a). By reframing the energy efficiency gap to pursue its cultural explanation, we intend to increase the overall level of implementation of EEM in the real business world.

Companies are an interesting study object for behavioral aspects of energy use as they consume large amounts of energy, shape their employees' behaviors, might offer energy efficient products themselves, and face "increasing opportunities to become providers of energy" (Andrews and Johnson, 2016, p. 196). Within manufacturing companies, energy efficiency is characterized as a rather interdisciplinary set of organizational problems. Abdelaziz et al. (2011) discussed three paths for improving energy efficiency: (i) regulations, (ii) technology, and (iii) management. In this context, energy and environmental management systems play an important role (Amundsen, 2000; Antunes et al., 2014; Introna et al., 2014). Driven by environmental management accounting (EMA) and organizational culture, a strategic approach to energy management could therefore lift industrial energy efficiency to a more prominent role within sustainable energy supply and sustainable development (e.g. Apeaning and Thollander, 2013; Cagno et al., 2013; Trianni et al., 2013). Stephenson et al. (2010, 2015a) introduced an energy cultures framework to understand cultural aspects of energy behavior. Their framework originates from a defined stream of interdisciplinary social science energy research concentrating on consumers (e.g. Lutzenhiser, 1993; Shove, 2003; Wilk and Wilhite, 1985). Energy cultures rest upon understanding energy behavior "of actors in all parts of energy systems" (Stephenson et al., 2015a, p. 118). The framework is suitable for evaluating attitude and behavioral aspects,

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underlying technologies, and organizational culture related to energy as a system of interdependencies. Until now, the energy cultures framework has neither been intensively applied to the industrial context nor been discussed as an advanced method for organizational challenges of energy efficiency within EMA.
On the other hand, the relationship of culture to environmental management and sustainability has already been investigated (Soini and Dessein, 2016; Tàbara and Ilhan, 2008), its influence on corporate culture assessed (Abett et al., 2010; Linnenluecke et al., 2009; Wehrmeyer and Parker, 1995), and its importance to the managerial perspective demonstrated (Eccles et al., 2012; Faruqui, 2013; Sugita and Takahashi, 2015). This research follows scholars' demands for an integration of sustainability into management control and strategy (Cooremans, 2007; Guenther et al., 2016; Heinicke et al., 2016; Schaltegger et al., 2013) and of culture as a set of values, beliefs, and social norms (Lebas and Weigenstein, 1986; Malmi and Brown, 2008). Cultural aspects are therefore neither new nor dispensable in related research topics.

We investigate whether the energy cultures framework is applicable for the case of energy efficiency within the manufacturing industry. First, we refined the existing generic energy cultures framework by Stephenson et al. (2010, 2015a) for the industrial context. We applied a systematic literature review (n=98) to identify factors that influence an uptake of EEM by the industry, so called barriers and drivers in past research. We used the high-level factors (dimensions) in the energy cultures framework as an organizing framework and, at the same time, we assessed whether this captures all essential influential factors. Second, we evaluated the quality of that assignment and rank the identified factors. Third, we examined the practical fit of that academic driven framework by mapping its elements onto a widely accepted, standardized controlling process for corporate energy management systems (EnMS). Understanding the academia-practice gap allows for a response to Cooremans' request (2007, p. 77) to ask "where the initial idea is coming from" and if there is "a stimulus" for every case in energy efficiency investments. Therefore, we ask:

1. *How can the energy cultures framework be refined to capture all essential barriers and drivers discussed in previous literature on industrial energy efficiency behavior?*
2. *How can barriers and drivers be ranked in order to support decision-making?*
3. *What can we learn from applying the energy cultures framework for the academia-practice gap?*

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For scholars, we broaden theoretical aspects, investigate the importance of the energy cultures framework for organizational energy management, and present the current state of the art. Therefore, we simultaneously respond to industrial and research demands by closing academia-practice gaps for the case of cultural aspects in the field of energy efficiency (Bunse et al., 2011; Taisch et al., 2009). We thereby respond to Stephenson and her colleagues' request to test the scalability of the energy cultures framework. We also support arguments of Andrews and Johnson (2016, p. 196) in addressing industrial energy behavior as an "important yet underdeveloped opportunity for social science research" to foster future "business decisions and public policy". We provide reasoning for academics and practitioners to pay more attention to behavioral and organizational factors and their interdependencies, which was also identified as a current academia-practice gap (Tucker and Schaltegger, 2016). For practitioners, we present a refined framework to identify cultural aspects that drive energy decision-making. For planners and regulators, our approach offers justification for specific stimulus through policies based on ranked results for each factor.

The present paper is structured as follows: Section 2 embeds our research project in the existing research landscape related to the energy efficiency gap (2.1), the interdisciplinary research on energy behavior and corporate sustainability practices (2.2), and the academia-practice gap (2.3). Above all, Section 2 introduces the original energy cultures framework of Stephenson et al. (2010, 2015a). Section 3 describes the methodology of the systematic literature review. In Section 4, the data and the results are presented. The refined framework is presented in 4.1. We assess and rank the assigned barriers and drivers in Section 4.2 and 4.3. In Section 5, we reflect on the high-level findings of our approach, its impact regarding the energy efficiency gap and its limitations (5.1). We showcase its practical implications for energy management with an ontology mapping (5.2). Further, we discuss the energy cultures framework in the context of the academia-practice gap (5.3).

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## 2. Background

This section introduces and defines key terms such as energy efficiency, the energy efficiency gap, its barriers and drivers (Section 2.1), organizational culture, and the energy cultures framework by Stephenson et al. (2010, 2015a) as a specific problem within interdisciplinary energy research (Section 2.2). In Section 2.3, we link the energy cultures framework to corporate sustainability practices with the aim to identify the framework's conceptual requirements for the case of industrial energy efficiency. Overall, we show that increasing energy efficiency can be reframed as part of a refined energy cultures framework integrated within a wider organizational culture.

### 2.1. Energy efficiency gap, its barriers and drivers

Measures for energy efficiency often fall into two categories of behavior: curtailment or efficiency (Scott et al., 2016). Energy efficiency is understood as the ratio of the output of the energy service to the energy input (Herring, 2006). Energy service is an indicator for human activity, such as the production of steel (Phylipsen et al., 1997). Energy input encompasses all energy inputs into a process or system (Patterson, 1996). Yet, the application of indicators depends on the specific situation (Bunse et al., 2011) as there is "no one unequivocal quantitative measure" for energy efficiency (Patterson, 1996, p. 377). However, standardized and comparable measurements are just one problem. Although manufacturing companies are assumed to "carefully manage and rationally allocate" their energy use (Lutzenhiser, 1993, p. 275), the National Academy of Sciences panel on human dimensions of energy use observed that this is not the case (Aronson and Stern, 1984). They identified several reasons for this behavior, which can be summarized as the so-called energy efficiency gap.

Researchers introduced the terms energy efficiency gap or energy paradox (Hirst and Brown, 1990; Jaffe and Stavins, 1994) to describe the low levels of investment into EEM despite the generally recognized economic potentials (Bunse et al., 2011; Cooremans, 2007). However, as governments and their stakeholders are interested in improving their compliance with SDGs #7 and #12, increased investments into EEM are necessary (UNDSD, 2017). The evaluation of the energy efficiency gap (e.g. Cooremans, 2007; de Groot et al., 2001; DeCanio, 1993) is therefore still driving current publications in the field of barriers and drivers for energy efficiency (e.g. Bunse et al., 2011; Sa et al., 2017; Trianni et al., 2016). Barriers and drivers are terms used for aspects or factors that influence the implementation of EEM within the industrial context: either

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negatively or positively, respectively. Palm and Thollander (2010) provided evidence that simply perceiving a barrier is enough to act as a barrier for EEM.

Early on, Aronson and Stern (1984) suggested that a lack of information and conflicting internal interests represent major barriers. Later, financial restrictions were often highlighted (de Groot et al., 2001; Gruber and Brand, 1991) and are still seen as main barriers today (Apeaning and Thollander, 2013). Alongside information barriers (Kounetas et al., 2011; Owens and Driffill, 2008; Thollander et al., 2007) the literature mainly investigated socio-technical barriers (Brunke et al., 2014; Cooremans, 2011; Stephenson et al., 2010; Sweeney et al., 2013), lack of ownership (Pellegrini-Masini and Leishman, 2011; Schleich, 2009), lack of time (Thollander and Ottosson, 2008), hidden costs (Sorrell et al., 2003, 2000), myopia (Aflaki et al., 2013), and organizational culture (Cooremans, 2007; Trianni et al., 2016). Over time, non-financial aspects of decisions like awareness or information-related barriers (Trianni et al., 2016) have regained greater attention. Barriers, however, face a fundamental problem: there are no empirically evident explanations for the lack of energy saving activities (Weber, 1997).
Among drivers for EEM, policy measures and awareness campaigns may address information deficits in case of market failures. However, empirical evidence for changing energy behavior by means of public campaigns or increased exposure is limited (Owens and Driffill, 2008; Sorrell et al., 2000; Sweeney et al., 2013). These authors rather recommend establishing co-operations with specialized research centers, a transdisciplinary approach, and foregoing traditional governmental subsidy policies. Ownership conflicts could be overcome through environmental pressure and the employees' attitudes (Pellegrini-Masini and Leishman, 2011). Other drivers include e.g. energy management systems (e.g. Abdelaziz et al., 2011), non-energy benefits (Aflaki et al., 2013; Nehler and Rasmussen, 2016; Rasmussen, 2017), increased competition (Rohdin and Thollander, 2006; Trianni et al., 2016), potential cost reductions and threats of rising energy prices (Apeaning and Thollander, 2013; Martin et al., 2012), and carbon reduction strategies (Schleich, 2009; Vine, 2008).

Various classification schemes for barriers and drivers were suggested. Blumstein et al. (1980) provided the first systematization with a focus on lack of information. Sorrell et al. (2000) classified barriers along three different perspectives: economic barriers, organizational failure, and rational behavior. This typology was not exclusive: each barrier shared all three aspects. Many succeeding authors, e.g. Palm et al. (2010), followed that defining approach of Sorrell et al.

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(2000). Cagno et al. (2013) further developed that classification and presented a new "taxonomy" for barriers. They clearly distinguished external and internal sources and added the new categories, namely competences and awareness. Markets, governments, service suppliers, manufacturers, energy suppliers, and capital suppliers were newly introduced external actors with specifically assigned barriers, such as "energy price distortions" within markets (Cagno et al., 2013, p. 296). That classification scheme was further refined and applied (Trianni et al., 2016, 2013). These authors added drivers, renamed categories, and examined six steps of the corporate decision-making process: from establishing awareness to start-up and training (Trianni et al., 2016).

Although years of research on the energy efficiency gap exist, the overall explanatory value is often limited to single case studies and mainly related to technical and economical rationality (Lutzenhiser, 1993; Sorrell et al., 2003). Previous research on the energy efficiency gap was mainly a response to rational thinking about a lack of investments (Stern and Cabinet Office - HM Treasury, 2007). Yet, industrial adoption rates of EEM lagged behind optimal social welfare levels (McKinsey & Company, 2009) and expectations that business imperatives would behave more economically than households faded (Stephenson et al., 2010). Early approaches fell short of explaining the more complex relations (Aune, 2007). In their action roadmap for sustainable manufacturing, products and services, Taisch et al. (2009) express their vision for a cultural change that enables energy efficient manufacturing through the enforcement of rules, organizational values, behavioral factors, and a regulatory framework between governments, industries, and societies. Trianni et al. (2016) were among the first to integrate a decision-making process following that understanding. In other words, interdisciplinary research on EEM is still relevant and could offer new insights by interconnecting anthropology, economics, and social science (Aune, 2007).

### 2.2. Existing interdisciplinary research on energy behavior

By including a cultural perspective in the energy efficiency gap, interdisciplinary energy research could prove to be of great use (Aune, 2007). In 2010, a large group of researchers from many different affiliations published the results of their interdisciplinary research project related to energy consumption behavior (Stephenson et al., 2010). Over time, Stephenson et al. (2015a) adapted that energy cultures framework to characterize energy behavior as "strongly influenced by the interactions between norms, material culture, and practices". In other words,

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behavior is understood as what aspirations play a role, what technology is chosen, and how technologies are used. Figure 1 illustrates its main elements.

-Insert *Figure 1: The energy cultures framework as starting point* here-

The background of energy cultures is grounded in consumer energy behavior and borrows ideas from structuration theory, socio-technical systems theory, and practice theory. As a framework, energy cultures "offer a relational and context-specific perspective on energy behavior" (Stephenson et al., 2015a, p. 119). It is feasible to evaluate attitude and behavioral aspects, underlying technologies, and organizational culture related to energy, as suggested by Stephenson et al. (2010, 2015a). For systematization, the framework differentiates between external influences and along three high-level factors, described here as dimensions: "norms", "material culture", and "practices" (Stephenson et al., 2015a, p. 119). One can also refer to the three dimensions as "think, have, and do" (Sweeney et al., 2013, p. 373).

Norms form the initial basis. Norms are often described as awareness and motivation in behavioral models (e.g. Aune, 2007; Hasanbeigi et al., 2010). They are hereby defined as "people's expectations and aspirations about their practices and material culture" (Stephenson et al., 2015a, p. 119) and encompass shared beliefs for a defined set of circumstances. Habitus, for example, is captured by the physical and social ambience of employees. Norms influence the choice of technologies and resulting practices (Stephenson et al., 2010). Norms display different characteristics across different sectors because each industry accepts particular technologies and practices. Material culture is defined as "the technologies, structures, and other assets that play a role in how energy is used" (Stephenson et al., 2015a, p.119). It symbolizes the "physical evidence" as well as functionality, such as buildings, infrastructure, and machines, and influences norms and potential practices of people (Stephenson et al., 2010). Sheller figuratively explains that influence for the case of aluminum on a "material culture of speed and lightness" (2014, p. 127). For the case of EEM, the endowment in energy infrastructure for each company has quantifiable effects on the realized practices. Practices describe regular and irregular activities and actions that occur throughout the life of a subject (Stephenson et al., 2015a). They also reflect changing values and beliefs, which are included within norms. Practices are therefore a result of the interplay with norms and material culture. They also determine the "people's belief and understandings" (Stephenson et al., 2010, p. 6124), i.e. business decisions also "shape the energy behavior of their employees" (Andrews and Johnson, 2016, p. 196).

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The energy cultures framework allows for the reconnection of underlying norms, available technologies, and resulting business activities, thereby achieving visibility. This is important as energy is rather "invisibly embedded" (Stephenson et al., 2015a) and described as an "abstract concept" (Vikhorev et al., 2013, p. 103). Users seldom connect their practices with its underlying energy use. Stephenson et al. (2010, p. 6127) argue that there might be interacting clusters of users with "similar patterns of norms, practices and material culture" that are separable. They defined and labeled these energy cultures to enable a quick evaluation of effective energy efficiency measures.

Scaling the framework to large energy systems demands the consideration of boundary conditions and context factors. The latter are characterized by little or no control by the focal organization. External influences describe the circumstances that affect the context of an energy culture and its interplay between the dimensions (Stephenson et al., 2015a). For each company or assessment situation, contextual factors will vary in size, number, and ownership. In addition, they might influence more than one dimension at the same time (Stephenson et al., 2015a). Stephenson et al. (2015a) already discussed the scalability of the framework to other industries and nations. Over time, they applied that framework to households (Hopkins and Stephenson, 2014; Lawson and Williams, 2012), residential communities (Scott et al., 2016), the timber industry (Bell et al., 2014), and a transportation case study (Stephenson et al., 2015b).

In summary, the energy cultures framework combines contextual analyses from behavioral research in consideration of microeconomics, behavioral economics, technology adoption, anthropology, and sociology (Stephenson et al., 2010 following Biggart and Lutzenhiser, 2007; Keirstead, 2006; Wilson and Dowlatabadi, 2007). The energy cultures framework has the potential to explain the internal and external influences on energy behavior that were previously summarized under the broad term culture (Bell et al., 2014). We believe that a further application to the industrial context, specifically its barriers and drivers towards EEM, could support the need for cultural change within companies through regulation and governmental influence, as suggested by Taisch et al. (2009).

### 2.3. Linking energy cultures to corporate sustainability

So far, corporate culture in the context of sustainability has so far been mainly addressed as a challenge in the field of environmental culture. Energy efficiency is then linked to SDG #7 and #12 (UNDSD, 2017). However, the energy cultures framework is relatively new to the research field of industrial energy efficiency and has not been considered in environmental

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management. Consequently, we search for parallels in the field of environmental organizational culture to improve the application of the energy cultures framework.

Energy efficiency as part of corporate sustainability, guided by management control systems, might be beneficial to corporate environmental performance (Guenther et al., 2016). Wehrmeyer and Parker (1995) identified beneficial effects of environmental culture on corporate economic performance. Among others, Sugita and Takahashi (2015) examined the relationship between the level of corporate culture and environmental management. They follow Cameron and Quinn (2006), who separated organizational culture into clan, adhocracy, hierarchy, and market cultures. Although cultural control through values, symbols, and clans could potentially support that process (Malmi and Brown, 2008), Guenther et al. (2016) concluded that organizational structures and parts of its control (namely clans) are still being neglected. Management control systems are relevant to bridging the strategic and operational levels of management accounting and management systems. The energy cultures framework strongly concentrates on energy behavior and the interplay between norms, practices and material culture under external influences (Stephenson et al. 2015b). That could result in a better understanding of organizational challenges in a management system.

In practice, energy efficiency is often managed through EnMS according to an international standard e.g., ISO 50001 (ISO, 2011). Such standards represents a trigger for future behavioral or energy cultural change. Implementation increases management commitment and puts in place a continuous improvement process necessary for fulfilling the requirements of (ISO, 2011). We suggest that an integration of EnMS, its management control (Guenther et al., 2016), and the energy cultures framework also satisfies the link between academia and industrial needs (Bunse et al., 2011; Tucker and Schaltegger, 2016). We see a potential improvement through transdisciplinarity collaboration and discuss its aspects for the case of energy management and the energy cultures framework in section 5.

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## 3. Methodology and Data

Our approach included three steps (see Figure 2). First (1), we preliminarily screened literature relevant to barriers and drivers and the energy efficiency gap to select a useful framework. The framework should provide a holistic means of understanding industrial energy behavior and a basis to assign past research. We ultimately decided to borrow conceptual ideas from the energy cultures framework of Stephenson et al. (2015a, 2010). Second (2), we identified and synthesized altogether 98 studies relevant to cultural aspects, energy management, and the energy efficiency gap. We applied a systematic literature review using content analysis techniques to evaluate and assign single aspects to the chosen framework. Third (3), we refined and assessed the resulting energy cultures framework for the manufacturing industrial context. To summarize our purpose, we used the high-level factors in the energy cultures framework as an organizing framework (1), systematically reviewed literature to identify factors that influence the uptake of energy efficiency amongst industry participants (2), and assessed whether this captures all essential influencing factors (3).

-Insert *Figure 2: The scheme of applied systematic literature review* here-

The first step (1) identified an existing, eligible framework. Using the search terms 'review', 'energy efficiency', 'barrier', and 'driver', we screened several conceptual and review papers that are also part of the final sample. We ultimately chose the energy cultures framework of Stephenson et al. (2015a, 2010). For clarity, although 'culture' is partly specified as a barrier, e.g. to explain adoption rates of EEM (Palm, 2009), energy cultures are hereby understood as a larger umbrella and could also be characterized as "cultural controls" (Malmi and Brown, 2008, p. 291). Culture here also refrains from using pre-defined culture groups, e.g. middle class culture. The energy cultures framework focuses on energy behavior "of actors in all parts of energy systems" (Stephenson et al., 2015a, p. 118). It is neither simple energy consumption behavior, nor limited in scale. For our research purpose, we focus on the manufacturing scale, i.e. industrial energy behavior. We reframe the problem of the energy efficiency gap as one of energy cultures.

As a second step (2), we extended the preliminary screening and applied a systematic literature review to assign barriers and drivers scholarly discussed as cultural aspects to the chosen energy cultures framework and its high-level factors, described here as dimensions. A systematic literature review is defined as "a systematic, explicit, and reproducible design for identifying, evaluating and interpreting the existing body of recorded documents" (Fink, 2013, p. 3). As a large

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share of relevant research on energy and organizational culture is often conducted through in-depth case studies or surveys (Abett et al., 2010), we believe in a review's strength to add knowledge to the research landscape and support evidence-informed management (Seuring and Gold, 2012; Tranfield et al., 2003) by condensing the vast amount of information and making it easier to digest. We applied the review in four stages: (stage 2.1) selecting bibliographic databases and research questions, adopting (2.2) practical as well as (2.3) methodological screening, and (2.4) synthesizing the results (Cooper, 1982; Fink, 2013; Seuring and Mueller, 2008). Within stage one (2.1), we scanned search engines of major publishers (Elsevier, Emerald, Springer, and Wiley), established bibliographic databases (EBSCOhost, Web of Science), and other research networks (SSRN, ResearchGate), as well as Google Scholar using the additional search terms 'energy management' and 'energy culture'. We checked cross-references and the list of references to saturate the pertinent sample. In stage two (2.2), previously determined criteria for the inclusion were applied in a practical screening: English as the language, peer-reviewed, related to energy (management), manufacturing industry or with a generic scope, and influence of culture. Only abstract and title were examined (Becheikh et al., 2006). In stage three (2.3), the methodological screening, we iteratively designed and applied a coding scheme to all identified full text articles. The starting point for the coding scheme was the three-dimensional energy cultures framework by Stephenson et al. (2015a, 2010). Barriers and drivers named within the studies were assigned as cultural aspects to the three dimensions. Those aspects are now labeled as factors within the refined framework. For example, "energy price level" is quoted in studies as acting like a barrier in case it is too low as a result of subsidization. In contrast, it acts as a driver signaling cost reduction potential if it includes externalities. Per article, each factor could be encoded multiple times or not at all. For some barriers and drivers, empirical data on rank order (Likert scale) or regression coefficients were available. This information was encoded, too. Contextual factors were differentiated from internal factors. For example, "threat of rising energy prices" (Thollander and Ottosson, 2008, p. 30) was sorted within the contextual factor 'energy price (level)' within the dimension practices. We encoded each article using MAXQDA 12, a qualitative data analysis software, and MS Excel. For each factor, we listed if it is i) part of the article's analytical framework, and if the statement is based ii) on deductive reasoning, iii) on cross-reference quotation, iv) on results of a survey, or v) on inferential statistics, e.g. regression analysis. The fourth stage of step two (2.4) serves as an umbrella. It summarizes and presents syntheses of the findings (see Sections 4 and 5). Step three (3) was iteratively included in stage 2.3.

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Overall, we identified 528 studies (2,258 in a much broader context); 342 were excluded during the first screening (2.2), another 85 during the second methodological screening (2.3), and 3 were not available. In the end, we captured a dataset of 98 studies, including different research and data analysis approaches to refine and conceptualize the framework. Surveys and in-depth case studies including interviews are used the most in our sample (52%). Regarding data analysis methods, inferential statistics (9%) and modeling and algorithms (5%) represent a minority as compared with exploratory data analysis (31%) and others, e.g. content analysis (55%). The sample starts with 1990 as the first year of publication (see Figure 3). We identified well-investigated reviews (e.g. Hirst and Brown, 1990; Schulze et al., 2016; Sorrell et al., 2000; Trianni et al., 2016) that cover relevant findings from research prior to 1990 (e.g. Blumstein et al., 1980; Sassone and Martucci, 1984). A group of ten journals combine for 76% of all articles: Energy Policy (24) and the Journal of Cleaner Production (18) clearly lead that list. The two authors with the most appearances are Patrik Thollander and Ernst Worrell (8 articles each). Authors affiliated with engineering dominate with a combined 36% of the sample. Colleagues with inter-disciplinary focus (21%) follow. A complete list of all articles is available from the authors upon request.

-Insert *Figure 3: The sample on cultural aspects and energy efficiency over time* here-

To achieve an acceptable level of research rigor, we applied a systematic approach to ensure objectivity. Research consistency was improved by a well-documented coding protocol, a coding scheme, a pre-defined search strategy, transparent documentation, and double coding by two authors (Kvale, 1995). Re-encoding all articles after iterative feedback loops maintained reliability. Language bias was not a concern as Moher et al. (2000) stated that concentrating on English literature would not lead to different conclusions. The research design was validated and sharpened after integrating other researchers' opinions in doctoral workshops (El-Diraby and Rasic, 2004).

Our research design is limited by the fact that we included reviews within our sample that evaluated single studies which were also part of our sample. This results in double-counting of past barriers and drivers, thereby distorting the results of vote counting or ranking values. Nevertheless, we consider each time research is published in a peer-reviewed journal as a reflection of the current understanding and rating of those barriers and drivers. To identify this relevancy is one overall target. We noticed a lack of documentation and evaluation of qualitative factors

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within the articles related to our conceptual dimension norms. We acknowledge that each interpretation of text segments reflecting barriers or drivers is challenging. Fleiter et al. (2012) characterize EEM using five criteria based on literature: relevance, applicability, specificity, independence, and distinctness. The latter two are difficult to meet completely, but we used them for the set-up of the refined framework. That problem is generally addressed as heterogeneity in energy efficiency literature. Classifying factors is “always a trade-off between data available” (Fleiter et al., 2012, p. 511) in the sample and accurate assignment. Although we base our findings on existing literature within this study, our own professional experience in large multinational companies in the field of site-level technical services, energy management, and corporate environmental management allows us to reflect on those conclusions.

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## 4. Results and Discussion

In this section, we explain the resulting refined energy cultures framework and present results of assigning existing academic research to that framework based on our sample of 98 studies. We reflect upon the current status quo: is the chosen energy cultures framework, after refinement, suitable to have existing academic research assigned along its three dimensions? Is there a ranking order for barriers and drivers based on past empirical metadata?

### 4.1. The refined framework of industrial energy cultures

The refined framework of industrial energy cultures is illustrated in Figure 4. It differentiates barriers and drivers, consolidated and labeled as factors, along the three dimensions of norms, material culture, and practices following Stephenson et al. (2015a, 2010). Each factor was derived, collected, and synthesized from the 98 studies. Past barriers and drivers were assigned to the three dimensions and distinguished into internal as well as external influences as presented in Sections 2 and 3. Most important, each resulting factor can be interpreted both as a barrier and a driver for a positive energy efficiency outcome. Assigning barriers and drivers is not trivial: it depends heavily on the descriptive data available (Fleiter et al., 2012, p. 511). The authors will provide a complete and detailed coding protocol upon request as we can only give pertinent examples within this subsection.

-Insert *Figure 4: The resulting refined framework of industrial energy cultures* here-

Norms form the initial basis in behavioral models and are hereby defined as “people’s expectations and aspirations about their practices and material culture” (Stephenson et al., 2015a, p. 119) and encompass shared beliefs for a defined set of circumstances. Research indicates that top management commitment (e.g. Blass et al., 2014) and bottom up initiatives (e.g. Yun et al., 2014) impact energy efficiency outcomes as encoded in ‘Hierarchy approach’. That factor differentiates between bottom up and top down approaches and handles information regarding top management commitment, lack of power, lack of (perceived) control, and complex decision chains. Although energy efficiency is commonly regarded as important, difficulties still exist in trying to “convince top management about its benefits because savings are often not visible” (Chai and Yeo, 2012, p. 465). Organizational, environmental, and social awareness are important for company behavior: here we refer to ‘Environmental concerns’ and ‘Social aspirations’. The former relates to the staff’s (and management’s) expectations about environmental impacts of their organization, including an existing awareness about environmental problems (Rohdin and Thollander, 2006). The latter covers their aspirations about sustainable issues, i.e.

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a desirable but not yet realized behavior. That allows the company "to move the facility toward a more sustainable energy future" (Aflaki et al., 2013, p. 510). 'Social aspirations' include social empathy and awareness of common goods, including workers' health, improved working environment, community neighborhood, real ambitions, willingness for change, but also inertia ("resist change because they are committed to what they are doing", Sorrell et al., 2000, p. xvii), respect for tradition, and expected comfort levels as negative impacts. 'Commitment, teamwork, and multidisciplinarity' accentuates motivational aspects of considering energy efficiency individually or as a team, such as trust or a strong sense for common corporate values. Common sense suggests that teams crossing corporate departments and disciplines increase the level of expertise on EEM. This is mirrored in academia by transdisciplinary research (e.g. Tucker and Schaltegger, 2016). 'Existing knowledge about EEM' also shapes awareness and is an essential building block for successive actions. It represents the level of internal knowledge about energy efficiency, EEM, and EnMS. It also encompasses the capability to qualitatively assess external information about EEM within a focal company. Negatively interpreted, it includes the inability to handle information, a lack of information or expertise, a lack of attention, and a lack of awareness about EEM. Learning curve effects with prior management systems, e.g. ISO 14001 and ISO 9001 (ISO, 2015a, 2015b), described here as 'Familiarity with management systems', additionally influence norms. 'General investment and risk behavior' comprises financial motives for EEM and risk behavior (e.g. bounded rationality, risk aversion under uncertainty, risk awareness, stranded asset discussions, thoughts on profitability, and myopia). For most subsequent factors, change agents are important: these individuals initiate innovations for EEM and keep innovation processes in motion (Siebenhüner and Arnold, 2007). In Figure 4, we sketched a box around norms containing contextual factors: we ignore those at this point.

Material culture is defined as "the technologies, structures, and other assets that play a role in how energy is used" (Stephenson et al., 2015a, p.119), including buildings, infrastructure, machines, etc. The outfit in energy infrastructure, for example, has effects on the realized practices for each company. Material culture comprises factors representing technologies that measure energy (e.g. submetering, 'Measuring infrastructure'), signal energy consumption ('Dashboard technologies for users'), use and control energy ('Building envelope', 'Building services', and 'Production equipment'), and manage information about energy flows ('IT and software supporting EEM'). Dashboard technologies like web-based dashboards showing real-time electricity consumption for the whole building provide instant feedback for users about their energy

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use based on energy-related data. Energy usage feedback is a powerful motivation for conservation behavior (Andrews and Johnson, 2016). That would also include perceived beliefs of peers and publicly stated commitments by top management, an interplay with preceding norms. ‘Building envelope’ focuses on technologies for the outer parts of the building (e.g. grass-roof, insulation). ‘Building services’ contains building automation, air conditioning, lighting, heating systems, etc. Together, they form ‘Building infrastructure’, integrating facility characteristics like size, position, and surroundings. ‘Production equipment’ includes all devices directly involved in the production process (e.g. machines). IT includes existing or prospective information technology and software used to support energy management functions (e.g. IT hardware, integration in enterprise resource planning or project management software). Naturally, ‘material culture’ contains the used ‘Energy sources’. Again, we ignore contextual factors here.

Practices encompass regular and irregular activities as well as actions that occur and are common (Stephenson et al., 2015a). Within the industrial context, corporate practices reflect business decisions that influence each employee’s behavior. One significant difficulty is found in connecting employees’ actions with underlying energy use, as energy is seen as “invisibly embedded” (Stephenson et al., 2015a). Practices also reflect changing values and beliefs, which are parts of norms, and existing or available energy efficiency technologies, which are parts of material culture. All three dimensions are characterized by a complex interplay. Organizations can be certified with management systems, e.g. ISO 14001 or ISO 50001 (ISO, 2015b, 2011). Here, we encoded the existence of certification. Whereas that is rather common for large multinationals, it differs drastically with country, size, and industry: e.g. only 22% of surveyed Turkish companies were certified (Ates and Durakbasa, 2012). We also encoded mandatory items of the ISO 50001 (ISO, 2011) separately in other factors. Concepts that describe the performance of an energy management, such as an implemented ‘External audits’ and ‘External reporting’, are among them. Here, the former refers to third party auditing of the focal company for certification purposes (i.e. it does not include initial internal audits for feasibility). Energy audits are very important for the identification of EEM, e.g. increasing energy performance by up to 40% (Thollander et al., 2007). But Dobes (2013) argues that a combination with certain accounting approaches is sufficient for a successful implementation of EEM. ‘External reporting’ of energy indicators and energy use patterns to the public often relates to the larger umbrella of sustainability or integrated reporting. Further management control tools like ‘Reward and compensation scheme’, ‘Training and awareness campaigns’, and ‘Implemented planning and policies’, ‘Implemented accounting’, and ‘Implemented controlling and monitoring’ are

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examined as they are described as relentless (Antunes et al., 2014; Bunse et al., 2011; Gontarz et al., 2015; Schulze et al., 2016). For example, management might ignore energy use if the accounting is wrongly treating energy costs "as overhead rate rather than as a cost category for which managers were directly accountable for" (Schulze et al., 2016, p. 3693). 'Implemented controlling and monitoring' includes performance measurement systems like benchmarking, monitoring of key performance indicators on the managerial level and its improvements, base-line adjustments, follow-up internal energy audits, internal reporting, or forming a database with data on best-practice cases. 'Implemented planning and policies' is defined as the broadest factor with ex ante planning processes to establish energy policies using key performance indicators, setting goals or standards to be achieved, and conducting initial internal audits for feasibility. It also includes information on strategic risk management, maintenance programs, adapted operation hours, guidelines, and implementing EEM. For example, "other priorities" (Trianni et al., 2013, p. 432) were assigned to that factor, too. 'Rewards' encompass any bonus and increased pay to employees or management depending on achieved targets for EEM, as well as internal staff contests and special awards. General or specific 'Training' should increase understanding in EEM and the EnMS (e.g. corporate awareness campaigns, regular and single-issue training, external and internal training, reading trade or academic journals on energy). Finally, practices are visible regarding the type of financial evaluation and 'Implemented investment and funding policies'. This includes if a dedicated internal budget (e.g. superfund) and an investment decision process (e.g. investment thresholds, financial evaluation criteria, integration of non-energy benefits, non-prioritization) for EEM exist. The company-specific practices and the implementation of EnMS follow a set of intraorganizational structures, e.g. 'Energy center of competence', 'Energy manager', 'Exchange with departments and other companies', or 'External consultancy'. The first of which comprises a team of EEM experts advising top management or operating engineers. Often, such teams are formed to introduce ISO 50001, which is the first standard which recommends companies place that responsibility "in the hands of a team" (Karcher and Jochem, 2015, p. 379). An 'Energy manager' is mandatory for ISO 50001 and refers to someone specifically managing energy targeted topics. 'Exchange with departments' within a company is essential for sharing best practices regarding EEM and EnMS (e.g. includes pilot sites, collaboration across business units). It might be extended to external partners like trade associations, industrial task force groups on EEM, and supply chain actors (Trianni et al., 2013). 'External consultancy' is a way to compensate for a lack of internal knowledge by hiring external experts to support the planning, assessment, and implementation of EEM. Finally, it is of interest whether companies are hired for 'External energy services'

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(e.g. maintenances of machines, software, building services) and if it is based on performance contracting. Outsourcing activities may lead to problems of split incentives and ownership issues (Pellegrini-Masini and Leishman, 2011; Rohdin and Thollander, 2006; Schleich, 2009).

So far, the energy cultures framework allows for an integration of underlying norms, available technologies, and resulting business practices, offering transparency for that complex energy behavior. However, scaling the framework to industrial applications within an energy system requires the consideration of boundary conditions and the definition of context variables with little or even no control by the company (see Section 2). We assigned the external factors 'Depth of value added', 'Energy price level', 'Sector specific energy intensity level', and 'Social marketing' as influential to practices. Energy consumption is dependent on value-adding processes (Vikhorev et al., 2013), therefore we include all information regarding its depth. Energy prices or regional differences influence behavior (Owens and Driffill, 2008; Rietbergen and Blok, 2010). That factor refers to current or future energy price levels, uncertainty about prices, utility dependency, power rates, and price sensitivities. Here, we see an example of overlap with material culture: companies update their technical equipment depending on energy price and availability (Tanaka, 2008). Whether energy costs attract management's attention closely correlates with the company's energy intensity levels (Schulze et al., 2016). For example, cement plants presumably consider energy (costs) with higher priority. 'Social marketing' relates to the impact of changing consumption patterns, reputational benefits of being a green company, and its linkage to market value (Pellegrini-Masini and Leishman, 2011). It includes marketing activities using EEM or energy efficiency achievements (on product, production, or administrative level) for selling, bargaining, or even recruiting purposes.
The characteristics of norms depends on external factors like 'Stakeholder pressure', the staff's 'Education level', and their 'Demographics'. The latter two may be included in personnel structure (Siebenhüner and Arnold, 2007) or treated as an exclusive variable (e.g. "age" in Sweeney et al., 2013). At first glance, studies do not provide "demographic factors such as top management age, gender, marital status, education, and political orientation" (Blass et al., 2014, p. 570), although effects on corporate environmental and financial performance were detected. Stakeholders could include employees, though the focus here is on external actors. Energy efficiency behavior is affected by "norms of business partners, customers and other stakeholders" (Andrews and Johnson, 2016, p. 204), neighbors, environmental organizations (Christoffersen

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et al., 2006), and other non-governmental organizations (Thollander and Ottosson, 2008). Customer influence is encoded within ‘Social marketing’ (e.g. Pellegrini-Masini and Leishman, 2011) and that of business partners in ‘Exchange within and with other companies’.
The material culture is affected by external regulatory, market, and technical conditions. The latter collects barriers and drivers related to the availability of EEM and services in the market. ‘Mimetic and industry conditions’ refers to the current and prospective situation of the focal industry and relevant market (Liu et al., 2012). It also includes the business cycle, competitive pressure, and market structure. Upfront and future investment costs as well as hidden costs (e.g. uncertainties related to production loss, unplanned installation hours and interruptions, available staff) belong to the factor ‘Purchase, installment, and hidden costs’. Hidden costs also encompass management’s ability to gather and assess the relevant information to investigate new opportunities for EEM or train staff for the proper use of new technology (Trianni et al., 2013). ‘Company income and budget conditions’ covers the company’s general financial situation and simultaneously its size (number of employees, total sales). We encode potential or factual cost reductions by EEM. Certainly, one could also argue that the company’s income is a rather internally controlled item and even influenced by energy savings. We decided that, from the perspective of an energy manager, the company’s financial situation is predominantly arbitrary and predetermined. All told, the sheer number of factors within practices (21) is greater than within material culture and norms (12 each).

As compared to the original framework of Stephenson et al. (2015a, 2010), we kept the three-dimensional structure and the existence of external influences, but specified subordinated factors for the industrial context. Stephenson et al. (2015a, p. 118) state that the framework would be scalable. So far, the research team around Stephenson has tested the framework mainly for households, and therefore not so much within a business context (see Section 2.2). Other extensions of the framework can be found in Sweeney et al. (2013). These authors name their model “practice-based energy-cultures framework” (Sweeney et al., 2013, p.371). Our approach might be called an industrial energy cultures framework, but we see no advantage of relabeling and losing the direct reference to the original work of Stephenson and her colleagues. It is conceivable that additional classification schemes could extend the dimensions. We see suitable approaches within the industrial context, such as energy management maturity models (e.g. Antunes et al., 2014; Introna et al., 2014) for the practices dimension. Relevant factors could then be classified by occurrence and quality into five energy management maturity levels.

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Factors within material culture can be differentiated along the time horizon: future versus existing, i.e. prospective versus current technologies. All factors within norms could as well be interpreted as either aspired or expected. We ignore all those extensions in this review.
Another interesting aspect is the potential to develop clusters of companies. Stephenson et al. (2015a) suggest four related to households: Energy Economical, Energy Easy, Energy Efficient, and Energy Extravagant. This could be compared to existing clusters by (Palm, 2009 i.e. the ignorant company, implementer of easy measures, economically interested company, innovative environmentalist), Cameron and Quinn (2006, i.e. collaborate clan, create adhocracy, compete market, control hierarchy), Baumgartner (2009, i.e. introverted, extroverted, conservative, and visionary corporate sustainability strategies) or Wehrmeyer and Parker (1995, i.e. co-operative environmentalism, technological growth orientation, centralized damage limitation, and socially concerned administration). However, that is not part of this review. We discuss those issues in further research (see Section 5.3). Ultimately, we add to the theoretical development of the framework by applying the energy cultures framework to a new industrial context and use its core idea as a basis for assigning the broad research stream under investigation.

### 4.2. Assessing the assignment of factors within the refined framework

This subsection is driven by questions such as "What barriers and drivers were assigned to each factor?" and "What did not fit into refined energy cultures framework?".
First, we analyze at the dimension level. At first glance, the total number of codings assigned to practices (2,025) is much larger than to material culture (1,389) and norms (1,110). That is consistent, independent of counting the total appearances or the binary-coded logic, with a maximum value of 1 per factor per study (714 versus 424 and 404, respectively). But there is a non-neglectable, methodological effect: the number of factors within practices (21) is larger for norms and material culture (12 each). Indeed, if corrected for that imbalance, the binary-coded appearances converge: 714, 719, and 685, respectively. With a second look, it is possible to assess the existence of the equally diverse research offered by each dimension. Yet, we also see a positive time trend: in 2013 and 2014, codings for norms outnumbered those for material culture. Regarding the distribution of studies over time, we count 63 articles prior to 2011 and 35 after 2010. 2010 was chosen, as it represents the publishing year of Stephenson et al. (2010). Considering the difference in absolute years, that calculates as 3.2 studies per year prior to 2011, versus 5.0 after 2010. Thus, there seems to be increasing interest in the field.

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Second, the factor level is examined following the binary-coded logic. The factors with the highest penetrations are as follows: ‘Implemented planning and policies’ (72 studies, i.e. 75.8%) belonging to practices, ‘Regulatory conditions’ (69 studies) in material culture, and ‘Existing knowledge about EEM’ (62 studies) in norms. That means, for example, 72 studies discuss ‘Implemented planning and policies’ as part of their own analytical framework or quote a reference naming that factor. In contrast, ‘Demographics of staff’ is only discussed in two studies: Blass et al. (2014) and Stephenson et al. (2010). This is no surprise as we assumed there would be limited information. Seven other factors attract less than 20 studies: ‘Familiarity with management systems’ (12), ‘Energy sources’ (15), ‘Energy center of competence’ (17), ‘Dashboard technologies for users’, ‘Hierarchy approach: Bottom up’ (18 each), ‘Depth of value added’, and ‘Implemented external reporting’ (19 each). The interest in the last one is smaller than expected as one might anticipate the reporting of energy efficiency achievements to a large audience within external reports. No single factor is reported or discussed in all 98 articles. The median average for all factors amounts to 35.5 studies. In other words, on average each factor is discussed within half of the articles.

Another observation is the relatively large number of assorted dummies: 56 codings in 20 studies for practices, 29 in 17 for material culture, and 38 in 23 for norms. Does this suggest that the refined framework is insufficient to reflect all past research? First, only barriers are concerned. The mismatch between aspects discussed within our sample and our categorized factors is zero for factors acting as drivers. In other words, we could assign all drivers but not all barriers to our refined framework. A second look reveals that dummies usually result from unspecific descriptions within the articles (e.g. “internal organisational conditions; all characteristics are believed to influence the energy savings and energy management made by the firm”, Christoffersen et al., 2006, p. 516; “corporate energy culture”, Cooremans, 2011, p. 475; “Technical infrastructures and social norms interact”, Owens and Driffill, 2008, p. 4414), defining statements (e.g. “barriers represent a hurdle for any investment in energy-efficient technologies”, Cagno et al., 2013, p. 303), or information related to alternative classifications (e.g. “barriers are broadly classified under three main categories namely Economic, Organizational and Behavioural”, Apeaning and Thollander, 2013, p. 206). The latter two subcategories were eventually ignored in subsequent analyses. Among dummy entries, ownership (Blass et al., 2014), slim organization, improved working conditions (Apeaning and Thollander, 2013), improving product quality (Hasanbeigi et al., 2010), processing conditions (Phylipsen et al., 2002), capacity utilization (Posch et al., 2015), heterogeneity (Rohdin and Thollander, 2006), form of information (Cagno et al., 2013), “feel good” factor (Chai and Yeo, 2012), problems of focus and

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attention (DeCanio, 1993), time inconsistencies (Lopes et al., 2012), “Others will do” syndrome (Nagesha and Balachandra, 2006), and feeling of helplessness (Sweeney et al., 2013) are relevant and difficult to match with existing factors, but in general do not put the energy cultures framework into question. In sum, dummies are rather working categories and will be ignored and eliminated in further analyses.

Based on these observations, we will now suggest a reduction of the somewhat complex refined framework. That could allow managers to concentrate on fewer impact spheres and worry about less factors.

### 4.3. Ranking of assigned factors within the refined framework

The subsequent ranking scheme will allow for a prioritization between the identified and assigned factors at each dimension level. To rank the assigned factors, we counted the number of appearances (vote counting) and differentiated them three subcategories: i) reported as part of the article’s analytical framework, ii) underpinned by deductive reasoning, and iii) supported by citing cross-references (see Section 3). We also collected and aggregated meta-analytical data related to survey rankings and inferential statistics. For example, we converted given Likert scale values of existing survey rankings into pseudo metric percentages. We then assorted each resulting data value into the subcategories ‘unknown ranking’, ‘below 25%’, ‘above 25%’, ‘above 50%’, and ‘above 75%’.

Eventually, we developed a ranking index which integrates all vote countings and collected meta-analytical data in order to assess each factor’s relevance. That index mirrors all past academic research in a single ranking value per factor measured in a percentage. We aggregated the index on the dimension level to keep the holistic characteristic of the overall framework. Ranking each factor allows for a prioritization and shortening of the refined framework. The resulting focal points for management’s attention might be of greatest interest to practitioners: it could simplify and reduce the number of factors to investigate. A threshold is chosen with 7.5%. As a result, we formed two simplified frameworks: one focusing on the ‘barrier’ effects of all factors and one where factors act as drivers.

We start with the ranked framework which represents detaining factors (see Figure 5). Among them, ‘General investment and risk behavior’ (25.5%), ‘Existing knowledge about EEM’ (24.2%), and ‘Implemented investment and funding policies’ (18%) lead the list of ranked internal factors, whereas ‘Demographics of staff’ (0.3%), ‘Energy center of competence’ (0.1%), and ‘Familiarity with management systems’ (0%) mark the overall bottom three. ‘Purchase, installment, and hidden costs’ (28.3%), ‘Company income and budget conditions’ (14.9%), and

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'Availability of EEM and related information' (12.2%) lead the ranking of external factors acting as barriers.

-Insert *Figure 5: The refined framework of industrial energy cultures with ranked factors acting as barriers* here-

Figure 6 illustrates the ranked framework for supporting factors. Whereas 'Regulatory conditions' (29.8%), 'Company income and budget conditions' (14.3%), and 'Energy price level' (9.3%) are the most important external factors, 'Top down approach' (15.8%), 'Environmental concerns' (14.6%), and 'Existing knowledge about EEM' (13.8%) are the highest ranked internal factors driving energy efficiency. Internal factors such as 'Familiarity with management systems' (0%), 'Dashboard technologies for users' (1.5%), and external 'Depth of value added' (2%) are the lowest ranked. Figures 5 and 6 also provide a sense of distribution of ranked factors: whereas two factors which have 'barrier' effects within norms account for roughly 48%, the picture for drivers is more diverse, with six factors sharing equal weights of roughly 14%: 'Hierarchy approach: Top Down', 'Environmental concern', 'Existing knowledge about EEM', 'Social aspirations', 'Commitment, team spirit, and multidisciplinarity', and 'Stakeholder pressure'.

-Insert *Figure 6: The refined framework of industrial energy cultures with ranked factors acting as drivers* here-

In sum, we illustrate to what extent each factor of our framework is characterized as a 'barrier' or 'driver' based on past research. We acknowledge that each factor has a detaining and driving character. Nevertheless, each factor is characterized by a tendency. As an example for norms, 'General investment and risk behavior' is mostly seen with a negative influence, ergo a 'barrier', on energy efficiency outcomes (25.5% versus 5.1%), whereas 'Stakeholder pressure' is rather seen as a driving force (2.3% versus 11.9%). In other words, the former could be characterized as a threat and the latter as an opportunity. 'Existing knowledge about EEM' has both impacts: having too little or wrong knowledge clearly hinders energy efficiency projects from being implemented successfully ('barrier'). Certainly, companies need enough qualified knowledge about their energy situation at hand ('driver'). Above all, practitioners should examine these factors in detail and may refine each factor for its underlying variables.

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## 5. Conclusions

Here, we conclude on the high-level findings to reflect on practical implications and further research. This is relevant for practitioners, academics and planners at the same time. First, we summarize our operating experiences by assigning past academic research on barriers and drivers to a refined energy cultures framework and answer the research questions. Second, we then map the energy cultures framework to the standardized process of continuous improvement of EnMS. Third, we argue for a transdisciplinary approach as a direction for further research and the refined energy culture framework.

### 5.1. Supporting the mean of energy cultures

We recall the first research question: *How can the energy cultures framework be refined to capture all essential barriers and drivers discussed in previous literature on industrial energy efficiency behavior?*

We can answer this first research question positively. A key finding is that the framing of energy cultures provides a comprehensive structure for understanding industrial energy efficiency behavior. It captures the themes discussed in the literature on barriers and drivers to energy efficiency, i.e. EEM. As indicated in Section 5.2, a few aspects could not be assigned to our suggested factors and were shifted to dummy categories. We recall Fleiter et al. (2012), who stress achieving the best possible assignment, but also discuss constraints. We respond by applying a rigor review, including the criteria relevance recommended by those authors, applicability, specificity, independence, and distinctness. The positive ('driver') and negative impacts ('barrier') of each factor are illustrated, too. We believe that such an integrated view of the ambiguity of each factor offers more advantages than the separate lists of barriers and drivers found in previous research.

The second research question is as follows: *How can barriers and drivers be ranked in order to support decision-making?*

By ranking all factors within each dimension, we are able to reduce complexity and offer a simplified decision model to practitioners. The ranking is developed as an index encompassing vote counting, but also meta-analytical data on single ranking values (e.g. Likert scale) of each study. Some factors enjoy low vote countings, but high aggregated ranking values. Our research provides a preliminary ranking of past barriers and drivers. However, a clear ranking is currently not possible. That indicates a need for further research.

We also acknowledge limitations of our methodology that influence the ranking index. First, we cannot guarantee that we have identified all relevant research. Additionally, our sample

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includes reviews that examined single studies additionally included in our literature pool. Therefore, double-counting occurred. Although we think that it is justified when considering each review's focus and the process of evaluating publications by peers, it distorts the exact picture. However, our methodology does not allow for a direct examination of the interplay between norms, material culture, and practices. Causality and intercorrelation analysis between the three dimensions deserve investigation in future research. It would allow for a redesign of current regulatory policies and business strategies.

A limitation, imposed by the use of published articles as external data, is that companies are usually seen as a black box. There is little detailed information what happens inside companies except for quotes and descriptions within the articles. Included surveys, in addition, face the shortcoming of relying on companies' self-reporting (e.g. Suk et al., 2013). Results forming Likert scale values within our ranking index could be biased by the "unwillingness to reveal personal lacks or faults" (Trianni et al., 2016, p. 1542) in handling EEM. We see another challenge to integrate all energy targeted research streams. There are a few studies that see the potential of behavioral research in the field of energy efficiency as well, but rarely with the aim to achieve energy innovation beyond the energy efficiency gap. Moreover, current academic research is scarce for the non-energy intensive sectors and small or medium sized companies. We cannot provide answers to phenomena like rebound effects (Herring, 2006) and non-energy benefits (Nehler and Rasmussen, 2016; Rasmussen, 2017), as only aspects were integrated into our review.

Above all, our paper offers a comprehensive literature review of existing academic research and introduces a promising framework for energy use: the refined energy cultures framework. Figures 7 and 8 summarizes our findings: both illustrate shortened frameworks and all relevant studies that report and discuss factors identified as acting as the most important barriers and drivers for energy efficiency (see Section 4.3). These figures allow interested readers to quickly recognize studies for specific issues. Studies are encoded as numbers that are indexed in the list of references.

-Insert *Figure 7: All relevant studies allocated to the shortened framework with factors acting as barriers* here-

-Insert *Figure 8: All relevant studies allocated to the shortened framework with factors acting as drivers* here-

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Nevertheless, we need to consider that "what qualifies as a reliable, cost effective, worth-while energy saving measure in one socio-cultural domain might count for nothing in another" (Shove, 1998, p. 1109). For practitioners, a first impression regarding the company's energy culture level is a window to the corporate understanding of energy: is it rather seen as a commodity, strategic material, environmental resource, or social necessity (Burgess and Nye, 2008). Further, it may help to think of services that demand energy rather than energy per se, such as mobility, heating, cooling, and lighting as suggested by Haas et al. (2008 in Jonsson et al. 2011). Understanding the interdependencies along the three dimensions and contextual factors seems to be equal importance as perfectly assigning each 'barrier' or 'driver' to the refined framework. As the dimension norms is partly seen as "too fuzzy and just for idealists", according to Palm (2009, p. 268), innovative practitioners might gain advantages from their pioneering outlook.

### 5.2. Practical implications for energy management

Finally, we reply to our third research question: *What can we learn from applying the energy cultures framework for the academia-practice gap?*

So far, the refined energy cultures framework allows for a better academic understanding of industrial energy behavior. Section 4 reveals relevant barriers to and drivers for energy efficiency that might be essential for reaching SDG #7 and #12 (UNDSD, 2017). So how can we support the application of the energy cultures framework in corporate practice regarding the academia-practice gap? In organizations, the ISO 50001 for EnMS is a management system to control energy efficiency. EnMS, in general, are "an important tool to establish a sustainable mindset to improve energy efficiency" (Brunke et al., 2014, p. 523). Our dataset supports this claim: 'Hierarchy approach: Top down' (15.8%), 'Environmental concern' (14.6%), 'Implemented planning and policies' (12.2%), and 'Implemented controlling and monitoring' (8.1%) are closely interlinked to EnMS and rank among the most relevant drivers. In this section, we present parallels between the energy cultures framework and ISO 50001 in order to enhance the academic and practical understanding through an ontology mapping.

First, we introduce the ISO 50001. It has the overall purpose of contributing to the efficient usage of energy resources and, finally, reducing greenhouse gas emissions (ISO, 2011). As with environmental management and quality management systems, the continuous improvement through plan, do, check, and act of processes and resources is fundamental (ISO, 2011). There-

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fore, the implementation of EnMS demands an energy policy, a planning process, and the application and control of them, which is reported in a regular review to management (ISO, 2011). The presented refined energy cultures framework includes normative and practical aspects as well as technical aspects through material culture. Through an ontology mapping of the energy cultures framework and EnMS, it is possible to assign the results of Section 5 to ISO 50001. Figure 9 therefore presents of definitions and descriptions from ISO 50001 (ISO, 2011) for the refined energy cultures framework in a manufacturing environment. The context variables are not included in detail, as their influence might affect organizational behavior directly and the energy culture as a whole.

-Insert *Figure 9: Ontology mapping of the refined energy cultures framework and energy management system* here-

An ‘Energy policy’ includes a belief system and attitudes of the management level. Values are influenced by ‘Environmental concerns’ and a reluctant ‘General investment and risk behavior’ can be a consequence of missing ‘Existing knowledge about EEM’. However, ‘Implemented planning and policies’ and ‘Existing knowledge about EEM’ are elements of the energy cultures framework that affect almost each step of the energy management process. ‘Energy planning’ bridges ‘Energy Policy’ and ‘Implementation and operation’. Those steps are strongly related to each other and, therefore, elements of practices within the energy cultures framework are mainly allocated here. ‘Monitoring, measurement, and analysis’, ‘correction and prevention’, and the ‘Internal audit of the EnMS’ are iterative for checking a management system. Therefore, the allocated elements of the energy cultures framework are similar in its wording. ‘Certified management systems’ is the basis for audits and the results of those audits are corrective and preventive actions that might demand further measurements and analyses. Depending on the interaction between the hierarchical levels of organizations and their ‘Certified management systems’, the ‘Management review’ influences ‘Implemented controlling and monitoring’. Controlling and monitoring measure the success of EEM. Depending on the results of the management review, the ‘Energy Policy’ might need adjustment and influences the subsequent steps.

In sum, we see clear parallels between EnMS and the refined energy cultures framework. Overall, practices are relatively easy to map within the standard process. For practical implications, we underline the elements of the energy cultures framework that are related to more than one

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step of EnMS ('Existing knowledge of EEM', 'Implemented planning and policies', 'Certified management systems'). We recommend concentrating on those elements. Further research should focus on the interplay between energy management practices and identified barriers and drivers. Transdisciplinary research might offer another opportunity to bridge gaps between the needs of practitioners and academics. This is presented in the next section.

### 5.3. Further research

We assume that cross-sectoral teamwork and interdisciplinary methods are key to the successful implementation of EEM. This is supported by our ranking index: 'Commitment, team spirit, and multidisciplinarity' reaches 13% among the drivers within norms (see Figure 6). For example, the production operation department is unlikely to provide an opportunity to realize EEM if the engineering department is perceived to have low technical capabilities. They might fear production downtimes, encoded as hidden costs (e.g. Cagno et al., 2013; Palm and Thollander, 2010; Rohdin and Thollander, 2006). The refined energy cultures framework is, by definition, an interdisciplinary approach. Chai and Yeo support this view, arguing for an "interplay between technological, organizational and behavioral barriers to energy efficiency" (2012, p. 468).

In our own experience, the framework is complex and understanding all its nuances is a demanding task. However, it motivates decision-makers to think not only about business practices, but underlying norms and available technologies. Alternative frameworks, e.g. Trianni et al. (2016), similarly suggest analyzing the complete decision-making process starting with awareness building. We recall Cooremans' request (2007, p. 77) to identify the "initial idea" for a stimulus of EEM. The refined energy cultures framework is not the only option, but a concise starting point for such analysis. Consequently, we recommend further applications of the energy cultures framework.

-Insert *Table 1: Further research as suggested by past research* here-

We mapped topics for further research as discussed within the studies of our sample (see Table 1). Further academic research should focus on its practical application in detail, following (Bell et al., 2014; Stephenson et al., 2015a) and supported by 'Empirical validation / additional cases' (13 studies). More interdisciplinary research directed at 'Understanding changes in behavior'

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or 'Non-energy benefits' while 'Applying social energy science techniques' (totaling 13 in Table 1) is recommended by other authors, too. That research stream might also identify new clusters of energy cultures (see Section 4.1). Moreover, the complex interplay between norms, material culture, and practices requires causal analysis, e.g. by means of qualitative comparative analysis (4 studies in Table 1). Examining further integration within sustainability management accounting or EMA along management control systems could help to better understand the control of energy cultures (Guenther et al., 2016; Malmi and Brown, 2008), as demanded by Palm (2009). This is also demanded in past studies (combined 14 counts). Our findings suggest large relevance of external influences (see Section 4.3). Hence, further research should carefully distinguish internal drivers with people effectively operating energy efficiency and external barriers.

For practitioners, closer collaboration with academia offers a fresh look on EEM. Within our dataset, 'Existing knowledge about EEM' is a clear barrier (24.2% in Figure 5). Table 1 illustrates that need in establishing networks on industry and research level, e.g. for 'Best practice exchange' (totaling 9). Like Bunse et al. recommended to foster collaboration of academia and industry partners to "ensure applicability" and to ease the "diffusion of management approaches" (2011, p. 677). We see transdisciplinarity collaboration as a promoting path for the energy cultures framework. Its application in academia would be a new interdisciplinary insight into energy attitudes (Owens and Driffill, 2008). Transdisciplinary collaboration requires a collaboration between academia and practice as well as interdisciplinary endeavors by researchers and practitioners that realize collaborative effects for both (Schaltegger et al., 2013).
Transdisciplinary qualities therefore include interdisciplinary academia-practice collaboration as a combination between cross-sector and cross-disciplinary characteristics of research and practices (Schaltegger et al., 2013). For sure, such energy behavior research is resource intensive. Table 1 therefore lists 'Improving data availability / comparability' with 6 counts. However, transdisciplinary action research and Delphi surveys, for example, have the potential to combine experts from academia and practice. The growing field of energy management is a further practical application of the energy cultures framework (see Section 5.2). Quantifying energy behavior in the field of EnMS, however, could be a way to acquire and mix interdisciplinary quantitative and qualitative data as well (Lopes et al., 2012). In addition, our research may initiate the creation of strategic alliances as proposed by Tucker and Schaltegger (2016).

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**Supplementary material**

We will provide a separate MS Word document containing large tables with a full list of all studies investigated (Table A) and a full description of defined factors and boundary criteria for each dimension (Table B, C, and D) upon request.