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Thollander, Patrik; Andrei, Mariana; Jalo, Noor; Rohdin, Patrik; Palm, Jenny; Sannö, Anna; Colding, Johan; Barthel, Stephan; Uddin, Gazi Salah; Xavier, Bruna Maria

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Patrik Thollander[1,2], Mariana Andrei[1], Noor Jalo[2], Patrik Rohdin[1], Jenny Palm[3], Anna Sannö[4], Johan Colding[2,5], Stephan Barthel[2,6], Gazi Salah Uddin[7] & Bruna Maria Xavier[1]

Energy efficiency is essential for climate change mitigation. Energy management, shaped by both technical artefacts and social constructions, can overcome barriers and achieve greater emission reductions than technology-focused approaches alone. Nine social constructions of energy management emphasize the need for a broader view that includes operations, processes, and knowledge creation and diffusion. By adopting these strategies, corporations and policymakers can substantially reduce industrial energy use and emissions. We estimate that effective energy management policies and voluntary initiatives could cut at least 5% of global industrial fossil CO_2 emissions.

The International Energy Agency (IEA)[1] denotes energy efficiency as the "first fuel" to achieve net zero emissions, and the European Commission has formulated the "energy efficiency first principle"[2] as a foundational part in the striving towards climate neutrality. An array of barriers to energy efficiency gives rise to the energy efficiency gap[3]. Energy management (EnM) is not only a key means for removing several of the more prominent barriers, but also provides a double energy efficiency potential compared with solely technology deployment[4]. Energy management practices and energy management systems (EnMS) have been mentioned in the Intergovernmental Panel for Climate Change (IPCC) assessment report related to its potential for climate change mitigation of industry, including its central role for improving energy efficiency compared to stand-alone technology policy programs[5,6]. Notably, however, in the United Nation's 28th Conference of the Parties (COP28) "Global renewables and energy efficiency pledged"[7], energy management or energy management systems (e.g., ISO 50001:2018) was not mentioned at all.

Energy management systems have been shown to increase energy efficiency by 165% in an Austrian energy efficiency policy program, compared with business-as-usual[8]. Energy policies, which include certification of energy management systems, have been in place for nearly two decades based on national energy management systems such as the management policy program in Denmark[9]. The ISO 50001-standard titled with Energy Management Systems is a harmonized version of the Danish, Swedish and Irish Standards and the Netherlands Specification, conform to the ISO 14000 (Environmental Management) structure and requirement[10]. Since the introduction of the ISO 50001:2011 and later the ISO 50001:2018, the number of industrial companies adopting energy management systems has steadily increased. Many companies view energy management as an effective tool to optimize their production systems and operations, leading to improved energy efficiency[11]. However, the inclusion of energy management practices and EnMS in energy policies is still relatively uncommon in most countries. Leading countries with the largest number of EnMS certifications (ISO 50001:2018) are Germany with 16,452 certificates, followed by China (7620), France (5307) and Spain (4636)[12].

Advances in energy management to date

The 1970s energy crises marked the beginning of modern EnM, as rising energy costs and concerns over energy security prompted

[1]Dep. of Management and Engineering, Division of Energy Systems, Linköping University, Linköping, Sweden. [2]Faculty of Engineering and Sustainable Development, University of Gävle, Gävle, Sweden. [3]IIIEE, International Institute for Industrial Environmental Economics, Lund University, Lund, Sweden. [4]Dept. of Chemistry – Ångström Laboratory, Uppsala University, Uppsala, Sweden. [5]The Beijer Institute of Ecological Economics, Royal Swedish Academy of Sciences, Stockholm, Sweden. [6]Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden. [7]Dep. of Management and Engineering, Division of Economics, Linköping University, Linköping, Sweden. e-mail: patrik.thollander@liu.se

industries to seek efficiency improvements. This period laid the foundation for EnM practices, with organizations focusing primarily on reducing energy use as a cost-saving measure. Government policies began influencing energy use through taxation and price mechanisms, encouraging companies to reduce costs by conserving energy[13]. Historically, however, energy was inexpensive, leading industries to prioritize capital investments over energy-efficient operations. With energy costs starting to rise, EnM practices have started to become essential, with energy audits increasingly used to guide investment decisions. This shift underscored the need for informed and skilled industry professionals with a deep understanding of energy implications. As a result, EnM began to emerge as an interdisciplinary field combining technical knowledge and management skills, suitable for advanced study at the graduate level[13]. These early efforts, however, highlighted the potential for efficiency gains, but were mostly limited to technical improvements without broader systemic approaches[14].

During the 1980s and 1990s, government policies and environmental mandates began to shape EnM practices, particularly within energy-intensive sectors. Events such as the Kyoto Protocol in 1997 underscored the importance of emissions reductions, further integrating EnM into regulatory frameworks. Jaffe and Palmer[15] argue that this period saw environmental policies actively influencing innovation in energy efficiency, encouraging organizations to adopt more structured, compliance-driven approaches to manage energy use effectively. Later, in 2005, Price[16] reviewed 23 voluntary agreements for energy efficiency from 18 countries and showed that voluntary agreements programs can effectively motivate industries to enhance energy efficiency and reduce emissions when implemented within a comprehensive and transparent framework.

Initially, EnM practices in industrial settings concentrated on optimizing individual components, particularly electric motors, given their substantial energy use. This component-level focus aimed at improving the efficiency of specific machinery to reduce energy usage. However, the limitations of this narrow approach became evident over time, prompting a shift toward a broader, system-wide perspective on EnM. Research by Thollander and Ottosson[17] emphasized the transition from focusing solely on individual components to adopting a systems approach, underscoring the benefits of optimizing the entire production process. This was later confirmed also by Paramonova et al. [18] showing that the energy efficiency measures with the high potential go beyond technology diffusion and have a more operational character. This evolution reflects a growing recognition that effective energy management requires an integrated approach that considers complex interactions within industrial systems, allowing for more substantial and sustainable energy efficiency improvements.

The release of the ISO 50001 in 2011 (ISO 50001:2011) marked a pivotal step in the standardization of EnM practices across industries. This framework provided guidelines for organizations to establish, implement, and maintain energy management systems, promoting a structured, systematic approach to energy efficiency. The ISO 50001:2018 emphasized continuous improvement and has become a global benchmark for EnM, helping organizations align their operations with sustainability goals[19].

In the 2000s and 2010s, digital technologies, such as advanced sensors, smart meters, and data analytics, started to transform EnM practices by enabling real-time monitoring and data-driven decision-making. In 2015, Shrouf and Miragliotta[20] showed how Internet of Things played a crucial role for EnM practices by increasing visibility into real-time energy use at machine and production line levels through smart sensors and meters. The IEA[21] highlighted that digitalization allows for significant improvements in energy efficiency across various sectors by enabling more precise control and optimization of energy use. Later, in 2019, the IEA[22] published another report showing how digital technologies could improve energy efficiency in industry when accompanied by the right policies. In a 2022 policy report published by the European Union (EU) Joint Research Centre[23], the role of digitalization in energy management was suggested as crucial, especially for energy-intensive industries. This is particularly important since 15-30% of emissions reductions over the last 30 years were largely due to energy efficiency improvements, but the impact of further efficiency gains may be limited. Advanced energy management practices driven by digitalization are claimed to be essential to achieving meaningful emissions reductions of key importance especially for the energy-intensive industries.

In 2011, Price and Lu[24] conducted another survey of 22 industrial energy audit programs from 15 countries and one region (EU) and found that integrated policy programs – where audits are combined with voluntary agreements or governmental mandates – promote broader adoption of energy-efficient practices compared to standalone energy auditing programs. In the same year, Tanaka[25] published a review of over 300 global policies and measures for industrial energy efficiency, highlighting that energy efficiency measures are influenced not only by their technical considerations, but also by local energy markets, economic conditions, business contexts, managerial priorities, and implementation barriers. Voluntary initiatives have the potential to bridge the 'ambition gap' between current emission trends and what is necessary to limit global temperature rise to 2 °C[26]. However, for voluntary initiatives to reach their potential, their design needs to include robust accountability mechanisms and monitoring frameworks to track the effectiveness beyond the already pledged national targets[27].

Research on barriers to energy efficiency ranges from global studies on barriers in industry[28] studies of Italian SMEs (small- and medium-sized enterprises)[29] to German service sector companies[30] and numerous other sectors and countries. Hasanbeigi et al.[31] studied barriers to energy efficiency in the Thai industry and showed that the perceptions of barriers differed between industry and sector organization representatives. Later the same year, Palm and Thollander[32] defined barriers themselves as a social construction, meaning that what is perceived to be an important barrier is based in part on an individual's ontological foundation as embedded in a socially shaped reality that also could be codified in laws[33]. A 2011 literature review on barriers to industrial energy efficiency[28], highlighted that the primary issue is the cumulative impact of different barriers - such as hidden costs and lack of information – which is especially pronounced in SMEs with low energy intensity. As a result, these overlapping barriers make it almost inevitable that energy efficiency opportunities are overlooked. How 'real' transition barriers are perceived to be is hence shaped by a complex web of knowledge, beliefs, norms, values, and other socially shared features[34–36]. In fact, technological development is not purely a result of scientific or technical progress, but is shaped by social, cultural, and political factors[37]. Cooremans[38] outlined the importance of making energy efficiency a strategic issue to achieve greater degree of energy efficiency investments. Over time, EnM has evolved from a purely technical pursuit to a strategic organizational practice shaped by social constructs such as corporate culture, norms, and values. Backlund et al.[4] re-defined the energy efficiency gap, advocating that energy efficiency potential is not solely a matter of technological advancements but is equally influenced by how technology is managed and used, thus introducing the concept of the extended energy efficiency gap. This extended gap highlights the role of social constructs—such as norms, values, and beliefs about energy management—that shape perceptions and decisions around energy use. In this view, the energy efficiency gap expands beyond technical limitations to encompass organizational practices and social contexts that influence how efficiency measures are prioritized and implemented. Figure 1 displays the various gaps outlined in the literature, illustrating both technical and socially constructed barriers that affect energy efficiency outcomes.

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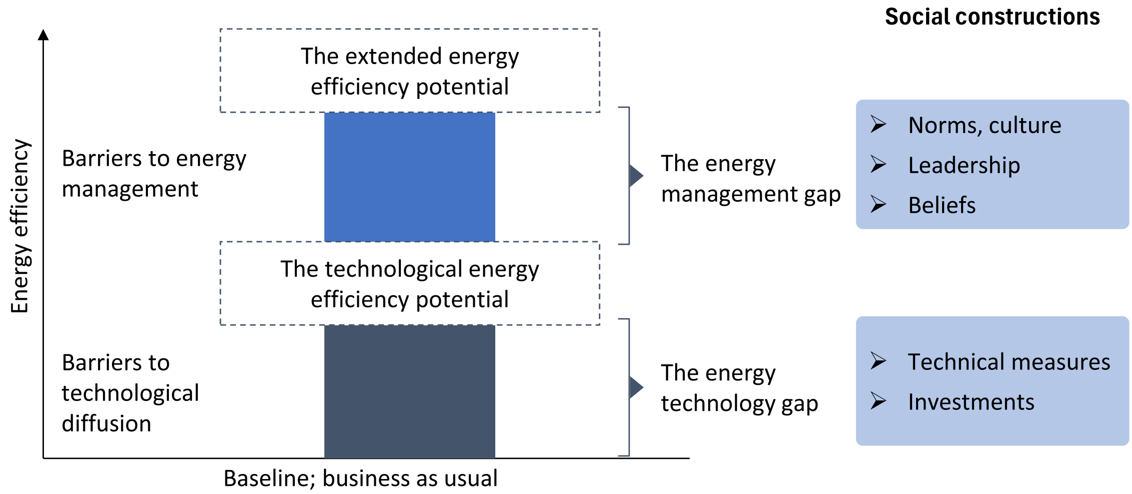

Fig. 1 | The energy efficiency and energy management gaps providing the extended energy efficiency gap. Representation of the description of the Energy Efficiency Gaps[4,79] with the inclusion of the different social constructions, e.g., norms, beliefs, situated in relation to the energy efficiency gaps.

The importance, existence and impact of the energy management gap was further explained by Schulze et al.[11], who provided a general framework for how energy management can be understood. Energy efficiency networks (EENs) are also a form of energy management where companies, through participation in the network, receive a form of insourced energy management function. Köwener et al.[39] showed that participation in such German EENs doubled energy efficiency improvements. Johansson et al.[40] confirmed the findings from Germany, showing that a regional Swedish EEN doubled the deployed energy efficiency improvements compared with companies undertaking only an energy audit.

Energy management and energy efficiency as a social construction

There is an urgent need to further understand the role of social constructions for achieving energy efficiency in order to develop successful corporate in-house energy management programs and effective efficiency policies. Not only physical or technical artefacts, but also dominant social constructions in corporations determine energy efficiency management. Due to the evolution dynamics of social constructions, it is more likely than not that there are several dominant forms of social constructions regarding energy management. A social construction in a corporation refers to a concept, practice, or understanding within the organization that is shaped by collective human perception, interaction, and agreement rather than being an objective, natural reality. These constructions are created and sustained through shared language, culture, norms, and behaviours within the corporate context. These constructions exist because members of the corporation collectively recognize them and accept them[32,41]. We provide nine examples of social constructions related to energy management in the following sections.

Energy management knowledge demands

The social constructions identified in earlier and current research can be related to the three Aristotelian knowledge forms: *phronēsis*, *epistēmē*, and *technē* which in turn has a bearing on an organization's resilience building[42]. Technē is understood as the "technical knowledge" needed to produce an artefact and the knowledge that comes with it[43]. Epistēmē relates to the possession of "scientific" knowledge, as opposed to tacit knowledge[43]. Phronēsis is related to "practical wisdom", concerning decisions and choices made in the manner of an expert person[44]. Andrei et al.[45] provides a more thorough presentation of these knowledge terms in relation to energy management practices. Different actors in a corporation can learn, combine, share experience and knowledge, innovate, and adjust responses to changing external and internal circumstances[46]. The importance of knowledge as a critical part of energy efficiency was denoted by Solnørdal et al.[47] in a study using a national Norwegian dataset showing higher deployed energy efficiency and eco-innovation improvements among companies with a more significant number of highly educated staff[47]. Years before it was shown by Dewar and Dutton[48] that investing in human capital, particularly by hiring specialists and re-educating staff appears to be a key facilitator of adopting technical process innovations. Implementing radical innovations, where the complexity of changing technology and production processes is high, requires new skills, advanced technologies, increased investment, and a deeper understanding of how energy efficiencies impact the entire operation. This calls for the development of multidisciplinary energy teams within companies, incorporating staff from operators to management. Such teams can leverage existing knowledge frameworks, ensure continuous learning to address the growing demand for new expertise, and promote effective cross-disciplinary collaboration[45]. In 2022, Andrei et al.[45] introduced a knowledge framework that combines Aristotle's concepts of *phronēsis*, *epistēmē* and *technē* to better understand the types of knowledge used in industrial energy management; they also reviewed industrial energy management articles published between 2010 and 2020, stated that the *technē* form of knowledge is the primary type of knowledge employed in energy management and a paradigm-changing towards Industry 4.0 is emerging.

Whether and how organisations decide to adopt efficiency measures is also an important field of research for improved industrial energy efficiency opportunities and net zero[49]. Moreover, the fact that co-benefits can be much larger than the energy efficiency improvements as outlined by Cooremans[50] is of key importance. The multiple non-energy benefits of energy efficiency can greatly enhance the financial evaluation of these projects, yet they are rarely reported, quantified, or considered in project assessments[51]. Without neglecting and acknowledging the importance of this part of the literature, the scope of this paper takes a stand from Bourdieu's work[52] on habitus and social constructions of energy efficiency and energy management in a broader sense.

Figure 2 shows how the inclusion of knowledge contributes to an enhanced understanding and interpretation of how energy management can advance. This includes not only technical expertise but also socially constructed elements - social learning and collective understanding within organizations. Furthermore, it defines the maximized energy efficiency potential, meaning that beyond the deployment and

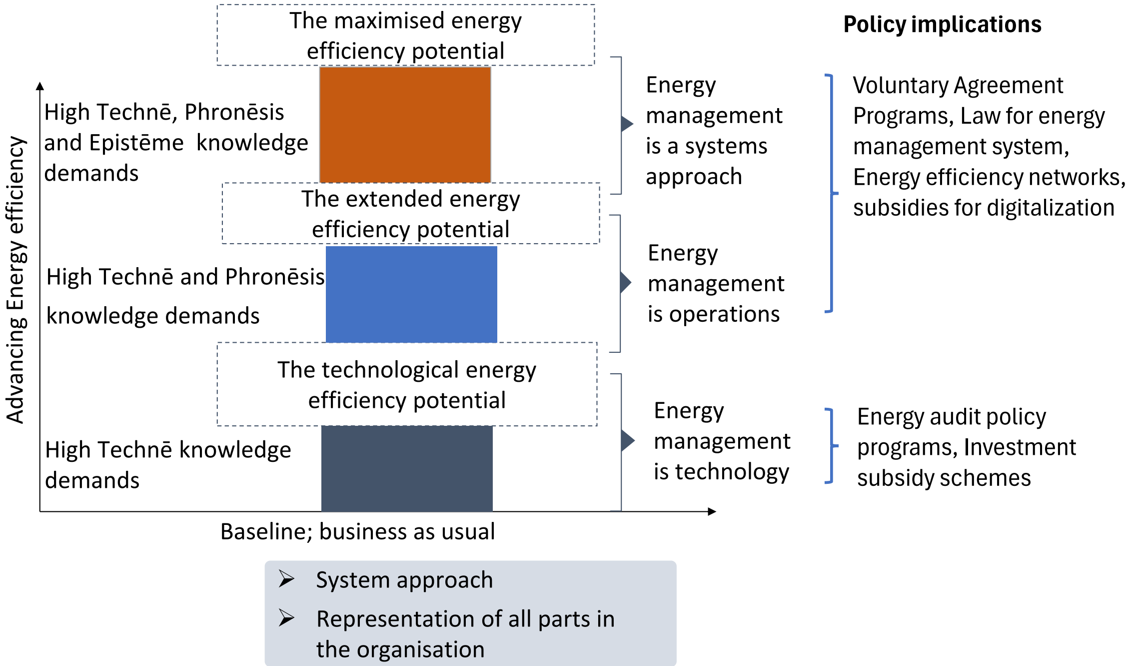

Fig. 2 | The energy efficiency gaps, where the potential is maximized when knowledge is included, and leadership is established to excellently steward knowledge development. Figure 2 illustrates that achieving the maximised energy efficiency potential in organizations requires a shift from isolated technological improvements to an integrated systems approach. It conceptualizes energy efficiency progression in three stages, each associated with distinct knowledge demands and corresponding policy interventions. At the technological energy efficiency potential level, improvements are driven by technological upgrades and process optimization. Here, energy management is largely technical in nature, relying on technē knowledge. Policy measures, such as energy audit programs and investment subsidies, are designed to encourage companies to adopt new technologies. However, the impact of technological improvements alone is limited, often plateauing unless supported by more comprehensive operational changes. The extended energy efficiency potential and maximized energy efficiency potential share a focus on deeper organizational integration. The extended stage emphasizes optimizing operational processes. This requires both technē and phronēsis knowledge to guide operations and management. Energy management becomes an operational practice rather than a series of isolated technical upgrades. The maximized potential builds on these operational improvements by adopting a system approach. Here, organizations align technology, operations, and manufacturing systems to achieve maximum energy efficiency potential. Achieving this level requires epistēmē knowledge in addition to technē and phronēsis. Both stages are supported by policies that promote system-level coordination, such as voluntary agreements, energy management frameworks, incentives for digital transformation and energy efficiency networks. These measures foster collaboration, digital transformation, and continuous improvement across organizational boundaries. The key idea is that maximizing energy efficiency requires a transformation of energy management from a purely technological focus to a fully integrated system, where technological upgrades, operational practices, and system approach work synergistically. Policies measures must support the alignment of technology, operations, and systems to enable organizations to reach the maximised energy efficiency potential.

use of technology, there is a knowledge dimension related to successful energy management that is still left to be explored, deployed and further researched. In a constantly changing external environment for corporations, there is a continuous need for social learning. To successfully implement energy management in an organization, integration and acceptance from staff who together hold various forms of knowledge is key. This social learning process, shaped by shared beliefs and practices, is essential for realizing the full potential of energy management initiatives.

The social constructions of technological efficiency solutions

One of the dominant social constructions identified in research can be named the *generalist social construction*, where the central understanding emanates from what is visible, e.g., investments primarily related to support processes such as Light Emitting Diode (LED) and air-to-air heat pumps[53]. Investments are often minor and can be operationalized within the corporation's investment threshold, e.g., a payback time of one to three years[54], and is rooted in technology diffusion models[55,56].

A second identified social construction is the *innovative large-scale technology social construction* based on the perception of large-scale new energy-efficient technologies as a key means for improved energy efficiency. This diverges from the *generalist social construction* approach by focusing on both support and production process-related measures. These include investments such as capital-intensive ground heat pumps for space heating and building insulation measures, with a greater degree of financial and production risk-taking, manifested in longer pay-pack periods compared with the measures within the generalist's social construction, indicating the need for strategic decision-making as initially outlined by Cooremans[38]. Notably, Schumpeter's notion of significant innovations that drive growth in progressive cycles[57] is often associated with significant technological and industrial innovations that give rise to periods of new industrial development blocks, e.g., see ref. 58. Thus, with the *innovative large-scale technology social construction*, higher degrees of improved energy efficiency can be reached. This social construction is rooted in *technē* and *epistēmē* knowledge dominated by techno-economic perspectives.

A third social construction identified is the *technical specialist social construction*. Rooted in technology diffusion, the *technical specialist social construction* also places importance on a profound understanding of the company's technical energy systems and its components, processes and systems, representing more of a technical (*technē*) contextual perspective. Energy efficiency improvements mainly stem from technical solutions that demand contextual technical knowledge[59]. It often involves one or a few individuals who possess deep contextual tacit knowledge of the processes. If the corporation allocates budget funding to this individual or group of individuals, results can be a technically very advanced and efficient energy system, in particular if combined with the *innovative large-scale social construction* and brought up on a strategic corporate level.

The social constructions of management

Energy management practices and EnMS are also embedded in social constructions. We have identified that one often employed belief is that a certified EnMS provides energy efficiency improvements, i.e., in the company's structure and strategies. This is what we call the *energy management system social construction*. However, without key factors in place, such as top management support and a dedicated person or team for the assignment, etc., improvements are more likely to be found in the way energy management is being administrated, rather than actual efficiency improvements[53]. This social construction is the energy management equivalent to the generalist social construction (for technology) reaching shallow deployment levels.

The *advanced energy management social construction* is rooted in the belief that individual employees can make a vast change in the way energy (technologies and processes) is being used or managed. And it is the leader's responsibility to provide the employees with the prerequisites to succeed in this. It is in part rooted in the existence of the extended energy management gap, often heavily influenced by *Lean* management principles[60] in the operationalization and can be modelled by behavioural sciences[61], i.e., how efficiently energy is being used or managed[11,62]. These values and beliefs are rooted in staff capacity building, including training and visualization of energy use in the organization, thus emerging from a solid *phronēsis* knowledge part, i.e., leadership-related issues and a moderate level of *epistēmē* knowledge development. Improvements often tend to be low or zero-cost and related to changes in operations, improving the overall efficiency of the value stream, less so on technical solutions, and also a focus towards a leaner value flow between production units in a production line, including employee well-being in the workplace. Inefficient use of energy is, in this social construction, often seen as a waste that, according to lean principles, normatively should be minimized[63]. If a corporation deploys this social construction, the result can over time be a lean production with minimization of waste, very well-established pro-environmental habits[64] and operational standards on how to operate the processes in an efficient way. Improvements of idle loads of more than 50% have been documented deploying this social construction[65]. For the *energy management system social construction*, knowledge demands are shallow to moderate. In contrast, advanced energy management calls for high *phronēsis* knowledge and adherence to lean production principles and pro-environmental practices.

Emerging social constructions

Apart from the technical and management social constructions, there are also an array of *emerging social constructions* related to energy management that can be categorized in what Churchman[66] refers to as a systems approach, i.e., approaching a challenge with a wider system boundary and other perspectives. These have still not saturated in becoming dominant social constructions. The *digitalization social construction* is one such example which includes the utilization of AI (artificial intelligence) and other digital tools[45,67]. The rapidly advancing Industry 4.0 (and Industry 5.0) highlights the crucial role of Advanced Information Technologies-enabled energy management, which requires integrating and analysing multiple parameters, conditions, and data to effectively control energy use and costs in manufacturing[54]. Socially constructed frameworks, such as formal and informal institutions (e.g., laws, norms, and conventions) also play a fundamental role in shaping economic performance and societal development[68,69]. Another example is the *resilience energy management social construction*, resembling the importance of qualitative knowledge in resilience thinking[70]. This includes resilient energy supply and flexibility solutions.

These social constructions may entail demand for high levels of *epistēmē*, *technē*, and *phronēsis* knowledge and, in addition, entail absorbing knowledge from scientific fields such as natural resource management[70,71]. Kotler[72] states that management regards coping with complexity by creating practices and procedures in various forms, i.e. embracing a systems perspective. Leadership on the contrary regards coping with change to become more resilient. Embracing (energy) leadership, not only (energy) management, may be a critical knowledge frontier in future advances in the field, including a new scientific frontier on the social construction of energy efficiency leadership in the Anthropocene[73,74].

A third example of emerging social construction identified is the *supply chain energy management social construction* going beyond a strict focus on direct and indirect emissions at the plant level (known as scope 1 and 2) to also embracing emissions upstream in the supply chain, e.g., among the corporation's suppliers (known as upstream scope 3). Within this social construction, a key means is to support the corporation's suppliers to create a more energy-efficient, climate-neutral, resilient, circular and decarbonized supply chain. This social construction may entail a high knowledge demand in all three primary knowledge forms. In addition, specialist knowledge may be required regarding operating a supply chain energy efficiency and resilient management program, stretching beyond the more well-established in-house energy management paradigm. Yet a fourth example is the *process integration social construction* including pinch analysis and optimization and other decision support tools, normally demanding very high epistemic knowledge, often brought in from academia where whole systems of heat exchangers or energy end-using processes are modelled[75]. This social construction entails a high knowledge demand in all three primary knowledge forms and is normally only adopted for process industry and energy intensive companies.

Bourdieu[52] developed the concept of *habitus* meaning habits, skills, and dispositions that individuals develop through their life experiences, mainly within their social environment. Inspired by Bourdieu[52], this paper applies this concept to *habitus* or *social constructions* in the energy field. *Habitus* forms *doxa*, meaning a shared set of beliefs, values, and norms that are blended into the context and thus are taken more or less for granted. Outlined examples here are thus not per se a complete list as e.g. new emerging social constructions are formed over time in the transition landscape creating and re-forming the *habitus*[52] of energy efficiency and energy management.

Figure 3 displays the various social constructions on how energy efficiency and energy management can be understood advocating that corporations and policymakers should embrace social constructions beyond the *technical social construction*. It is stressed that this can only be achieved by adopting sound energy management as well as sound energy leadership practices.

Future advances of energy management and energy efficiency policies

The *social constructions* presented in this paper serve as a foundation for further development in corporations and among policymakers on how energy management and energy efficiency can be understood, improved and deployed systematically.

Implications for corporations

From a corporate perspective, it is key to consider social constructions used including all various forms of knowledge and advance not only energy management practices but also energy leadership practices. Moreover, the paper's notion also calls for corporations to build in-house (absorptive) capacity to assimilate new knowledge and new social constructions, e.g., for climate change mitigation[76]. Notably, if, for example, adopting a technical social construction on digitalization, the likelihood of exploiting the maximized potential is annulled. Instead, it may result in an array of energy meters being installed

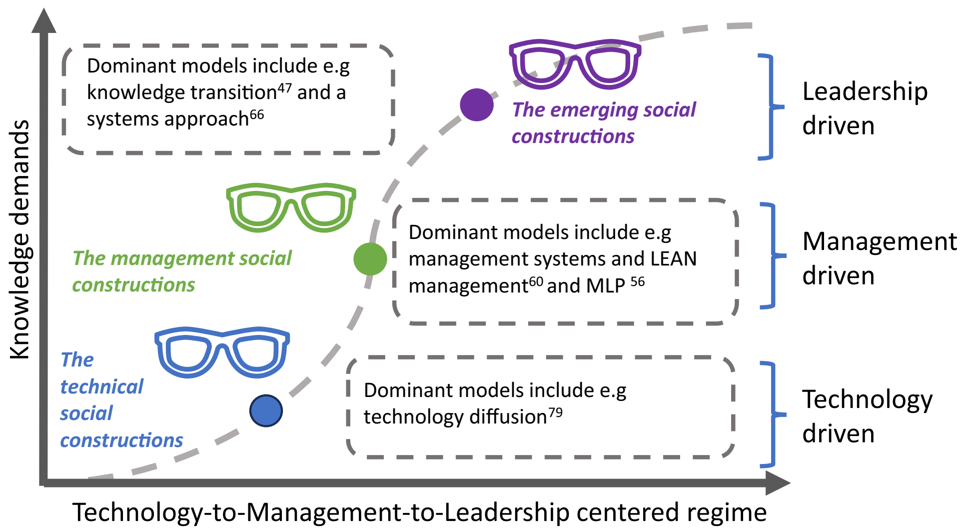

Fig. 3 | The three dominant forms of social constructions being achieved by a transition from technology to management to leadership centred regime. Figure 3 illustrates the evolving social constructions in energy management practices, transitioning from a technology-driven to a leadership-driven regime, along a continuum of increasing knowledge demands and organizational integration. At the base of this progression are the technical social constructions, which focus on technology adoption and optimization. This phase is driven by technological models, such as technology diffusion, where improvements are largely achieved through the deployment of new technologies. Knowledge demands here are primarily technical, requiring expertise in technological systems and innovation. The next stage involves management social constructions, where organizations emphasize the coordination of processes and people to enhance operational efficiency. This stage is management-driven and supported by models such as management systems, LEAN management, and multi-level perspective (MLP) frameworks. Knowledge requirements expand beyond technical expertise to include practical and organizational knowledge, enabling companies to manage complex systems and optimize resource use effectively. At the highest level, emerging social constructions represent a shift towards a leadership-driven approach. Organizations at this stage adopt a strategic, system-wide perspective, emphasizing sustainability, innovation, and long-term planning to steward new emerging concepts. Models like knowledge transition and systems approaches become dominant, reflecting the integration of multiple knowledge domains to drive continuous improvement and resilience. Knowledge demands are at their peak, requiring leaders to synthesize technical, managerial, and strategic insights to guide the organization through dynamic and uncertain environments. The key message is that effective energy management evolves through distinct social constructions, from a narrow focus on technology to a comprehensive, leadership-centered regime. Organizations must continuously build and integrate technical, managerial, and leadership capacities to meet growing knowledge demands and achieve sustainable energy efficiency. This transition highlights the importance of knowledge sharing, adaptive learning, and strategic collaboration across all organizational level.

without a sufficient approach to how data can provide enhanced value for various key professionals in the organisation. In such a scenario, advanced analysis skills that requires more technē and process knowledge are needed to make use of the data.

The outlined social constructions also guide corporations for enhanced resilience during the societal transformation towards a climate-neutral future. Considering the outlined social constructions, the implications for corporations striving to become more resilient and successfully deploy an energy management program is to focus on staff capacity building and knowledge creation of energy management as a social construction. Such capacity building and social construction knowledge creation should preferably include learning about the significant social constructions regarding how energy efficiency and energy management are understood and hence can more easily be improved among the staff. One such way is to organize cooperative initiatives with companies with shared challenges. A shared social construction working as a joint vision, preferably with some guiding principles of what energy efficiency and energy management are understood to be by staff and managers, remains a key responsibility for managers to deploy. Participatory processes are often easily understood in theory but more challenging to apply in practice. A participatory model is often needed, designed to actively involve others besides just academic experts and professionals[41,77,78].

Implications for policymakers

At this stage of the development of climate change mitigation policies, it is crucial to encourage policymakers on a global level, such as United Nations Conference of the Parties, to highlight the important role of energy management in achieving short-term climate targets. Beyond technical innovations, based on former studies, e.g., Schützenhofer[8], we estimate that if social constructions beyond the technical social construction are embraced, the emission cuts for energy management policies and programs as well as voluntary initiatives can be increased within the range of at least 5% (about 0.45 Gt) of global industrial energy-related fossil CO_2 emissions cuts. This corresponds to emissions of ten developed countries the size of Sweden. Furthermore, we suggest using the outlined perspective on social constructions as a foundational part in the design of future energy efficiency policies and programs. We recommend policymakers to consider moving beyond the technology social constructions paradigm (without excluding the importance of it), and also embrace the management and emerging social constructions. Hence, we identify three key actions to raise the profile of industrial energy management in climate change mitigation policy:

First, comprehensive assessment by IPCC Working Group III. The IPCC's Working Group III on Mitigation of Climate Change is encouraged to conduct a comprehensive assessment at global level of measures implemented and reported under national governmental industrial energy efficiency and energy management programs, since IPCC has the capacity to highlight and promote the measures beyond the implementation of an energy management system and purely technological focus, to the leadership-driven measures focused on enhanced learning of the in-house industrial energy end-using processes and systems. The assessment should include the measures reported under voluntary agreements (e.g., Program for Energy Efficiency in Energy-Intensive Industries -PFE Sweden, Long-Term Agreements on Energy Efficiency LTA Netherlands, etc.), under governance regulations such as the National Climate and Energy plans, as well as under global voluntary initiatives such as Science Based Targets. Such an assessment can enable an international understanding of industrial energy management's potential for mitigating climate change.

Second, enhancing capacity building through global voluntary initiatives. Existing global voluntary initiatives (e.g., Sustainable Energy for All - the Global Energy Efficiency Accelerator Platform, International Partnership for Energy Efficiency Cooperation, World Resources Institute WRI - Energy Program, etc.) should develop and support capacity-building policy programs that focus on in-house learning of industrial energy end-using processes and systems. The measures identified in the previous policy suggestion can represent best practices for these capacity-building programs. We suggest the development of National Energy Management Training Centres to provide structured training programs for corporate staff at all levels, focusing on different industrial energy end-use processes and systems. Where applicable, these can be sector specific. These centres can organize workshops and seminars on best practices in energy management, hands-on training sessions for practical skills in using digital technologies to improve the efficiency of industrial processes, and leadership development programs to enhance leadership skills for energy management. Additionally, public-private partnerships between government agencies, industry leaders (especially from energy-intensive sectors), and academic institutions are encouraged to deliver training programs, particularly for energy-intensive sectors undergoing retrofitting of industrial processes. Such programs can leverage the strengths of the involved sectors in driving knowledge for specific industrial processes and foster a culture of continuous improvement in industrial energy management.

Third, resilience and adaptation programs by national government agencies. National government agencies (e.g., European Environment Agency, U.S. Federal Emergency Management Agency, etc.) are encouraged to create resilience and adaptation programs that focus on preparing industries for current and future challenges, such as fluctuating energy prices, supply chain disruptions, and climate-induced changes. These programs can provide tools, training, and support to develop robust energy management strategies for industries. By focusing on resilience and adaptation, industrial companies can ensure continuous and efficient energy use even during disruptions, contributing to long-term sustainability and climate change mitigation.

Connecting social constructions and empirical findings

One main take-away from here is that the *habitus* and *doxa* of energy efficiency and energy management needs to be re-shaped. Social construction theory suggests that various facets of social reality- such as concepts, beliefs, norms, and values are formed through continuous interactions and negotiations among society's (or the sub-group's) members, rather than through empirical observation of physical reality. Without contradicting the social science literature, the emphasis made in this paper is that if our social construction is a technical social construction of energy efficiency, higher energy efficiency potentials and thus potentially higher emissions cuts may remain undeployed. For example, if our social construction or ontological foundation is that energy efficiency is investing in new more efficient light bulbs (to simplify the discussion), the potential for effective use of light bulbs such as shutting these off when not needed, remains unadopted. This holds even more so in industrial energy systems where a vast array of technologies forms processes and systems which are far more complex in nature than the investment and use of light bulbs. If for example energy management is not included in the social construction of what energy efficiency is among policymakers, policies face the risk of targeting primarily technology measures.

The inter-, multi,- and transdisciplinary implications: no single scientific discipline provides the full answer to how climate change can be mitigated. Improving energy efficiency remains a core part of climate change mitigation and it is thus essential to adopt inter-, multi-, and transdisciplinary research of energy efficiency and energy management. In this paper, we argue that energy efficiency and energy management are embedded in social constructions, which implies that activities, in turn, are affected by these various social constructions of what energy management and energy efficiency should be and are understood to be. A vital climate change mitigation policy for the scientific community is hence to finance especially social- and behavioural sciences for studies on energy efficiency and energy management to advance understanding of how energy management of corporations can be rapidly transformed.

In conclusion, the socially constructed reality of how energy efficiency and energy management are understood and can advance will, in the foreseeable future, remain an important knowledge frontier for corporations, policymakers, and scientists.

Data availability

All data are available from the corresponding author upon request.

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Author contributions
P.T.: writing-original draft preparation, conceptualization, validation and visualization; M.A.: writing—original draft preparation, conceptualization, validation and visualization; N.J.: writing-original draft preparation, conceptualization, validation and visualization; P.R.: conceptualization, supervision and writing—reviewing and editing; J.P: writing—original draft preparation, conceptualization, validation and visualization; A.S.: supervision and writing—reviewing and editing; J.C.: supervision and writing—reviewing and editing; S.B.: supervision and writing—reviewing and editing; G.S.U.: supervision and writing—reviewing and editing; B.M.X.: writing—reviewing and editing.

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Additional information
Correspondence and requests for materials should be addressed to Patrik Thollander.

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