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Evaluation of research performed on energy efficiency in energy-intensive manufacturing companies

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The implementation of climate protection cannot succeed without increasing energy efficiency in companies. Increasing energy efficiency is an important success factor for the energy transition, but unfortunately, the energy saving potentials are only insufficiently exploited. The aim of this study is, therefore, to highlight the current state of research on energy efficiency potentials in companies at the technology level. For this purpose, an extensive literature search was conducted with more than 30 keywords. After screening and cleaning, 101 articles were selected and reviewed in detail. The literature search was performed using eight evaluation criteria: origin and year of publication, type of company, type of industry, type of data, survey method, number of participants, data collection method, and analysis method. In order to evaluate the statements and results of the considered works, a SWOT analysis was used. Our analysis revealed that: 1) studies explicitly addressing energy efficiency measures and potentials at the technology level are scarce. Even fewer studies address the relationships and interactions (positive or negative) between individual measures; 2) most studies focus on large and manufacturing companies, most of which are energy intensive. SMEs in the non-manufacturing sector, such as trade, commerce, and services, are far less represented; and 3) the chosen research focus and content are often barriers, drivers, and theory models for energy efficiency, and secondary data are mostly used. Of the studies that considered primary data, 71% used a questionnaire survey. Research into the interactions between individual measures enables policymakers to target business support programs.

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Abbreviations: CO_2, carbon dioxide; EEM, energy efficiency measures; EnMS, energy management system; ERDF, European regional development fund; EU, European Union; IoT, Internet of Things; KEFF, energy efficiency competence center; LEACH-LMMN, Levenberg–Marquardt neural network; LED, light-emitting diode; LSCCOA, Lagrangian suboptimal convergent computation offloading algorithm; SME, small and medium-sized enterprises; SWOT, strengths-weaknesses-opportunities-threats; UM BW, ministry of the environment of Baden–Württemberg; WOA, whale optimization algorithm; WSN, wireless sensor network.

KEYWORDS

scientometric evaluation, energy efficiency, energy-intensive manufacturing companies, SWOT (strengths, weaknesses, opportunities, and threats), interactions of measures and potentials

1 Introduction

The aim of this work is to highlight the current state of research on energy efficiency potentials in companies at the technology level and to examine whether sufficient research exists and, if so, whether there is empirical evidence to support it.

The climate protection goals required by the European Union (EU) cannot be achieved without increasing energy efficiency in companies. Increasing energy efficiency is an important success factor for the energy transition, but unfortunately, the energy saving potential, for example, in Germany is only insufficiently exploited (Gamst, 2019).

In addition to the potential within companies, however, the external potential of the energy network is also of crucial importance. For example, the Internet of Things (IoT) is being used for smart cities and grids and holds enormous potential. Hybrid approaches such as the whale optimization algorithm (WOA) are already being used to optimize energy consumption, which has efficiency advantages compared to the other algorithms (Iwendi et al., 2021).

Models such as the Lagrangian suboptimal convergent computation offloading algorithm (LSCCOA) for optimized multi-access edge computation (MEC) should also be used, as they have been shown to contribute to energy consumption reduction (Anajemba et al., 2020).

In the context of efficient communication in the wireless sensor network (WSN), routing protocols are needed to increase the detection rate. Here, the Levenberg–Marquardt neural network (LEACH-LMNN) should be mentioned as it achieves the highest detection rate (Mittal et al., 2021).

In order to promote energy efficiency, the EU is making a number of efforts to remove obstacles in companies and to increase existing potential. Energy efficiency in companies is an important contribution to climate protection [Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (BMUB), 2015].

Energy efficiency potentials in companies are often not well known and cannot be implemented as a result. In addition to information deficits (Schmid, 2004) in companies, acceptance deficits for new technologies and solutions are often an obstacle (Hertel, 2014).

Deficits can be observed in technical solutions such as LED installation or smart meter retrofitting, organizational solutions such as energy purchasing *via* digital portals, but also behavioral changes such as switching off lights after work.

Many companies also have little or no knowledge of the actual total energy consumption within their company (Mittelstandsinitiative Energiewende und Klimaschutz, 2019). A further breakdown of energy consumption by work area or at plant level is also not possible in most cases (Deutscher Industrie und Handelskammer, 2018). The lack of transparency makes it difficult to identify and leverage existing energy efficiency potential, as no assessment based on economic efficiency is possible for the decision-maker.

Another challenge is that few studies address energy efficiency potential as an actual measure at the technology level (Trianni et al., 2013), for example, lighting technology. However, when this is performed, the relationships between these measures are not further considered (Sudhakara Reddy, 2013).

Therefore, Cagno et al. (2019) recommend analyzing a single company in relation to several different energy efficiency measures (EEMs) to understand the potential synergies (positive or negative) that result from implementing multiple EEMs. Stefana et al. (2019) identify and recommend further research related to the mutual influence of individual measures and their interactions. Other studies cite the investigation of correlations between individual efficiency measures as possible research studies (Trianni et al., 2021). The correlation and influence of different measures are recommended in the form of further case studies (Stefana et al., 2019).

The correlations between the individual measures and potentials are an important parameter for estimating what a company will need in the future, for example, if it has already implemented individual measures. If a correlation can be formed, for example, more targeted expansion and promotion concepts can be drawn up and investments in energy efficiency can be triggered more quickly. Therefore, it is precisely these correlations and their effects on energy efficiency measures and potentials that should be researched further.

Schützenhofer (2021) is one of the few to address the fact that an EnMS has an impact on EEM. However, the study focuses on energy efficiency as a whole and not on individual measures or even potentials. Moreover, the corridor of consideration is limited to large companies.

The following studies state that the EnMS has a positive effect on energy efficiency. Olsthoorn et al. (2017) demonstrated a positive effect of EnMS on energy efficiency. Moreover, the results of Schulze et al. (2018) provide strong empirical evidence that EnMS has a positive relationship with the energy efficiency performance of companies.

The positive and negative effects of EEM on other areas are examined in the study by Trianni et al. (2021).

Stefana et al. (2019) also show that the use of management systems is associated with an improvement and implementation of measures. In addition, the study identifies potentials at the technology level and studies are presented that look at measures for lighting and compressed air, for example.

What is missing so far, however, is a study that examines which measures are influenced by other measures and empirically demonstrates these interactions and dependencies.

In addition, most studies in the field of energy efficiency deal with manufacturing non-SME companies (Finster and Hernke, 2014; Stefana et al., 2019; Andrews and Johnson, 2016; Backlund et al., 2012; Brunke et al., 2014; Cagno et al., 2013; Cagno et al., 2019; Chiaroni et al., 2016; Cooremans, 2012; Costa-Campi et al., 2015; del Río González, 2005; Fawcett and Hampton, 2020; Fiedler and Mircea, 2012; Fleiter et al., 2012a; Fleiter et al., 2011; Hampton, 2019; Haq and Jacobsen, 2018; Hasan et al., 2019; Henriques and Catarino, 2016; Hertel and Menrad, 2016; Hoyer et al., 2020; Kinelski, 2020; König, 2020; Mickovic and Wouters, 2020; Morais et al., 2020; Olsthoorn et al., 2017; Perroni et al., 2017; Phylipsen et al., 1997; Ponomareva et al., 2019; Pye and McKane, 2000; Rohdin and Thollander, 2006; Sa et al., 2015; Safarzadeh et al., 2020; Sardianou, 2008; Schlomann and Schleich, 2015; Schulze et al., 2018; Shinkevich et al., 2020; Soepardi et al., 2019; Stephenson et al., 2015; Stephenson et al., 2010; Sudhakara Reddy, 2013; Thollander, 2010; Thollander et al., 2013; Thollander et al., 2007; Thollander and Ottosson, 2008; Trianni et al., 2014a; Trianni et al., 2017; Wagner et al., 2020; Wakabayashi and Arimura, 2020; Williams and McKane, 2013; Wohlfarth et al., 2018; Wolniak et al., 2020; Zierler et al., 2017). Smaller companies should not be ignored, however, as they exist in greater numbers overall than larger companies and the total potential of all smaller companies is enormous. Therefore, further studies should focus even more on smaller companies (SMEs) so that the general awareness of these companies for more energy efficiency becomes more present and thus a copycat effect can be triggered. There are some studies on SMEs, but they are also focused on the manufacturing sector (Anderson and Newell, 2004; Parker et al., 2009; Fernández-Viñé et al., 2010; Jochem et al., 2010; Palm and Thollander, 2010; Fleiter et al., 2012b; Thiede et al., 2012; Trianni and Cagno, 2012; Cagno and Trianni, 2013; Kostka et al., 2013; Thiede et al., 2013; Trianni et al., 2013; Williams and Schaefer, 2013; Bell et al., 2014; Cagno et al., 2014; Cagno and Trianni, 2014; Semkov et al., 2014; Trianni et al., 2014b; Catarino et al., 2015; Leloux et al., 2015; Allarton, 2016; Meath et al., 2016; Muzamwese, 2016; Rahbauer et al., 2016; Solberg Hjorth and Brem, 2016; Tallini and Cedola, 2016; Trianni et al., 2016; Fresner et al., 2017; Hilger et al., 2018; Krutwig, 2019; Schleich and Fleiter, 2019; Chen et al., 2020; Cunha et al., 2020; Giraudet, 2020; Hung and Chu, 2020; König et al., 2020; Palm and Backman, 2020; Özbuğday et al., 2020; Nigohosyan et al., 2021; Trianni et al., 2021). Therefore, in future studies, they should look at smaller non-manufacturing companies. Therefore, the study should also critically examine how many of the existing studies examine these small companies. The research question of the current state of energy efficiency in companies in relation to the interactions of individual efficiency measures at the technology level will therefore be examined.

The article is organized as follows. Section 2 presents the methodology used in this study. A comprehensive literature review was conducted. Integrated is a SWOT analysis of the literature reviewed. Section 3 presents the results of the research. This includes a discussion of the eight evaluation criteria listed in Section 2, which are used to review the publications studied. In addition, the results of the SWOT analysis are presented. In Section 4, a critical discussion of the results follows. Finally, Section 5 places the results of the work in a broader context and explains the need for further research in the field of energy efficiency.

2 Materials and methods

Sections 2.1–2.7, shown in Figure 1, illustrate the process of the systematic literature review. In the beginning of 2.1, the planned research question is presented, which is to be answered with the help of the existing literature. Subsequently, 2.2 describes how the search terms and combinations are created and transferred into a keyword list with the help of a so-called mind map software. Moreover, 2.3 deals with the question of which databases are used for the search and how the basic search is carried out. In 2.4, the fine search is carried out on the basis of the basic search. To achieve even better search results, the exact search is used. Then, in 2.5, the analysis and selection of keywords for the literature search is performed. Thereby, the search terms and combinations are determined. 2.5.1 shows the results of the search and 2.5.2 shows the cleaning of the search results. In 2.6, the articles are read in full and initially screened and categorized. In 2.6.1, the articles are sifted and categorized by content. The results that relate to one's research questions can be compared with the statements of these research results. Eight evaluation criteria are used to evaluate and screen the literature. The desired research gaps are identified. In 2.6.2, a SWOT analysis is conducted with the 101 articles in relation to some criteria to critically examine the statements made in 2.6.1. In this final step 2.7 of the method, it is tested whether the research question and gap can be answered and closed by the results of the literature review and SWOT analysis.

2.1 Planned research question

What are the current energy efficiency potentials in companies in terms of individual measures at the technology level and how do they interact with each other?

The research question is to be investigated and answered in the course of the literature review. Measures and potentials at the technology level are understood in this study, for example, LED

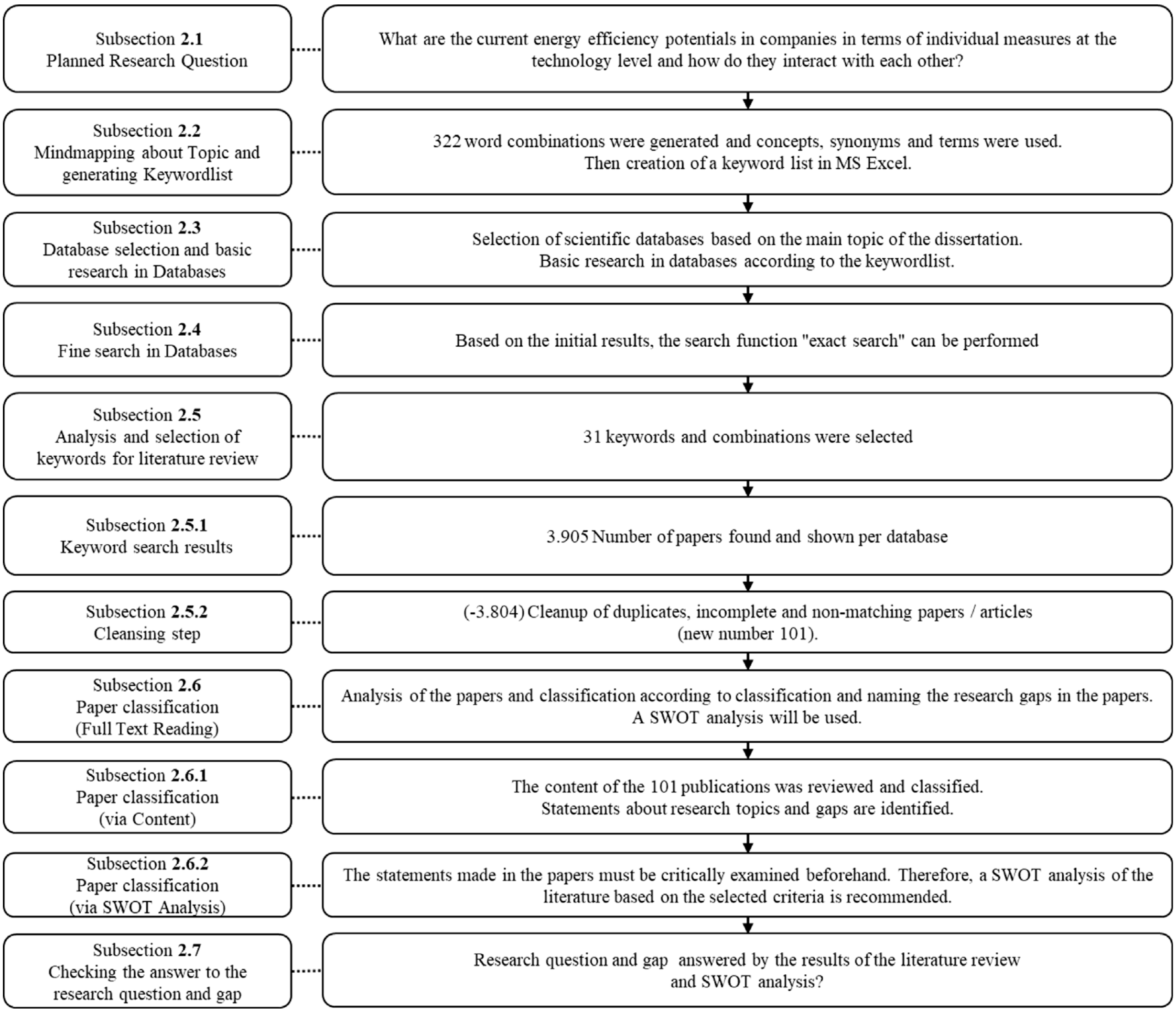

FIGURE 1
Procedure literature review.

lighting replacement or the use of electric drives. If LED lighting replacement has been undertaken, have other measures been implemented or not? This question will be examined by the literature review.

The result of this literature review is to confirm or reject the research gap by the existing literature.

2.2 Mindmapping and keyword list

With the help of a "mind map" software, the search terms were systematically collected and further developed (Kollmann, 2016). In addition, suitable concepts, synonyms, and terms were used. The search terms were developed and agreed upon with energy efficiency experts at an event organized by the Competence Center for Energy Efficiency. Subsequently, the search terms were successively refined. Supplementary Appendix A shows how the search terms are further refined by so-called sub-nodes and sub-sub-nodes. Software is helpful at this point in the work because it refines the search terms further and further to make them suitable for one's research question. This helps in the subsequent database search. The main focus of the database search should be on the topics of energy efficiency and digitization in companies. It is important to find study results that address energy efficiency and digitization measures at the technology level. An extract of the keyword list, see Figure 2, was then created in MS Excel. The overall presentation of the keyword list can be found in Supplementary Appendix B.

Database	google scholar		web of science		scopus		Wiley online library	
Keywords	Search hit	sorting by number 100.000	Search hit	sorting by number 300	Search hit	sorting by number 300	Search hit (2000-2020)	sorting by number 100.000
Dependency on energy efficiency measures	432.000	do not check	281	please check	176	please check	478.268	do not check
Dependency on energy efficiency measures potential	362.000	do not check	48	please check	42	please check	360.368	do not check
Energy saving through energy efficiency	3.79 Mio.	do not check	5.827	do not check	45.499	do not check	89.244	please check
Energy saving through energy efficiency companies	1.12 Mio.	do not check	245	please check	1.928	do not check	36.060	please check
Energy saving through energy efficiency Company	1.8 Mio.	do not check	245	please check	1.928	do not check	36.060	please check
Energy saving through energy efficiency Enterprise	724.000	do not check	104	please check	963	do not check	14.243	please check
Energy saving through energy efficiency firm	648.000	do not check	50	please check	263	please check	22.300	please check
Energy saving through energy efficiency SME	49.100	please check	7	please check	103	please check	2.044	please check
Energy saving through energy efficiency Industry	2.2 Mio.	do not check	698	do not check	5.858	do not check	46.642	please check
Survey of energy efficiency	5.38 Mio.	do not check	5.561	do not check	8.410	do not check	109.517	do not check
Survey of energy efficiency companies	1.4 Mio	do not check	304	do not check	453	do not check	34.338	please check
Survey of energy efficiency Company	2.6 Mio.	do not check	304	do not check	453	do not check	34.338	please check
Survey of energy efficiency Enterprise	985.000	do not check	112	please check	165	please check	14.479	please check
Survey of energy efficiency firm	1.28 Mio.	do not check	125	please check	133	please check	25.681	please check
Survey of energy efficiency SME	77.300	please check	10	please check	51	please check	2.181	please check
Survey of energy efficiency Industry	3.5 Mio.	do not check	604	do not check	1.093	do not check	43.699	please check
Cost reduction energy efficiency	5.3 Mio.	do not check	10.514	do not check	16.412	do not check	249.662	do not check
Economy energy efficiency	3.7 Mio.	do not check	8.958	do not check	14.486	do not check	152.656	do not check
Economy energy efficiency private households	550.000	do not check	16	please check	34	please check	13.764	please check
Economy energy efficiency Company	2.4 Mio.	do not check	450	do not check	866	do not check	59.961	please check
Economy energy efficiency Enterprise	1.66 Mio.	do not check	336	do not check	564	do not check	24.520	please check
Economy energy efficiency firm	1.57 Mio.	do not check	195	please check	216	please check	38.405	please check
Economy energy efficiency SME	83.300	please check	14	please check	54	please check	3.406	please check
Economy energy efficiency Industry	3.2 Mio	do not check	1.868	do not check	3.190	do not check	85.813	please check
Energy efficiency as a driver	2.9 Mio.	do not check	2.284	do not check	3.298	do not check	263.578	do not check
Energy efficiency as an enabler	133.000	do not check	206	please check	468	do not check	225.307	do not check
Energy efficiency decision private households	400.000	do not check	25	please check	25	please check	50	please check
Energy efficiency decision Company	3 Mio.	do not check	619	do not check	968	do not check	56.582	please check
Energy efficiency decision Enterprise	1.6 Mio.	do not check	291	please check	457	do not check	23.894	please check
Energy efficiency decision firm	1.74 Mio.	do not check	254	please check	223	please check	38.915	please check
Energy efficiency decision SME	85.800	please check	16	please check	54	please check	3.161	please check
Energy efficiency decision small enterprises	1.13 Mio.	do not check	67	please check	93	please check	20.784	please check
Energy efficiency decision Industry	3.2 Mio.	do not check	1.329	do not check	2.085	do not check	70.048	please check
Opinion poll energy efficiency companies Potentials	22.000	please check	0	please check	0	please check	2.534	please check
Energy efficiency measures implemented by firm	714.000	do not check	55	please check	29	please check	29.740	please check
Energy efficiency measures implemented by SME	63.800	please check	3	please check	24	please check	2.904	please check
Energy efficiency company potential	4.4 Mio.	do not check	868	do not check	1.723	do not check	85.407	please check
Energy efficiency measures	4.8 Mio.	do not check	43.243	do not check	24.530	do not check	491.151	do not check
Energy efficiency measures firm	1.77 Mio.	do not check	376	do not check	288	please check	50.959	please check
Energy efficiency measures SME	88.900	please check	25	please check	95	please check	4.469	please check
Energy efficiency measures company	2.7 Mio.	do not check	912	do not check	1.279	do not check	87.107	please check
Investment efficiency measures	3.3 Mio	do not check	4.492	do not check	4.268	do not check	166.613	do not check
Investing in energy efficiency	383.000	do not check	1.169	do not check	608	do not check	83.271	please check
Implementation of measures in companies	3.2 Mio.	do not check	3.577	do not check	4.023	do not check	175.470	do not check
Implementation of energy measures in companies	2.5 Mio	do not check	327	do not check	489	do not check	67.077	please check
Implementation of energy measures in enterprises	1.1 Mio.	do not check	152	please check	233	please check	26.290	please check
Energy efficiency measures industry	3.2 Mio.	do not check	3.007	do not check	3.405	do not check	137.474	do not check
Energy efficiency company SME	98.300	please check	28	please check	137	please check	3.094	please check
Energy efficiency company	5 Mio.	do not check	4.466	do not check	10.534	do not check	105.086	do not check
Energy saving SME	52.900	please check	43	please check	177	please check	2.489	please check
Energy consumption companies	1.8 Mio.	do not check	4.000	do not check	8.040	do not check	96.724	please check
Energy consumption Industry	3.77 Mio.	do not check	16.621	do not check	29.182	do not check	143.100	do not check
Energy consumption Enterprise	2 Mio.	do not check	1.842	do not check	4.327	do not check	31.814	please check
Energy consumption firm	1.3 Mio.	do not check	815	do not check	1.101	do not check	57.874	please check
Energy consumption SME	83.300	please check	77	please check	251	please check	4.442	please check
Decision for energy efficiency	3.79 Mio.	do not check	9.349	do not check	15.061	do not check	156.123	do not check
Decision for energy efficiency company	2.8 Mio.	do not check	576	do not check	986	do not check	56.582	please check
Decision for energy efficiency Enterprise	1.69 Mio.	do not check	259	please check	457	do not check	23.894	please check
Decision for energy efficiency Industry	3.3 Mio.	do not check	1.207	do not check	2.085	do not check	70.049	please check
Decision for energy efficiency SME	86.600	please check	15	please check	54	please check	3.164	please check

FIGURE 2
Basic search in databases.

2.3 Database selection and basic research in databases

2.3.1 Database selection

Four scientific databases/publishers were used for the systematic literature search: Google Scholar, Web of Science, Scopus, and Wiley online library. The selection made aims to find a comprehensive and up-to-date number of articles related to the research focus (in the fields of management, engineering, computer science, and industrial engineering). In order to find a large number of articles, Google Scholar has been integrated into the database search. Google Scholar is the largest scientific database with about 400 million documents. In comparison, the Scopus database contains about 75 million documents.

TABLE 1 Fine search.

Database	Google Scholar			Web of Science		Scopus		Wiley online library	
Keywords	Search hit	Search hit "exact search"	Search hit "exact search" 2000–2021	Search hit	Search hit "exact search"	Search hit	Search hit "exact search"	Search hit (2000–2021)	Search hit "exact search"
Dependency on energy efficiency measures potential	362.000	0	0	48	0	42	0	360.368	0
Energy saving through energy efficiency	3,790.000	43	0	5,827	0	45,499	8	89.244	0
Survey of energy efficiency	5,380.000	250	0	5,561	7	8,410	12	109.517	3
Cost reduction energy efficiency	5,300.000	133	0	10,514	3	16,412	8	249.662	1
Economy energy efficiency	3,700.000	1,670	18	8,958	17	14,486	35	152.656	23
Energy efficiency decision	3,900.000	555	3	10,251	8	15,061	35	156.121	3
Energy efficiency measures implemented by companies	1,400.000	3	0	168	0	163	0	46.538	0
Energy efficiency measures SME	88,900	0	0	25	0	95	40	4.469	0
Investment efficiency measures	3,300.000	117	101	4,492	2	4,268	2	166.613	8
Investing in energy efficiency	383.000	2,750	2,480	1,169	22	608	43	83.271	31
Decision for energy efficiency	3,790.000	36	25	9,349	0	15,061	7	156.123	1
Energy efficiency digitization	88,400	3	3	78	0	168	0	11.993	0
Energy efficiency digitalization	37,300	49	38	83	0	183	1	83.311	1
Energy efficiency building automation	749.000	70	60	601	1	1,742	1	33.036	1
Acceptance of energy efficiency	1,400.000	34	22	1,422	4	2,136	4	254.098	1
Energy efficiency acceptance criteria	1,200.000	1	1	79	0	107	0	81.143	0
Raising awareness of energy efficiency	455.000	61	50	344	2	128	2	37.509	1
Empirical study of energy efficiency	3,880.000	40	29	3,119	3	3,223	4	118.991	0
Potential energy efficiency	6,400.000	3,240	2,990	57,456	85	77,827	112	450.750	47
Case study energy efficiency	5,100.000	215	193	22,420	4	29,283	6	417.724	3
energy efficiency hypotheses	1,190.000	9	0	2,758	0	3,056	0	199.604	1
Energy efficiency systematic literature review	2,230.000	2	0	276	0	284	0	137.078	0
Energy efficiency energy management	5,300.000	1,630	1,310	26,961	0	55,392	6	188.023	3
Literature review (of) energy efficiency	5,360.000	144	133	2,771	2	3,399	0	145.556	1
Energy management hypotheses	1,120.000	1	0	1,228	0	1,511	1	145.157	0
Smart meter empirical studies	68,700	0	0	66	0	73	0	4.778	0
Industry 4.0 empirical studies companies	264.000	0	0	74	0	113	0	6.268	0
Smart meter rollout	8,000	1,120	0	72	14	101	29	404	15
Smart meter rollout energy efficiency	7,650	0	0	21	0	22	0	283	0
Smart meter acceptance	70,600	141	1	111	3	92	6	11.174	0
Smart meter energy efficiency	278.000	32	32	982	0	1,200	0	10.041	0
	66,600.550	12,349	7,489	177,284	177	300,145	362	3,911.503	144

TABLE 2 Fine search and search results.

Database	Search hits	Search hits "exact search"	Search hits "exact search" 2000–2021	Publications studied
Google Scholar	66,600.550	12.349	3.222	—
Web of Science	177.284	177	177	—
Scopus	300.145	362	362	—
Wiley online library	3,911.503	144	144	—
1. Results fine search	**70.989.482**	—	—	—
2. Results fine search (exact search hits)	—	**13.032**	—	—
3. Final search results	—	—	**3.905**	—
4. Result after cleaning step	—	—	—	**101**

In addition, a high scientific standard and the topicality of the researched works are important. In addition to these aspects, it is elementary that the articles have been reviewed by experts from the relevant fields in a so-called peer review process. This can be achieved for the selected databases and their contributions. A critical review of the existing articles according to these basic criteria will be carried out.

2.3.2 Basic research in databases

The basic search in the databases was carried out from 15.11.2020 to 27.06.2021. A large number of search hits were found for the 322 search terms generated. Initially, an "IF-THEN FUNCTION" was used to numerically divide the search hits in the databases into "please check" and "do not check" due to their high number of search hits. This had the advantage of removing the search hits with an excessive number of results from the search and subsequently refining the search.

The basic search could be continued on this basis. Samples were drawn from the databases and initial results were collected on the abstracts. These results help to conduct the fine search in a plausible and targeted way.

2.4 Fine search in databases

In order to conduct the fine search in a plausible and targeted way, it is necessary to check in advance, which topic areas have received less attention than others. It is precisely on these topics that a literature search should focus, because it is here that new findings and interpretations can contribute to the research. In reviewing the initial results, the following areas of focus emerged.

The basic research helped to narrow down the topic area and define focal points. Subsequently, as described in Table 1, the fine search was started and the exact search was applied. In this study, exact search means searching with the help of operators. Here, AND, OR, and NOT operators are used in the search to reduce and concretize the search results. In addition, the search results were limited to the years 2000–2021, especially in the large databases (for example, Google Scholar and Wiley online library). Moreover, 31 search terms and combinations were used for the literature search.

This resulted in significantly fewer documents per subject area and database. The selection of search terms is shown below.

2.5 Analysis and selection of keywords for literature review

2.5.1 Keyword search results

The 31 selected search words and combinations from Table 1 result in a solid basis of 71 million documents in total. This is shown in Table 2. It turned out that with the help of an exact search this number could be reduced by 99.98% to about 13,032 documents. This selection could be reduced again by about 70% to about 3,905 documents by refining the search again and partially delimiting database results (e.g., from Google Scholar).

2.5.2 Cleansing step

The process of data cleaning, see Table 2, was applied to the 3,905 hits from the database search. The goal of the data cleaning was to find and eliminate multiple publications in the databases and to evaluate and review the titles and abstracts of the remaining publications for thematic relevance. Overall, the data cleaning resulted in a set of 101 publications, while 3,804 hits from the online search were not followed up because they either appeared multiple times in the sample (as they were listed in more than one of the selected online databases) or because their content was not specifically related to the topic at hand. It was particularly noticeable that energy efficiency and digitization measures were often mentioned in the abstracts or in the titles, but were too theoretical or broad in the studies. Technology level results were rarely listed. These studies were deleted from the literature search.

2.6 Article classification (full-text reading)

Analysis of the articles and classification according to the classification and naming of the research gaps in the articles. A systematic literature review and SWOT analysis were conducted.

2.6.1 Article classification (*via* content)

The content of the 101 publications was reviewed and classified. The full texts were downloaded using literature software and reviewed for the following eight evaluation criteria and the strengths, weaknesses, opportunities, and threats of the publications. The contents were colored differently using the marker function. Subsequently, the contents could be evaluated as described in Section 3. This resulted in the statements on research topics and gaps.

2.6.1.1 Origin and year of publication

The origin of the study shows in which country the topic of energy efficiency in companies is important. The year of publication shows the development of the topic. This allows conclusion to be drawn about the political and economic orientation of the individual countries. Suitable articles from all over the world were found and evaluated.

2.6.1.2 Type of company

It is examined which company sizes were the subject of the studies and works found. Company size plays an important role in the implementation of energy efficiency and digitalization measures. Therefore, it is investigated how large the share of the respective company sizes was. A distinction is made between SMEs and non-SMEs. There are also studies that deal with both SMEs and non-SMEs. The definition of company size is based on the definition of the European Commission (EMPFEHLUNG DER KOMMISSION vom 6. Mai 2003 betreffend die Definition der Kleinstunternehmen sowie der kleinen und mittleren Unternehmen. Europäische Kommission, 2003).

2.6.1.3 Type of industry

It is examined whether the companies investigated are manufacturing or non-manufacturing companies. Manufacturing companies are usually more energy-intensive than non-manufacturing companies. Energy efficiency is worthwhile for all companies, but it is more likely to find economic measures where a lot of energy is consumed with high energy costs.

2.6.1.4 Type of data

The data basis used for the respective studies is to be examined. A distinction is made between primary and secondary data. Were the data collected by the authors themselves or were data from previous surveys and studies used? This distinction is initially value-free, since both sets of data have their raison d'être. Primary and secondary data can, for example, be interpreted and processed in different ways and thus promote a new perspective on a subject area (Adams, 2007).

2.6.1.5 Collection method

The collection method of the data is a meaningful tool for the literature review. It sheds light on the quality of the data. It is examined by which methods the respective author comes to the data used by him. An absolute and relative evaluation should take place.

2.6.1.6 Number of participants

Studies are available in which the data collection was generated *via* the participants. The absolute number of participants per study, the average number of participants, and the range should be presented.

2.6.1.7 Type of data collection (subjective or objective)

The distinction between subjective and objective data collection always depends on the respective perspective. Therefore, it should be noted that subjective data collection in this literature review means data collection that has been carried out by the company itself, that is, if the author of a study sends a questionnaire to the company and the company fills it out, then it is subjective data collection.

The danger with subjective data collection is that the same potential (whether economic or technical) may be assessed differently when evaluating energy efficiency potential. This can result in a study losing its actual validity. In practice, this means that investments in a measure are not made.

In the literature review, we speak of objective data collection when the data collection is carried out by an expert. This can be performed on site or by interview. The expert always proceeds in the same way and can make an equivalent evaluation from his empirical values.

2.6.1.8 Evaluation method

The evaluation methods used in the studies and articles considered are examined. The most important evaluation methods are listed and evaluated. An absolute and relative evaluation will be made.

The individual statistical evaluation methods covered in the considered studies and articles are to be counted together as statistical evaluation. The evaluation methods were, for example, linear regression, Mann–Whitney U-test, logit models, probit models, structural equation models, hypothesis tests, nonparametric techniques such as data envelopment analysis (DEA), and parametric techniques such as stochastic frontier analysis (SFA) and corrected ordinary least square (COLS) to measure efficiency, multivariate statistics, Gretl software, and Pearson's coefficient.

The results of the eight evaluation criteria listed are presented in Section 3.1.

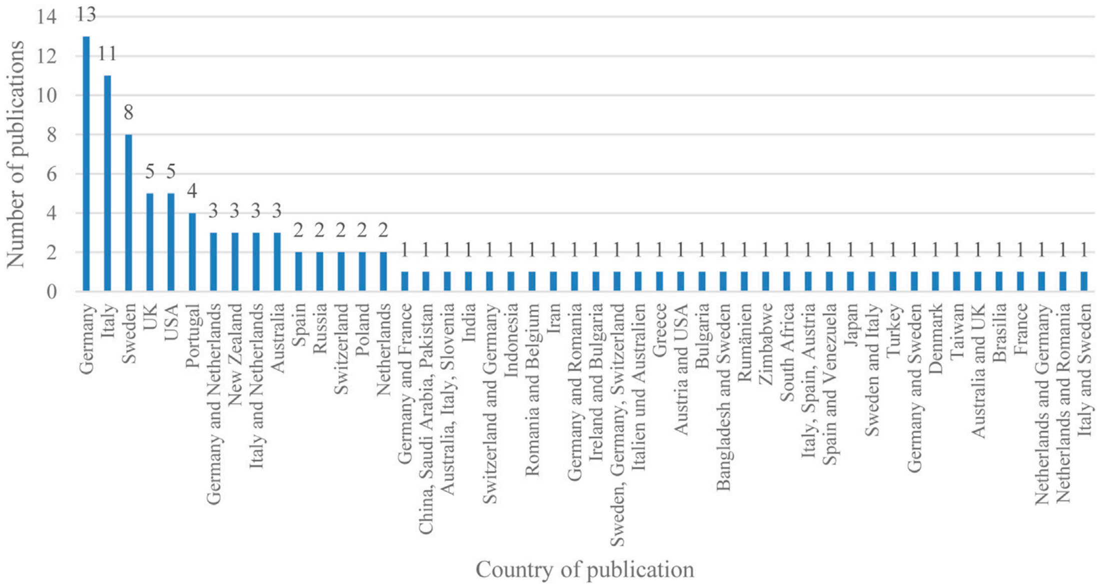

FIGURE 3
Countries of studied publications.

2.6.2 Article classification (*via* strengths–weaknesses–opportunities–threats analysis)

The statements made in the articles must be critically examined beforehand. Therefore, a SWOT analysis of the literature based on the selected criteria is recommended.

SWOT analysis is a method of strategic planning (Weihrich, 1982; Hill and Westbrook, 1997) and is an acronym for strengths, weaknesses, opportunities, and threats, which characterize the dimensions along with the entities or situations.

The analysis should be performed as follows. The evaluation of each of the authors' statements and findings will be conducted in relation to the research question considered in this literature review. For example, technology level measures, the industry, size, and number of companies studied in the studies, and the method of data collection are important. The analysis should help define and flesh out one's research questions and gaps.

The results of the SWOT analysis performed are included in Section 3.2.

2.7 Checking the answer to the research question and gap

In this final step 2.7 of the method, it is tested whether the research question and gap can be answered and closed by the results of the literature review and SWOT analysis. If the research question can be answered, it is proven that the research gap has already been considered and answered by another research. Nevertheless, in this case, another work in the same direction with a different focus can be purposeful.

The results of the considerations made in subsection 2.7 are discussed and interpreted in Section 4.

3 Results

3.1 Results of the literature review

3.1.1 Origin and year of publication

Figure 3 shows the number of publications by country. Most of the 101 articles reviewed were from Germany (13 articles) followed by Italy (11 articles) and Sweden (eight articles). Together, these articles account for about one-third of all the articles in this literature review. If the participation of these countries in other studies and articles is added, the number increases to 22 for Germany, 19 for Italy, and 13 for Sweden, resulting in a total share of over 50% of the articles reviewed (54 articles).

Figure 4 shows the number of publications studied by year of publication. The oldest publication is from 1994, in which the energy efficiency gap was defined for the first time by Jaffe and Stavins (1994). Until today, a positive trend (dotted line) can be derived. Increasingly, more studies on energy efficiency in companies are successively elaborated.

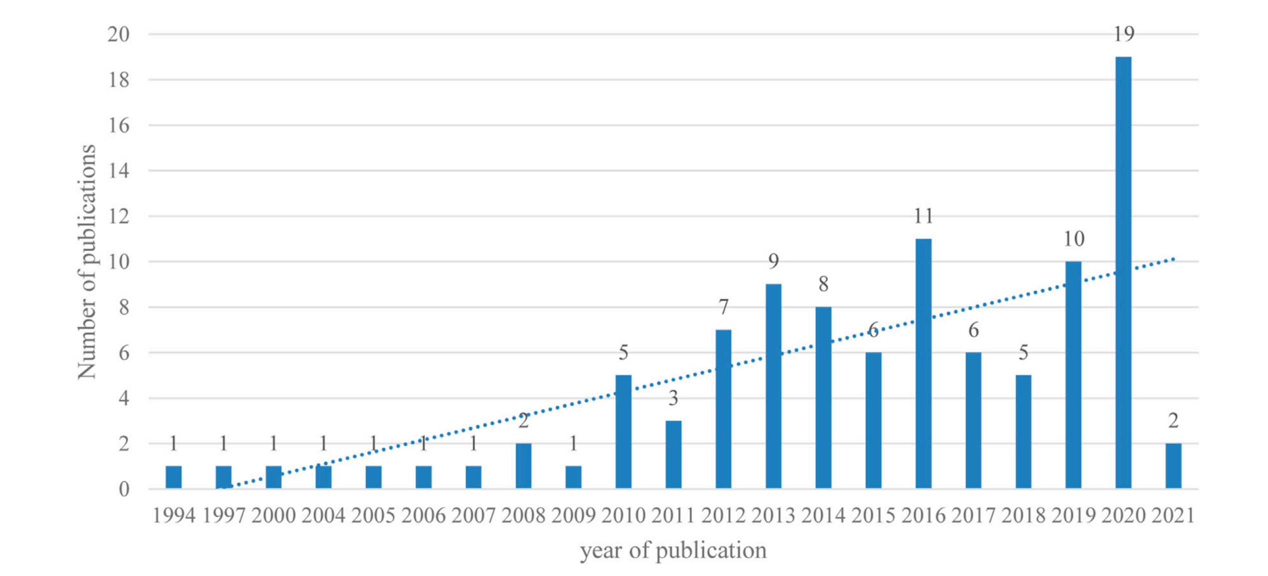

FIGURE 4
Year of studied publications.

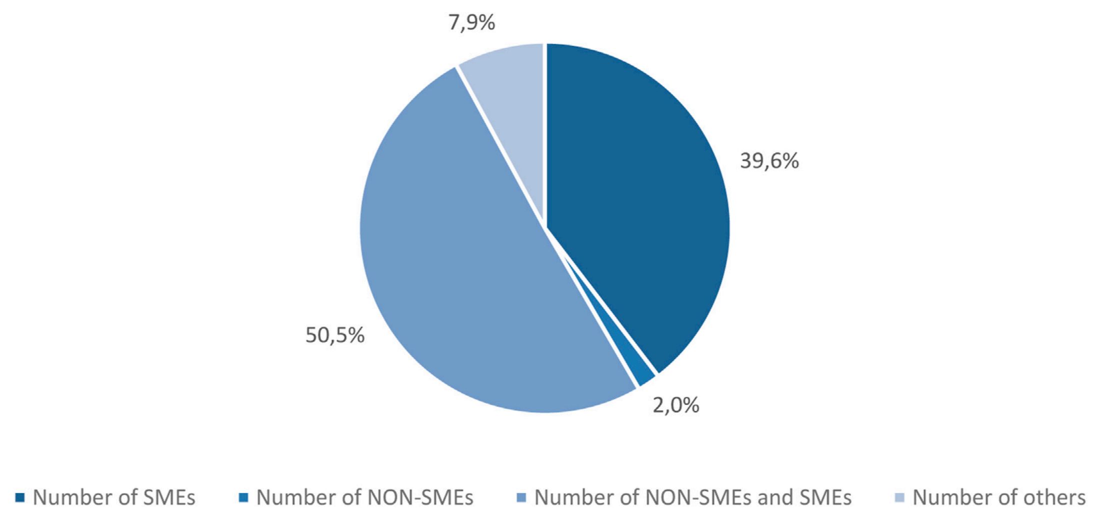

FIGURE 5
Type of company of studied publications.

3.1.2 Type of company

Figure 5 shows the classification of the types of companies in the publications studied. Of the total 101 articles, 50.5% deal with non-SME companies, with 39.6% dealing with SME companies. In addition, 8% of the publications include, for example, 5x private households + 1x public ownership + 2x other institution/organization. The remaining 2% deal with both SMEs and non-SMEs. Table 3 shows the classification of the types of companies in the publications studied, sorted by the authors.

3.1.3 Type of industry

Figure 6 shows the classification of the industries of the publications studied. Moreover, 65% of the examined article deals with manufacturing companies. These companies usually have higher energy consumption than non-manufacturing companies. Among them, industries such as foundries (Thollander et al., 2013), the wood industry (Bell et al., 2014), the iron and steel industry (Brunke et al., 2014), metal processing companies (Cagno et al., 2014), automotive industry, cement,

TABLE 3 Classification of articles by type of company.

Type of company	Author
SME	Anderson and Newell (2004), Parker et al. (2009), Fernández-Viñé et al. (2010), Jochem et al. (2010), Palm and Thollander (2010), Fleiter et al. (2012b), Thiede et al. (2012), Trianni and Cagno (2012), Cagno and Trianni (2013), Kostka et al. (2013), Thiede et al. (2013), Trianni et al. (2013), Williams and Schaefer (2013), Bell et al. (2014), Trianni et al. (2014b), Cagno et al. (2014), Cagno and Trianni (2014), Semkov et al. (2014), Catarino et al. (2015), Leloux et al. (2015), Allarton (2016), Meath et al. (2016), Muzamwese (2016), Rahbauer et al. (2016), Solberg Hjorth and Brem (2016), Tallini and Cedola (2016), Trianni et al. (2016), Fresner et al. (2017), Hilger et al. (2018), Krutwig (2019), Schleich and Fleiter (2019), Chen et al. (2020), Cunha et al. (2020), Giraudet, (2020), Hung and Chu (2020), König et al. (2020), Palm and Backman (2020), Özbuğday et al. (2020), Nigohosyan et al. (2021), Trianni et al. (2021)
Non-SME	Finster and Hernke (2014), Stefana et al. (2019)
SME + non-SME	Andrews and Johnson (2016), Backlund et al. (2012), Brunke et al. (2014), Cagno et al. (2013), Cagno et al. (2019), Chiaroni et al. (2016), Cooremans (2012), Costa-Campi et al. (2015), del Río González (2005), Fawcett and Hampton (2020), Fiedler and Mircea (2012), Fleiter et al. (2012a), Fleiter et al. (2011), Hampton (2019), Haq and Jacobsen (2018), Hasan et al. (2019), Henriques and Catarino (2016), Hertel and Menrad (2016), Hoyer et al. (2020), Kinelski (2020), König (2020), Mickovic and Wouters (2020), Morais et al. (2020), Olsthoorn et al. (2017), Perroni et al. (2017), Phylipsen et al. (1997), Ponomareva et al. (2019), Pye and McKane (2000), Rohdin and Thollander (2006), Sa et al. (2015), Safarzadeh et al. (2020), Sardianou (2008), Schlomann and Schleich (2015), Schulze et al. (2018), Shinkevich et al. (2020), Soepardi et al. (2019), Stephenson et al. (2015), Stephenson et al. (2010), Sudhakara Reddy (2013), Thollander (2010), Thollander et al. (2013), Thollander et al. (2007), Thollander and Ottosson (2008), Trianni et al. (2014a), Trianni et al. (2017), Wagner et al. (2020), Wakabayashi and Arimura (2020), Williams and McKane (2013), Wohlfarth et al. (2018), Wolniak et al. (2020), Zierler et al. (2017)
Others	Jaffe and Stavins (1994), Hwang and Colyvas (2011), Olmos et al. (2011), Muresan and Attia (2017), Zhang et al. (2018), Hesselink and Chappin (2019), Samuels and Booysen (2019), Camarasa et al. (2020)

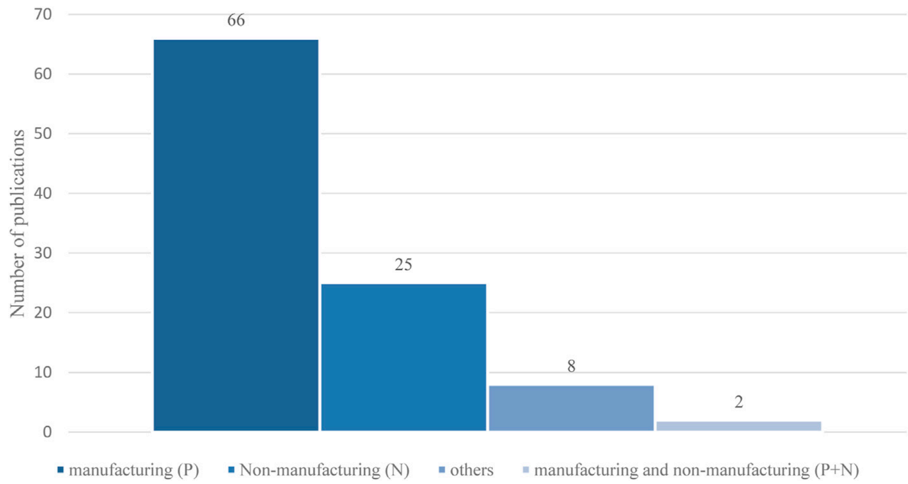

FIGURE 6
Type of the industry of studied publication.

iron and steel, pulp and paper (Chiaroni et al., 2016), and food industry (Catarino et al., 2015; Solberg Hjorth and Brem, 2016) are examined. These are among the most energy-intensive industries.

Moreover, 25% of the studied articles deal with non-manufacturing companies. These companies are less often in focus than manufacturing companies due to their lower energy consumption.

3.1.4 Type of data

When looking at the data used, there is a clear tendency toward secondary data (see Figure 7). Secondary data were used more

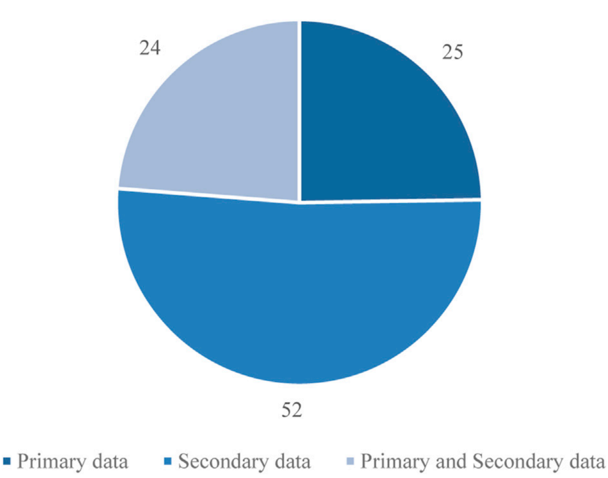

FIGURE 7
Type of data of studied publications.

frequently. Looking at the absolute number of cases, 51% of the data used came from secondary data and 25% from primary data.

If one looks purely at the number of pure primary data and the pure number of secondary data without the paper using both data, the proportion of secondary data increases relatively to 68%. This underlines the high data usage of about two-thirds of secondary data of the 101 articles considered. Table 4 shows the classification of the types of data in the studied publications sorted by authors.

3.1.5 Collection method

The 101 articles are divided into three types of methods (see Figure 8). The most frequent method is the literature search with 59% (60 articles). Also, frequently used was the possibility to conduct a questionnaire/survey (online or telephone). This was used in 35% (35 articles). Another 4% (four articles) were identified in which the authors or experts collected data directly from the companies. Two more articles were examined that used data from previous studies and projects, these are not included in the figure.

3.1.6 Number of participants

Figure 9 shows the number of participants in the publications studied. The participants of the 35 articles that used the questionnaire/survey method were examined. A range from four participants (Solberg Hjorth and Brem, 2016) to 2,440 participants (Olsthoorn et al., 2017) was possible. The average number of participants can be given as about 294 participants. As can be seen in Table 5, 6 publications have a higher average number of participants and 29 publications have a lower average number of participants to report.

3.1.7 Type of data collection

The two collection methods, questionnaire/survey and on site at the companies, are to be tested for subjectivity of data collection. Of the 101 articles, 49 articles used primary data. The 35 articles that used the questionnaire/survey method were all completed by the companies themselves. Therefore, these data are 100% subjectively collected and account for

TABLE 4 Classification of articles by type of data.

Type of data	Author
Primary data	Bell et al. (2014), Brunke et al. (2014), Catarino et al. (2015), Cunha et al. (2020), del Río González, (2005), Fresner et al. (2017), Haq and Jacobsen (2018), Hasan et al (2019), Hertel and Menrad (2016), Hilger et al. (2018), Hung and Chu (2020), Kostka et al. (2013), Morais et al. (2020), Palm and Backman (2020), Semkov et al. (2014), Soepardi et al. (2019), Thollander et al. (2013), Thollander et al. (2007), Thollander and Ottosson (2008), Trianni et al. (2016), Trianni et al. (2014b), Trianni et al. (2013), Wagner et al. (2020), Williams and Schaefer (2013), Zierler et al. (2017)
Secondary data	Jaffe and Stavins (1994), Phylipsen et al. (1997), Pye and McKane (2000), Anderson and Newell (2004), Sardianou (2008), Parker et al. (2009), Palm and Thollander (2010), Stephenson et al. (2010), Thollander (2010), Fleiter et al. (2011), Hwang and Colyvas (2011), Olmos et al. (2011), Fleiter et al. (2012a), Backlund et al. (2012), Fleiter et al. (2012b), Fiedler and Mircea (2012), Thiede et al. (2012), Cagno et al. (2013), Sudhakara Reddy (2013), Thiede et al. (2013), Williams and McKane (2013), Trianni et al. (2014a), Finster and Hernke (2014), Stephenson et al. (2015), Andrews and Johnson (2016), Meath et al. (2016), Muzamwese (2016), Rahbauer et al. (2016), Tallini and Cedola (2016), Muresan and Attia (2017), Olsthoorn et al. (2017), Perroni et al. (2017), Trianni et al. (2017), Wohlfarth et al. (2018), Hesselink and Chappin (2019), Krutwig (2019), Ponomareva et al. (2019), Schleich and Fleiter (2019), Stefana et al. (2019), Camarasa et al. (2020), Chen et al. (2020), Fawcett and Hampton (2020), Giraudet (2020), Hoyer et al. (2020), Kinelski (2020), Mickovic and Wouters (2020), Safarzadeh et al. (2020), Shinkevich et al. (2020), Wakabayashi and Arimura (2020), Wolniak et al. (2020), Özbuğday et al. (2020), Nigohosyan et al. (2021)
Primary and secondary data	Rohdin and Thollander (2006), Fernández-Viñé et al. (2010), Jochem et al. (2010), Cooremans (2012), Trianni and Cagno (2012), Cagno and Trianni (2013), Cagno et al. (2014), Cagno and Trianni (2014), Costa-Campi et al. (2015), Leloux et al. (2015), Sa et al. (2015), Schlomann and Schleich (2015), Allarton (2016), Chiaroni et al. (2016), Henriques and Catarino (2016), Solberg Hjorth and Brem (2016), Schulze et al. (2018), Zhang et al. (2018), Cagno et al. (2019), Hampton (2019), Samuels and Booysen (2019), König (2020), König et al. (2020), Trianni et al. (2021)

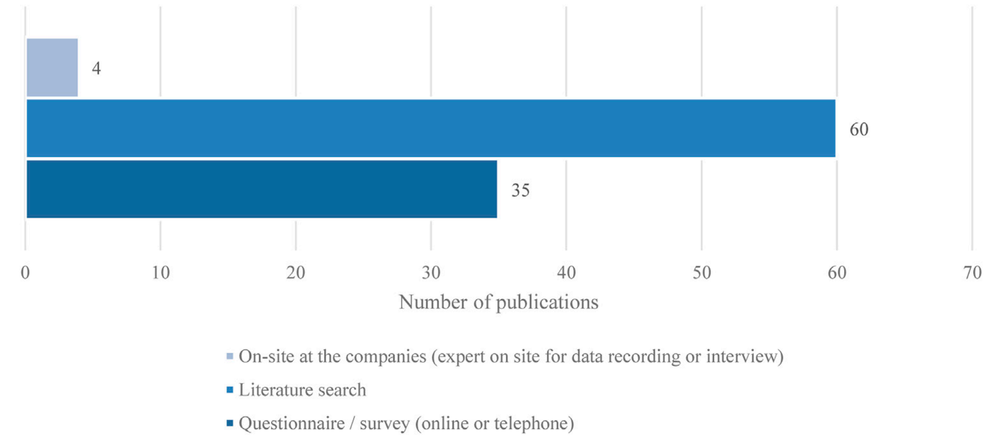

FIGURE 8
Collection method of the publications studied.

about 71% of the primary data. This means that 71% of all primary data is based on a subjective assessment by companies. This is to be critically questioned, since due to the subjectivity, even exactly the same situations can be assessed completely different with regard to energy efficiency potentials or measures. This depends on the economic and political situation in the countries as well as the individual know-how of the surveyed employees in the companies.

Only in four articles were the primary data collected by experts on site in the companies. These four articles correspond to about 8% of the total primary data.

3.1.8 Evaluation method

Figure 10 shows the type of evaluation method used for the publications studied. Also, 39 articles were evaluated by means of literature analysis. In addition, 37 articles dealt with the statistical methods mentioned in 2.6.1.

Moreover, 22 of the articles were examined conducted and evaluated as case studies. Table 6 shows the type of evaluation method of the studied publications sorted by authors.

3.2 Strengths–weaknesses–opportunities–threats analysis of the articles reviewed

The SWOT analysis takes up the main statements and most important results of the examined articles with reference to the own research question and divides them into four categories: strengths, weaknesses, opportunity, and threats.

The research studies reviewed are intended to provide evidence that the energy efficiency potential in companies has been underrepresented at the technology level and that the interactions of these potentials and measures can make an important contribution to energy efficiency research.

Table 7 provides a comprehensive overview of the publications covered in the SWOT analysis. It shows which publication was used in which category of the SWOT analysis. The following summarizes the results of the SWOT analysis.

3.2.1 Strengths

- Many of the studies have a good data basis and a high number of participants (Sardianou, 2008; Jochem et al., 2010; Cooremans, 2012; Kostka et al., 2013; Trianni et al., 2014a; Catarino et al., 2015; Schlomann and Schleich, 2015; Allarton, 2016; Chiaroni et al., 2016; Hertel and Menrad, 2016; Meath et al., 2016; Trianni et al., 2016; Haq and Jacobsen, 2018; Wohlfarth et al., 2018; Hampton, 2019; Schleich and Fleiter, 2019; Hung and Chu, 2020; König et al., 2020; Palm and Backman, 2020) in the methods used. This results in a high informative value and enables transferability to other areas.
- The author (Fresner et al., 2017) collected data from 280 companies from Austria, Bulgaria, Cyprus, Italy, Romania, Slovakia, and Spain on site in the companies. In the process, the potential of the companies were recorded at the technology level.
- Starting from the feasibility assessments, the study aims to establish a possible correlation between energy efficiency indicators and a limited number of power system parameters related to production, operation, and electricity consumption (Tallini and Cedola, 2016).
- Within the scope of this study, a positive effect of energy management systems (EnMS) on energy efficiency was proven (Olsthoorn et al., 2017).

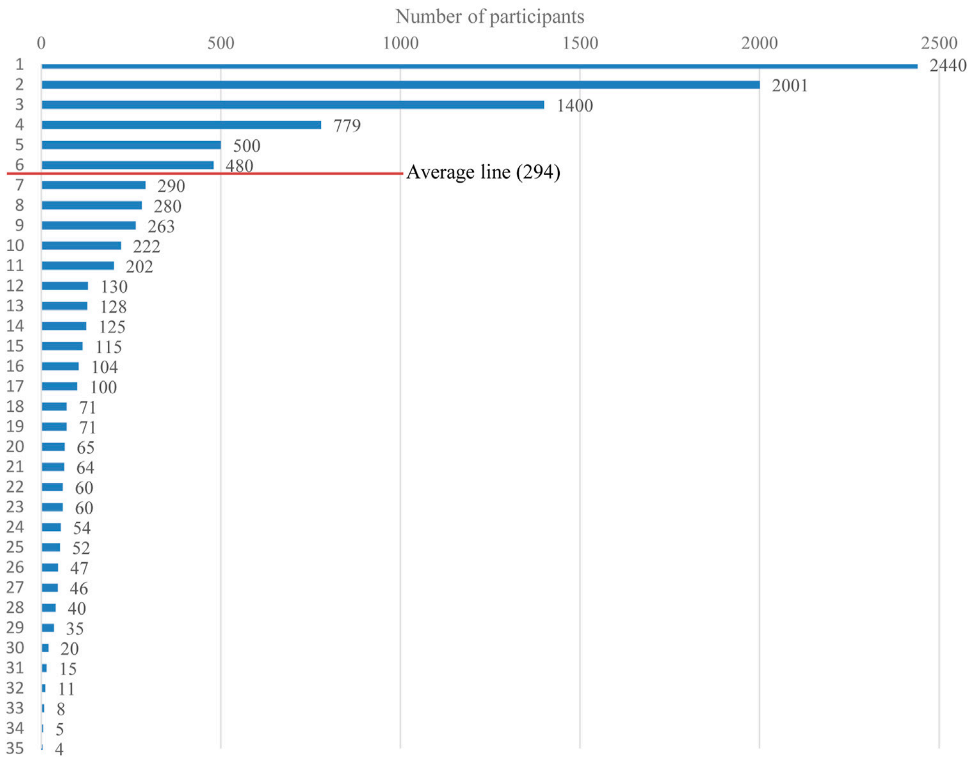

FIGURE 9
Number of participants of the publications studied.

- The results of the study provide strong empirical evidence that EnMS has a positive relationship with the energy efficiency performance of firms (Schulze et al., 2018).
- The study highlights potentials on the technology level and studies are presented in which, for example, the measures for lighting and compressed air occur. Furthermore, it is shown that the use of management systems is accompanied by an improvement and implementation of measures (Stefana et al., 2019).
- The article reviews studies of corporate energy behavior and suggests areas for additional social science research (Andrews and Johnson, 2016).
- The positive and negative effects of energy efficiency measures (EEM) on other areas are examined (Trianni et al., 2021).
- Energy management and related practices are cited as one of the most important tools for improving energy efficiency in manufacturing companies (Sa et al., 2015).
- Combine investments in energy-efficient technologies with the promotion of good energy management practices. The authors argue that the inclusion of energy management components is important (Backlund et al., 2012).
- Analysis of the propensity of Portuguese SMEs to adopt EEMs. The barriers that lead to the decision of not adopting EEMs are also examined (Cunha et al., 2020).
- This article has made it clear that energy policy needs to focus much more on SMEs. They are largely overlooked by energy policy and therefore do not benefit from energy saving opportunities or contribute sufficiently to reducing carbon emissions (Fawcett and Hampton, 2020).
- Challenges and benefits of ISO 50001 implementation in an industrial environment will be presented, as well as the methodology and systematic approach, but also tools such as energy control systems and measurement devices that are useful to achieve energy transparency (Fiedler and Mircea, 2012).
- Authors propose a classification scheme for EEMs in the industry to provide a better understanding of their adoption by industrial companies and to help in the

TABLE 5 Classification of articles by number of participants.

Number of participants	Number of articles
Higher than average (>294)	6
Lower than average (<294)	29

TABLE 6 Classification of articles by research approach.

Evaluation method	Author
Literature review	Jaffe and Stavins (1994), Phylipsen et al. (1997), Pye and McKane (2000), Sardianou (2008), Parker et al. (2009), Palm and Thollander (2010), Stephenson et al. (2010), Thollander (2010), Fleiter et al. (2011), Hwang and Colyvas (2011), Olmos et al. (2011), Fleiter et al. (2012a), Backlund et al. (2012), Fiedler and Mircea (2012), Thiede et al. (2012), Cagno et al. (2013), Sudhakara Reddy, (2013), Williams and McKane (2013), Trianni et al. (2014a), Finster and Hernke (2014), Stephenson et al. (2015), Andrews and Johnson (2016), Muzamwese (2016), Rahbauer et al. (2016), Muresan and Attia (2017), Trianni et al. (2017), Wohlfarth et al. (2018), Zhang et al. (2018), Stefana et al. (2019), Chen et al. (2020), Fawcett and Hampton (2020), Giraudet (2020), Hoyer et al. (2020), Kinelski (2020), Mickovic and Wouters (2020), Safarzadeh et al. (2020), Nigohosyan et al. (2021), Trianni et al. (2021)
Statistical methods	Anderson and Newell (2004), Fernández-Viñé et al. (2010), Jochem et al. (2010), Fleiter et al. (2012b), Cooremans (2012), Trianni and Cagno (2012), Kostka et al. (2013), Williams and Schaefer (2013), Brunke et al. (2014), Trianni et al. (2014b), Catarino et al. (2015), Costa-Campi et al. (2015), Leloux et al. (2015), Schlomann and Schleich (2015), Allarton (2016), Henriques and Catarino (2016), Hertel and Menrad (2016), Tallini and Cedola (2016), Fresner et al. (2017), Olsthoorn et al. (2017), Perroni et al. (2017), Zierler et al. (2017), Haq and Jacobsen (2018), Hilger et al. (2018), Schulze et al. (2018), Hampton (2019), Hasan et al. (2019), Krutwig (2019), Ponomareva et al. (2019), Schleich and Fleiter (2019), Camarasa et al. (2020), Hung and Chu (2020), Morais et al. (2020), Shinkevich et al. (2020), Wakabayashi and Arimura (2020), Wolniak et al. (2020), Özbuğday et al. (2020)
Case study	Bell et al. (2014), Cagno et al. (2019), Cagno and Trianni (2013), Cagno and Trianni (2014), Cagno et al. (2014), del Río González (2005), König (2020), König et al. (2020), Meath et al. (2016), Palm and Backman (2020), Rohdin and Thollander (2006), Sa et al. (2015), Samuels and Booysen (2019), Semkov et al. (2014), Soepardi et al. (2019), Solberg Hjorth and Brem (2016), Thiede et al. (2013), Thollander et al. (2013), Thollander et al. (2007), Thollander and Ottosson (2008), Trianni et al. (2013), Wagner et al. (2020)
Others	Chiaroni et al. (2016), Trianni et al. (2016), Hesselink and Chappin (2019)

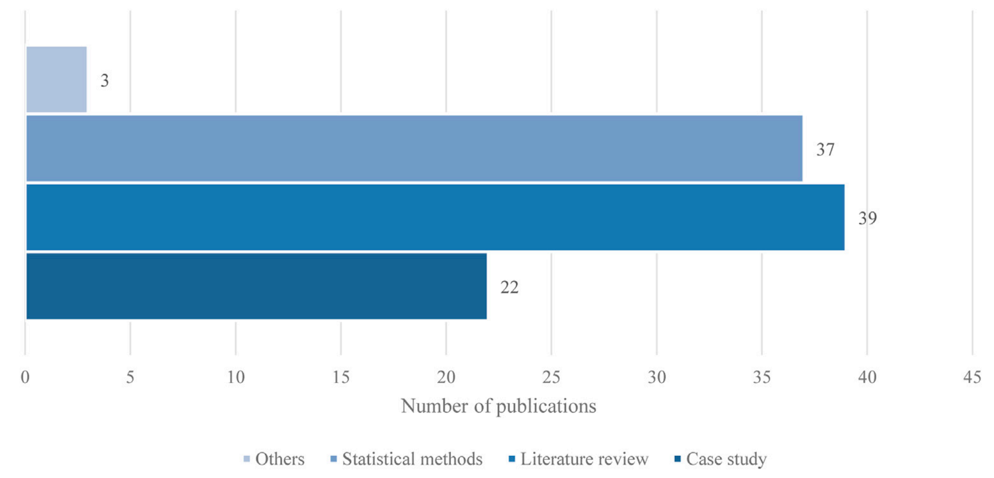

FIGURE 10
Energy efficiency in companies—type of evaluation method.

selection and design of energy efficiency strategies (Fleiter et al., 2012a).

- Evidence that quality of energy audits influences the adoption of energy efficiency measures. On-site audits were conducted by an expert (Fleiter et al., 2012b).
- Information deficits and information barriers for energy savings are the subjects of the investigation (Giraudet, 2020).
- Investigation on the technology level with measurements has taken place (Morais et al., 2020).
- Analysis of effects of digitization on energy efficiency (Shinkevich et al., 2020).
- The authors develop a theoretical approach to understand energy behavior holistically and to achieve greater adoption of energy-efficient behaviors (Stephenson et al., 2010; Stephenson et al., 2015).

TABLE 7 Comprehensive SWOT-table of the studies reviewed.

Study	Strengths	Weaknesses	Opportunities	Threats
Allarton (2016)	X	X		
Chiaroni et al. (2016)	X	X		
Catarino et al. (2015)	X	X		
Hampton (2019)	X			
Haq and Jacobsen (2018)	X			
Hertel and Menrad (2016)	X	X		
Hung and Chu (2020)	X			
Wohlfarth et al. (2018)	X			
Trianni et al. (2016)	X			
Cooremans (2012)	X			
Jochem et al. (2010)	X		X	
König et al. (2020)	X		X	
Kostka et al. (2013)	X			
Meath et al. (2016)	X			
Palm and Backman (2020)	X		X	
Sardianou (2008)	X			
Schleich and Fleiter (2019)	X		X	
Schlomann and Schleich (2015)	X			
Trianni et al. (2014b)	X	X		
Fresner et al. (2017)	X			
Tallini and Cedola (2016)	X			
Olsthoorn et al. (2017)	X		x	
Schulze et al. (2018)	X			
Stefana et al. (2019)	X		x	
Andrews and Johnson (2016)	X			
Trianni et al. (2021)	X		x	
Sa et al. (2015)	x			
Backlund et al. (2012)	X	X		
Cunha et al. (2020)	X			X
Fawcett and Hampton (2020)	X			
Fiedler and Mircea (2012)	X			
Fleiter et al. (2012a)	X	X		
Fleiter et al. (2012b)	X			
Giraudet (2020)	X			
Morais et al. (2020)	X	X		X
Shinkevich et al. (2020)	X			
Stephenson et al. (2010)	X			
Stephenson et al. (2015)	x			
Thollander (2010)	X			
Safarzadeh et al. (2020)	X			
Hesselink and Chappin (2019)	X			
Olmos et al. (2011)	X			
Jaffe and Stavins (1994)	X			
Phylipsen et al. (1997)		X		
Anderson and Newell (2004)		X		
Bell et al. (2014)		X		
Cagno and Trianni (2014)		X		
Cagno et al. (2014)		X		

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TABLE 7 (*Continued*) Comprehensive SWOT-table of the studies reviewed.

Study	Strengths	Weaknesses	Opportunities	Threats
Chen et al. (2020)		X		
del Río González (2005)		X		
Costa-Campi et al. (2015)		X		
Finster and Hernke (2014)		X		
Fleiter et al. (2011)		X		
Hasan et al. (2019)		X		
Henriques and Catarino (2016)		X		
Wolniak et al. (2020)		X		
Thollander et al. (2007)		X		
Mickovic and Wouters (2020)		X		
Palm and Thollander (2010)		X		
Parker et al. (2009)		X		
Ponomareva et al. (2019)		X		
Rohdin and Thollander (2006)		X		
Soepardi et al. (2019)		X		
Solberg Hjorth and Brem (2016)		X		
Thiede et al. (2012)		X		
Thiede et al. (2013)		X		
Thollander et al. (2013)		X		
Thollander and Ottosson (2008)		X		
Williams and McKane (2013)		X		
Wagner et al. (2020)		X	X	
Trianni et al. (2017)		X		
Sudhakara Reddy (2013)		X		
Krutwig (2019)		X		
Hilger et al. (2018)			X	
König, (2020)			X	
Rahbauer et al. (2016)			X	
Leloux et al. (2015)			X	
Kinelski (2020)			X	
Hoyer et al. (2020)			X	
Özbuğday et al. (2020)			X	
Nigohosyan et al. (2021)			X	
Muzamwese (2016)			X	
Cagno et al. (2019)			X	
Cagno and Trianni (2013)			X	
Fernández-Viñé et al. (2010)			X	
Trianni et al. (2014a)			X	
Trianni and Cagno (2012)			X	
Brunke et al. (2014)			X	
Cagno et al. (2013)			X	
Perroni et al. (2017)			X	
Pye and McKane (2000)			X	
Semkov et al. (2014)			X	
Camarasa et al. (2020)			X	
Muresan and Attia (2017)			X	
Zierler et al. (2017)				X
Williams and Schaefer (2013)				X

(Continued on following page)

TABLE 7 (*Continued*) Comprehensive SWOT-table of the studies reviewed.

Study	Strengths	Weaknesses	Opportunities	Threats
Wakabayashi and Arimura (2020)				X
Zhang et al. (2018)				X
Samuels and Booysen (2019)				X
Hwang and Colyvas (2011)				X
Trianni et al. (2013)				X

- The 15 theoretical barriers are divided into three different categories, depending on the system complexity of the respective barrier (Thollander, 2010).
- In this article, the authors review and rank the major academic studies that have addressed the environmental and economic aspects of industrial energy efficiency programs (IEEPs) based on a systematic review (Safarzadeh et al., 2020).
- This study provides a systematic review of agent-based modeling studies for household energy efficiency adoption. Transfer to other actors would be possible (Hesselink and Chappin, 2019).
- The use of advanced indirect feedback on consumption behavior, critical peak pricing, and simple time-of-use tariffs is being encouraged (Olmos et al., 2011).
- The authors describe and define the energy efficiency gap (Jaffe and Stavins, 1994).

3.2.2 Weaknesses

- Most studies deal only with manufacturing and production companies (Phylipsen et al., 1997; Allarton, 2016; Anderson and Newell, 2004; Bell et al., 2014; Cagno and Trianni, 2014; Cagno et al., 2014; Catarino et al., 2015; Chen et al., 2020; Chiaroni et al., 2016; del Río González, 2005; Costa-Campi et al., 2015; Finster and Hernke, 2014; Fleiter et al., 2012a; Fleiter et al., 2011; Hasan et al., 2019; Henriques and Catarino, 2016; Hertel and Menrad, 2016; Wolniak et al., 2020; Thollander et al., 2007; Mickovic and Wouters, 2020; Morais et al., 2020; Palm and Thollander, 2010; Parker et al., 2009; Ponomareva et al., 2019; Rohdin and Thollander, 2006; Soepardi et al., 2019; Solberg Hjorth and Brem, 2016; Thiede et al., 2012; Thiede et al., 2013; Thollander et al., 2013; Thollander and Ottosson, 2008; Trianni et al., 2014a; Williams and McKane, 2013; Wagner et al., 2020; Trianni et al., 2017). These are often energy-intensive.
- Measures are usually not considered on a technological level, but on a more abstract and theoretical level such as obstacles and barriers.
- If measures are recorded at the technology level, no relationships between the individual measures have been examined to date (Sudhakara Reddy, 2013; Krutwig, 2019).
- Energy management practices are still too little in focus (Backlund et al., 2012).

3.2.3 Opportunities

- When it comes to data collection, more experts could go into companies and do on-site collection and assessment (Hilger et al., 2018; König, 2020; Palm and Backman, 2020; Wagner et al., 2020).
- Many studies that previously focused on manufacturing companies can be extended to other industries. Small and medium-sized enterprises (SMEs) are now also being examined more frequently in studies (Leloux et al., 2015; Muzamwese, 2016; Rahbauer et al., 2016; Hoyer et al., 2020; Kinelski, 2020; König et al., 2020; Özbuğday et al., 2020; Nigohosyan et al., 2021).
- A consideration at the technology level should be conducted, and the relationships of the individual measures to each other.
- The authors recommend analyzing a single company in relation to several different energy efficiency measures (EEMs) to understand the potential synergies (either positive or negative) that result from adopting a number of EEMs (Cagno et al., 2019).
- Future research should further explore factors that characterize supply chain complexity and the relationship between energy efficiency drivers and a company's innovation characteristics (Cagno and Trianni, 2013).
- The study shows that it is important to consult and examine the opinion of an expert in a company. The statements of the employees should be critically scrutinized and plausibility checked (Fernández-Viñé et al., 2010).
- The study does not show which individual measures could influence each other and thus have a positive impact; this would be a research requirement (Stefana et al., 2019).
- Further correlations between individual efficiency measures should be investigated (Trianni et al., 2021).
- The correlation and influence of different measures can be carried out in the form of further case studies (Stefana et al., 2019).
- The authors are not aware of any study to date in which utility ownership (e.g., heating systems) influences EEM

adoption (optimization or replacement) (Olsthoorn et al., 2017).
- The authors have applied this scheme to a wide range of EEMs in cross-cutting technologies, that is, motors, compressed air, lighting, and HVAC systems. First, the analysis provides a relevant contribution to structuring and sharing knowledge about EEMs, and thus to understanding the barriers that currently hinder their adoption (Trianni et al., 2014a).
- In addition, an important contribution to this research could be to evaluate the existing differences between perceived and actual barriers (information, skills, and awareness) and thus investigate them through a deeper analysis (Trianni and Cagno, 2012).
- Overview of studies on energy efficiency and management in companies. The authors confirm that an ENMS is a driver for the implementation of measures. A positive effect can be interpreted but without correlation between the individual measures (Brunke et al., 2014).
- Future research is needed to develop a taxonomy for drivers of energy efficiency and then to unfold the relationships between drivers and barriers (Cagno et al., 2013).
- Networks and best practices help companies understand and improve their energy efficiency (Jochem et al., 2010).
- The authors address the question of the relationship between the efficiency of companies and the implementation of energy efficiency measures (Perroni et al., 2017).
- Study examines how to increase management understanding in the context of energy efficiency decisions (Pye and McKane, 2000).
- The authors made a comparison between manufacturing and non-manufacturing companies (Schleich and Fleiter, 2019).
- Waste heat was studied at the technology level, transferable to other technology levels (Semkov et al., 2014).
- Future research should focus on an in-depth analysis of the differences between energy-efficient technologies (Camarasa et al., 2020).
- Detailed studies and research should be conducted in the area of thermal performance of buildings, energy performance of building services, and renewable technologies (Muresan and Attia, 2017).

3.2.4 Threats

- Evaluation methods are mostly based on subjective assessments of employees in companies, for example, (Williams and Schaefer, 2013; Zierler et al., 2017; Zhang et al., 2018; Cunha et al., 2020; Wakabayashi and Arimura, 2020).
- The investigation at the technology level is limited to the “low hanging fruits” such as lighting (Morais et al., 2020).
- Data basis and participants is partly low (Samuels and Booysen, 2019).
- Secondary data were often used in the studies (Hwang and Colyvas, 2011).
- There are hardly any known studies of efficiency potentials at the technology level (Trianni et al., 2013).

4 Discussion

4.1 Starting point of this work and objective

Energy efficiency potentials in companies are often not known and, therefore, cannot be implemented. In addition to information deficits, acceptance deficits towards new technologies and solutions are often an obstacle.

In subchapter 2.1, the research question was formulated, which should be answered with the present work. For this purpose, the current state of research was reviewed and it was checked whether an existing research gap could be identified.

The following research question was to be investigated:

> What are the current energy efficiency potential in companies in the form of individual measures on the technology level and how do they interact with each other?

The research question was investigated during the literature review, but could not be answered. Thus, the research question is still valid as the research work did not answer the research question.

4.2 Origin and publication of the article

The 101 articles from the literature search were considered and evaluated using eight different evaluation criteria and a SWOT analysis. The evaluation showed that most studies were published in Germany, Italy, and Sweden. Nevertheless, it is a topic that is studied worldwide. A general trend can be observed that energy efficiency is gradually gaining momentum not only in scientific articles but also in companies.

4.3 Type of company and type of industry

Most of the studies reviewed dealt with manufacturing companies that are not SMEs. However, smaller companies should not be ignored, as they exist in greater numbers overall than larger companies, and the overall potential of all smaller companies is enormous. Therefore, further studies should focus even more on smaller companies, so that the general sensitization of these companies to more energy efficiency becomes more present and thus a copycat effect can be triggered. The current climate protection development and the CO_2 levy encourage this, as all companies now have to achieve monetary savings by avoiding CO_2 emissions, even through smaller measures in order to remain competitive.

4.4 Type of data, collection method, and type of data collection

Significantly more secondary data (51%) than primary data (25%) were used in the studies. The collection method was mainly *via* literature review and questionnaires. The questionnaires were conducted online or over the phone. This favors a subjective perception and collection of data by the employee in the company. One and the same measure or potential can be evaluated completely differently. Certainly, this uncertainty is minimized by the scientific questionnaire design, but it can lead to a strong deviation in the evaluation. Only a few studies (8%) have resorted to the possibility of sending an expert directly to the companies and recording the data directly on site. This is costly and time-consuming but ensures that the data collected are estimated with the same consistency. This does not imply that the data are more correct or accurate than those collected *via* questionnaires, but it does ensure consistency throughout.

4.5 Main conclusion from the strengths–weaknesses–opportunities–threats analysis of the peer-reviewed articles

Most of the articles considered had a good data basis and a high number of participants. This increases the quality of the statements and gives a good validity. In principle, this makes it possible, under the premise that the data can be collected, to extend the study to other types of companies and industries. A frequent feature of the articles is the discussion of barriers and drivers for energy efficiency.

These include the aforementioned lack of information and acceptance of new technologies, financial and economic barriers, and a lack of know-how in companies. Drivers are often efficiency issues such as cost savings and CO_2 reduction.

The lack of know-how in the field of energy efficiency in the companies is often mentioned as one of the major barriers in the literature, nevertheless mainly collection methods are used in the articles, which presuppose know-how or at least a certain affinity to the topic of energy efficiency from the companies and their employees. Due to this, more experts should be sent to the companies within the framework of research work to record the measures and potentials on site in order to obtain more meaningful evaluations.

Few articles deal with energy efficiency potentials as an actual measure at the technology level, such as lighting technology. However, when this takes place, the relationships between these measures are not considered further.

The relationships between the individual measures and potentials are an important parameter for estimating what a company will need in the future, for example, if it has already implemented individual measures. If a correlation can be formed, more targeted expansion concepts can be created, for example, and investments in energy efficiency can be triggered more quickly.

Therefore, exactly these correlations and their effects on energy efficiency measures and potentials should be researched.

4.6 Limitations of our work

Only 101 articles on the subject were examined. The majority of the work originates from the European Union and is, therefore, not easily transferable to all countries and their resident companies.

The method chosen to select the search terms and synonyms is partly subjective. Even if the method subsequently follows a clear framework, this cannot be completely eliminated. Also, the cleaning process in selecting the articles to be studied is a weakness of the work. One reason may be the excessive focus on technology level measures. These measures should be examined and should be left at the end of the search and cleaning process, but this strict focus may also exclude studies that examined these technology level measures as side effects in their studies but did not contextualize them directly through the titles and abstracts.

4.7 Further research and contribution

The research question is still valid, as the reviewed articles cannot fully answer the research question. Thus, it has become apparent that there is a research gap in the area of relationships and interactions between individual energy efficiency measures and potentials from the literature review developed, there are several potential research gaps related to the research question that has been insufficiently explored. Thus, this thesis makes a theoretical contribution to a better understanding of energy efficiency research. Based on the existing literature, a specific research gap is identified and justified.

The results of this thesis have also shown that more research on smaller and non-manufacturing companies in the field of energy efficiency and digitalization is useful and necessary. Simply due to the fact that there are many small businesses and the attitudes of small and large businesses towards this topic can be diametrically different.

More studies should be conducted that capture and map energy efficiency potentials at the technology level. To this end, very practical energy efficiency potentials (e.g., LED technology and electric drives) are recorded in the companies. In addition to the potentials, a survey should also identify the measures that have already been implemented or whose potentials are classified as low or non-existent. A correlation between the individual technologies can then be derived from this and a transferable quantitative statement made for other companies.

Studies dealing with the correlations between the individual measures and their influence are also scarcely available to date.

A positive and negative effect of an energy management system (EnMS) on other energy efficiency measures and potentials has already been empirically demonstrated in a few studies. However, the empirical evidence of these studies is limited to subjective assessments, a small number of participants (here: employees and companies), and to effects on overall energy efficiency. Also, the distinction between small and large companies has not been sufficiently considered so far.

5 Conclusion

The aim of this work was to answer the research question of what energy efficiency potentials exist at the technology level in companies and what interactions they have with each other. An extensive literature search was conducted and 101 articles were found. To answer the research question, the articles were examined using a literature review and a SWOT analysis. The research question could not be answered conclusively and sufficiently and the research gap in the field of interactions between individual energy efficiency measures and potentials could thus be identified. When interactions are researched, they usually refer only to large and energy-intensive producing companies of selected industries (e.g., the steel industry). Also, the level of detail is often not extended to the technology level and is limited to the overall efficiency of a company. In addition, research data is rarely taken directly on-site and critically reviewed by an expert. These and other findings of the present study indicate a need for research in theoretical energy efficiency research, as the interactions between energy efficiency measures and potentials have not yet been explored or have been explored only inadequately.

The results of further research can primarily make a theoretical contribution to a better understanding of the interactions and effects of individual energy efficiency measures.

If it is known what interactions exist as a result of energy efficiency measures, the state can, for example, launch more targeted support programs and thus achieve greater acceptance of the programs among companies, which leads to higher implementation. Companies often do not know which measures they should implement next, while the government does not know the implementation status of the companies. This knowledge gap makes synergies difficult but can be gradually overcome through best practice measures and research such as the present one.

For companies, regardless of whether they take advantage of subsidy programs or not, it is possible to deduce which measures other companies are implementing or which existing potential can trigger synergy effects.

In the following, it is planned to answer the open research question by means of a case study and to qualitatively and quantitatively answer the interactions of the individual measures with the help of hypotheses on individual technology areas. Research data on this has already been collected *via* the EU-funded project network of regional competence centers for energy efficiency. The case study picks up 12 focus topics (measures on technology level) from the companies and compares their frequencies in the companies. From this, the current status of energy efficiency in the companies can be presented. In addition, the selected hypotheses are used to compare measures at the technology level with each other, so that, for example, empirical evidence can be provided as to whether companies with an energy management system have a lower energy efficiency potential than companies without an energy management system. Furthermore, the findings obtained in this study are empirically tested in the case study.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material; further inquiries can be directed to the corresponding author.

Author contributions

TK and NK contributed to the conception and design of the study. All authors contributed to manuscript revision and read and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenrg.2022.934859/full#supplementary-material

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