A measure of control: about sensors, measurement and control equipment in German companies

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Abstract
Taking stock of energy flows is central for energy management activities within companies: It is needed to identify the most appropriate energy efficiency measures, to implement them and to monitor their impact. While the use of sensors, monitoring and control equipment helps to enhance transparency, few studies seem to provide empirical data about the use of these technologies and about the expectations for achievable energy savings across a larger sample of companies. Against this background, this paper aims to broaden the understanding of the use of measurement infrastructure and control technologies for enhancing energy efficiency within industrial companies based on a sample of German companies. The insights in this paper use survey results obtained from companies participating in a national funding programme for sensors, measurement and control equipment. The analysis covers, among others, the expected savings associated with measurement infrastructure and control technology, how companies monitor energy flows and how they make use of this information. While the selection of companies is not representative and limitations apply, the results seem to underline that there are various ways how energy-related measurement infrastructure and control technologies are used and implemented in practice. Among others, the companies in the sample seem to monitor electricity more often than thermal or other properties, they have largely left the pen-and-paper era for data acquisition and data is kept in in-house storage systems. The assessment of data appears still seems to include a substantial amount of handiwork and AI-based automation was still rare at the time of conducting the survey. In general, expected triggered savings vary but tend to be in a range of 2 to 5 % of the covered energy demand.

Introduction
Infrastructure for metrology has often limited visibility, yet it is considered as essential to drive growth and innovation (European Commission 2013). Many modern concepts used in in industry would not be feasible without sensors, metering and control equipment. To name a few examples, such concepts include Industry 4.0 (e.g. Da Tesch Silva et al. 2020; Hasan and Trianni 023), sustainable manufacturing (e.g. Cai et al. 2022), condition monitoring (e.g. Zhou et al. 2017), digital twins (e.g. Billey and Wuest 2023) or internet of things applications (e.g. Bedi et al. 2018). These concepts have their particular focus on production, but they also touch on energy-related matters and corresponding data. Sensors, meters, and other measuring and monitoring equipment are also at the heart of energy efficiency as a topic of its own. They are a pre-requisite for energy management and for enhancing energy efficiency as they allow to make energy flows transparent: They contribute data that is necessary to identify and evaluate measures for energy savings.

There are abundant possibilities to use such equipment: They include direct measurements of energy demand, e.g. by determining electricity or fuel consumption, but they can also concern properties indirectly used to influence energy demand. Examples for the latter include pressure readings (e.g. to adjust compressor speeds), luminosity values (e.g. to control the intensity of artificial lighting), temperature data (e.g. to adjust fuel feed to a heater) and many others. Such values can focus on main energy flows, but they can also be used to optimize processes and/or individual production steps on a more detailed, but less comprehensive level. Also, measurements may serve online-process control only, they can be used for active operational energy management and they may also be a basis for a longer-term planning and the identification of opportunities for energy efficiency enhancements. In short, there is a multitude of possibilities, how, where and for what purpose metrological infrastructure and control technology (MICT) can be used in industrial companies to enhance energy efficiency.

While MICT is omnipresent, little overarching information on the use of such equipment in the context of energy efficiency in industrial companies seems available. Against this background, the aim of this paper is to gain an understanding on the use of MICT for enhancing energy efficiency within industrial companies. The data underlying this analysis has been collected within the evaluation of a funding scheme for enhancing energy efficiency in German industry. The considered programme specifically subsidizes metrology and related control equipment for energy- and resource-related data. In the following, we will first provide a methodological overview, starting with a brief background of the funding programme, then proceeding to data acquisition and the conceptual basis for the analysis. This is followed by a presentation and discussion of results which yields insights on the application of energy metrology as covered by the funding scheme and final, overarching conclusions.

Background

The funding of sensors, measurement and control equipment is part of a broader German funding scheme for enhancing Energy and Resource Efficiency in the Economy (EEE). The EEE is described in further detail in Neusel et al. (2023). The overall scheme consists of several individual modules with their independent funding topics and conditions. Most modules in the EEE offer the possibility to either obtain a grant or a subsidized credit.

The particular module on MICT, referred to as 'Module 3' in the overall scheme, is generally intended to stimulate investments to enhance energy and resource efficiency, to reduce carbon dioxide emissions and to improve the competitiveness of the targeted companies. An overview of the characteristics of 'Module 3' is summarized in Table 1. It subsidizes investments in sensors, related equipment and also energy management software and staff-training. Differently from most other funding activities in the EEE, MICT as well as its software counterpart in Module 3 do not entail direct energy savings, such as saving energy from replacing a motor by a more efficient model. They rather pave the ground for such savings by enabling companies to monitor energy flows and to react to the obtained data and derived conclusions.

For orientation, Table 2 provides an overview of selected key performance indicators obtained from an evaluation of 'Module 3' with more detailed information available in Neusel et al. (2023). In the four years since its inception in 2019, more than 2,200 funding requests were approved, obtaining approximately 80 million Euro in funds and triggering expected greenhouse gas savings (GHG) savings of about 46 kt CO_2-eq. In terms of companies addressed by the programme, the majority (62 %) are large ones.

The programme administration logic of 'Module 3' distinguishes investments in measurement equipment, control technology and energy management software. Companies may request funding for one or several of these topics. Table 3 provides an overview about how often funding per topic has been requested. About two thirds of the requests concern measurement and control technologies while the remaining third concerns software. The focus of the remainder of this paper is on the

Table 1. Summary of Module 3 characteristics.

Target group	Private-sector companies (SMEs and large companies), municipal companies, freelancers (conditional) and contractors representing a company. Details with exceptions are specified in funding guideline.
Eligible investments	Metrology infrastructure and control technology Energy management software and related staff training
Funding rate	Grant: 30% of eligible investments (SME: 40 %) and up to 15 Mio. Euro
Financed by	Federal Ministry For Economic Affairs and Climate Protection (BMWK) via the Energy and Climate Fund
Implementing agency	Grant: German Federal Office for Economic Affairs and Export Control (BAFA), Credit: German development bank (KfW)

Source: based on Neusel et al. 2023.

Table 2. Key performance indicators for the funding programme.

Key performance indicator(s)	2019	2020	2021	2022
Number of approvals [number]	233	452	619	945
Funding volume / triggered investments [M€]	5.0 / 15.8	15.0 / 47.5	18.9 / 59.9	40.7 / 123.5
Net GHG [kt CO_2-eq.] / energy costs [M€/a] savings	5 / 1.5	9 / 3.9	12 / 3.8	20 / 11.3
Micro / small / medium / large companies [%]	2 / 9 / 30 / 58	3 / 11 / 27 / 59	2 / 6 / 24 / 67	3 / 10 / 26 / 61

Source: based on Neusel et al. 2023.

Table 3. Overview of funding by funding topic as declared within the application for Module 3.

Funding object per application	2019	2020	2021	2022
Measurement technology	148	303	451	659
Control technology	43	123	173	316
Software	138	230	308	470

Source: based on Neusel et al. 2023.

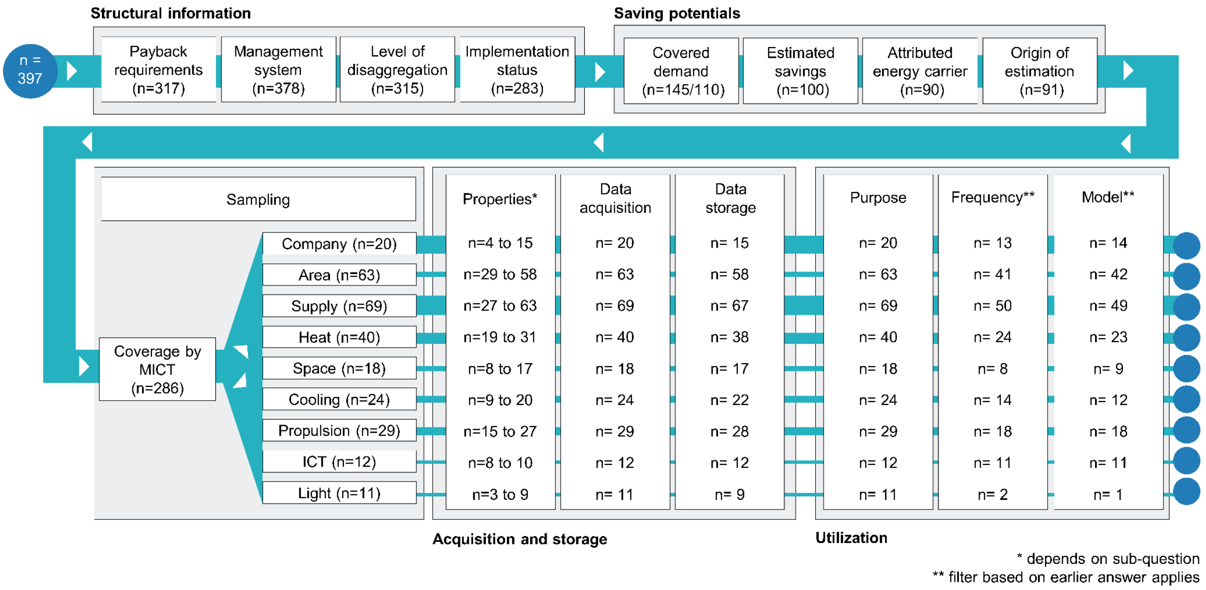

Figure 1. Overview of the structure of investigation and the number of answers per item covered in this paper. Light-blue arrow are used for illustrative purposes, but not to scale. The indicated number of answers account for provided answers only, excluding none-responses or omissions.

measurement and control technology only, excluding software from further considerations.

The existing evaluation work in Neusel et al. (2023) covers key performance indicators related to the overall evaluation of the Module and the entire EEE. The specific analysis of MICT in this paper extends this analysis.

Methodology

To obtain data about ‘Module 3’ besides administrative information available from the implementing agencies, a regular online survey among participants with an ‘approved’ application to the funding scheme is carried out within the evaluation of the EEE on an annual basis, i.e. for each year of funding. For this, participants are invited by e-mail and reminded once in case of non-response. The invitation is accompanied by a document containing frequently asked questions about the survey and an invitation letter by the Ministry responsible for the EEE. If individual contacts submitted several requests in the year under investigation, they are only asked to participate for one specific case of funding. The survey in its entirety covers information to complete all key performance indicators and issues of interest of the evaluation. At the beginning of the survey, it is underlined that all questions address the specific site that benefited from funding, i.e. not the entire company in case of multi-site enterprises. Some parts of the survey are asked uniformly across all modules of the EEE; others contain specific contents for each module. The entire questionnaire takes about 20 to 30 minutes to complete, depending on the individual case and branching within the questionnaire.

The specific data source for this investigation is based on an extended part with additional questions about MICT and software in Module 3. This extension was added to the questionnaire for the evaluation years 2019, 2020 and 2021. The corresponding surveys were in the field for 2019 from 23 March to 18 April 2021 (233 invitations for ‘Module 3’, 37 % return rate), for 2020 from 8 September to 8 October 2021 (387 invitations, 39 % return rate), and for 2021 from 13 September to 7 October 2022 (474 invitations, 34 % return rate). This yielded a total of 397 completed questionnaires as the basis of the subsequent analysis which focuses on MICT.

The questions deal with information about the general use of MICT at the site and specific questions about the funded MICT. Figure 1 provides an overview of the topics covered in the survey and which are detailed in the results section: Following general information, the investigation focuses on saving potentials associated with the funded MICT. Thereafter, information about data acquisition and storage is covered and finally, the utilization of the measures data is analysed. To understand the role of the context of application and to obtain more precise information, the latter two topics are disaggregated by utilization. For this, the investigation distinguishes three levels of disaggregation: The first level is the site-level which seeks to cover the most important energy flows for the entire local energy system, e.g. the energy flow over main connectors and/or from central local power plants. The second level is the area-level which covers the main energy flows in distinct areas of the site using sub-metering, e.g. the energy demand of individual buildings. The third level covers families of application areas or systems. In view of the numerous potential uses of energy in industry, generic applications have been chosen which were loosely structured along German end-use energy balances (Rohde and Arnold-Keifer 2023) with the addition of a category 'energy supply' and a selection/aggregation of subgroups. The following utilizations are distinguished here:

- Site-level: The overall site [=Company/Site]
- Area-level: Individual areas of the site [=Area]
- Application: Energy supply [=Supply]
- Application: Lighting systems [=Light]
- Application: Process heat [=Heat]
- Application: Space heating and hot water [=Space]
- Application: Space and process cooling [=Cooling]
- Application: Propulsion system [=Propulsion]
- Application: Information and communication [=ICT]

Only one of these utilizations was covered per survey for limiting the burden on the participant. In the survey, the participant was informed and reminded about the relevant utilization at the top of each page of the questionnaire. The utilization was chosen randomly from a pool of elements that sought to limit the choice to relevant utilizations for the company while still obtaining insights into all different utilizations. To determine the elements available in the pool of potential selections, companies were presented with a list of applications and those that were covered by the subsidized MICT were added to the pool. If no such application-level was covered, the area-level or – if this was missing, as well – the site-level entry was added to the pool and one element was randomly chosen. Depending on the available elements in the pool, varying numbers of participants were guided to each in-depth path for each utilization. To transparently indicate the number of participants per branch, the obtained number of answers per utilization are indicated in Figure 1.

Results and discussion

The extent of using MICT in companies for monitoring energy demand will depend on many factors. Some structural information about the participating companies is provided first to characterize their general setup.

With regard to energy or environmental management systems, it should be noted that an established management system or the imminent introduction of such a system is a requirement to obtain funding. As a consequence, 84 % of the participating companies had an established system according to DIN EN ISO 50001, 3 % an environmental management system according to EMAS, another 11 % an alternative system permitted for SMEs by national legislation and the remaining 3% were still in an ongoing certification process. Next to the earlier mentioned high share of large companies in the sample, the prevalence of management systems underlines that the subsequent results may not be representative of the broad number of companies in Germany.

Another indication about the engagement of companies for investments in energy savings can be obtained from requirements to payback time without funding. The shorter the requirement, the more risk averse is a company. In the sample, 13 % set a cut-off at a maximum of 2 years, a majority of 61 % accepts 2 to 4 years, another 24 % allows between 4 and 8 years and the remaining 2 % go beyond 8 years.

Installing and integrating new MICT takes time. Depending on whether an application for funding was made early or late in the evaluated year, the annual survey addresses companies that had well above one year for implantation after their request for funding, but it also covers those companies that were still only a few month into the process. Therefore, the status of implementation differs: 61 % of the companies indicated that they completed the introduction and that the MICT is in use while another 39 % were still in the introduction phase. In conclusion this means that the majority of companies had the opportunity to see the MICT in actual operation.

Following the methodological distinction by site, areas and application, companies were asked to specify on which level of disaggregation they use energy related MICT in a targeted manner. One or several levels could be selected and Table 4 provides an overview of the answers. In most cases, metrology encompasses all levels, yet there are also various cases that focus on two or one level only.

COVERAGE OF ENERGY DEMAND AND SAVINGS

Beyond this basic characterization, the subsequent analysis focuses on the subsidized MICT only. Several aspects are covered here to describe how it is expected to cover and affect energy demand.

One question of interest is to understand to what degree energy demand is covered by the subsidized MICT, i.e. whether it covers a substantial share of overall demand or whether it focuses on smaller shares. For this, the participants were asked to indicate what share of the site's energy demand is approximately covered by the subsidized MICT. Figure 2 visualizes the answers by distribution functions, distinguishing electricity demand (left) and other energy carriers (right). In both cases, it can be observed that in some cases, no demand is covered. This will be the case if the MICT is only used for the respective other group of energy carriers. It can also be seen that in some cases, the entire demand, especially for electricity, is covered, pointing at situations where the main energy flows and/or all areas/applications are included.

To understand the perceived impact of the MICT, the participants were also asked about their expectations on triggered savings for their specified coverage, i.e. the savings that are triggered by the MICT and the related follow-up activities. For this, they could choose savings on a scale, starting with no savings and then moving up in logarithmic segments. The answers are illustrated in Figure 3 (left). It can be noted that 7 % did not associate the MICT with any savings on the one hand, and another 7 % expected substantial savings of more than 10 % on the other hand. The remaining majority of 86 % perceived savings

Table 4. Use of MICT by level of disaggregation (Question: On what level is energy-related measurement and control technology used in a targeted manner at the site, also independently of the funding?)

Level of disaggregation	Number
Main energy flows on aggregate level only (e.g. main meter) [=Site]	23
Main energy flows of individual areas only (e.g. sub meters) [=Areas]	20
Energy flows of individual applications or equipment only [=Application]	49
[Site], [Areas] and [Application]	144
[Site] and [Areas]	26
[Site] and [Application]	19
[Areas] and [Application]	16

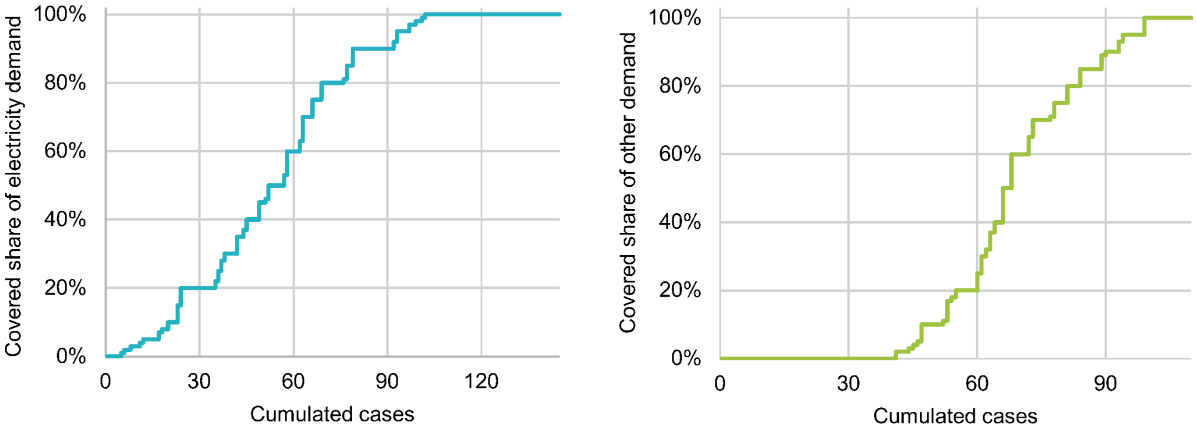

Figure 2. Distribution of the covered shares of electricity demand (left) and other energy demand (right) (Questions: What share of the site's energy demand is approximately covered by the supported measurement and control technology? Covered share of electricity demand between 0 and 100 % (left)/Covered share of other energy demand between 0 and 100 % (right)).

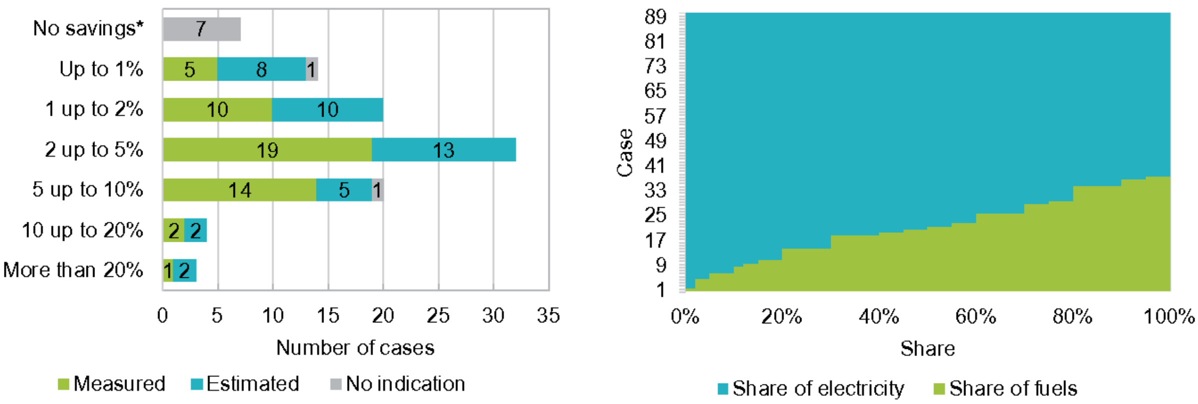

Figure 3. Overview of expected savings and their origin (left) (Questions: What is the approximate order of magnitude of the annual savings resulting from the supported measurement and control technology and of activities triggered by it for the previously mentioned coverage?/ What are the indicated savings based on?) and attribution of these saving to electricity and other fuels as shares (right) (Question: Which part of the savings is approximately attributable to electricity?) (: In case of no savings, the follow-up question was skipped. Note that 'up to 1 %' (left) summarizes several items from the questionnaire, i.e. 'up to 0.1 %', '0.1 to 0.5 %', '0.5 to 1 %'.).*

in the range of up to 10 %. This seems to suggest that expected savings vary substantially which may explain why generalized statements about the benefits of MICT are difficult to compile. To further understand what the provided values are based on, participants were also asked whether the indicated savings are based on estimations or measurements. Based on the limited available data, it seems that there is no substantial difference between both groups in terms of the indicated savings. Note that in some cases, this follow-up question was not answered (indicated by 'no indication'), also because it was not applicable (in case of 'no savings'). To further understand where these savings originate from, another follow-up about the share of electricity in these savings was asked. Figure 3 (right) shows the results which indicate that in most cases, savings are attributed to electricity.

DATA ACQUISITION AND STORAGE

To understand to what degree applications are covered by MICT, participants were asked to indicate relevant applications for their site and they were further asked whether applications are (at least partially) covered by MICT. Either the applications were already covered before the funding application, i.e. there was no change due to funding. Or the MICT in the applications was introduced or extended as part of the funding process. Figure 4 shows the answers for the different applications and cases. It can be observed that in relative terms, some applications are covered more often than others, even if it has to be kept in mind that the level of aggregation and the sample sizes per application vary. Furthermore, many applications were already covered prior to the funding process but there is also a substantial number of applications where the funding helped to introduce or extend MICT usage.

As underlined earlier, MICT can cover different physical properties. To understand which properties are actually covered by the subsidized MICT, a segmentation by five categories of properties was done: a) Electrical properties (e.g. current, voltages), b) thermal properties (e.g. heat flow metering, temperature) c) volumetric properties (e.g. volumes of gases or liquids), d) mechanical properties (e.g. pressures, weights, rotations) and e) others (e.g. luminosities). For each property and utilization, it was asked whether the property was monitored or influenced by the MICT. Figure 5 shows the results for categories a) to d). The overall results indicate that electrical properties are, in relative terms, most often measured or influenced (measured: 187; influenced: 43). An explanation could be that electricity is typically the most expensive energy carrier. In terms of ranking additional properties, electricity is followed by thermal properties (measured: 103; influenced: 33), volumetric properties (measured: 90; influenced: 28) and mechanical properties (57: measured, 25: influenced). The group of 'Other properties' was also relevant, but to a lesser degree (11: measured; 18: influenced). It should also be noted that in a few cases, some indications are difficult to interpret, e.g. measuring mechanical properties for light, but such answers cannot be ruled out as implausible (e.g. monitoring the rotational speed of active LED coolers might be a corresponding use case). As a general conclusion, energy-related properties seem most monitored and less often used for control purposes, at least not on an operational level. With regard to the individual utilizations, not particular patterns seem to emerge, but such conclusions are also limited by the available disaggregated numbers.

Information about whether the obtained data is collected automatically (e.g. directly fed into another system), manually (e.g. by reading off a display) or by a combination of both is given in Figure 6 (left). Again, no particular pattern is discernible by the different utilizations. Yet it can be observed that in most cases, automation is used, most often as stand-alone option, but sometimes in combination with manual data collection. The manual approach as the only solution is used in only few cases. Information on where the data is stored has been distinguished by five categories: a) No storage, just fleeting data for control purposes, b) manual protocols, i.e. no electronic data storage, c) decentralized storage, e.g. on location at the machine or plant d) a centralized storage, e.g. on local premise or a cloud-based but own data storage system or e) the use of external hosts by service providers. The results in Figure 6

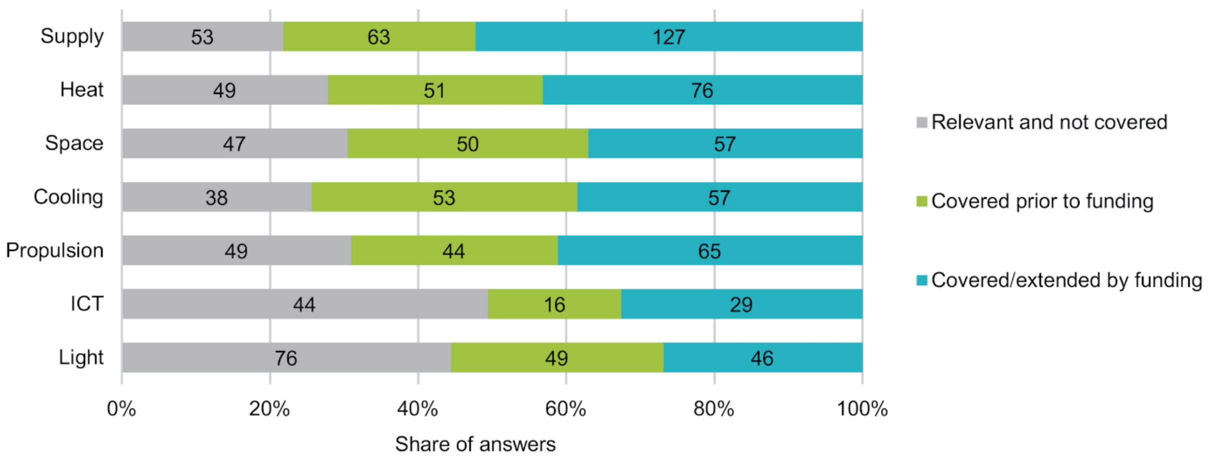

Figure 4. Overview of MICT usage by applications, either prior to funding or as part of the support activities (Question: Which of the following applications are basically relevant at the site from an energy perspective and which ones are already covered (in parts or fully) by measurement and control technology?).

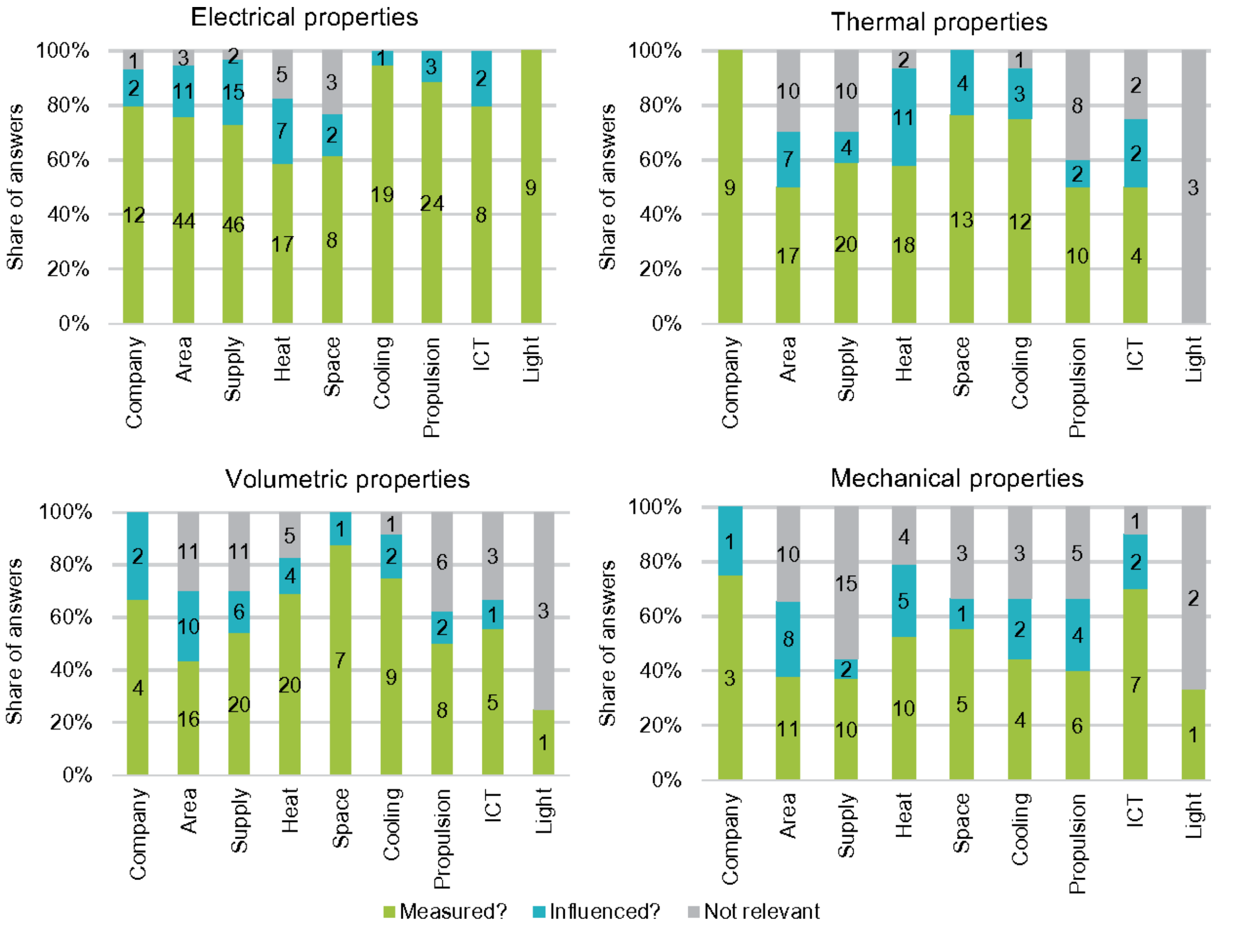

Figure 5. Overview of covered properties by type and utilization (Question: What kind of properties are recorded or influenced by means of the supported measurement and control technology?).

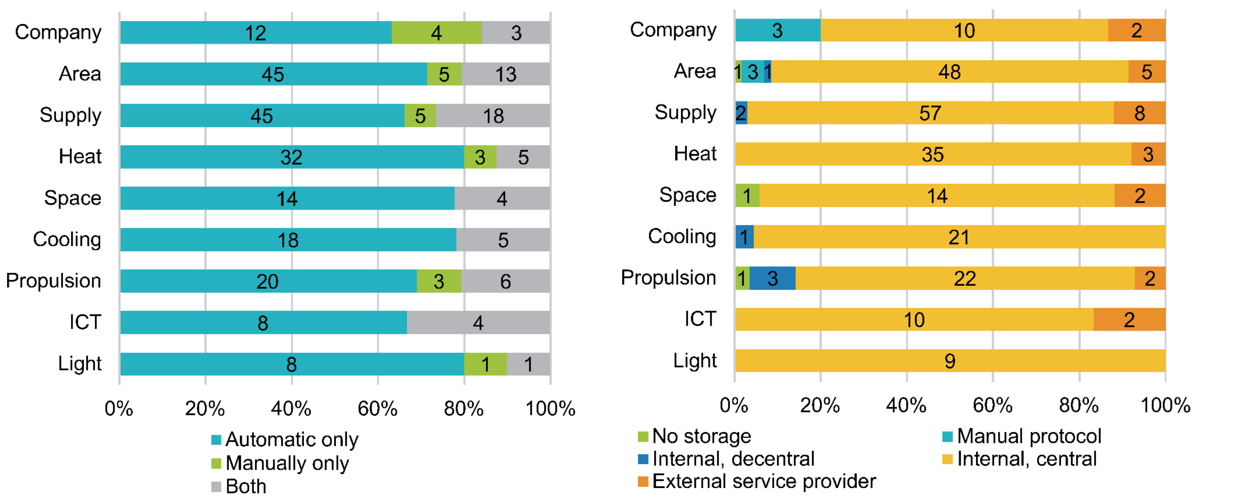

Figure 6. Acquisition of data (left) (Question: How are the measurements acquired?) and location of storage (right) (Question: Where is the measurement data stored?).

(right) show that the situation also points to one direction: In most cases, in-house central storage systems are used. Manual protocols or decentralized storage systems are used in a few cases; data use for control purposes is the exception. Relying on external service providers seems little popular.

USE OF MEASUREMENTS

As a follow-up to data storage, the actual utilization of measured data can be further analysed. For this, the participants could choose whether they were using the data for a) continuous active control of processes and plants, b) periodic assessments of processes and plants and c) for reporting purposes or a combination. Table 6 details the obtained answers. It can be noted that in most of the cases, the data is used for several purposes. Reporting is listed most often (in total by 231 answers), followed by periodic assessment (189 answers) and continuous control is mentioned least often (140 answers).

One key activity for improving energy efficiency besides operational process control are assessment activities. Those participants that indicated using the data accordingly were further inquired about the frequency of these assessments and data processing. Results in Figure 7 (left) are structured by the frequency of analysis, ranging from daily or more frequent data use (e.g. for individual shifts) to annual or more rare assessments (e.g. as part of an annual energy review). It can be observed that in more than 4 out of 5 cases, data is used on a monthly basis or more frequently, i.e. data is actively incorporated in regular reviews; the data is also relatively often used on a daily level, suggesting that the information is directly integrated operational processes. Participants could also indicate whether assessments are created a) manually, b) using traditional automation or c) using AI-based automation. In Figure 7 (right), manual and traditional automation clearly dominate roughly to equal parts. As of the data of collecting the data, AI-based assessments were still uncommon. Again, the distribution by utilizations appears to be relatively uniform.

LIMITATIONS

Within the presentation of results, some observations and conclusions were made concerning the use of MICT in industrial companies. Yet it must be kept in mind that these are subject to limitations. This includes that the data has been collected via a survey and in consequence, limitations of survey approaches generally apply.

As it has been pointed out in the introductory part to the results, they are not necessarily representative for all MICT appli-

Table 5. Use of measurement data (Question: What are the energy-related measurements used for?).

	Company	Area	Supply	Light	Heat	Space	Cooling	ICT	Propulsion	All
[Assessment] and [Reporting]	4	20	29	2	14	3	8	2	11	93
[Control], [Assessment] and [Reporting]	7	22	18	1	6	5	4	8	6	77
For reporting purposes [Reporting]	3	11	5	3	1	4	3	0	2	32
[Control] and [Reporting]	1	3	5	1	8	3	2	1	5	29
Continuous active control of processes and equipment [Control]	1	5	6	2	6	2	4	0	3	29
Periodic assessment of processes and equipment [Assessment]	3	1	5	0	3	0	1	0	1	14
[Control] and [Assessment]	0	1	0	0	1	1	1	1	0	5

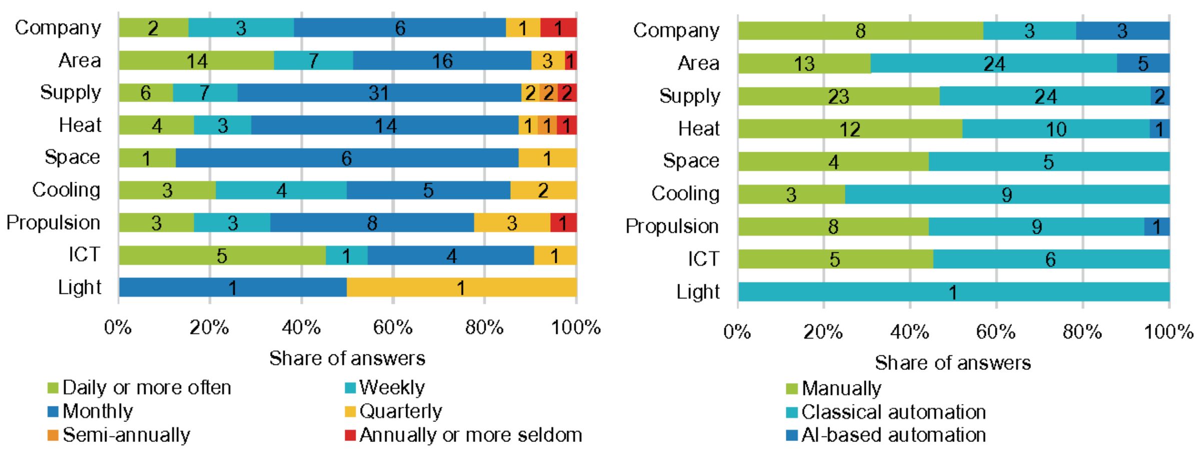

Figure 7. Frequency of using energy-related data for periodic assessments (left) (Question: How often are the energy-related measurements actively assessed?) and type of assessment models used for these assessments (right) (Question: How are these assessments made?).

cations in industry. The funding programme reaches a relatively high-share of large companies. That these companies use MICT more often does not seem surprising: The energy demand and costs in these companies are regularly higher. This justifies investments in more sophisticated and dedicated MICT than in cases where energy demand, energy costs and thus saving potentials are limited. Also, the higher relevance of energy demand allows to dedicate more resources and personnel to energy-related tasks. Furthermore, participation in the funding is limited to those companies with an energy management or equivalent system. Thus, there is a selection bias and the companies covered by the analysis are likely those that are more active in terms of managing and seeking to influence energy demand than an average company. Also, the sample of companies is per se limited to Germany.

Furthermore, it should be noted that data acquisition stretches across a longer period. Thereby, the data does not reflect the situation at one point of time, but the last collection period ended in late 2022 and thus approximately 1.5 years after the first one started. Since the most recent data collection, AI-based technologies have gained broad attention and therefore, assessments especially concerning the use of AI-assisted systems might already look different today.

Conclusions

The aim of this paper was to gain an understanding on the use of MICT for enhancing energy efficiency within industrial companies. For this, survey data was collected and analysed to understand to what degree MICT influences energy demand and how it is collected, stored, and used. With regard to energy efficiency improvements in general, the results underline that the investigated companies associate substantial energy savings with the use of MICT and subsequently triggered activities, most often within a range of 2 to 5 % in the area covered by the MICT. Yet the detailed analysis also shows that there is a variety of ways how energy-related MICT is used and implemented in practice. In turn, the achievable savings from MICT differ considerably from case to case and the intensity of using information from MICT for energy-related assessments varies, as well. In general, it can be observed that manual data acquisition seems largely overcome and data is often stored centrally using in-house solutions. The assessment of data appears to still include a substantial amount of handiwork and AI-based automation was still rare at the time of collecting the data. In general, the companies in the sample seem to monitor electricity more often than thermal or other properties. Yet it should be noted that the results are not necessarily representative and further research and data from other investigations is advisable to validate these observations further.

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