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Deeper and Persistent Energy Savings and Carbon Dioxide Reductions Achieved through ISO 50001 in the Manufacturing Sector

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Abstract
It is critical that industrial sector emissions are reduced significantly to minimize the worst effects of human-induced climate change. The first, and most cost-effective, step in reducing these emissions is energy efficiency. Current approaches to energy efficiency typically rely on project-by-project implementation without an established system to maintain the energy reductions. Conversely, an energy management system based on the Plan-Do-Check-Act structure, such as ISO 50001, provides a systematic and structured approach to identifying, implementing, and maintaining energy efficiency measures. This paper analyzes verified energy performance data from 83 manufacturing facilities that implemented ISO 50001 to better understand typical energy performance improvements and their persistence. This paper shows that manufacturing facilities which implement ISO 50001 achieve and maintain energy performance improvement rates far exceeding those achieved through current approaches or targeted by policymakers for energy efficiency's contribution to decarbonization goals. It is shown that ISO 50001-certified facilities, on average, achieve annual energy performance improvement rates of around 4.1% in the initial year of implementation and maintain rates of around 3.4% twelve years after implementation. Further, the results show that the energy management system is embedded in the facility's operational processes. The results provide confidence that implementation of ISO 50001-like energy management systems warrants consideration as a key policy lever for mitigating climate change.

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) has stated that there is an absolute necessity to limit human-induced global warming to 1.5°C in order to limit the risks associated with un-impeded climate change (IPCC, 2022). Those risks include increased heavy precipitation, extreme drought, disruption of ecosystems, ocean acidification, sea level rise, and multiple other compounding factors both projected and unforeseen (Hoegh-Guldberg et al., 2018). Aligned with this dictate, the International Energy Agency (IEA) has compiled a Sustainable Development

Scenario (SDS) with a projection for meeting this goal. In the latest version of the SDS, IEA projects energy efficiency being responsible for over 40% of the emissions abatement needed by 2040 (IEA, 2021). This sets an ambitious goal of reducing energy intensity across the economy at the rate of about 1.3% per year. The American Council for an Energy Efficient Economy (ACEEE) has determined a similar goal of 1.7% per year (Ungar, 2019). In addition, the IEA notes that 80% of that energy efficiency potential could be achieved cost-effectively and recommends that "[g]overnments should put in ambitious policy frameworks to promote… energy efficiency improvement in the industry sector" (IEA, 2021). These reports highlight the importance of energy efficiency as the first tranche of the drive to decarbonize – reducing emissions and energy cost expenditures, simultaneously. More tangibly, it provides a target for the rate of energy efficiency improvement, with the implicit understanding that the improvements are sustained.

This paper evaluates facility-level annual energy performance improvements associated with adoption of a structured energy management system (EnMS), as defined by the International Organization for Standardization (ISO) 50001 energy management standard. For the purposes of this paper, the terms energy performance and energy efficiency are interchangeable with both connoting the productive use of energy. Focusing on the U.S. manufacturing sector, this paper analyzes the energy performance improvement records for facilities that have implemented ISO 50001 to show with high confidence that:

1. third party verified energy performance improvements realized by U.S. manufacturing plants with an ISO 50001 certified EnMS are achieved and sustained over many years at rates surpassing historic and projected energy efficiency improvements in manufacturing, and
2. the implementation of an ISO 50001 energy management system at a manufacturing plant shifts the dependence for achieving energy savings from a single person or persons to the wider corporate/management practices and operations, thereby making energy efficiency improvements intrinsic to business operations.

The paper is structured as follows. Section 2 provides contextual background information on historic energy efficiency improvements for U.S. manufacturing and present how an EnMS leads to greater and sustained improvements. Section 3 describes the data used in the analysis and the methods employed. Section 4 presents the results and is followed by a discussion of the results in Section 5. This paper shows that widespread adoption of ISO 50001 and similar EnMS can be a key piece to fulfilling energy efficiency's role in decarbonizing our economy and keeping global emissions reductions on track to meet a 1.5°C future.

2. Background

2.1 Historic Energy Efficiency Improvements

Historically, the U.S. manufacturing sector has seen consistent energy efficiency gains. Between 2007 and 2015, U.S. manufacturers reduced their energy intensity by 4.9% which equates to just over a 0.5% reduction per year (Morrow et al., 2017). Energy intensity in manufacturing is projected to decline by 0.5% per year through 2050, primarily driven by greater energy efficiency of new capital equipment (EIA, 2020). This means that manufacturing energy efficiency is projected to decrease nominal energy usage by about one-half percent per year for the next thirty years. This projected energy efficiency rate is not enough to put the U.S. on pace to meet the emissions reductions called out in the IEA's SDS and the Paris Climate Agreements (Rissman et al., 2020). These energy efficiency improvements were typically driven by three factors: economics (e.g., cost savings), incentives (e.g., utility rebate programs), and official recognition (e.g., Environmental Protection Agency (EPA) or U.S. Department of Energy (DOE) programs) (Paramonova et al., 2015; EIA, 2018). This, then, highlights the need for realization of energy efficiency improvements at much higher rates across all of the U.S. manufacturing sector.

2.2 Limitations of Current Approaches to Energy Efficiency

Despite widespread knowledge of energy cost and emissions savings potential, there are still many barriers to adoption of energy efficiency measures (DOE, 2015; Smith et al., 2021). Among those most cited are prioritization of process over energy needs, lack of budget or staff, lack of executive buy-in, and uncertainty around new technologies (Johansson and Thollander, 2018).

Even when these barriers to adoption are overcome, what is currently common in U.S. industry are non-standardized approaches to energy efficiency improvement which rely on implementation of energy saving projects in an unsystematic manner. Energy efficiency projects implemented under these approaches include capital improvements, maintenance actions, operation control, and behavioral actions. However, these approaches lack a cyclical structure of maintenance and upkeep and often rely on a single employee or group of employees championing implementation of projects. As a result, energy savings can diminish over time, and energy efficiency can be ignored in the face of other priorities (EIA, 2018).

2.3 Theory behind Energy Management Systems

Published in June 2011, ISO 50001 – Energy Management Systems is an international standard that provides a framework for the implementation of an EnMS for the purpose of continuously improving energy performance (ISO, 2011). In accordance with the previously stated importance of government's role in promoting the adoption of energy efficiency programs, the U.S. DOE has developed the ANSI-accredited 50001 Superior Energy Performance (SEP 50001) program in which facilities implement an EnMS based on the ISO 50001 standard and pursue third-party verification after achieving established energy performance improvement targets (U.S. DOE "Superior"). ISO 50001 and SEP 50001 are data driven, using measured energy and relevant data to calculate energy performance.

ISO 50001 uses the Plan-Do-Check-Act framework oriented towards improving energy efficiency to overcome organizational limitations and drive greater energy savings (McKane et al., 2017). When energy savings are realized under an unstructured approach to energy efficiency and reliant on a single employee to drive action, future and sustainment of already realized improvements are at risk if the employee leaves their position. With a comprehensive EnMS, the business processes should become embedded in the organizational structure and do not waver if a staff member or energy champion leaves.

ISO 50001 provides guidance to industrial and commercial facilities to integrate energy efficiency into their management practices, including fine-tuning production processes and improving the energy efficiency of industrial systems (McKane et al., 2009). The standard gives organizations and companies technical and management strategies to reduce energy, carbon intensity, costs, and improve environmental performance. By the end of 2020, ISO 50001 had been implemented at over 45,000 facilities worldwide by companies seeking to cut operating costs while furthering competitiveness and resilience (ISO, 2020).

Most ISO 50001 facilities have identified alignment with existing energy goals and values as the primary factor for implementation of an ISO 50001-based EnMS. Other reasons for implementation and identified benefits include commitment to sustainability, alignment with government regulations and/or incentives, potential cost savings, and an improved company image. These facilities most often identified engagement and support of upper-level management paired with an energy-aware company culture as two primary keys to successful implementation of an ISO 50001-based EnMS (Fuchs et al., 2020).

The SEP 50001 certification program provides a transparent, globally accepted system for verifying improvements in energy performance and management practices achieved with an ISO 50001 certified EnMS (ANSI, 2019a; 2019b). Energy performance improvement is determined through use of the 50001 Superior Energy Performance Measurement & Verification (SEP M&V) Protocol, which is a normative reference to key standards within the ISO 50001 suite (U.S. DOE, 2019). The SEP M&V Protocol requires use of linear regression models that meet specified statistical validity requirements to calculate energy savings attributable to energy efficiency actions. The SEP M&V Protocol allows for non-routine adjustments, such as major process line changes, further ensuring that the EPI determined through its use isolates gains achieved via the adoption of energy efficiency actions. When a facility applies for SEP 50001 certification, it must demonstrate certification to an ISO 50001 EnMS and achievement of one of three energy performance improvement targets over a three-year time frame: Silver (≥5% to <10%), Gold (≥10 to <15%), or Platinum (≥15%).

While it has been shown that SEP 50001 certified facilities achieve greater energy savings than non-certified facilities, the persistence of these savings, previously, has only been predicted and not proven (Therkelsen et al., 2015; McKane et al., 2017; Liu et al., 2017). With this paper, we demonstrate that SEP 50001 facilities realize these above-average energy savings upon institution of the EnMS and the savings persist throughout the active life of the program.

3. Methods

The data utilized in this study originated from a dataset containing records of 90 facilities that have received SEP 50001 certification. This dataset (updated as of January 12, 2022 for this study) contains information on each certification cycle (i.e., Reporting and Achievement Periods) for every SEP 50001 certified facility. The Achievement Period, which follows the Baseline Period, is typically between 12 and 36 months but can extend up to 10 years. Some facilities will have multiple data points if they have re-certified after their initial certification expired. The Reporting Period is the last 12 months of the Achievement Period and is the time period for which energy savings are determined and reported. Figure 1 (U.S. DOE, 2019) illustrates the relationship of the Baseline Period, Achievement Period, and

Reporting Period with t_0 being the start of the Achievement Period, the Baseline Period starting 12 months prior, and the end of the Reporting and Achievement Periods being between 1 and 10 years after t_0.

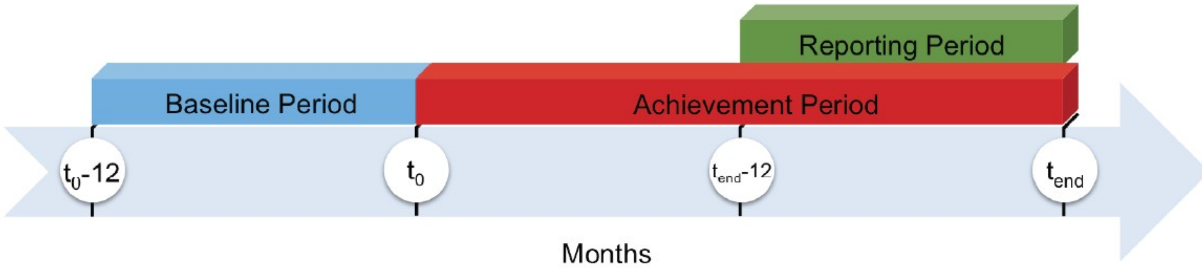

Fig. 1. Relationship between Baseline, Reporting, and Achievement Period (U.S. DOE, 2019)

This study is exclusively focused on manufacturing facilities and, thus, these were selected from the dataset. In total, 83 manufacturing facilities were identified to have either previously certified to SEP 50001 or were actively certified at the time of study. These certifications followed individual Reporting Periods that ranged from 1 to 10 years in length, with the majority (61) being 3 years. For each certification, the dataset includes information on the facility (company, location, NAICS code, facility size), the SEP 50001 certification (certification number, Reporting Period, Achievement Period, scope, certification date), and the energy performance (Baseline Period, verified energy performance improvement, adjustment model used). Demographic data of the location and North American Industry Classification System (NAICS) code for this dataset are shown in Figures 2 and 3. NAICS is a classification system used by the U.S. Census to disaggregate the U.S. economy by activity.

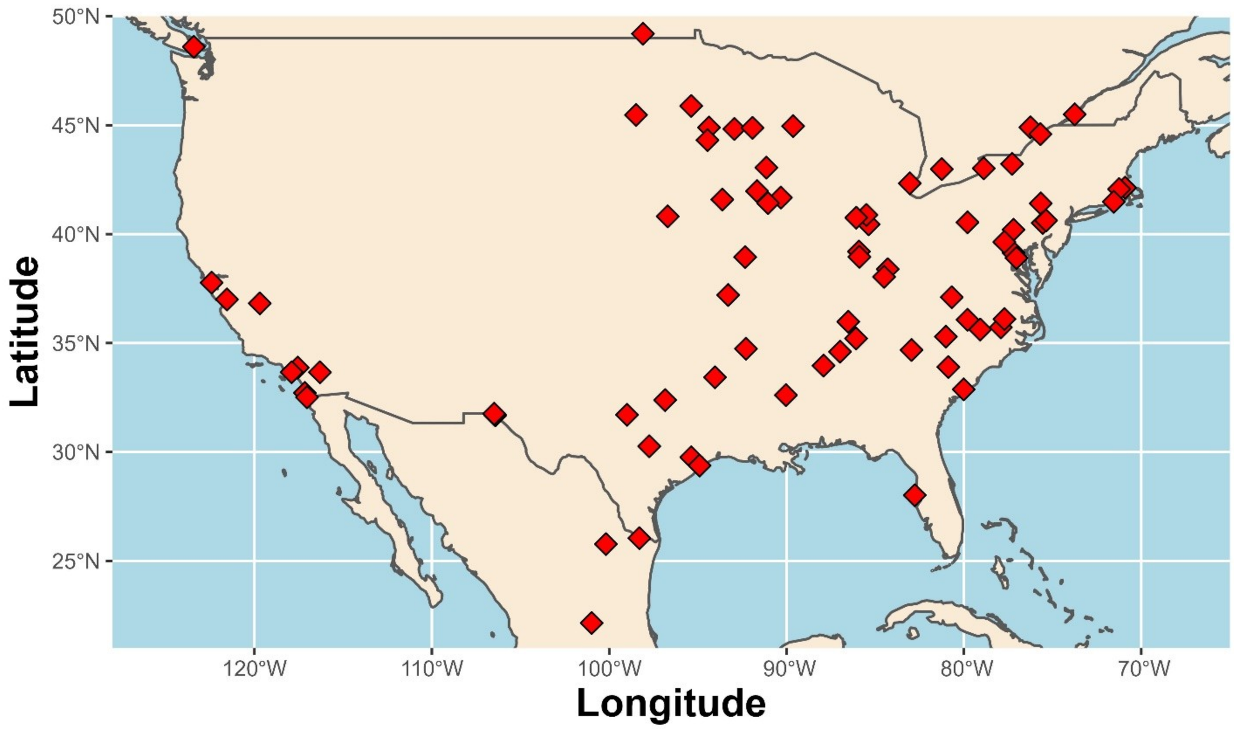

Fig. 2. Location of SEP 50001 Facilities Included in this Study Across North America

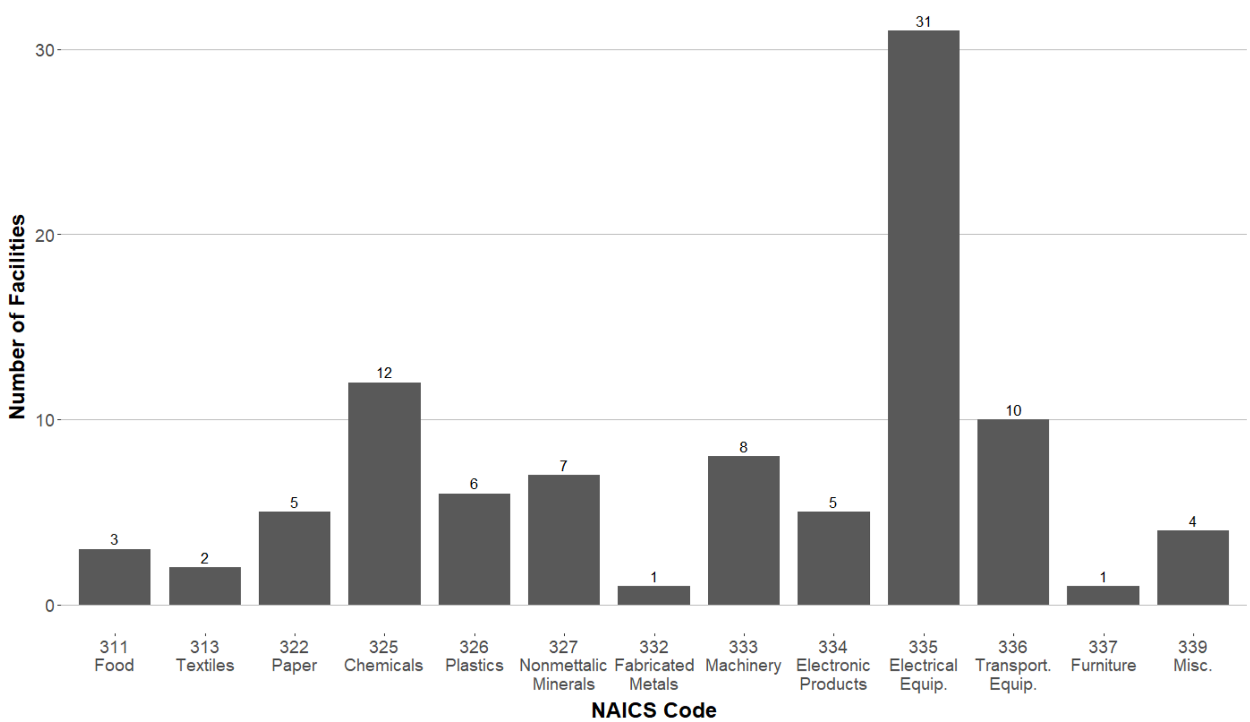

Fig. 3. SEP 50001 Facilities Included in this Study by NAICS Code

Use of the SEP M&V Protocol provides statistical confidence in the estimated energy performance improvements. All collection, validation, and calculation methods are detailed in the SEP M&V Protocol (U.S. DOE, 2019).

Of import for this study was each facility's respective certification cycle, Achievement Period, and energy performance improvement (EPI). With this information, the annual EPI for each certification cycle was calculated using Equation 1.

$$\text{Annual EPI (\%)} = \frac{\text{Verified EPI (\%)}}{\text{Achievement Period (years)}}$$

Eq. (1)

Due to irregularities in the data, some corrections were made to entries after utilizing Equation 1. There were two different types of corrections made – overlapping Achievement Periods and fractional Achievement Periods. The first case involved six facilities in which they had updated their EnMS after an initial certification and thus had "overlapping" Achievement Periods. In these cases, the most recent data was used as precedent when any years overlapped. The second case involved ten facilities in which their Achievement Period contained a fractional year (e.g. 2.66 years). For any such fractional year the weighted average was calculated for the relevant time period.

Thus, an annual EPI for each of the 83 facilities for each of their certification cycles was obtained. The range in time for facilities varies from a single year to sixteen years' worth of annual EPIs. This data was then collapsed down into columns relating solely to the year of the EPI, thus ranging from 83 entries at year one to a single entry at year sixteen. For inclusion in this analysis, any year with less than seven facilities represented were ignored due to small sample size. As a result, EPIs for years 13 to 16 are not considered in this analysis.

Next, a descriptive statistical analysis was performed on this dataset for each year. This study was focused on certain key statistics of the annual EPI, including count, mean, median, maximum, minimum, and range. With this data, graphical representations were created in the form of box-and-whisker and best-fit line graphs.

Finally, further analysis was performed on the EPI records associated with each facility's certification and re-certifications to determine if changes in EnMS leadership (as demonstrated by the name(s) on the EPI record) resulted in changes in the rate of energy performance improvement. Each facility with multiple EPI records was analyzed and it was determined whether the facility contact person (as dictated on the forms) stayed the same or changed with each successive certification. A constant facility contact person indicated that the EnMS leadership team was consistent whereas changes to the facility contact person indicated changes to the EnMS leadership team. The EPIs of the two groupings was compared to each other to identify any impact on energy performance improvement.

4. Results

The results show that the mean year-over-year annual EPI is positive throughout a facility's engagement with SEP 50001. The average annual year-over-year EPI rate peaks in year 1 at 4.1% and slowly decreases to 3.4% in year 12 (see Figures 4 and 5). While there is a slight degradation in the realization of year-over-year additional annual EPI, facilities are still realizing significant improvements in year 12 that far exceed the average improvement in energy intensity across all of industry (0.5% per year as reported in EIA's Annual Energy Outlook) and are more than 2.5 times the manufacturing energy efficiency improvements target (1.3% per year) set by the IEA for achieving a 1.5°C future. Due to differences in the constitution of the sample in the current study and the manufacturing sector in the EIA and IEA values and differences in the objective of each value comparison between the absolute EPI achieved by the SEP 50001 facilities and the EIA or IEA values for energy intensity/efficiency is not advisable. The IEA value is a target for energy efficiency's contribution to decarbonization goals, the EIA value represents autonomous change in U.S. industrial energy intensity for any reason including those unrelated to energy efficiency, and the SEP 50001 value represents improvements due to implementation of energy efficiency practices under an ISO 50001 energy management system. The EIA and IEA values are provided for contextualizing the results from the SEP 50001 facilities with regards to business-as-usual improvements (EIA) and decarbonization targets (IEA). Additionally, the value provided by the EIA represents U.S. industry at-large which has largely not adopted ISO 50001. Consequently, the reference point from the EIA also provides context for the SEP 50001 EPIs with regards to facilities that have largely not adopted ISO 50001.

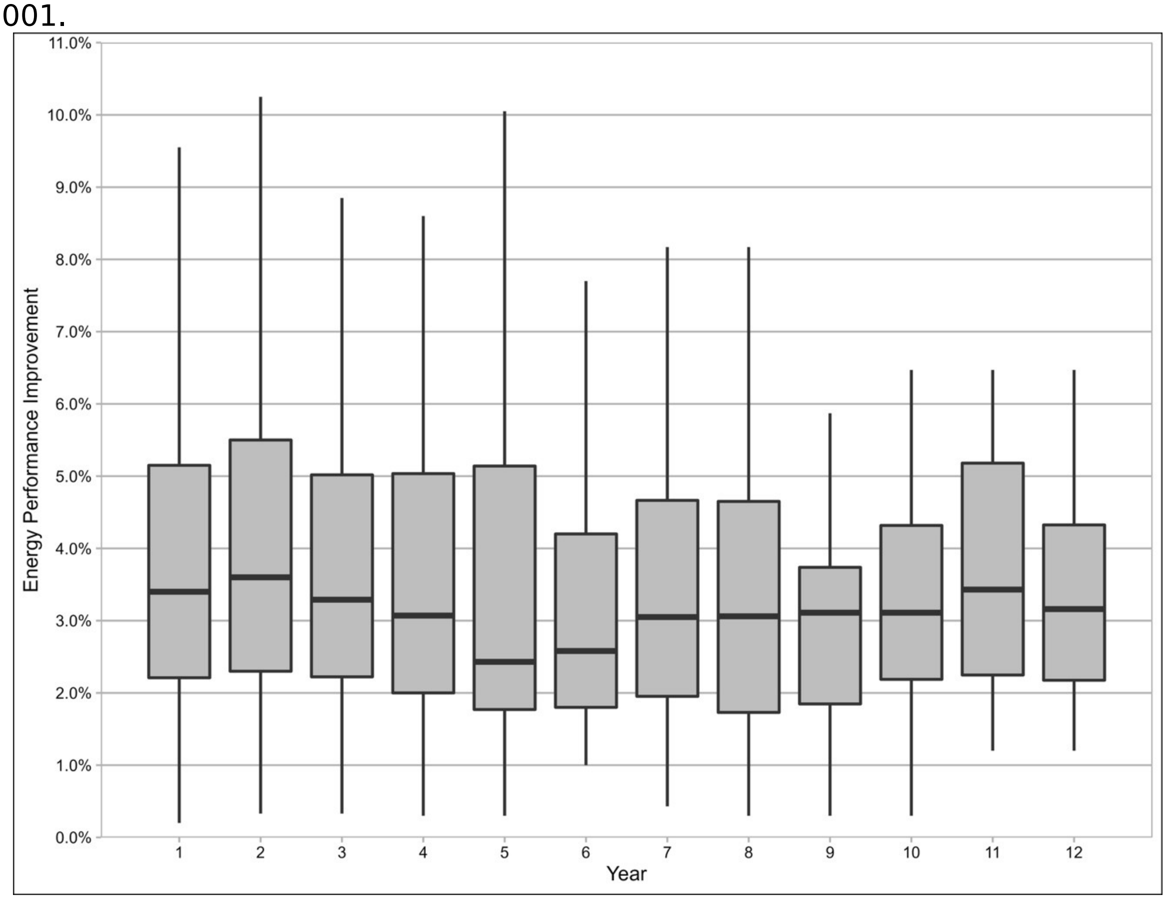

Fig. 4. Box-and-Whisker Plots of Year-Over-Year Annual Energy Performance Improvement for Years 1-12. The shaded boxes represent the lower and upper quartile, with the middle line representing the median. The whiskers denote the statistical minimum and maximum (spanning 12.5% to 87.5%), while the dots above represent outliers (data points that fall outside that span). The width of the boxes is determined by the relative data population size, with larger boxes representing larger datasets. All the above values are detailed in Table 1.

Figure 5 displays the mean annual year-over-year EPI for years 1 to 12. The best fit line is described by the equation $y=-0.0007(x)+0.0414$ indicating that the mean annual EPI starts off at 4.14% at year 1 then the incremental year-over-year energy savings rate decreases by 0.07% every subsequent year. In other words, facilities in the SEP 50001 program typically realize over 4% of energy savings in their first year in the program, and as time progresses, that annual savings is sustained and the additional energy savings amount is only 0.1% less per year. Table 1 provides a detailed breakdown of energy performance improvement for all SEP 50001 facilities by year of program engagement.

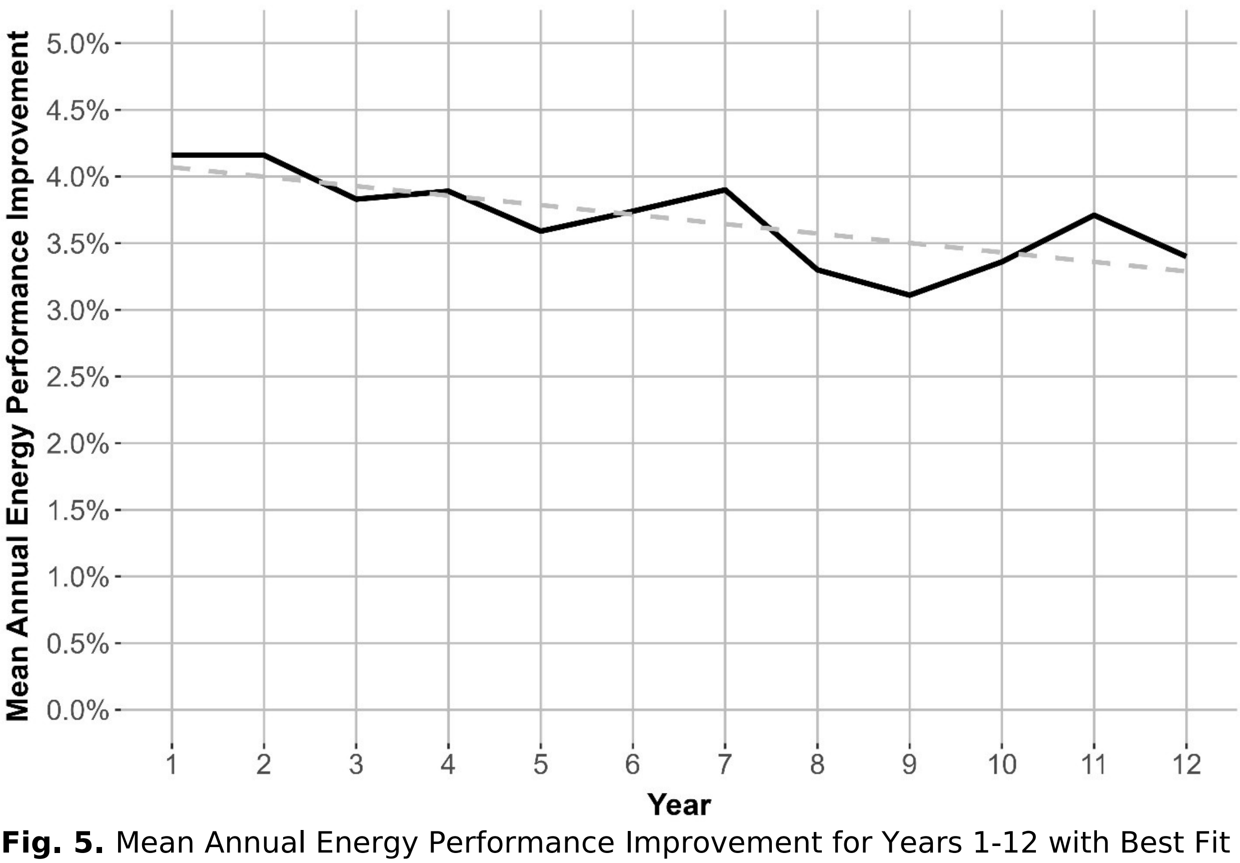

Fig. 5. Mean Annual Energy Performance Improvement for Years 1-12 with Best Fit Line

Table 1
Summarized Statistical Output for All Years (1-12)

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Count	83	74	61	40	37	30	23	21	18	12	8	7

Mean	4.2 %	4.2 %	3.8 %	3.9 %	3.6 %	3.7 %	3.9 %	3.3 %	3.1 %	3.4 %	3.7 %	3.4 %
Median	3.4 %	3.6 %	3.3 %	3.1 %	2.4 %	2.8 %	3.1 %	3.1 %	3.1 %	3.1 %	3.4 %	3.2 %
Max	18.7 %	12.5 %	12.5 %	12.5 %	10.2 %	12.2 %	11.7 %	9.5 %	8.2 %	6.5 %	6.5 %	6.5 %
Min	0.2 %	0.3 %	0.3 %	0.3 %	0.3 %	1.0 %	0.4 %	0.3 %	0.3 %	0.3 %	1.2 %	1.2 %
Range	18.5 %	12.2 %	12.2 %	12.2 %	9.9%	11.2 %	11.3 %	9.2 %	7.9 %	6.2 %	5.3 %	5.3 %

4.1 Embedded EnMS Analysis
Further analysis into “embedded” (i.e. incorporated into typical facility business operations) EnMS programs was conducted to determine whether EPI varies between embedded and un-embedded programs. A lack of correlation between the consistent use of key personnel over subsequent SEP 50001 certifications and EPI would indicate that the EPI achieved under an EnMS is autonomous of specific facility staff members and intrinsic to the business operations. The facility contact person (POC) is typically the SEP 50001 audit lead at the facility.

While 83 facilities were included in the energy savings analysis, 15 did not submit an EPI record. Most of these certifications predated the use of EPI records. Of the 68 facilities that did submit one, 39 facilities submitted more than one and the remaining 29 only had one certification cycle and thus only submitted one record. As shown in Table 2, of the 39 facilities that submitted more than one EPI record, 26 facilities had the POC changing on successive forms and 13 had the same POC. The facilities with a changing POC saw an average (percent, not absolute) decrease in reported EPI on successive Achievement Periods of 3.81%, while the facilities with the same POC saw an average decrease of 3.75%. For context, the average decrease between Achievement Periods for all 83 facilities was 3.79%. This analysis required certificate-to-certificate analysis, as opposed to annual breakdowns as with the previous analysis, because the data did not allow us to look within any single Reporting Period to determine the POC. The results indicate no significant correlation between EPI and the use of the same staff.

Table 2
Statistical Analysis of Embedded and Un-embedded EnMS

Energy Performance Improvement Reports		
Category	*Count*	*Change in EPI*
Facilities w/ Multiple EPIRs:	39	-3.79%
Facilities w/ Changing POC:	26	-3.81%
Facilities w/ Same POC:	13	-3.75%

5. Discussion
Our analysis demonstrates that on average SEP 50001 certified facilities achieve and sustain significant EPI year-over-year. The EPIs achieved in the years immediately following the implementation of the EnMS are highest and could be attributed to the “low hanging fruit” energy saving measures being addressed first

during the early years and capital-intensive projects being implemented in later years (Therkelsen and McKane, 2013). In addition to the shift from low hanging fruit measures to capital projects, the slight degradation in energy performance could be reflective of a facility approaching a theoretical minimum level of energy consumption for their operations. While maintaining the same EPI in the second Achievement Period may require less absolute energy savings than the first Achievement Period (due to re-baselining, see Figure 1), it will be more difficult to realize due to the facility's improved energy efficiency. In all years, the observed EPI exceeded the target for manufacturers set by the IEA SDS for staying below 1.5°C.

5.1 Embedded EnMS Analysis

In theory, a properly implemented EnMS is integrated into normal business operations (McKane et al., 2017). As such, its effective execution should not be tied to any individual in a company. While reliance on an individual champion is insufficient to conclude that the EnMS was not implemented properly, it does raise questions regarding its expected benefits. If the EnMS relies on an individual, then EPI realized through the EnMS would also be reliant upon an individual, as is typically seen in non-standardized energy efficiency programs. Reliance on an individual for operation of the EnMS risks degradation in energy performance (and even backsliding) if that individual leaves their current role.

The results of the analysis indicate that for facilities where the lead SEP 50001 auditor does not change during the SEP 50001 engagement, the energy savings are similar to those that do. Moreover, they are similar to the EPI realized across all 83 SEP 50001 facilities analyzed. This indicates that SEP 50001 produces an embedded EnMS and is independent of a single person attempting to drive all savings. A properly embedded EnMS establishes procedures and processes that leads to continuous identification, implementation, and maintenance of energy savings. In these situations, all personnel are working together towards a common goal of continuous energy improvement. The results support the claim that proper implementation of an EnMS intrinsically delivers energy savings. The ramification of this result is that implementation of an EnMS can be considered alongside other energy efficiency actions (e.g., installation of variable frequency drives, steam economizers) when developing policies and programs to improve a facility's energy efficiency.

5.2 Persistence of Energy Savings

The availability of financial incentives, such as utility rebates or federal tax breaks, would accelerate the mass adoption of EnMSs (Goldstein and Therkelsen, 2017). The incentives would reduce the initial implementation cost to the organization for implementing an EnMS and improve the return on investment. Previous analyses show that the majority of the implementation costs are labor charges for the energy team (Therkelsen et al., 2013 and Therkelsen et al., 2015). The incentives are commonly from public taxes or customer surcharges on utility bills that are approved by a governing body representing the public's interest (e.g., a public utility commission). As such, before developing programs to provide incentives, entities need to be able to demonstrate to these governing bodies that the use of funds is in the interest of the public. To demonstrate this, there needs to be a clear connection between the incented action and the realized energy savings. Further, the incented energy savings should "persist", meaning that the level of savings should remain stable through the useful life of the action with allowances for expected degradation. For an action like installing a more efficient product (e.g., motor, lighting), persistent energy savings can be shown via product testing using approved methods and procedures. However, the direct tie between energy savings and implementation of the EnMS has historically been more difficult to justify due to a lack of precedent and data on the impacts of EnMSs on energy savings. EnMSs lead to the adoption of actions that lead to energy savings. The energy savings can be directly tied back to these actions even though the action was identified and implemented under the construct of the EnMS.

In addition, it can be determined that ISO 50001-based EnMSs have greater persistence (i.e. useful life of energy savings) than other EnMS programs. It has previously been reported that other EnMS programs (i.e. non-ISO 50001) have self-reported useful lifespans around four years and save, on average, between 2% to 5% per year (Therkelsen et al., 2021). Compare this to the twelve years of persistent energy savings showcased in our analysis for SEP 50001 facilities. This would confirm that at or above average energy savings can be achieved and persist longer in an ISO 50001-based EnMS as opposed to other EnMS programs.

Benefiting from several years of high-quality data on the energy efficiency improvements realized under an EnMS, this analysis shows that the incorporation of an EnMS into business operations reliably leads to a relatively high level of energy efficiency improvement that persists year-over-year. While the energy savings come from a variety of energy saving actions, the results give confidence that enough actions will be implemented such that the facility will reliably realize a steady improvement in energy performance. Further, as previously discussed in section 5.1, the results provide confidence that an organization employing an EnMS will realize these energy savings as part of their natural business processes. Subsequently, disruptions or changes to operations (e.g., staffing changes, process changes, supplier disruptions) will not impact the level of energy savings realized. Therefore, the results presented here show that an EnMS leads to persistent energy savings.

This conclusion is key as it will allow for incentivizing the implementation of operational improvements. Past research has shown that over 70% of the energy savings achieved under an EnMS are attributable to non-capital projects (Therkelsen et al., 2013). These include actions like improved maintenance procedures, submetering processes, and employee awareness programs. Since these actions are not tangible, they are overlooked by incentive programs. However, by incentivizing EnMS implementation, these actions will be encouraged.

5.3 Applicability of findings to other sectors

The analysis and results conducted here only considered manufacturing facilities. However, seven non-manufacturing facilities – primarily within the hospitality sector – are also represented in the SEP 50001 EPI database. This is in addition to many institutional and commercial facilities that are ISO 50001 certified. To understand the ability to translate the results observed for the manufacturing sector to others, the seven “commercial” facilities also had the statistical analysis performed on them. The results are provided in Appendix A. The commercial facilities followed a similar trend of above-average energy savings, averaging 4.8% in each of the first three years. Only one facility sought a second certification rendering any conclusion regarding the rate of EPI for years four and onwards statistically insignificant. Even with the relatively small sample size for years 1 to 3, the initial results (in addition to many standard ISO 50001 certifications) indicate that commercial facilities may reap similar energy improvements from a properly implemented EnMS as manufacturing facilities. Additional data would be required to statistically confirm these results and also identify any unique characteristics of the EPI achieved by commercial facilities under an SEP 50001 EnMS.

5.4 Addressing Bias in Data

The EPI records carry intrinsic bias. For example, they shed no information on the EPI for facilities that chose not to recertify. If those facilities chose not to recertify due to inability to achieve the needed EPI, then this would impact the finding that the EnMS is embedded in the organization and energy savings are intrinsic to business operations. To better understand the EPI trends for facilities that chose not to recertify (inactive facilities), this subset of facilities was analyzed individually. The statistical analysis and results are included in Appendix B. Using the previous requirement that at least seven facilities should be represented in any given year before drawing conclusions from that year, years 1 through 3 provide sufficient data to examine the results. For the inactive facilities, a more significant degradation in EPI is observed, though the EPI remains above 3% which is sufficient for recertification. However, the higher rate of savings degradation combined with the decision to not re-certify points to an EnMS that may not have been implemented as comprehensively as the facilities that continue to achieve successive certifications. This finding underscores that the expected results discussed here can only be expected from a comprehensively implemented EnMS.

Additional bias may be introduced by the requirement to achieve a certain level of energy performance. This eliminates facilities that do not perform well and sets a minimum to any EPI in the SEP 50001 database. The minimum required EPI has to be positive over the Achievement Period (greater than 0.1% EPI). Given that the observed average EPI is far greater than this, the minimum performance requirement appears to bear no influence on the results.

6. Conclusion

Previously, it was assumed but not proven that a properly implemented EnMS would result in higher than average energy savings that persist over a significant time period at a rate far greater than those achieved under traditional approaches. While above-average energy savings resulting from EnMS implementation had been proven before, this paper sought to confirm the longevity and persistence of energy savings. After analyzing 83 SEP 50001 manufacturing facilities, it was confirmed that above-average energy savings are realized and persist throughout the life of the EnMS. In addition, it was shown that both the magnitude of savings and lifespan of the program was greater with SEP 50001 facilities than standard non-ISO 50001 EnMSs. This sets a precedent that proper establishment of an ISO 50001-based EnMS would both systematize and prioritize energy savings at any facility which would allow for the deep energy and emissions reductions required to meet the IPCC’s goal to maintain a 1.5°C increase to minimize the worst effects of human-induced climate change.

CRediT authorship contribution statement

Patrick Fitzgerald: Methodology, Formal Analysis, Investigation, Data Curation, Writing – Original Draft, Writing – Review & Editing, Visualization. **Peter Therkelsen:** Writing – Original Draft, Writing – Review & Editing. **Paul Sheaffer:** Writing – Original Draft, Writing – Review & Editing, Funding Acquisition. **Prakash Rao:** Conceptualization, Methodology, Validation, Writing – Original Draft, Writing – Review & Editing, Supervision.

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Appendix A: Analysis of "Commercial" Facilities

Table A.1: Summarized Statistical Output for "Commercial" SEP Facilities

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Count	7	7	7	1	1	1
Mean	4.81%	4.81%	4.81%	2.60%	2.60%	2.60%
Median	5.30%	5.30%	5.30%	2.60%	2.60%	2.60%
Maximum	7.57%	7.57%	7.57%	2.60%	2.60%	2.60%
Minimum	2.10%	2.10%	2.10%	2.60%	2.60%	2.60%
Range	5.47%	5.47%	5.47%	0.00%	0.00%	0.00%

Appendix B: Analysis of "Inactive" Facilities

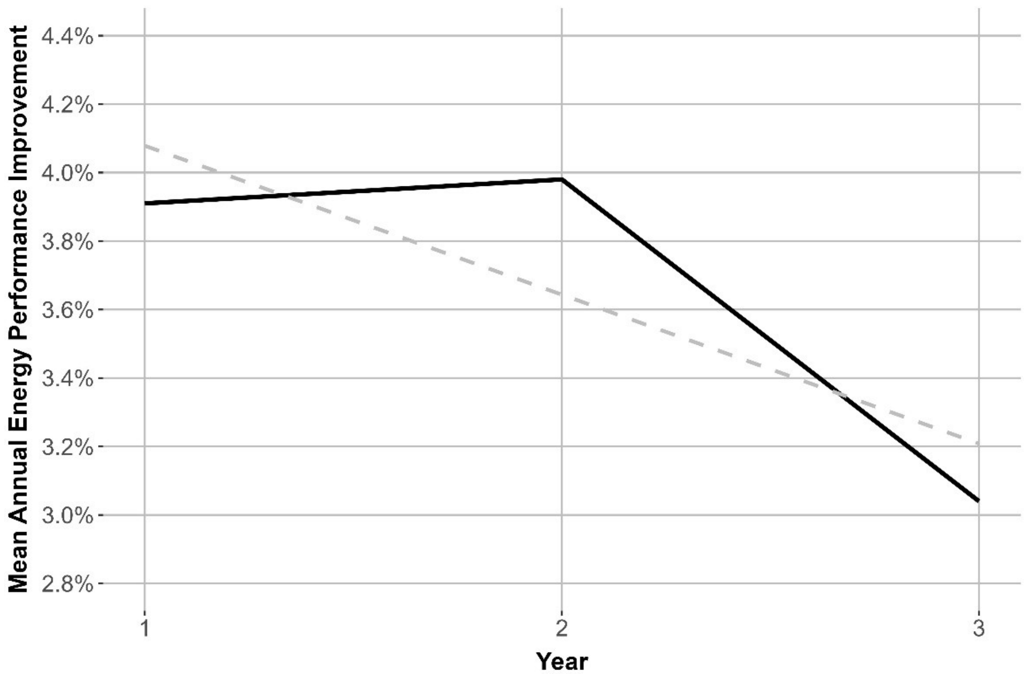

Fig B.1: Mean Annual Energy Performance for "Inactive" Facilities with Best Fit Line

Table B.1: Summarized Statistical Output for "Inactive" SEP Facilities

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
Count	18	17	13	4	3	2	2	2	2	2	1	1
Mean	3.91%	3.98%	3.04%	5.13%	4.68%	1.92%	1.92%	1.92%	1.92%	1.92%	2.32%	2.32%
Median	3.69%	3.97%	2.32%	4.41%	2.32%	1.92%	1.92%	1.92%	1.92%	1.92%	2.32%	2.32%
Maximum	7.65%	7.65%	5.67%	10.20%	10.20%	2.32%	2.32%	2.32%	2.32%	2.32%	2.32%	2.32%
Minimum	1.51%	1.51%	1.43%	1.51%	1.51%	1.51%	1.51%	1.51%	1.51%	1.51%	2.32%	2.32%
Range	6.14%	6.14%	4.24%	8.69%	8.69%	0.81%	0.81%	0.81%	0.81%	0.81%	0.00%	0.00%

References

ANSI, 2019a. Superior Energy Performance 50001 Program – Additional Requirements for Energy Management Systems (ANSI 50028-1:2019). American National Standard.

ANSI, 2019b. Superior Energy Performance 50001 Program – Requirements for verification bodies for use in accreditation or other forms of recognition (ANSI 50028-2:2019). American National Standard.

DOE, 2015. Barriers to Industrial Energy Efficiency. United States Department of Energy. https://doi.org/10.1108/IJESM-05-2013-0008.

EIA, 2018. Manufacturing Energy Consumption Survey 2018. U.S. Energy Information Administration. Retrieved from https://www.eia.gov/consumption/manufacturing/data/2018/.

EIA, 2020. Annual Energy Outlook 2020. U.S. Energy Information Administration's Annual Energy Outlook 2020 with projections to 2050.

Fuchs, H., A. Aghajanzadeh, P. Therkelsen, 2020. Identification of drivers, benefits, and challenges of ISO 50001 through case study content analysis. Energy Policy 142. https://doi.org/10.1016/j.enpol.2020.111443.

Goldstein, D. B., P. Therkelsen, 2017. A Structure for Incentivizing Greater Achievements in Strategic Energy Management. Proceedings of the ACEEE Summer Study on Energy Efficiency in Industry.

Hoegh-Guldberg, O., D. Jacob, M. Bindi, S. Brown, I. Camilloni, A. Diedhiou, R. Djalante et al., 2018. Impacts of 1.5C global warming on natural and human systems. Global warming of 1.5 C. An IPCC special report.

IEA, 2021. World Energy Outlook 2021. World Energy Outlook. Retrieved from https://www.iea.org/reports/world-energy-outlook-2021.

IPCC, 2022. Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

ISO, 2011. ISO 50001 Energy Management Systems – Requirements with guidance for use. Geneva: International Organization for Standards.

ISO, 2022. ISO Survey 2020. Accessed May 12, 2022. https://www.iso.org/the-iso-survey.html.

Johannson, M. T., P. Thollander, 2018. A review of barriers to and driving forces for improved energy efficiency in Swedish industry – Recommendations for successful in-house energy management. Renewable and Sustainable Energy Review 82: 618-628. https://doi.org/10.1016/j.rser.2017.09.052.

Liu, J., P. Rao, P. Therkelsen, P. Sheaffer, P. Scheihing, Y. Tamm, 2017. ISO 50001 and SEP Faster and Cheaper – Exploring the Enterprise-Wide Approach. Lawrence Berkeley National Laboratory. Retrieved from https://escholarship.org/uc/item/16x663gz.

McKane, A., D. Desai, M. Matteini, W. Meffert, R. Williams, R. Risser, 2009. Thinking Globally: How ISO 50001 – Energy Management can make industrial energy efficiency standard practice. Retrieved from https://escholarship.org/uc/item/92d8q553.

McKane, A., P. Therkelsen, A. Scodel, P. Rao, A. Aghajanzadeh, S. Hirzel, R. Zhang, R. Prem, A. Fossa, et al., 2017. Predicting the quantifiable impacts of ISO 50001 on climate change mitigation. Energy Policy 107: 278-288. http://dx.doi.org/10.1016/j.enpol.2017.04.049.

Morrow, W. R., A. Carpenter, J. Cresko, S. Das, D. J. Graziano, R. Hanes, S. D. Supekar, S. Nimbalkar, M. Riddle, A. Shehabi, 2017. US industrial sector energy productivity improvement pathways. Proceedings of ACEEE Summer Study on Energy Efficiency in Industry, August. Retrieved from https://www.osti.gov/biblio/1524314.

Paramonova, S., P. Thollander, M. Ottosson, 2015. Quantifying the extended energy efficiency gap – evidence from Swedish electricity-intensive industries. Renewable and Sustainable Energy Reviews 51: 472-483. https://doi.org/10.1016/j.rser.2015.06.012.

Rissman, J., C. Bataille, E. Masanet, N. Aden, W. R. Morrow, N. Zhou, N. Elliott, R. Dell, N. Heeren, B. Huckestein, J. Cresko et al., 2020. Technologies and policies to decarbonize global industry: Review and assessment of mitigation drivers through 2070. Applied Energy. https://doi.org/10.1016/j.apenergy.2020.114848.

Smith, K. M., S. Wilson, M. E. Hassall, 2021. Could focusing on barriers to industrial energy efficiency create a new barrier to energy efficiency? Journal of Cleaner Production 310. https://doi.org/10.1016/j.jclepro.2021.127387.

Therkelsen, P., A. McKane, R. Sabouini, T. Evans, 2013. Assessing the costs and benefits of the superior energy performance program. Proceedings of ACEEE Summer Study on Energy Efficiency in Industry. Retrieved from https://escholarship.org/uc/item/86c5r08v.

Therkelsen, P., A. McKane, 2013. Implementation and rejection of industrial steam system energy efficiency measures. Energy Policy 57: 318-328. https://doi.org/10.1016/j.enpol.2013.02.003.

Therkelsen, P., P. Rao, A. McKane, R. Sabouni, P. Sheihing, 2015. Development of an Enhanced Payback Function for the Superior Energy Performance Program. Proceeding of ACEEE Summer Study on Energy Efficiency in Industry. Retrieved from https://eta.lbl.gov/publications/development-enhanced-payback-function.

Therkelsen, P., H. Fuchs, W. Miller, A. Whitlock, E. Rightor, 2021. Strategic Energy Management Program Persistence and Cost Effectiveness. North American Strategic Energy Management Collaborative. Retrieved from https://www.aceee.org/research-report/ie2101.

Ungar, L, S. Nadel, 2019. Halfway There: Energy Efficiency Can Cut Energy Use and Greenhouse Gas Emissions in Half by 2050. American Council for an Energy Efficient Economy. Retrieved from https://www.aceee.org/fact-sheet/halfway-there.

U.S. DOE, 2019. Superior Energy Performance 50001 Program Measurement & Verification Protocol: 2019.

U.S. DOE – Better Buildings. "Certify and Get Recognized." Better Buildings Solution Center. https://betterbuildingssolutioncenter.energy.gov/iso-50001/sep-50001/certify-and-get-recognized (accessed 14 March 2022).

U.S. DOE – Energy Efficiency & Renewable Energy. "Superior Energy Performance." Advanced Manufacturing Technical Partnerships. https://www.energy.gov/eere/amo/superior-energy-performance#how-to-qualify (accessed 10 May 2022).