# Integrating ISO 50001:2018 into Engineering Education: Advancing Energy skills for Industry 4.0 and 5.0

Marwa Ben Ali, Erwin Rauch

*Abstract*— **The present paper explores the integration of ISO 50001 energy management standards into engineering education in Europe, aiming to align academic training with the demands of Industry 4.0 (I4.0) and Industry 5.0 (I5.0), as well as the evolving technologies and regulations. It underscores the strategic importance of equipping future engineers with the competencies necessary for energy efficiency, sustainability reporting, and smart sustainable industrial practices. By embedding ISO 50001 into curricula, students can acquire essential skills that enhance their employability, innovation potential, and readiness to contribute to modern energy management systems. The paper also discusses the mutual benefits for companies, including smoother implementation of energy strategies and a workforce better prepared for sustainability-driven transformation. Despite its potential, ISO 50001 adoption remains limited, with many companies still hesitant, highlighting the need for stronger educational-industry collaboration and curriculum reform. However, this approach of academia-industry collaboration could serve as a starting point for initiating the internal audit towards external certification.**

*Keywords: ISO50001, Industry 4.0, Industry 5.0, Education 5.0, Energy Management, Energy Efficiency, Engineering Education.*

## I. Introduction

Energy consumption plays a vital role in the industrial sector, particularly for both industrial processes and non-process applications such as heating, cooling, and lighting [1]. The industry's reliance on energy-intensive operations, fossil fuels, and large-scale production makes it a major contributor to global $CO_2$ emissions. In the third quarter of 2024, manufacturing accounted for 21.6% of greenhouse gas emissions in Europe, marking it as the largest source [2]. This underscores the significance of both large corporations and small and medium enterprises (SMEs), which are predominant in the European business environment [3]. Enhancing energy efficiency is essential for transitioning to clean energy and meeting global climate and sustainability objectives.

Europe has seen numerous initiatives for sustainable energy management and carbon emission reduction. The continent's climate action commitment is shown through policies like the Kyoto Protocol [4], the European Green Deal Industrial Plan targeting net-zero emissions by 2050, and the goal to limit global warming to 1.5°C, requiring emissions to peak by 2025 and decrease 43% by 2030 [5, 6]. However, did Europe meet the 2025 target? 2024 was the hottest year in 175 years of records, with temperatures 1.55°C above pre-industrial levels, exceeding the 1.5°C threshold. The continent needs action from all enterprises through cooperation, reporting, and improvement. Better management will lead to energy efficiency and renewable energies (REs) integration.

One of the key tool in reaching these goals is the implementation of ISO 50001: 2018, the international standard for energy management systems (Although both EMS and EnMS are commonly used abbreviations, in this paper we will adopt the abbreviation EMS to refer to Energy Management System) [7].

Europe is a well-established market for ISO standards, driven by regulatory compliance and customer advocacy for quality and sustainability [8]. With increasing focus on energy management (ISO 50001) due to policy-driven climate objectives, enhancing energy efficiency has become essential to achieving these environmental goals. Management tools like EMS have shown promising outcomes, including reduced operational costs and improved environmental metrics. Nevertheless, many companies, particularly SMEs, face obstacles in adopting these systems, including high certification costs, insufficient skills and knowledge, and resistance to change [9, 10]. To address these challenges, European governments offer training programs and financial incentives to support ISO 50001 adoption in businesses. Italy provides incentives for SMEs to implement energy management systems compliant with ISO 50001 and for energy audits every two years until 2030 [11]. In Germany, to encourage SMEs to conduct energy audits, the German Federal Ministry for Economic Affairs and Climate Action launched a Special Fund program providing financial assistance for energy audits in SMEs, administered by a state-owned German institution—an investment and development bank "KfW" in cooperation with regional partners and chambers of industry and commerce. The program aimed to overcome information barriers related to implementing energy efficiency measures with an energy audit [12]. Figure 1 illustrates the number of certifications in selected European countries [13], highlighting that Germany leads with 10,362 certifications, both in Europe and globally.

Sustainable Manufacturing Lab, Faculty of Engineering, Institute for Industrial and Energy Engineering, Free University of Bozen. Bolzano, Piazza Università 1– 39100 Bolzano, Italy, e-mail: marwa.benali@unibz.it).

Businesses, particularly those that are small to medium in size, should improve their energy management. Concurrently, Europe is rapidly updating its regulations. These elements are driving companies to focus more on sustainability objectives. This situation aligns with the need to reskill and upskill both the current and future workforce in Europe [14].

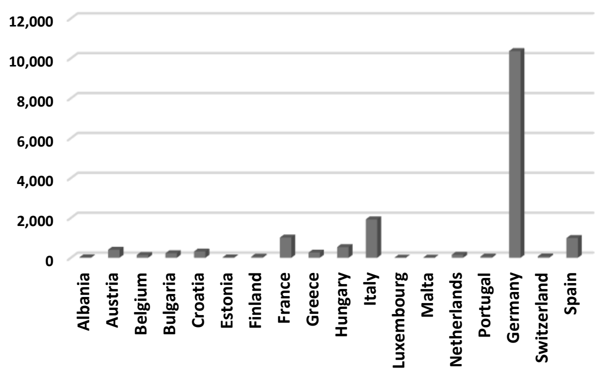


Figure 1. Number of ISO 50001: 2018 Certifcations per country, 2023 (Own Elaboration).

Skill shortages remain a major obstacle to business transformation worldwide. According to the Future of Jobs Report 2025, 63% of employers consider skill shortages a major obstacle between 2025 and 2030 [15]. This is fueling demand for roles such as renewable energy engineers, environmental engineers, and specialists in electric and autonomous vehicles, all among the 15 fastest-growing jobs

This underscores the increasing importance of collaborative relationships between academia and industry, which are crucial for fostering innovation and maintaining the relevance of educational programs [16]. These collaborations enable the sharing of knowledge, abilities, and resources, which better equips students to meet workforce requirements, particularly in fields that demand not only skills but also time, commitment, and investment. Industry experts bring real-world insights and current trends into academic settings, while universities offer cutting-edge research and theories that influence industry practices, especially in the critical areas of sustainability and energy management. Here, the research questions (RQ) is: *What are the benefits and challenges of integrating energy audits (ISO 50001) into engineering education for students and industry?*

### A. Objectives and Value Added

Beyond fostering green skills, higher education institutions (HEIs) play a crucial role in supporting the transition to a European net-zero economy. By reshaping training programs, HEIs equip students with the necessary tools and strategies to tackle environmental challenges. They redesign curricula to integrate green and digital technologies, offering students (future workers) practical, hands-on experiences primarily through Problem-based Learning (PBL) and Project-based Learning (PjBL), alongside other active learning methodologies. This approach evolves with new technologies in the context of Industry 4.0 and Industry 5.0, including artificial intelligence (AI), IoT, and electric vehicles (EVs), among others. These strategies provide students with the skills demanded by the labor market. By incorporating Education 5.0 principles [17], the initiative ensures personalized learning experiences, enabling individuals to develop twin skills that are critical for the transformation of the job market.

### B. Outline of the present paper

The structure of this paper is as follows: Section II delivers a comprehensive introduction to ISO 50001: 2018. Section III examines the shortcomings in current engineering curricula and proposes measures to advance industry academia collaboration. Section IV delves into the proposed framework. Section V showcases a case study on the early education of ISO50001. Lastly, Section VI summarizes the overall conclusions.

## II. Overview of ISO 50001: 2018: Overview

Energy management entails the proactive and systematic oversight, regulation, and enhancement of an organization's energy usage to achieve environmental objectives through energy conservation and economic objectives by reducing energy expenses. An EMS comprises interconnected components that define energy policies, goals, processes, and procedures to meet energy performance targets [18]. The EMS provides companies with a structured approach for evaluating and improving their energy efficiency, consumption, and usage on an ongoing basis [19].

The EMS implementation model incorporates the Plan-Do-Check-Act (PDCA) cycle [20], which includes 10 clauses (chapters) such as Leadership, Planning, and Support, among others. It is applicable to organizations of all types and sizes across various sectors and is founded on the principle of continuously improving energy performance. System components involve creating an energy policy, setting objectives for more efficient energy use, establishing a timeline with target dates for achieving these objectives, and developing an action plan that details how the organization will accomplish its goals.

### A. Benefits of adopting ISO50001

The company implementing the energy audit ISO 50001 is reaping various benefits. As illustrated in Fig. 2, these benefits are categorized into direct benefits, such as cost savings and improved energy efficiency, and indirect benefits, such as enhanced company image and reputation, as well as increased employee engagement and awareness [20-24].

Despite these advantages, many companies, particularly SMEs, remain hesitant to adopt it due to various barriers and challenges. In the following subsections, we will explore these barriers based on findings from the literature review.

### B. Barriers and challenges to implementation of the ISO 50001: Literature review European Insights

This subsection gathers the obstacles and difficulties highlighted in recent studies and case analyses (2024, 2025) [25-

29], as detailed in Table I, from the initial adoption to the actual implementation. These issues include a lack of comprehensive

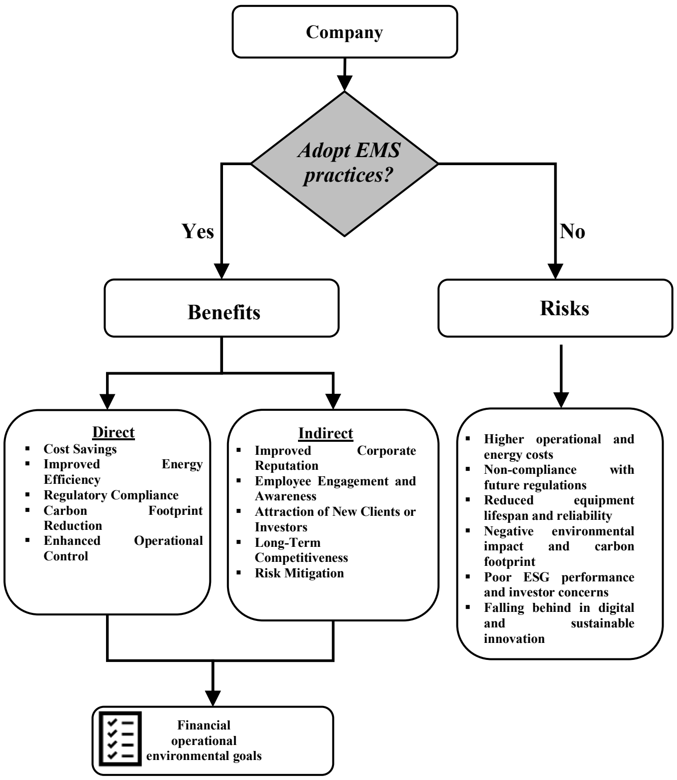


Figure 2. Flowchart of the Importance role of the EMS (Own Elaboration).

understanding of ISO 50001 practices and their benefits, the financial costs associated with certification and necessary technologies, and a shortage of skilled personnel needed for the successful implementation and ongoing enhancement of these practices.

TABLE I. CHALLENGES TO IMPLEMENTATION OF THE ISO 50001

| ***Challenges*** | **References** |
|---|---|
| *Lack of awareness and knowledge about ISO 50001* | 1, 5 |
| *Lack of financial resources* | 1, 2, 4, 5 |
| *Weak leadership commitment* | 1, 4, 5 |
| *Cultural barriers* | 1, 5 |
| *Lack of Clear policy and subsidies* | 2, 5 |
| *Lack of stakeholder collaboration and knowledge-sharing initiatives* | 3,5 |
| ***Deficiencies in competencies*** | **4, 5** |
| *Lack of clear, measurable benefits* | 4, 5 |
| *Data acquisition and management* | 5 |
| *New technologies* | 5 |

## III. GAPS IN CURRENT ENGINEERING CURRICULA

### *A. Overview*

Industry 4.0 and Industry 5.0 have introduced new technologies like AI, cloud computing, robotics, and IoT. They also stress the need for humans and machines to work together, focus on sustainability, and be socially responsible. New technologies like renewable energy, electric vehicles, and smart grids need better management. These changes are affecting jobs worldwide and require changes in education. Education 5.0 supports teaching methods that focus on the learner.

To close the gap between academic and industry needs, a robust partnership between academia and industry is crucial. This collaboration can help align curricula with practical applications, provide exposure to current and emerging technologies, and promote experiential learning opportunities like internships, co-designed projects, and interdisciplinary teamwork. By embracing the fundamental principles of Education 5.0, including technology integration, ethical orientation, and collaborative new teaching methods (e.g., PBL and PjBL, among others), educational institutions can better equip students for the dynamic careers of today and tomorrow, providing them with both the technical skills and soft skills necessary for success in an increasingly complex and interconnected world. Most researchers and policymakers concur that STEM education is a vital area that requires further development.

### *B. Bridge the gap: IAC Examples*

IAC is critical to accelerate transition and enable students to engage in real-world job environments. In the energy sector, equipping students with green skills will help companies, particularly SMEs, implement strategies applied during studies. A case study "Toward a Sustainable Educational Engineer Archetype through Industry 4.0" highlighted the need for transforming engineering education to align with sustainability goals and technological advancements. The authors proposed an archetype integrating technical and managerial competences for I4.0. The research mapped educational outcomes and professional skills to prepare engineers for modern industrial challenges. They identified gaps in engineering profiles regarding sustainability and advocated for a framework aligning with the United Nations Sustainable Development Goals (UN-SDGs). By illustrating methods to assess sustainability impacts and promoting collaboration, the study called for curricular reforms to develop engineers equipped to address industrial and environmental challenges [30].

Authors in [31] investigated non-academic stakeholder engagement in higher education agricultural programs, emphasizing action-oriented education for sustainability. They developed a process model for stakeholder engagement, outlining steps for effective partnerships and integrating non-academic knowledge. Their aim was to bridge theory and practice, enhancing academic institutions' societal impact in agriculture.

In [32], the authors demonstrated that co-management effectively equips environmental engineers for green innovation. Results indicate that collaboration between academia, industry, and government is essential for developing a workforce capable of addressing environmental challenges. They examined 65 students, six industry representatives, and 14 lecturers, analyzing participation and evaluation criteria. Hackathons fostered teamwork, skill diversification, and problem-solving. Participants reported increased confidence, showing this model's value in connecting theory and application. The outcomes suggested partnerships can improve education quality and support innovative solutions in environmental engineering.

Researchers in [33] explored Finland's IAC program, Need for Speed (N4S), from 2014 to 2017, focusing on knowledge transfer between industry and academia. N4S aimed to enhance software research with a €50 million budget involving 40 companies and institutions. It produced results in a digital repository, the "Treasure Chest," with over 100 actionable items and industry narratives. Findings highlight collaborative networks as crucial for innovation, showing complex challenges require interdisciplinary collaboration. They concluded with recommendations for future projects on integrating academic research with industry needs.

Despite emphasis on collaboration, educational programs face obstacles. One major issue is outdated curricula lagging behind advancements in energy systems and sustainability [34]. Graduates often lack practical experience vital in energy engineering. IAC can address these deficiencies through internships, cooperative education, and real-world projects, providing hands-on experience missing in traditional settings. Discussing ISO 50001, particularly the internal audit, serves as an initial step for student projects, providing a starting point to review processes and consumption.

## IV. Proposed Framework

In this paper, we introduce a framework, Motivation, Objectives, Vision, and Execution (MOVE), as depicted in Fig. 3, designed to guide change in our case study.

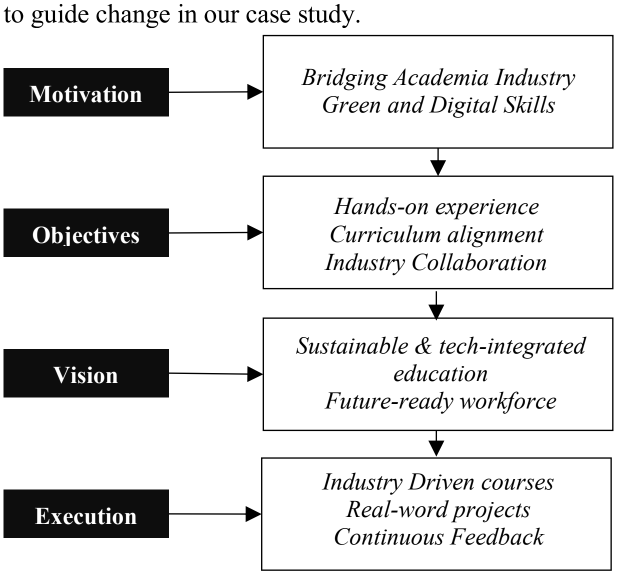


Figure 3. Adopted Framweork (Own Elaboration).

Within energy engineering education, the Motivation phase involves recognizing the need for change, prompted by technological advancements, environmental challenges, and the transition from Industry 4.0 to 5.0. This phase emphasizes equipping students with skills aligned to emerging trends like automation, AI, and sustainability, crucial to Industry 4.0 and 5.0. The Objectives phase focuses on establishing measurable goals, such as integrating practical industry experience to align the curriculum. The Vision phase involves formulating a plan for a future where education is sustainable and technology-integrated, preparing a workforce for forthcoming challenges. Finally, the Execution phase outlines steps to implement these strategies.

By applying the MOVE framework to IAC, educational programs can align with industry demands while preparing students to address evolving energy sector challenges.

## V. The Case for Early ISO 50001 Education

### A. Objectives

Prior to organizing the Lecture and aligning it with the established framework phases, both general and specific learning objectives were outlined. The course aims to equip master energy engineering students in their final year with the following learning objectives and competencies.

*General Objective*: To equip students with a comprehensive and interdisciplinary foundation in energy management, combining ISO 50001:2018 principles, theoretical and practical audit tools, green and digital competencies, and real-world collaboration with industry to prepare them for professional roles in sustainability and environmental compliance.

*Specific objectives*:

- Understand the structure, goals, and key requirements of ISO 50001:2018.
- Analyze energy consumption and efficiency using quantitative methods.
- Plan and perform a complete energy audit aligned with ISO 50001 standards.
- Collect, manage, and interpret industrial energy data to recommend improvements.
- Experience real-world challenges through case study analysis.

### B. Teaching approach

To effectively qualify students, it is crucial to adopt a practice-oriented approach, as outlined in Fig. 4. Our proposed concept begins with the fundamentals of Energy Management and ISO5001: 2018, focusing on energy audits (concept, chapters, requirements, energy monitoring, steps, etc.). These theoretical lessons are followed by a series of exercises designed to apply various tools (PDCA, Political, Economic, Social, Technological, Environmental, Legal (PESTEL); Strengths, Weaknesses, Opportunities, Threats (SWOT), heat map; risk assessment). In the subsequent phase, after reviewing the entire concept and preparing relevant questions, students visit a company where the management team presents the company's vision, objectives, current status, technology usage, and operations. Following this, participants work in groups on a project-based task, where they must prepare an energy report and presentation based on data collected from the company. Finally, the energy reports, complete with analysis, recommendations, and market research, are delivered to the company for internal review.

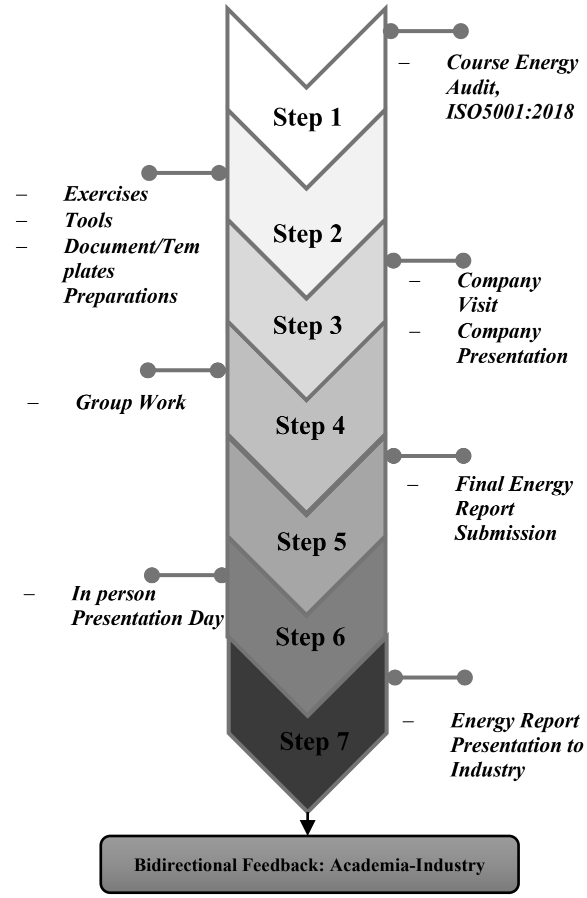


Figure 4. Steps for Teaching Energy Audits in an Engineering Master's Course (Own Elaboration).

## VI. Discussion

The authors implemented the discussed method using the MOVE framework for second-year master's students in Energy Engineering. Student feedback indicated that presenting topics through theory alone, without real case studies or company collaboration, would not aid their understanding of implementation. The development of analytical thinking and ability to present ideas to industry stakeholders enhanced their comprehension of real-world challenges (see Fig. 5). The resources and students' findings serve as a starting point for the internal schedule audit process, with ready-made templates (internal checklist, Energy policy, general audit, etc.). Success is measured by student and company satisfaction, student requests for theses and internships in energy management, further company collaboration, and scientific publications based on course findings.

## VII. Conclusion and Future Work

This paper addresses how many companies, particularly SMEs, encounter difficulties adopting the ISO 50001:2018 energy management system as technology advances and energy management becomes crucial to Europe's carbon neutrality goals by 2050. We introduced the MOVE framework for industry-academia collaboration, aimed at preparing the future European workforce through project-based learning while providing companies insights into energy management and internal audit processes for future certification. We suggest a lecture for energy engineering students to apply their tools and knowledge in a real-world case study. The approach has shown promising success for all parties, and the case study results will be detailed in a forthcoming paper.

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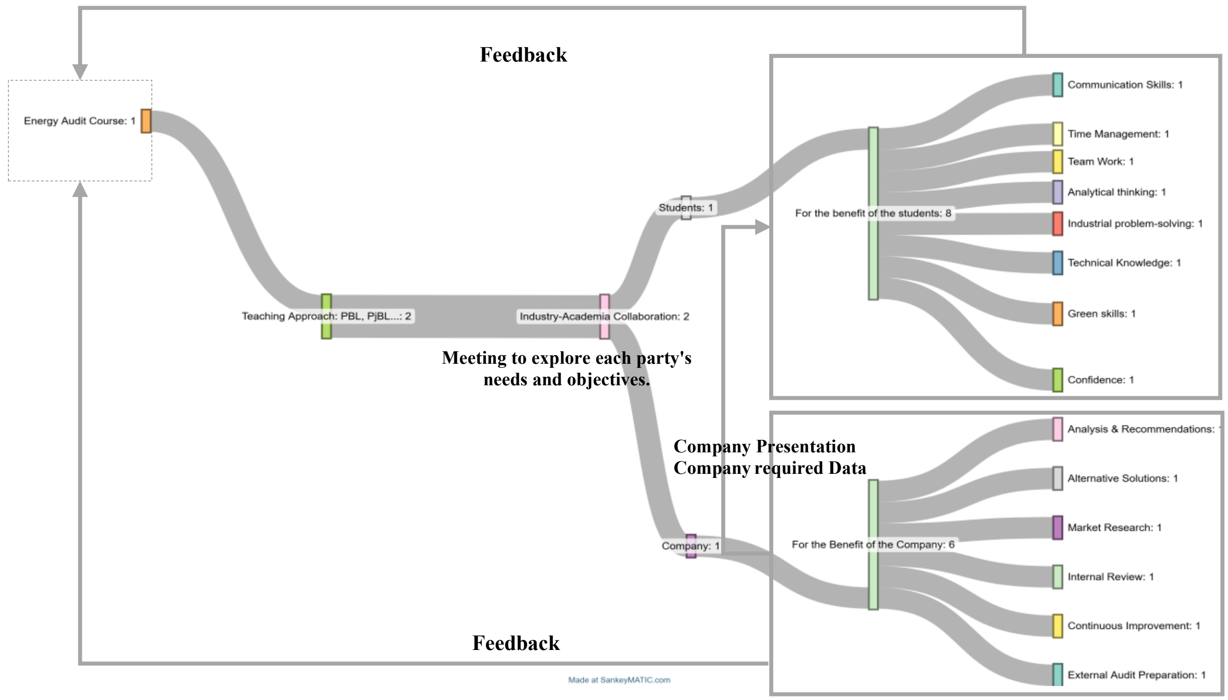


Figure 5. The Bidirectional Benefit from IAC (Own Elaboration using SankeyMATIC).


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