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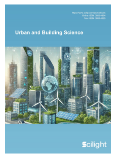

Article

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Cyclical Methodology to Optimize an Integrated Energy-Environmental Management System towards Sustainability †

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Abstract: Based on a sustainability approach, the synergy between the current most implemented standards for Energy Management Systems (EnMS) ISO 50001:2018 and Environmental Management Systems (EMS) ISO 14001:2015 is addressed in this work to propose a general cyclical methodology for improving organizational comprehensive performance and promoting the transition to renewable energy. Nowadays, organizations are required to establish robust and integrated management systems, responding to intensive competition and complex market dynamics. The combined implementation of these standards is a recent research field, due to the recent arrival of ISO 50001 in 2011. There are already some studies regarding the benefits, drivers, challenges, and barriers that companies face with this integration. Therefore, this paper unprecedentedly explores a divergence coupling approach to propose a methodology framed in the Plan-Do-Check-Act cycle, for the promotion of good energy-environmental practices, continuous improvement and sustainability. The main divergences of the standards appear in the planning and operation clauses and are mostly related to ISO 50001 requirements not included in ISO 14001. Thus, through extrapolation the divergences are harmonized to shape the "Plan" and "Do" stages of the methodology. The "Check" and "Act" stages consist of compliance with sustainability principles and feasible courses of action. This proposed approach improves the integrated energy and environmental performance, and increases economic benefits and sustainability in any organization, but especially in fossil fuel-based industry, as in the referenced case study at the Tula refinery. Moreover, the findings presented can be used by standardization bodies and policymakers in accelerating energy transition and sustainable development.

Keywords: synergy between ISO 50001 and ISO 14001; coupling divergence approach; sustainability principles; comprehensive energy and environmental performance; continuous improvement PDCA cycle; feasible courses of action

1. Introduction

There is an evident symbiosis between energy and the environment. Energy generation unavoidably requires environmental resources, and in some way, the use of energy has an impact on the environment. This synergy between energy and the environment should not necessarily imply negative effects, which are becoming increasingly imminent nowadays. Fossil fuel-based industries still predominate globally, generating a cumulative environmental impact with serious consequences for the planet and all its species [1,2]. Indeed, fossil fuels remain the world's primary energy source [3]. Global warming is becoming more and more critical today and urges for radical actions that avoid a planetary collapse [4–6]. Thus, there is an eminent need to change traditional energy sources with significant impacts on the environment such as fossil fuels; a paradigm shift toward clean, renewable and free energy is urgent, for a healthy environment and social well-being. First introduced in 1987 by the United Nations, the concept of sustainable development is defined as the necessity of the "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" [7] and, consequently aims to balance three fundamental dimensions: environment, society, and economy [8–10].

As a course of action to address sustainable development, the United Nations proposed in 2015 the 2030 Agenda with 17 main goals. Regarding energy, Goal 7 considers to "ensure access to affordable, reliable, sustainable and modern energy for all"; and concerning the environment, Goal 13 intends to "take urgent action to combat climate change and its impacts" [11]. At a more operational level, the concept of sustainable resource management is currently being considered, leading to good practices in energy efficiency and the adoption of renewable energy [12]. In this regard, Herman Daly proposed a set of principles including sustainable collection, sustainable issuance, sustainable emptying, and sustainable technology selection [13], which are together an important reference point for verifying the progress in the specific sustainability of any organization.

Also in 1987, the International Organization of Standardization (ISO) released the first management system standard, ISO 9001 for Quality Management Systems. ISO standards for management systems are related to sustainable development as they are based on the systemic approach [14,15] to promote the sustainability of organizations. Thus, a management system is a set of interrelated or interacting elements of an organization to establish a policy and objectives focused on a specific purpose, and processes and procedures to achieve those objectives [16]. After quality, the disciplines involved in management systems have become very varied, thanks to the worldwide success of the ISO 9001 standard and the systems, processes and improvement approach in organizations. Since its recent arrival in 2011, ISO 50001 has been the most well-known and implemented Energy Management Systems (EnMS) standard; just before the second and current version was published in 2018, more than 22,000 organizations had implemented ISO 50001 [17]. This popularity was the result of a growing need to use energy efficiently [18], due to a gradual increase in energy costs as global demand significantly rose along with industrialization [19].

The implementation of ISO 14001-based Environmental Management Systems (EMS) started in 1996 with the release of the first version, a framework for protecting the environment and responding to changing environmental conditions [20]. The second version was released in 2004, and the third and current one in 2015. ISO 14001 is globally the most implemented standard for EMS [21–24] and after ISO 9001, is the second ISO standard most adopted in the world [25,26]. The benefits associated with EMS are waste minimization [27], savings in related management, improved corporate image, less consumption of energy and materials [28], and cleaner, safer, and healthier products and workplaces [29–31].

Nowadays, companies are facing complex market dynamics and intense competition, therefore, more of them need to integrate several management systems. Consequently, ISO management systems standards have evolved to have corresponding structures between them [32–35]. Recently, the International Organization for Standardization (ISO) has established a Harmonized Structure (HS) for all management systems standards, which implies identical clause numbers, clause titles, text, common terms and core definitions [36]. Additionally, these standards are based on the continuous improvement approach, which consists of the Plan-Do-Check-Act (PDCA) cycle as a routine practice [37,38].

Nevertheless, in particular, the integration of EnMS and EMS is still few referred to in the literature [32], despite the close relationship between energy and the environment. Some studies have been carried out to integrate these standards based on their correspondence [39–41]. However, it has been argued that even in organizations with both EnMS and EMS implemented, increasing energy efficiency does not always align adequately with environmental improvements [42], mostly in the fossil fuel-based industry. The integration of EnMS and EMS should lead to an increment in energy efficiency and better environmental performance. Energy generation should not mean negative environmental impacts [43]. Climate change and environmental pollution may be mitigated by adequate energy management [44]. In this sense, the most relevant barriers organizations currently face in this integration include the scarcity of resources such as time, information and funding, inadequate organizational strategies or the lack of leadership commitment, and the high use of non-renewable fossil energy [43].

Moreover, ISO 50001 and ISO 14001 are said to be weak in fostering the use of renewable energy [44]. Therefore, based on the unprecedented approach of coupling the divergences between these two standards to establish a deeper synergy, this work aims to propose a general and cyclical methodology, framed within the PDCA continuous improvement cycle, to optimize the integration of energy and environmental management systems, thereby increasing sustainability and even fostering better economic performance. This methodology led to promoting good energy-environmental practices and necessary drive the transition to renewable and clean energy. It is emphasized that this methodology can be very useful not only to industrial leaders but also to standards bodies and policymakers in promoting the use of cleaner and more efficient energy to better contribute to sustainable development.

Finally, an example of the application of this proposed methodology is described in a critical industry with high energy consumption and substantial environmental impact: the Tula refinery in Mexico. The energy-environmental integrity and continuous improvement cycle approach allows for the evaluation of technological changes in the cogeneration plant, yielding significant benefits in energy, environmental, and economic performance, thereby increasing sustainability and representing a first step in the transition to renewable energy [11].

2. Methods

The proposed methodology is fundamentally the result of deepening the synergy between the ISO 50001 and ISO 14001 standards. Deployed in the four stages of the PDCA cycle, the harmonization of the standards' divergences corresponds to the "Plan" and "Do" stages. Then, a compliance review with the principles of sustainability is included in the "Check" stage, and the proposal of general and feasible courses of action represents the "Act" stage.

Therefore, the core method to obtain the methodology is a novel synergetic analysis for integrating EnMS and EMS. In this way, a point-by-point comparison between ISO 50001:2018 and ISO 14001:2015 is conducted. A similar approach was used by Uriarte-Romero et al. [40] with the previous versions, ISO 50001:2011 and ISO 14001:2004, to propose a methodology for integrating an EnMS with an existing EMS. However, the structure and some relevant terms have been updated in the current versions according to HS, so a new correspondence analysis is appropriate. Moreover, in this case, the analysis focuses on identifying the divergent aspects and proposing how to couple them through a comprehensive approach. Thus, Figure 1 shows the methods design framed in the continuous improvement for sustainable development.

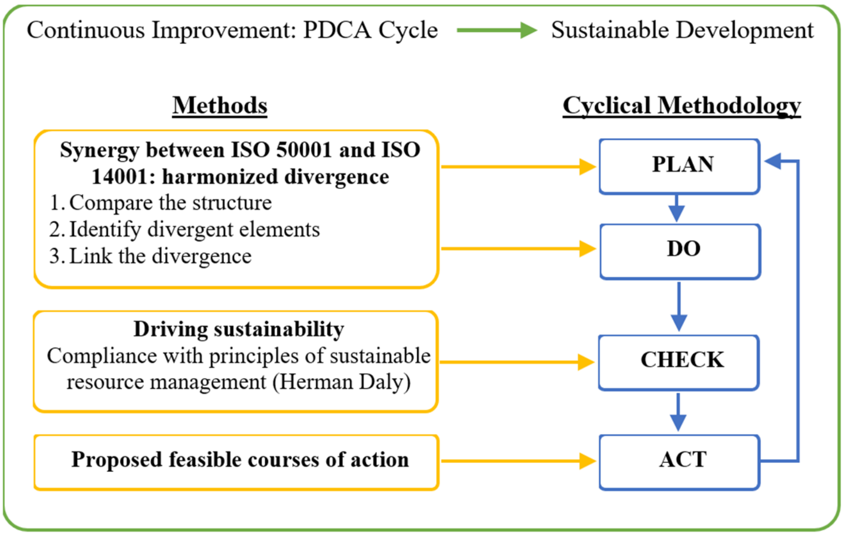

Figure 1. Methods design.

2.1. Synergy between ISO 50001 and ISO 14001: Harmonized Divergence

A step-by-step comparison between the sections and subsections of the standards is performed, seeking the correspondence but particularly the divergence. The analysis focuses on the sections with significant divergence, where each discrepant aspect is identified by comparing the subsections. A proposal on how to couple the divergent aspects is made, integrating common concepts that can lead to better energy-environmental performance, the optimization of organizational resources, and higher sustainability.

The high correspondence between the structures of ISO 50001:2018 and ISO 14001:2015 is illustrated in Figure 2, as well as the divergences. For both standards all clauses are the same, starting with the three introductory clauses "Scope", "Normative references" and "Terms and definitions", and then seven clauses with the requirements and guidance for EnMS and EMS respectively. For these clauses, the total sections of ISO 50001, the sections of ISO 14001 that match, those that do not match, and those that partially match are shown in Figure 2.

In the clauses "Context of the organization", "Leadership", "Support", "Performance evaluation" and "Improvement" a complete matching is observed. In contrast, 4 of 6 sections of the "Planning" clause do not match, as well as 2 of 3 sections of the "Operation" clause. These two clauses contain the more relevant divergent aspects between the standards.

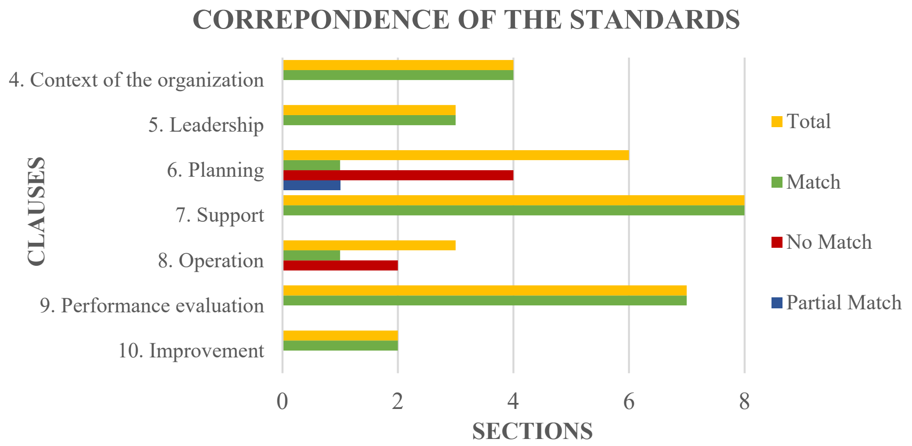

Figure 2. Correspondence of the structure between ISO 50001:2018 and ISO 14001:2015.

In a detailed analysis of the divergent aspects, Table 1 shows a parallel of the "Planning" and "Operation" clauses, showing the sections in both cases. Matching sections are shaded in white, partially matching sections in light gray, and unmatched sections in dark gray.

Table 1. Divergent aspects between ISO 50001 and ISO 14001.

Clause	ISO 50001:2018 Section		ISO 14001:2015 Section	
6 Planning	6.1	Actions to address risks and opportunities	6.1	Actions to address risks and opportunities
			6.1.1	General
			6.1.2	Environmental aspects
			6.1.3	Compliance obligations
			6.1.4	Planning action
	6.2	Objectives, energy targets, and planning to achieve them	6.2	Environmental objectives and planning to achieve them
			6.2.1	Environmental objectives
			6.2.2	Planning actions to achieve environmental objectives
	6.3	Energy review		
	6.4	Energy performance indicators		
	6.5	Energy baseline		
	6.6	Planning for collection of energy data		
8 Operation	8.1	Operational planning and control	8.1	Operational planning and control
			8.2	Emergency preparedness and response
	8.2	Design		
	8.3	Procurement		

Match: ; Partial Match: ; No Match: .

Regarding the "Planning" clause, the "Energy review", the "Energy performance indicators", and the "Energy baseline" are exclusive requirements of ISO 50001. They involve identifying the Intensive Energy Uses (IEUs) that must be prioritized to improve energy performance. The "Environmental aspects" are the exclusive requirement of ISO 14001 in this clause. Here, the Significant Environmental Aspects (SEAs) are established and managed to minimize environmental impacts. About the "Operation" clause, "Design" and "Procurement" are exclusive requirements of ISO 50001 (ISO 14001 only refers to the "procurement needs" as an operative control). The exclusive requirement of ISO 14001 in this clause is "Emergency preparedness and response".

Hence, the proposal to couple these divergent aspects of the standards is summarized in Figure 3. Based on the synergy between energy and environment and the correspondence of the standards provided by HS, extrapolation is used to extend to a comprehensive context the exclusive requirements of each standard. In this sense, the proposal promotes good energy-environmental practices, which means optimized resources and efforts, the transition to clean and renewable energy and a higher contribution to sustainable development.

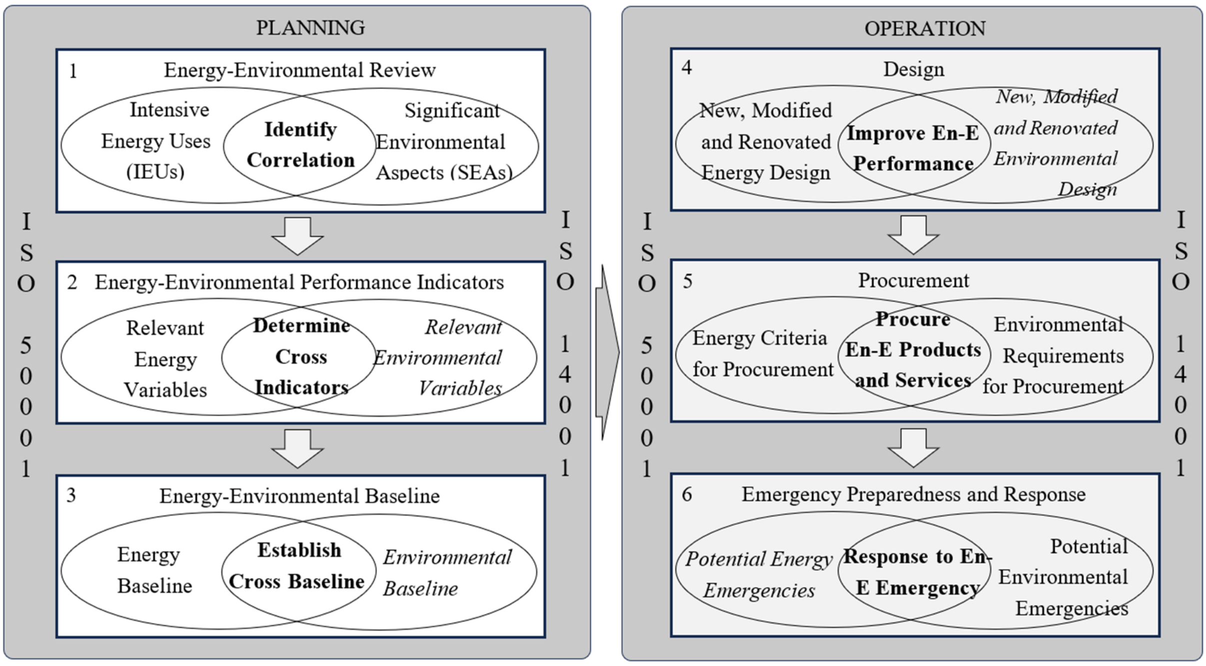

Figure 3. Six-step proposal for coupling divergences between ISO 50001:2018 and ISO 14001:2015.

As shown in Figure 3, three steps for the "Planning" clause and three more for the "Operation" clause are proposed to harmonize the exclusive requirements of ISO 50001, at the left, and those of the ISO 14001, at the right. Each step involves an intersection remarked in bold. Also, proposed aspects, not included in one of the standards, are marked in italics. This comprehensive proposal is discussed in the next section, as part of the general cyclical methodology provided.

2.2. Driving Sustainability

To verify the improvement in sustainability with this synergistic approach, organizations are encouraged to evaluate their compliance with the operational principles of sustainable resource management. Among the principles proposed by Daly [13], four operational ones are adopted to form the "Check" stage in the cyclical methodology. These are defined as follows, and discussed in the next section:

- Principle of sustainable emission: the waste emission rate is equal to the natural assimilation capacity of the ecosystems where they are emitted.
- Principle of sustainable emptying: the rate of consumption of non-renewable resources is limited to the creation of renewable substitutes.
- Principle of sustainable selection of technologies: the appropriate technology for sustainable development is that which increases the productivity of resources, rather than increases the amount extracted from them.
- Principle of sustainable collection: the collection rate of renewable resources is equal to that of their regeneration.

2.3. Proposed Feasible Courses of Action

The "Act" stage consists of four main and feasible courses of action based on experience collaborating with organizations, as in the case study presented in the article "Towards Sustainable Cogeneration in an Oil Refinery: A Synergy between ISO 50001 and ISO 14001 Management Systems" [11]. This is a pilot study that shows the applicability and benefits of the proposed cyclical methodology.

3. Proposed General Methodology

The proposed general methodology applies to all types of organizations, as do the ISO 50001 and ISO 14001 standards. However, it is expected to have a greater impact on the fossil fuel industry, given its contribution to the energy transition and, consequently, to sustainable development. As noted, Figure 4 shows that the harmonization of the divergences in the "Planning" and "Operating" clauses of the standards corresponds to the first two stages of the methodology, "Plan" and "Do", associated with the continuous improvement cycle. The third stage "Check" involves reviewing the principles of sustainable resource management. And the fourth stage "Act" completes the spiral cycle, proposing feasible and general courses of action as feedback-driven improvement around sustainable development.

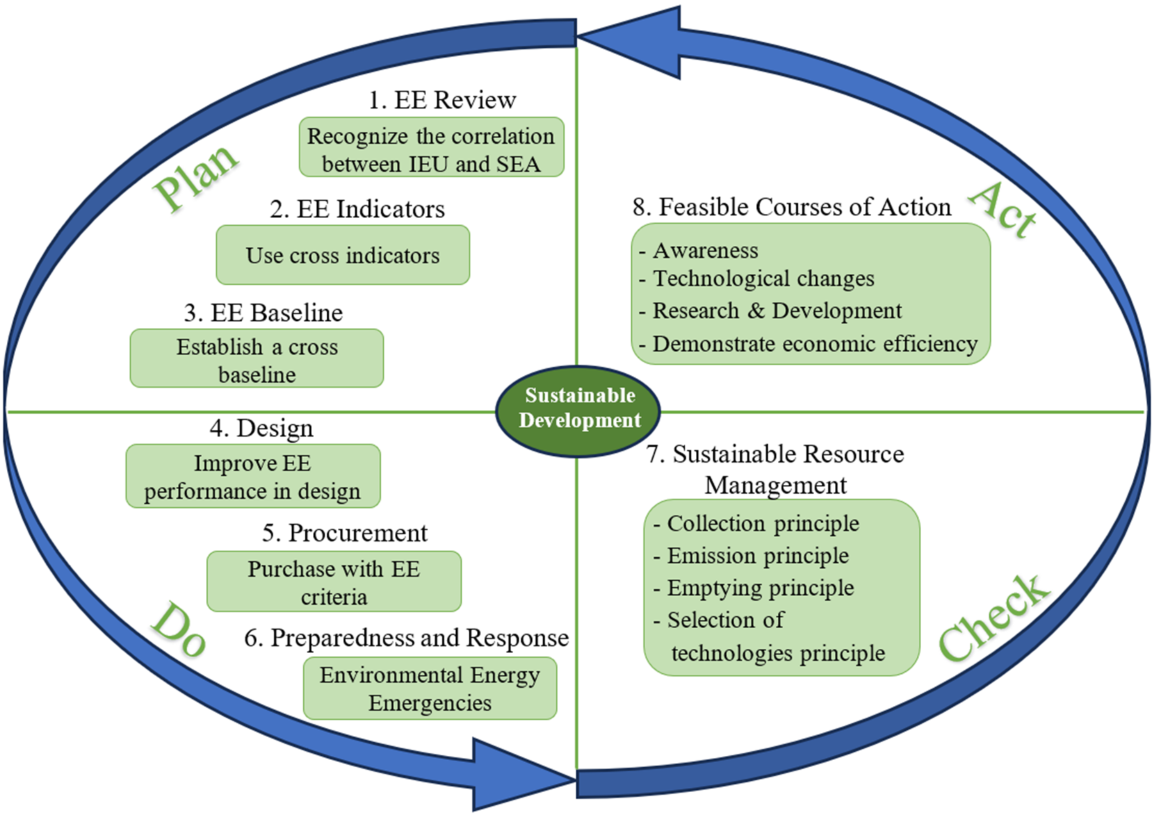

Figure 4. Cyclical methodology to optimize an integrated energy-environmental management system.

The description of each of the elements of the methodology is then expanded, for its proper implementation in the organizational context.

3.1. Plan

The three steps of the "Plan" stage arise from the synergy between the standards in the "Planning" clause. As described, this synergy entails the coupling of the divergent aspects using an extrapolation perspective.

Energy and Environmental Review: For the planning of an EnMS, the ISO 50001 standard requires an organization to develop and conduct an energy review essentially to identify the energy consumption, based on past and current data related to every type of energy used within all processes involved in the energy management system. According to this analysis, IEUs that account for substantial energy consumption and offer the potential to improve energy performance must be identified. Opportunities for this improvement need to be determined and prioritized. This approach is not explicit in the ISO 14001 standard but can be extrapolated to an environmental review, which is actually the requirement to identify its environmental aspects as any activity, service, and product that interacts with the environment. And then identify the associated environmental impacts that adversely or beneficially change, wholly or partially the environment, seeking to improve environmental performance.

Taking advantage of the important synergy among the standards and also between energy and the environment in general, this approach can be integrated into an energy and environmental review. In this sense, probably in most cases, SEAs that imply considerable environmental impacts should be associated with IEUs. This is a fact in industries that have an intensive use of fossil fuels as identified IEUs, where some of their SEAs are the air emission of pollutants such as greenhouse gases, and criteria pollutants. Therefore, this methodology aims for an organization to identify the correlation between its IEUs and SEAs, for integrated treatment, optimized performance, and higher contribution to sustainability.

The stronger this correlation, the greater the causality between energy use and environmental impact; thus, the greater the need for sustainability, and the greater the opportunity to comprehensively manage energy and environmental performance. A low correlation between IEUs and SEAs may mean that the energy sources used do not have a significant environmental impact. In this case, the organization can focus its efforts on environmental remediation for impacts that have already occurred, which can also be defined as generating positive environmental impacts.

Energy-Environmental Performance Indicators: While indicators are a primary requirement in ISO 50001 in the planning stage, ISO 14001 only refers to them as a general requirement in the performance evaluation.

However, in both cases, indicators are needed to monitor and measure the performance. From the quantitative approach of ISO 50001, regarding the energy review an organization must determine the relevant variables that significantly impact energy performance in terms of quantifiable factors that routinely change. Then, appropriate energy performance indicators should be established to measure, monitor, and demonstrate performance improvement.

The comprehensive approach proposed aims to also determine the relevant environmental variables that significantly impact environmental performance. Then, in addition to conventional indicators, use cross indicators to monitor the combined energy-environmental performance and demonstrate its overall improvement. For example, in related research developed, a proposed cross indicator in the case study of an oil refinery is the amount of air emissions per unit of energy generated. Furthermore, some conventional indicators are indeed cross indicators that can be used in this approach of integrated energy-environmental performance, such as the emission factors consisting of pollutant emission level per unit of a specific fuel consumed. The use of conventional and cross indicators allows for a broader perspective of energy-environmental performance, enriching the analysis and generating greater criteria for decision-making towards sustainability.

Energy-Environmental Baseline: Not included in the ISO 14001 standard, the requirement of a baseline is part of the planning stage of ISO 50001 and consists of a quantitative reference providing a basis for comparing energy performance over consecutive periods or in different states such as technological changes. The energy baseline must be established according to the information obtained in the energy review and is the result of calculating the performance indicators for a suitable period or specific state. In this sense, establishing a basis for comparison of environmental performance, that is, an environmental baseline, is relevant for the search for environmental improvements.

Even more relevant for sustainability purposes is a cross baseline that provides a quantitative reference for inclusive energy and environmental performance. Depending on the nature of each organization, an energy-environmental cross baseline could be a time series over a specific period or a special state that provides complete information on energy efficiency behavior related to the preservation of the environment, using different units of measurement. A broader outlook of the performance is more helpful for managers to take decisions and action courses, in this inclusive perspective that better supports sustainable development.

3.2. Do

The three steps of the "Do" stage arise from the synergy between the standards in the "Operation" clause, and are integrated and transversal activities to the deployment of the mission processes of each organization, such as production, service provision, public management, etc.

Design: In the operation of an EnMS, the ISO 50001 requires involving energy performance improvement with the design of new, modified, and renovated facilities, equipment, systems, and energy-using processes that can have a significant impact on its energy performance. Considering that ISO 14001 fosters the environmental improvement of not only an organization's processes but also its workplaces and products from a life cycle perspective, the requirement of the design is also lacking in this standard.

Consequently, the present methodology aims to promote organizations to adopt a comprehensive basis for the new, modified, and renovated design of processes, systems, facilities, equipment, workplaces, products, and every element having a relation to the integrated energy and environmental performance, involving the life cycle and lifetime perspectives. This holistic approach intends to lead organizations to obtain sustainable performance for optimized use of energy and minimized environmental impact of their activities, as well as their final products facing consumers. But also, this broader design allows companies to optimize the use of resources. For instance, some facilities could design independent systems of clean energy supply for the operation of their equipment as a complement to the purchased energy, which would mean higher energy efficiency, less environmental impact, and even financial savings. Also, companies with I&D departments could develop or replace any synthetic material for an organic-based one in the manufacturing of their products, bringing similar advantages and even benefiting the final customer.

Procurement: As a direct stipulation of ISO 50001, an operating EnMS must establish and implement criteria for the procurement of products, equipment, and services expected to have a significant impact on energy performance, including the purchase of energy. For its part, less explicit in ISO 14001, as operational control of an EMS, an organization must determine environmental requirements for the procurement of products and services consistent with a life cycle perspective. Both standards emphasize communicating the respective energy criteria and environmental requirements to the suppliers, providers, and, if there are, contractors for the procurement of their products and services.

In this case, with higher correspondence between the standards regarding the procurement requirements, the proposal in this methodology is to establish integrated criteria for the purchase of products and services that satisfy the improvement of the energy and environmental performance of an organization and its interested parties, mainly the environment and the society, including the clients, customers, and workers, from a sustainable approach. The acquisition of equipment for the supply of clean energy, such as photovoltaic or wind generation systems, are adequate examples in this case, as well as the use of biofuels. Since this issue is closely related to the providers' performance, mutual growth synergies are driven, that is, win-win relationships for further sustainable development.

Emergency Preparedness and Response: This is the only divergent aspect not included in the ISO 50001 standard. In contrast, ISO 14001 deploys a detailed section requiring the establishment, implementation, and maintenance of the processes needed to prepare for and respond to potential emergency environmental situations. Planning actions to prevent and mitigate the environmental impact of emergency situations are required for an operative EMS. Likewise, test the planned actions where practicable and review them after the tests and the occurrence of real emergency situations, as well as provide information and training for preparedness and response, to people working within the organization and other relevant interested parties.

While environmental emergencies are very important to consider, emergency situations regarding energy are also preponderant for most organizations; especially facilities where a power outage or any disruption in the supply of an energy source may cause major damage or loss, not only to production or processes, but also to the integrity of people and the environment. For example, many cases related to oil facilities such as refineries, wells, and platforms have involved the explosion of fuel sources, causing human victims, environmental damage, material losses, production stops, and economic impacts.

In this sense, this methodology proposes considering energy emergencies in the action plans established, implemented, and maintained by an organization in an integrated approach with environmental emergency situations. Depending on the nature of each company, some emergencies are related to a single issue, but other situations may involve both perspectives, predominantly in industrial facilities. However, it is advisable to have a consolidated emergency plan for more effective preparation and response.

3.3. Check

In general, in any organization, but distinctly in the fossil fuel industry where energy efficiency is not adequately aligned with environmental preservation as noted, it is proposed that it be mandatory to review planning and operational processes to ensure continuous sustainability. To this end, it is crucial to verify the organization's performance through compliance with the principles of sustainable resource management outlined in the previous section. This ensures that the organization is moving in the right direction, benefiting not only its stakeholders but also the environment and society. A brief analysis of the implications of these principles in energy environmental performance follows.

Principle of sustainable collection: An Integrated Management System (IMS) with good energy and environmental practices should promote the substitution of non-renewable resources with renewable resources and encourage those who already use renewable resources to do so in a sustainable and responsible manner; this is, collect renewable resources up to the point where adequate regeneration exists. To achieve this, priority must be given to the use of unlimited renewable sources such as solar energy. This should be done with the aim of continuously improving energy and environmental performance. Therefore, the proposed methodology is an important driver for compliance with the principle of sustainable collection. Each organization should define its own indicators according to its specific characteristics. However, by definition, a key indicator is:

$$\frac{\text{Collection rate of renewable resources}}{\text{Regeneration rate of renewable resources}} \leq 1$$

Principle of sustainable emission: The proposed methodology makes it possible to demonstrate when an organization has a dynamic of unsustainable waste emissions. It also promotes the use of resources whose transformation generates non-polluting waste, which may even be reused under the approach of circular economy [45,46]. This is achievable if environmental performance is not compromised in the pursuit of improved energy efficiency. Both energy efficiency and environmental preservation must be improved comprehensively. Significant efforts can be made to mitigate environmental impact and demonstrate that the natural assimilation capacity of ecosystems is not exceeded. However, with greater awareness, these efforts could be better invested in radical changes to energy sources that substantially reduce or prevent environmental damage. By definition, a key indicator is:

$$\frac{\text{Emission rate}}{\text{Assimilation capacity of ecosystems}} \leq 1$$

Principle of sustainable emptying: It is highlighted that fossil fuels currently have so many renewable substitutes that, from a sustainability perspective, it is contradictory to continue exploiting these non-renewable and highly polluting sources. The main barrier to this change is the prevailing economic dynamics on the planet, which, related to consumption habits, are a highly relevant topic for which further research is recommended. Considering the possible planetary collapse resulting from ever increasing global warming caused by the large amount of atmospheric emissions, a paradigm shift is urgently needed, one that accelerates the principle of emptying from fossil fuels to renewable, clean, and free energy. The cyclical methodology aims for the comprehensive improvement of energy and environmental performance, so that organizations committed to the energy transition can guarantee compliance with this principle. By definition, a key indicator is:

$$\frac{\text{Rate of consumption of nonrenewable resources}}{\text{Rate of creation of renewable substitutes}} < 1$$

Principle of sustainable selection of technologies: This improvement methodology drives the alignment of an organization with this principle, since it promotes significant changes such as technological upgrades that continuously improve energy and environmental performance. This undoubtedly encourages the adoption or development of technologies that increase resource productivity, for instance, using unlimited energy sources; thereby achieving greater energy efficiency while minimizing or eliminating environmental impact and/or promoting environmental restoration. Considering this principle, the exploration and exploitation of oil, natural gas, minerals, and other non-renewable resources should be halted globally. Maintaining these activities poses a very high risk to the planet's sustainability, while the list of renewable and clean energy sources that can replace these traditional sources is already extensive. Furthermore, new technologies have already demonstrated high energy efficiency and environmental sustainability, and technological forecasts predict accelerated growth.

3.4. Act

To close the improvement cycle, in the "Act" phase, the methodology proposes four feasible courses of action that can lead organizations to apply the knowledge gained during the previous phases, effectively achieving a comprehensive improvement in energy and environmental performance, thus increasing sustainability. The end of one cycle should lead to the beginning of a new one, given that it is a process of continuous improvement. Therefore, it is proposed that the recurring application of this methodology follows a spiral behavior, since each cycle leads to ever greater growth.

Awareness: The review study of Chaves Almanza & León De Los Santos [43] identifies resource scarcity, inadequate organizational strategies, and a lack of management commitment as the main barriers in the integrated implementation of energy and environmental management systems. These barriers stem primarily from a lack of awareness, especially among organizational leaders, but also among all personnel involved with management systems, who generally comprise the majority of the organization's workforce. Management systems are often misinterpreted as an extra workload, but they are actually a progressive approach to achieving the organization's mission, one that considers the holistic well-being of all stakeholders.

Therefore, taking actions that raise awareness among members of an organization is fundamental for the proper functioning of management systems. For leaders and managers, this is crucial, as they are the ones who empower management at all levels. And the demonstration of the economic improvements resulting from management systems is a powerful tool for enhancing leaders' awareness, as discussed later. Furthermore, as mentioned, awareness must be extended beyond the organizational context; governments, policymakers, standardization bodies, and international entities must be actively involved in achieving true sustainable development that improves the current quality of life globally and ensures a better world for future generations.

Technological Changes: As observed in the case study of Chaves Almanza & León De Los Santos [11], a technological change can bring significant benefits to an organization, not only improving energy and environmental performance but also economic performance. Technological change can involve an infrastructure upgrade, the replacement of obsolete technology, or radical changes to the production systems. In general, across all industrial and organizational sectors, new or emerging technologies are associated with better energy efficiency and reduced environmental impact, thanks to the current paradigm shift toward sustainability. Of course, introducing a technological change involves considerable capital investment, making economic analyses that consider savings from energy efficiency and reduced environmental impact, among other factors, crucial within the investment payback period. Generally, investment in technological changes results in much greater economic benefits in the medium and long term. As noted, it is expected that technology evolves exponentially not only in energy use and environmental preservation, but in all aspects of life. This accelerated growth has been clearly seen in the recent past decades.

Research & Development: For any organization having a Research & Development process is a significant added value. It enables constant learning and growth, aligned with the continuous improvement philosophy of the ISO management systems standards. It is vital for organizational adaptation in a world with increasingly demanding requirements and intensive competition, as well as the need to become more economically sustainable, while also preserving the environment and increasing social benefit. Research & Development courses of action are closely associated with the design aspect of the "Do" stage, as they can provide significant solutions for improving facilities, processes, systems, equipment, jobs, and, consequently, products and services. It is worth noting that today, a Research & Development process can be more effective through a focus on cooperation, contribution, and partnerships, overturning the traditional concepts of confidentiality and physical and intellectual property. Research & Development is also closely linked to technological development, being a fundamental path for the continuous growth of sustainability.

Demonstrating Economic Efficiency: The economic dimension is transversal to virtually all organizational aspects, which is why it is of great importance and should be properly prioritized, but without being the only focus. As mentioned, demonstrating the economic benefits of investing in optimizing an integrated energy and environmental management system to organizational leaders, is a powerful tool for raising awareness and ensuring the system's effective operation. The referenced case study in an oil refinery [11] is an important example of the significant savings achieved for the organization by optimizing the management system and adopting the proposed hybrid technology in the cogeneration plant, while improving sustainability. Thus, prioritizing the benefit of stakeholders, such as the environment and, consequently, society, is neither costly nor a bad investment; on the contrary, it leads to economic growth. Therefore, organizations that pursue sustainability, not only environmental but also social, will experience better economic returns. Meanwhile, those that maintain a traditional stance of exclusive dedication to capital accumulation are at greater risk of collapse due to a lack of sustainability.

3.5. Methodology Roadmap

Table 2 shows the roadmap of the expected results of applying the methodology in a global organizational context. Section 5 includes a discussion of this topic based on existing literature.

Table 2. Roadmap of the methodology results.

Stage	Basis	Short Term	Medium Term	Long Term
Plan	Energy-environmental review Energy-environmental indicators Energy-environmental baseline	Identify the correlation and causality between IEU and SEA. Define main cross indicators and complement with conventional ones. Establish a cross baseline.	Plan to comprehensively improve energy efficiency and mitigate environmental impact. Monitor the improvement with respect to baseline.	Energy transition to renewable sources. Energy self-sufficiency. Environmental restoration.
Do	Energy-environmental design Energy-environmental procurement Energy-environmental emergency plan	Define energy-environmental criteria for design and procurement. Identify energy-environmental emergencies and establish a plan to manage them.	Implementation of operational controls in design and procurement to improve energy-environmental performance. Learning from simulations and the real implementation of the energy-environmental emergency plan.	Equipment, processes, systems, etc. designed to ensure comprehensive energy-environmental performance. Relationships with suppliers that ensure the energy-environmental performance of supply chains. Mitigation of the occurrence of energy-environmental emergencies.
Check	Sustainable collection Sustainable emission Sustainable emptying Sustainable selection of technology	Define compliance indicators with sustainable principles. Establish a compliance baseline.	Plan to improve sustainability. Monitor the improvement with respect to baseline.	Organizations with energy sustainability. Healthy environment: balanced collection of renewable resources, cero emissions, limited use of non-renewable resources, use of sustainable technologies. Social welfare.
Act	Awareness Technological change Research & Development Economic efficiency	Staff training at all organizational levels. Identify technology upgrade opportunities. Establish economic efficiency measures.	Culture of sustainable energy performance. Implement technology changes. Demonstrate economic improvement.	Expanded culture of sustainable energy performance in supply chains. Technology transfer. Economic benefits for all stakeholders.

4. The Case of the Tula Refinery

As presented in "Towards sustainable cogeneration in an oil refinery: a synergy between ISO 50001 and ISO 14001 management systems" [11] the proposed methodology was applied to obtain comprehensive benefits in a Mexican oil refinery. From the EnMS and EMS integrated approach, oil refining is a critical sector of industry due to its elevated energy consumption and significant impact on the environment. The Tula refinery is part of the state-owned corporation Pemex, thus, substantial public resources have been invested in a rehabilitation program over the last decade or so. Although the refinery has certified its EnMS with ISO 50001 and its EMS with ISO 14001, it has been operating at approximately 60% of its installed capacity, resulting in low energy generation, negative profits and significant environmental performance issues that also have a considerable social impact. It is located at the Tula-Vito-Apaxco industrial corridor, 90 km north of the metropolitan area of Mexico City, one of the largest megalopolises in the world; thus, the city's air quality is significantly impacted [47], and affects the health of more than 20 million people.

Thus, applying the proposed methodology to find solutions that promote the rehabilitation of the refinery, in the initial planning stage it was identified that the cogeneration plant includes the most significant IEU. The plant does not provide the total energy requirement of the refinery, generates around 75%; that is, the heat demand is almost met, but only about a third of the electricity requirement is provided (the rest is supplied by the public energy grid). Also, the plant consumes around 55% of the total energy used. Upon further investigation, it was found that the plant is primarily based on the operation of a group of natural gas boilers, which generate steam at different pressures to supply the refining processes and power turbogenerators for electricity production. This intensive natural gas combustion generates large amounts of atmospheric emissions, including CO_2, CO, SO_2 and NO, being one of the most important SEA. Therefore, a clear correlation between IEU and SEA is demonstrated in this case with the large use of natural gas. This shed light on the general fact that industries based on intensive fossil fuel consumption show a high correlation between IEU and SEA.

Based on this finding, a set of performance measures was established to determine the current state of the cogeneration plant in terms of integrated energy and environmental performance. Thus, conventional indicators were defined, as well as cross-energy and environmental indicators, which allowed for the establishment of the current state or cross-baseline as a reference for proposing technological changes to improve performance. Using simulation, the plant's baseline and two technological changes were represented. The first change optimizes natural gas usage by replacing boilers with gas turbines and a heat recovery system that recycles heat from exhaust gases to preheat the recovered condensate. The second change is an improvement on the first, introducing the use of solar thermal energy as a renewable and clean source to complement the recovered heat. This change represents a first step in the energy transition.

Proposing these technological scenarios through simulation represents a first step in the design of a new cogeneration infrastructure, considering energy and environmental criteria for improved integrated performance. The hybrid natural gas and solar energy technology (referred to as Transition to RE) demonstrated the best energy and environmental performance. As shown in Figure 5, It offers thermal and electrical generation levels above the refinery's demands, significant increments of electrical and cogeneration efficiencies, and the lowest amounts of CO_2, SO_2, NO and CO emissions per unit of energy generated.

In the verification stage, the sustainable resource management analysis shows how the change to the hybrid technology allows improvements in three principles. Introducing a supplementary heat source through solar energy represents a first step in the emptying principle, looking forward to the gradual replacement of non-renewable energy with renewable energy. Since the sun is an unlimited source of energy, the principle of energy collection begins to be fulfilled. The utilization of waste heat generates greater productivity in the use of natural gas; therefore, the hybrid system would be a sustainable technological selection. The level of emissions per unit of energy generated is decreasing, but since natural gas is still used as the primary source, the total level of emissions is so high that the natural capacity of Tula's ecosystems is exceeded. This remains a major concern that should drive a greater effort to replace fossil fuels. However, this technological change is an appropriate transition solution towards the exclusive use of renewable energy.

Finaly, further research beyond that reported in the article by Chaves Almanza and León de los Santos [11] shows that, as proposed in the cyclical methodology, a feasible and relevant course of action taken in the case of the Tula refinery was to demonstrate the economic efficiency of adopting the change to hybrid technology, so that the refinery's managers would be motivated by this initiative. In this way, the operating costs of energy generation were estimated for the three scenarios. This was based on the average market price of natural gas per GJ in Mexico for 2024 of $2.8 USD/GJ, an energy consumption rate of 25 MJ/kWh in the baseline scenario and 8 MJ/kWh for the proposed technologies, and the purchase of electricity shortfalls from the public grid in the baseline scenario at $0.06 USD/kWh, as well as the sale of surpluses to the public grid with the technological changes at $0.002 USD/kWh. Under these conditions, the cost of generating energy per hour in the baseline was $74,225 USD, with the first technological change $39,201 USD and with the second change $36,418 USD; the latter being the most profitable alternative for the refinery. Further analysis showed the lower cost of implementing and certifying an integrated management system of $116,000 USD versus the cost of implementing and certifying two independent systems of $178,000 USD.

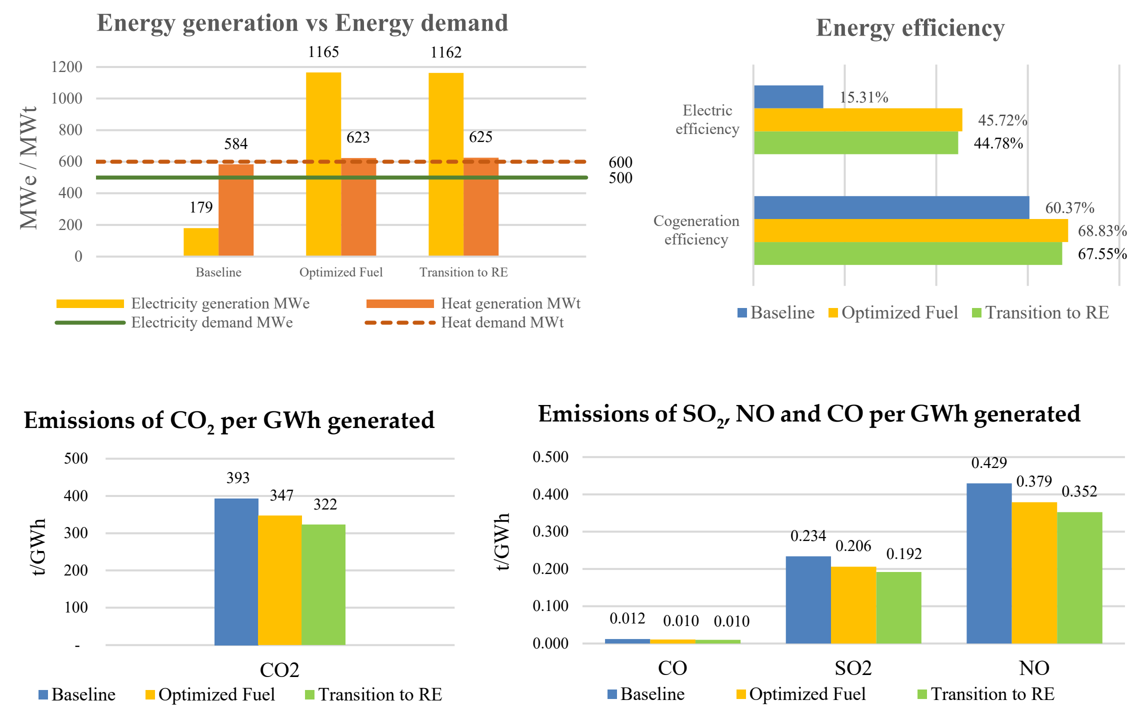

Figure 5. Improvement of the energy environmental performance at Tula refinery. Reprinted with permission from Ref. [11]. Copyright 2025 CC-BY-SA 4.0.

5. Discussion

A general framework for all ISO management system standards is deployed in HS, unifying their structure into ten common clauses. In the specific case of EnMS and EMS, ISO 50001 and ISO 14001 respectively, the synergy is greater given the symbiosis between energy and environment. Therefore, the integration of these standards seeks comprehensive improvement in energy and environmental performance. This is especially important in the fossil fuel-based industry, as the use of this energy source has an inherent environmental impact [11]. From a divergence coupling approach, the synergy between ISO 50001 and ISO 14001 leads to the revealing fact that it is essential to identify the correlation between IEU, a key factor in EMS, and SEA, a key factor in EMS, in order to generate sustainability.

A detailed analysis reveals that the main divergent aspects arise in the planning and operation clauses of the standards and are mostly related to requirements of ISO 50001 not included in ISO 14001. The former uses a quantitative approach, but the latter does not. Therefore, based on an extrapolation exercise, the divergences are linked to propose a path for the improvement of the integrated energy environmental performance, which define the "Plan" and "Do" stages in the proposed cyclical methodology. Subsequently, the review of compliance with the operative sustainability principles leads to the "Check" stage. Finally, four feasible courses of action for any organization are proposed as the "Act" stage. The cyclical methodology framed within the continuous improvement approach that characterizes the ISO management systems through the PDCA cycle, aims to encourage organizations to adopt a spiral behavior of constant growth through feedback dynamic. This is a general framework for any organization but is expected to have a significant impact on industry, exceptionally those that require intensive energy use.

At best, the methodology can help organizations achieve a complete transition from non-renewable to clean and renewable energy sources, improving energy performance while eliminating pollution impacts and increasing economic and social benefits, thus contributing to sustainable development. To a lesser extent, if there is no change in energy sources, environmental impact can be mitigated by increasing energy efficiency using more efficient and less polluting inputs and/or technologies, which can be leveraged during an energy transition period.

This latter scenario was observed in the case study of the Tula refinery. An industrial facility in the critical sector of oil refining, characterized by high energy consumption, mostly from fossil fuels, and a significant environmental impact that considerably affects the public health of nearby populations, necessarily implies a careful and gradual transition process towards sustainability. Applying the cyclical methodology approach, a technological change was proposed in the process where the IEU and the SEA converge, a set of natural gas boilers used in thermal and electrical cogeneration. Replacing the boilers with a set of natural gas turbines, coupled with a heat recovery system from the exhaust gases and a supplementary heat source using solar energy, increased energy generation and efficiency, reduced the amount of atmospheric emissions per unit of energy generated, lowered the operational cost of energy production, and consequently improved compliance with sustainability principles. This sustainable technology selection is the first step in the refinery's energy transition towards total sustainability.

Since the proposed methodology aims to strengthen the comprehensive improvement of energy environmental performance, driving the paradigm shift to renewable and clean energy, a potential obstacle that organizations could face when implementing it is the lack of commitment of the leaders. Since managers tend to focus mostly on financial issues, the perspective of sustainable progress that involves not only the economic but also the environmental and social dimensions is not well understood or avoided. Thus, leaders could ignore their commitment to this initiative, which could lead to a lack of necessary resources. This vision deficiency becomes evident when management systems are delegated to a single office or area, rather than somehow involving the entire organization. It is suggested to translate environmental and social benefits into financial terms to encourage managers to adopt such initiatives.

Another important obstacle is related to the resistance to changing fossil energy sources and restricting the improvement of environmental performance only in mitigating the impacts of pollution. As seen, this happens in the oil refining sector, for example, where fossil fuels are obtained but also used in the production process itself. In these cases, the role of governments would be crucial in formulating policies and providing incentives for the change in energy sources. Other strategies could address the implementation of waste treatment facilities for circular economy schemes [35,36].

Framed within the principle of continuous improvement to promote sustainable development and with an approach of harmonizing divergence, the proposed methodology makes an innovative contribution to operationalizing the symbiosis between energy and the environment, through a positive synergy between the international standards ISO 50001 and ISO 14001. Regarding the methodology roadmap, the vision of this synergy had already been reported as a great opportunity for exploiting untapped end-use efficiency reserves in the near term while making the transition towards lower carbon energy sources, including renewable energy, over the longer term [48]. The Tula refinery case study aligns with this approach, as technological changes first promote the optimization of fossil energy by recycling waste heat and then the incorporation of renewable heat from a solar source. Opportunities can relate to potential sources of energy, use of renewable energy, or other alternative energy sources, such as waste energy [16].

The implementation and certification of these standards have a significantly greater impact on the use of renewable energy in certified companies. Some of them have introduced the use of renewable energy with the implementation and certification of the EnMS [44]. Waide and Gerundino had already noted that international standards can provide a consistent and clear framework, describing technologies and good practices in the field concerned, including terminology, classifications, test methods, performances and good management practices [48]. Similarly, in 2007 ISO and the International Energy Agency (IEA) recognized the need for an international standard to promote energy efficiency and a shift to renewable sources [49], as a clear projection to increase energy sustainability.

In the long term, the international ISO standards studied are expected to facilitate energy efficiency and renewable energy sources for economic and social progress [50]. It is increasingly evident that these certificates for EMS and EnMS are primarily intended to inspire trust among stakeholders and to reinforce social legitimacy [51]. Additionally, ISO 50001 itself states that it is expected that procurement is an opportunity to improve energy performance using more efficient products and services. It is also an opportunity to work with the supply chain and influence its energy behavior. Energy purchasing specification elements could include energy quality, availability, cost structure, environmental impact and renewable sources. [16].

6. Conclusions

Although energy and environment are closely correlated, the integration of EnMS and EMS is a recent field with significant potential for academic research and empirical work. The most relevant standards nowadays, ISO 50001:2018 and ISO 14001:2015 respectively, are highly correspondent due to the HS that simplify their combination into an integrated management system. However, there are some divergent aspects between these standards, which no study has explored yet. Such divergences are principally associated with the stages of planning and operation, most of which are requirements of ISO 50001 that are not included in ISO 14001. Nevertheless, due to the similarities of the standards and the synergy between energy and environment, each differing element can be extrapolated and adapted from a comprehensive approach, in an integrated management system. Therefore, such a system may be planned according to an energy-environmental review for the establishment of conventional and cross indicators and baselines, as well as implement mixed energy-environmental criteria to satisfy design and procurement needs in the operation stage. Here, it is also very relevant to establish an action plan related to both energy and environmental emergency situations.

This synergy of harmonizing divergences shapes the “Plan” and “Do” stages of the proposed general methodology, which is framed within the PDCA cycle that characterizes continuous improvement in ISO management systems. In the “Check” stage, the methodology proposes evaluating integrated performance using sustainability principles related to collection, emission, emptying, and technology selection. The “Act” stage consists of four feasible courses of action for improvement through feedback. In this sense, the proposed methodology aims to promote good energy-environmental practices for any organization to optimize its integrated management system for better energy and environmental performance, bringing also significant financial benefits and sustainability. A greater impact is expected in fossil energy-based industry, as demonstrated in the Tula refinery. The results of this research are useful not only for organizational leaders but also for standardization bodies, governments, policymakers and international entities to accelerate sustainable development, for instance in the mitigation of climate change and the transitions to renewable and clean energy.

Further practical experience and academic research are needed in this recent field, as the wide global acceptance of ISO management systems standards is an important opportunity to implement the proposed methodology for the promotion of sustainable development. Specific areas for future work include testing the proposed methodology with a wide range of organizational actors in diverse sectors for multi-case validation, cost-benefit analysis with respect to previous practices, the evolution of technology in facilitating the implementation of this methodological approach, and the integration with social responsibility systems for a comprehensive contribution to sustainability. In any case, this methodology is based on a self-explanatory systemic reality. The environment provides the source, and energy enables environmental processes. The environment is an energy management system. Sustainability in its broadest sense is an evident necessity in the complex global landscape.

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Institutional Review Board Statement

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Data Availability Statement

Apart from the data presented in the published and referenced work on the Tula refinery [11], no further information is available due to the company’s industrial confidentiality policies and the regulations in Mexico.

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Conflicts of Interest

The author declares no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

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