Energy Management: Sustainable Approach towards Industry 4.0

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Abstract – **Industry 4.0 concept is captivating the attention globally in a substantial rate that encompasses industrial digitalization with the means of advanced technical features. Maintaining the highest standard of industrial processes, Industry 4.0 demands to ensure energy efficiency also. Industries must ensure energy efficiency during the process flows, keeping in mind about the energy cost, carbon emission, and resource efficiency. Unfortunately, despite a significant potential for energy efficiency exists, that can be addressed by industries, implementing energy management practices. However, industries are still disinclined to take advantages of such opportunities. Research in this domain has little explored the potential relationships between energy management and Industry 4.0. In the paper, we aim at offering an overview of industrial energy management and related tools as well as Industry 4.0, preliminary discussing potential opportunities and synergies.**

Keywords – **Industrial energy, Energy management, Industry 4.0, Energy efficiency.**

I. INTRODUCTION

The recent technical advancement embodied in industrialization has led the adoption of Industry 4.0, precisely the Fourth Industrial Revolution. Industry 4.0 formed with the integration of advanced communication & information technology, Internet of Things, advanced automation (e.g. robotics), smart manufacturing system, and artificial intelligence aim to develop a dynamic operating system that facilitates mass production with customization feature [1]. Notably to mention that Industry 4.0 demands maximum utilization of the resources to ensure the efficiency at each level of industrial processes [2]. In this context, energy is a pivotal factor in the industrial processes that must be addressed in an utmost efficient manner. Indeed ensuring energy efficiency is sought to be one of the utmost noteworthy pillars that can comprehend the adoption of Industry 4.0 and energy security as well as the resource depletion [1]. The enhanced energy efficiency has been identified as the fundamental strategy to deal with climate mitigation aspects also. The energy efficiency not only can contribute to emission reduction, but also incorporates a reduction in energy infrastructure, mitigation of fossil fuel dependency, and raise the customer benefit [3], [4]. Relating to energy efficiency, notably to mention that energy management & its practices are acknowledged as the imperative mechanism in order to enhance energy efficiency among the industries [5]. Interestingly, Industry 4.0 and energy management share indifferent aspiration, which is, enhancing the efficiency, whilst having unlike trajectories. Nevertheless, notwithstanding energy management in the industries, Industry 4.0 could remain stagnant and unsuccessful to facilitate the additional features of modern technology.

Incorporation of energy management through energy management practices can improve industrial energy efficiency, which is significant to adopt Industry 4.0 [6]. Energy management practices are clear examples of energy efficiency measures that, without significant changes in the heavy technological side, can facilitate multiple benefits in terms of energy efficiency and productivity [5]. It looks, even more promising in light of the existences of devices for real-time measurement, proliferation and so on which are within the broad "umbrella" of Industry 4.0. Unfortunately, this has been little explored from literature; therefore, a research gap exists between energy management and Industry 4.0 nexus. Besides, it is worth noting that the Industry 4.0 framework is a combination of sophisticated technical architectures; hence the practical implementation is still in a perplex phase. In this context, the study focuses on energy management at industries in light of Industry 4.0. Therefore, in state of the art, we try to review the link between energy management and Industry 4.0 focusing on energy management methods, international standards for energy management, and multiple frameworks related to energy domain. The remainder of the paper is divided as follows. In Section II a state of the art of energy management is illustrated. Industry 4.0 is presented in Section III, followed by the concluding discussion presented in Section IV.

II. STATE OF THE ART

A. Energy Management Characterization

The industry and academia experts have pointed to energy efficiency as an obligatory strategy to address the energy supply & security [7]. Several hindrances are figured out by multiple studies about the energy efficient measures adoption at industrial level, which evolve from small & medium sized enterprises to energy intensive industries. Notably, the studies covered regional, national & transnationals perspectives. Energy management has been referred by researchers as a valuable means to deal with energy efficiency barriers [3], [5], [8]. Energy management infers to the optimization of "energy system", a perplexed and influential technical and managerial aspects in the industries [9]. Nonetheless, energy management appertains to the aspects related to inventory, conversion, and employing of energy. Considerably, energy management incorporates the monitoring, assessing, archiving, analyzation, control as well as routing the energy and material flows via formalized systems for achieving worthwhile targets in the industries [10]. The main focus of energy management is to mitigate energy

consumption, maintaining the same energy productivity in the industries [11]. It acts as a stimulant towards cost optimization in the industries [11]. In addition, energy management is a substantial factor for endorsing the enterprise's internal action towards enhanced energy efficiency [12], [13]. Studies showed that the adoption of energy management practices can salvage up-to 40% usage of the total energy [14].

The characterization of energy management is contrasting among the works of literature. Just recently, Trianni et al. framed energy management practice in a broader & comprehensive way to achieve energy efficiency goals. The characterization encompasses the techniques, schemes, and rules at each level of the industrial energy management and covers technical, non-technical, or support function related to the enhancement of energy efficiency in an industrial venture [5]. As per the German Federal Environment Agency, energy management is defined as the inclusion of planning and complying of activities for ensuring expected performance by utilizing a minimum amount of energy [15]. In the book, "Guide to Energy Management" by B.L. Capehart, focused on efficient and effective usage of energy to address energy management [16]. Nonetheless, the symbolization of energy management is portrayed holistically in a majority of literature that includes the utilization of energy resources and its conversion [13]. Moreover, the scheme comprises of inspection, auditing, archiving, analyzing, and control of energy flows for ensuring highest energy productivity by minimal energy consumption [9]–[11].

Schulze et al. articulated few of the requirements for energy management in the industries, that are energy policy, energy-saving targets, dedicated energy activities, presence of energy management team, energy audit, planning of energy-saving programs, energy reporting, top management support, metering and monitoring, and employee engagement in energy management activities [13]. However, the issue of conclusiveness exists about the requirements of energy management.

B. ISO 50001

ISO 50001 is an international scheme in the domain of energy management, which is published first in 2011 by the International Organization for Standardization (ISO) and has been revised in 2018. The main objective of ISO 50001 is to enhance energy performance in organizations through energy management. ISO 50001 is a new energy management standard compared to the American National Standards Institute (ANSI)/ Management System for Energy 2000 (MSE), and EN 16001. It facilitates an organization to promote & apply a policy to detect possible improvement areas for energy consumption & reductions. The standard does not incorporate any explicit criteria compared to other standards by ISO; therefore, organizations find it convenient to conform energy management in their system [17].

C. Methods for Energy Management

The industries possess the option to accustom with an energy management system within their internal energy management activities. Many different methods are available to endorse energy management as well as energy efficiency in the industries. Tab. 1 presents a list of major energy management methods in the industries. Notably, to mention that anchoring in the organization is necessary to apply the methods.

TABLE I
TOOLS FOR ENERGY MANAGEMENT [3]

Name	**Tool Type**
ISO 50001	Standardization tool in energy management
Nordenaudit	Energy audit software
EN 16247; ISO 50002	Audit (energy) standards
reMIND, MARKAL, TIMES.	Industrial energy system Optimization
ProPi; EINSTEIN	Pinch analysis tools
Multiple software	Manufacturing simulation
Lean	Integrating energy efficiency in Lean
LEEN	Energy efficiency grid management systems
IAC, DEFRAM, NEAD	Databank consisted of actual time energy efficiency procedures

Apart from the aforementioned tools, there is obviously exergy analysis system that focuses on the minimization of the exergy losses and increases energy production. Notably to mention that the exergy analysis aims to recognize and assess the quantifiable sources of thermodynamic deficiencies in the energy stream. On the contrary, another essential tool, Lean, focuses on waste minimization by adding value for the customers.

D. Energy Management Model Assessment

In the industries and academia, four research streams are taken into consideration to comply the energy management assessment, such as: "Minimum requirements", "Maturity models", "Energy management matrixes", & "Energy-efficient measures characterization framework" [5], [18]. The ISO 50001, a standardization scheme is mainly synchronized with the first stream, "Minimum requirements", hence apprehends strategies to facilitate energy management system. "Maturity Models", the second stream that solicits a methodical outlook to assess energy management in the organization that comprises exploration for the requisite phases to endorse energy management system [9]. The Energy Management matrixes are integrated to third stream [19] which advise several resemblances with the maturity model. Finally, the Energy Efficiency Measures (EEM) characteristics are enquired by the fourth research stream, "EEMs characterization framework" [20]. However, much of the studies based on characterization engrossed on monetarist features.

III. INDUSTRY 4.0

A. What is Industry 4.0?

The Fourth Industrial Revolution (Industry 4.0) [21] is outlined by the enhanced automation system, information technology and communication networks that consist of smart sensors, robotics, Internet of Things, artificial intelligence, and machine learning [22], [23]. However, the transformation from the first to fourth industrial revolution includes not only technological features but also the whole supply chain network [24]. The academic pieces of literature have articulated various attributes of Industry 4.0 which are decentralization, big data analytics, horizontal integration, block-chain, smart manufacturing, Internet of Things, virtualization, semantic technologies, cloud data computing, and automation & industrial robotics.

The involvement of minimum human resources in the industrial process due to synchronized and inter-connected machines has been one of the notable features on Industry 4.0 [25]. Diverse benefits mostly related to production and waste reduction are incorporated for advanced machinery deployment in the industries. The resource efficiency is increased in the form of energy productivity due to adoption of Industry 4.0, whilst the productivity percentage might be connected to energy consumption & resource utilization. However, Liu and Bae argue on the inflation in environmental pollution due to engaging with more industrialization [26]. Moreover, industrial automation might have an impact on social as well economically in developing countries that includes unemployment [27].

B. Energy Management and Industry 4.0

The energy management scheme is not only comprised of technical aspects, rather encompasses diversified aspects and enjoin the engineering skills with management disciplines. Nonetheless, energy management confronts multiple challenges because of complex behavioural characteristics at individual energy consumption phase in the industries. Keeping in the mind of both tangible as well intangible features, energy management has been portrayed with Industry 4.0 in several academic papers.

In one of the studies, Silva et al. incorporated the "energy" in the perspective of Industry 4.0 elaborately. The authors identified the concerns in the perspective of energy and Industry 4.0 that are strongly correlated with energy management in a broader spectrum. The study emphasized on the incorporation of other technologies, precisely, Internet of Things, sensors, automation, cloud management and so on also for harnessing the full benefit of Industry 4. Nonetheless, the study not only focuses on the technologies but also, comprehends the energy efficiency strategies [1]. On the contrary, Adenuga et al. emphasized on energy management in the industrial processes keeping the life cycle cost perspective, whilst integrating big data analytics and energy efficiency analysis modelling system [2].

Shrouf et al. articulated smart factories based on the Internet of Things to propose an energy management scheme along with the guideline. However, the authors signified the issue of understanding about energy consumption behaviour in the studies [28], [29]. Another study conducted by Javied et al. focused on cloud based energy management system incorporating a web-based tool, namely "Totally Integrated Energy Management", whilst integrating DIN EN ISO 50001 [30]. Satuyeva et al. focused on Internet of Things for energy management in Kazakhstan. Though the study focused on smart grid, it encompassed the Industry 4.0 aspects into energy management framework [31].

IV. CONCLUDING DISCUSSION

Even though having tangible resemblances & enormous potential, energy management is not integrated fully in most of the industrial digitization schemes [30], [28]. Few aspects are required to change the scenario. One important issue is to get the understanding from a managerial perspective is that two themes are closely linked and needed to be achieved. Another issue is mapping the energy data with the help of proper tool and requires regular maintenance. However, there is reason to be optimistic, although, consciousness is increasing rapidly in the industrial sector with strategic decision-makers [28].

"Energy efficiency" is an unceasing word that has been focused on Industry 4.0. It is understood that majority of the literature discourse this term as the electric yield as per the aptitude of the manufacturing process, resource utilization, expenses, and sustainability criteria. Production cost minimization is the major stimulant factor towards Industry 4.0, being aligned with the similar goal of energy management. Therefore, the role of energy management is very crucial and can establish a way to adopt Industry 4.0. Notably, the improved energy system performs as an expeditor in the industries to apply for optimized and enhanced energy production. However, one question might arise about the readiness and adaptability of Industry 4.0 in the industries. The industrial experts find it convenient and comparable easy to adopt Industry 4.0 at the new industrial plants [32]. It is obvious from the energy management perspective to fathom the energy flows along with a consumption unit focusing on system observation or monitoring [1]. In addition, the energy management system should be incorporated with incessant improvement actions as like energy audit, software up-gradation and so on [1].

In one of the studies focused on multinational, including small and medium-sized industries, are studied by Dóra et al. to find out the suitability and readiness to Industry 4.0. The research explores that the management willingness to increase control and to enable the feature of real-time performance measurement as noteworthy drivers to Industry 4.0. In contrast, the organizational resistance that includes both the management and employees is a substantial barrier to Industry 4.0 technologies. Notable to mention that the multinational enterprises are found more convenient to contrivance industry 4.0 parallel to small and medium-sized industries [33]. However, these are only preliminary works on the topic, and research opportunities exist in terms of exploring the characteristics of specific technologies & practices for energy management in different industrial contexts. In terms of priority, it holds

quite a significance stand for academia as well as the industrial experts to explore potential theoretical opportunities related to the effective applicability from different features of Industry 4.0. In these contexts, multiple questions are needed to dig down, especially for the SMEs. For example, whether SMEs can implement super real-time expensive energy simulation? Considering the business revenue and individual market share, SMEs are very unlikely to adopt expensive technology. Therefore, researchers are still to exploit the energy management activities range that is enabled by industry 4.0. Besides, we should also consider the capabilities to implement energy management for Industry 4.0.

Frank et al. presented the front end technologies related to Industry 4.0, where the technical parameters (e.g. vertical integration, virtualization, energy management, flexibility, automation, and traceability) are discerned. The study instigated strongly about the interconnection among the technical parameters for successful adoption of Industry 4.0. Fig. 1 presents the smart manufacturing technical aspects where energy management is integrated along with other technical parameters.

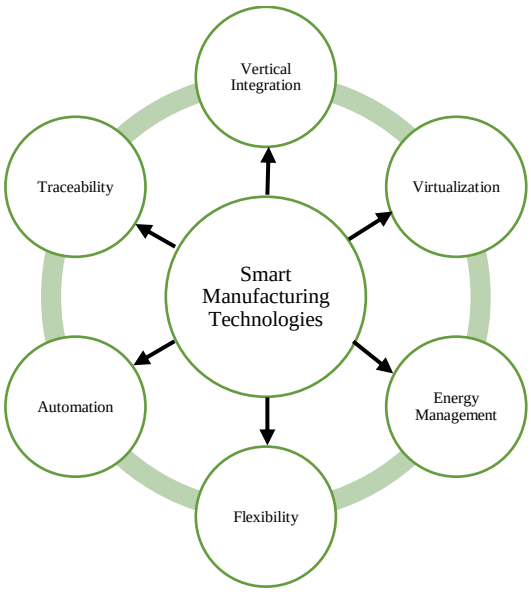

Fig. 1. Different technical parameters of smart manufacturing technologies [34]

In conclusion, it befitted more than obvious that Industry 4.0 is inevitable in the days to come, where manufacturing enterprises are facing resilient demand to proliferate the productivity by apprehending smart factories & smart industrialized system. Yes, it is possible to adopt Industry 4.0 with the help of modern high technical device & solutions. But we should not forget about energy security, global warming and resource depletion rate towards industrialization. Considering the energy security as well as the global warming, the industrial sectors must ensure the maximum usage of the resources. Our study is a preliminary work that aims to present the coherency between energy management and Industry 4.0. Literature reviews are presented in regards to both terminologies. We believe that a more intense inclusive study should be conducted to exploit further acumens, especially featuring the energy management practices in relation to Industry 4.0. It would be interesting to find how energy management practices can help the industries to adopt Industry 4.0. Certainly, one challenge belongs to the SMEs, considering their economic viability in terms of technical expenditure. On the contrary, another issue arises for the industries having intensive energy consumption with decrepit machinery. Another issue that must be taken into account is the developing country's adoption to Industry 4.0. So far studies are available to explore the technologies mainly, and case studies focus on developed countries. Indeed an interesting insight remains unexplored for the developing economies in regards to Industry 4.0. To do so, the future research scope must take into the account of energy management practices and the framework to adopt Industry 4.0, more specifically, how to facilitate the system and conforms the suitability. Furthermore, the exploration of barriers should be done in regards to energy management and Industry 4.0.

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