Exploring the Impact of Industry 4.0 Concepts on Energy and Environmental Management Systems: Evidence from Serbian Manufacturing Companies

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Abstract. It became more than evident that the era of Industry 4.0 is upon us, where industrial manufacturing companies are facing strong demand to increase their productivity and profitability by realizing or upgrading to smart factories and resource-efficient manufacturing processes. Having this in mind the aim of this paper is to provide insight regarding best practices in implementing Industry 4.0 concepts and their implications on manufacturing energy and environmental management systems and overall manufacturing energy efficiency. Our analysis used the Serbian dataset from the European Manufacturing Survey conducted in 2018. Furthermore, non-parametric correlation (Spearman's) analysis of the introduction of technologies on the one hand and EN ISO 50001 and EN ISO 14001 on the other was carried out. Results indicated significant correlation among Industry 4.0 concepts and both manufacturing energy and environmental management systems.

Keywords: Industry 4.0 · ISO 50001 · ISO 14001 · EMS

1 Introduction

Energy Management Systems (EnMS) and Environmental Management Systems (EnvMS) have emerged over the last two decades as a proven best practice methodology to ensure sustainable and progressing energy and environmental efficiency performance manufacturing firms [1–3]. EnMS outlines a structured and systematic approach on how to integrate energy efficiency in an enterprise management culture [4]. In contrast, Industry 4.0, a German strategic initiative, aims at creation of smart factories where manufacturing technologies are upgraded and transformed by Cyber-Physical Systems, the Internet of Things (IoT), and cloud computing [5, 6]. In the Industry 4.0 era, manufacturing systems can monitor physical processes, by generating so-called "digital twin" (or "cyber twin") of the physical system/process to make smart decisions through real-time communication and cooperation between humans,

Published by Springer Nature Switzerland AG 2019
F. Ameri et al. (Eds.): APMS 2019, IFIP AICT 567, pp. 355–362, 2019.
https://doi.org/10.1007/978-3-030-29996-5_41

machines, and sensors [7, 8]. Today, factors driving Industry 4.0 are paving the path for intelligent energy management. Nevertheless, when companies embark on efforts to introduce Industry 4.0, they mostly focus on the 'core' parameters of production efficiency, quality and cost. This is obviously what drives revenue. However, there is a strong case to also include EnMS in such projects. After all, systematically tracking energy consumption, production and costs is a major challenge nowadays in most industries – and one that has a lot in common with Industry 4.0 way of thinking. The development of technologies for instrumentation and monitoring of industrial processes enables data capture in ever-increasing resolutions, allowing increasingly powerful analyses. In the field of energy management, sophisticated physical meters (instruments) can interpret physical quantities that allow precise understanding of processes of interest, as well as monitoring variables that range from applied power, to harmonics that describe the quality of the electricity consumed. From the energy management perspective, Industry 4.0 is realized in the connectivity between measuring instruments and the entire information and automation architecture of industrial organizations. Bearing in mind a combination of environmental aspects, cost pressure, and regulation as well as the proactiveness of organizations when it comes to efficient consumption of energy, energy management becomes one of the main pillars of Industry 4.0. In energy management, the data available can give rise to prediction models for energy consumption (or generation) of operations, starting from planned production levels or other contextual variables.

This study reveals how and whether integrated EnMS, EnvMS and Industry 4.0 concepts influence on manufacturing efficiency. In addition, it provides insight on correlation between integrating energy management systems and Industry 4.0 concepts into daily practices. Our study relies on a unique dataset from the European Manufacturing Survey (EMS) with a sample of 240 industrial companies from the Republic of Serbia. Serbia is developing country with great foreign investments inflow into various types of manufacturing process. For instance, cost savings vs. EU-28 average 41% in electricity [9].

2 Background and Related Work

2.1 Implications of Industry 4.0 Concepts on Industrial Energy Strategies

For manufacturers to be competitive in the 4th industrial revolution, reducing production costs is of crucial importance. One way to achieve this is by creating a solid strategy when it comes to EnMS in Industry 4.0 environment. Among many factors that need to be optimized in order to stay competitive, one is energy efficiency which is still easily forgotten in most companies. While improved energy efficiency, as well as effectively implemented EnMS, is always welcome, it is rarely the main driver of Industry 4.0 deployments. However, energy savings have been reported by those organizations that have attempted to make Industry 4.0 a reality. For example, Daimler in Germany has reported a 30% improvement in energy efficiency for its robot systems that use Industry 4.0 techniques. Another example is Canadian Forest Products, which reported a 15% reduction in energy consumption by using real-time alerts for energy consumption outside of anticipated norms [8].

In previous literature, the highest impact on energy strategy is brought by IoT [10]. As a consequence of vast IoT solutions implementation, huge amount of data is being generated, introducing the Big Data term used to describe sets of data characterized by high volume, high velocity, and high variety [11], and for which the use of advanced analytical tools is required in order to process data into actionable information by identifying patterns, trends, and relationships [12]. However, it is estimated that less than 1% of all available data is currently analyzed [13]. Big data therefore creates important challenges and opportunities now and in the coming years. In addition, presence of Big Data opens the door to Blockchain technologies which represents distributed databases and ledgers made of blocks stored on a large number of machines, so that any changes made to the database are permanently recorded, while any record is made publicly available thanks to the distributed design [14]. This puts the spotlight on new opportunities for reducing or eliminating the need for a trusted middleman in many operations, ensuring a supply of certified renewable electricity coming from distributed energy generation, verification of legal energy provisions, etc. From the aspect of EnMS, Blockchain technology provides companies with the potential to analyze their energy consumption with greater accuracy and efficiency, monetize the data collected and validate energy consumption and savings in real-time. Additionally, this technology provides a new solution to record and monetize carbon credits where applicable. Rising electricity costs and energy sustainability are a critical risk for factory owners and asset managers worldwide. For instance, German energy executives see a wide range of possible applications for Blockchains in the energy sector and believe the technology could have the potential to reduce costs and spur new business models in it [15]. However, the Blockchain technology faces many challenges, privacy and data security issues, but also technical issues such as the currently still rather long time needed to conduct a transaction [16].

Rapid Prototyping technologies represent one of the major developments in the modern manufacturing [17]. Beyond prototyping, technologies such as additive-layer manufacturing also provide benefits to serial or mass manufacturing processes. For example, General Electric's LEAP engine, with 3D-printed fuel nozzles, has enabled to go from 18 sub-parts to only 1 [16]. This not only multiplied the durability of the component by 5% and reduced its weight by 25%, but also enabled a better optimized geometry to achieve higher combustion efficiency [18]. This caused to fuel savings throughout the life of the engine and reducing its CO_2 emissions. Another example is Augmented Reality (AR). Wide spread of AR use in EnMS through "Open Energy" concept is noticed [19]. For instance, Lobby Showcase of the Fraunhofer Center for Sustainable Energy Systems use thousands of sensors inside and outside of their headquarters, ensuring 5CC building to become living laboratory gathering and sharing live data.

2.2 Research Questions

Given the, the following research questions were proposed in the attempt to identify the relationship between implementation of digital technologies and implementation of energy and environmental management systems:

- RQ1: What is the relationship between implementation of Industry 4.0 concepts and energy management system in Serbian manufacturing companies?
- RQ2: What is the relationship between implementation of Industry 4.0 concepts and environmental management system in Serbian manufacturing companies?

3 Data and Methodology

For the analysis purposes Serbian dataset from the EMS conducted in 2018 was used. EMS is a survey on the manufacturing strategies and the application of innovative organizational and technological concepts in production in European manufacturing industry [20–23]. The survey was conducted among manufacturing companies (NACE Rev 2[1] codes from 10 to 33) having at least 20 employees. Each survey has been carried out based on a proportionally size- and industry-based stratified random sample. The dataset includes 240 companies of all manufacturing industries as given in Table 1. The comparison of data regarding firm size distribution shows no significant size bias.

Table 1. EMS database – distribution of companies by size

	20 to 49 employees	Company size 50 to 249 employees	250 and more employees
	n (%)	n (%)	n (%)
Serbia	110 (45.8)	103 (42.9)	27 (11.3)

Table 2. Classification on manufacturing sectors according to share on total sample

NACE Rev. 2	Manufacturing industry	Share on total sample (%)
10	Manufacture of food products	16.3
25	Manufacture of fabricated metal products, except machinery and equipment	15.0
22	Manufacture of rubber and plastic products	8.8
27	Manufacture of electrical equipment	6.3
28	Manufacture of machinery and equipment n.e.c.	6.3
14	Manufacture of wearing apparel	5.8
16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	4.6
23	Manufacture of other non-metallic mineral products	4.6
29	Manufacture of motor vehicles, trailers and semi-trailers	4.2
	Others	28.5

[1] NACE Rev. 2 stands for Statistical classification of economic activities in the European Community (more information regarding NACE Rev.2 could be found here).

The largest industry in the sample is the manufacture of food products (NACE 10; 16.3%), followed by manufacture of fabricated metal products (NACE 25; 15.0%) and manufacture of rubber and plastic products (NACE 22; 8.8%). Tables 1 and 2 depict the sample distribution of the dataset from Serbia. Lastly, to analyze the relationships between implementation of digital technologies on one side and EnMS and EnvMS on the other we employed non-parametric correlation (Spearman's) analysis.

4 Results and Discussion

Table 3 depicts results of the correlation analysis (i.e. Spearman correlation coefficient values) between implementation of Industry 4.0 concepts and implementation of energy (RQ1) and environmental (RQ2) management systems. Given analysis revealed that there is a significant positive relationship between implementation of each Industry 4.0 concept on one hand and implementation of EnMS and EnvMS on the other.

Table 3. Results of the correlation analysis

Technologies	RQ1	RQ2
Digital factory		
Mobile/wireless devices for programming and controlling facilities and machinery (e.g. tablets)	.304***	.276***
Digital solutions to provide drawings, work schedules or work instructions directly on the shop floor	.266***	.215***
Software for production planning and scheduling (e.g. ERP system)	.297***	.273***
Digital Exchange of product/process data with suppliers/customers	.303***	.199***
Near real-time production control system	.276***	.308***
Systems for automation and management of internal logistics	.307***	.248***
Product-Lifecycle-Management-Systems (PLM) for Product/Process Data Management	.282***	.205***
Virtual Reality or simulation for product design or product development	.237***	.295***
Automation and robotics		
Industrial robots for manufacturing processes	.279***	.269***
Industrial robots for handling processes	.304***	.249***
Additive manufacturing technologies		
3D printing technologies for prototyping	.256***	.246***
3D printing technologies for manufacturing of products, components and forms, tools, etc.	.274***	.248***
Energy efficiency technologies		
Technologies for recycling and re-use of water	.261***	.261***
Technologies to recuperate kinetic and process energy	.256***	.215***

Source: own research results; Note: $^{***}p < 0.001$

These results provide evidence that Serbian manufacturing companies recognize the importance of e EnMS and EnvMS integration along with implementation of indicated Industry 4.0 technology concepts. However, as it could be seen from the results, although this linkage is statistically significant, it is characterized as a low strength correlation. On the other hand, this cognition can be interpreted as verification of the previously given statement that implemented EnMS and EnvMS have been deployed by those organizations that have attempted to make Industry 4.0 a reality. Nowadays, manufacturing systems worldwide implement advanced manufacturing or Lean Manufacturing principles, in which minimal resources to bring maximum value to the business are applied. These same principles can and should be used for energy utilization. From this perspective, it is all about being efficient in the way the energy within manufacturing system is being used, with aim to reduce consumption where necessary, and transfer adequate knowledge to relevant personnel across the organization in order to bring the same value with less energy and thus reduced harmful emissions [8]. However, it is strongly believed that majority of manufacturing companies, both in Serbia and throughout the world, still lacking well-tailored developing strategies to integrate environmental sustainability into manufacturing which is in any case of utmost importance to gain competitiveness. Successfully implementing energy and resource efficiency programs, pollution prevention and control programs, or sustainability initiatives is of urgent need [24–26], which with the appropriate application of Industry 4.0 concepts, can be easily integrated into processes.

5 Conclusion

This study provides insight regarding best practices in implementing Industry 4.0 concepts and their implications on manufacturing EnMS and EnvMS and overall manufacturing energy efficiency. Based on analysis that used the Serbian dataset from the ENMS conducted in 2018, it was revealed that there is a significant positive relationship between implementation of each Industry 4.0 concept on one hand and implementation of EnMS and EnvMS on the other. More importantly, these results provide evidence that Serbian manufacturing companies recognize the importance of EnMS and EnvMS integration along with implementation of indicated Industry 4.0 technology concepts. However, although results indicate statistical significance, this linkage is characterized as a low strength correlation. Despite the obvious similarities and the huge potential, EnMS is not (yet) fully incorporated in most factory digitization projects. There is reason for optimism, though. Awareness is growing quickly with key decision makers in industry. Having this in mind, Industry 4.0 (with special emphasis on IoT and Big Data) and EnMS and EnvMS combined suggest an exciting future with reduced costs and emission of pollutants, while simultaneously ensuring improved performance. However, you could be left with a severe wondering where all the promise and money went. Or in other words, manufacturing decision makers should be taking full advantage of these Industry 4.0 tracking tools for EnMS and EnvMS carefully. Lastly, the sample was drawn from a single developing country, probably lacking the diversity that can be expected from a comparable sample chosen from across different economies, both developed and developing. Further research should test the model and relationships in the manufacturing companies within other EMS countries (e.g. Austria, Germany, Slovenia, Lithuania).

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