Industry 4.0 and environmental sustainability.
an empirical research inside a manufacturing company

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Abstract

Objectives. *The main objective of this paper is to investigate Industry 4.0 tools and how they can help reduce the environmental impacts of manufacturing organisations.*

Methodology. *The paper is based on empirical observation inside a large Italian company which has implemented Industry 4.0 and environmental management. The environmental impacts of the production and logistics activities of the company were identified and measured before and after the implementation of some Industry 4.0 tools.*

Findings. *We found different levels of effects on environmental performance. MES/SCADA and other software are not significantly improving environmental performance. With many difficulties, Big Data collected from sensors and equipment can be dedicated to environmental performance and analysis as well. Moreover, Automated Mobile Robots and Augmented Reality are not particularly affecting environmental performance. While smart sensors can really help in improving environmental performance.*

Research limits. *This research is based on observations within a company using qualitative inquiry and consequently cannot be generalized.*

Practical implications. *The paper supplies a practical table and comments for improving environmental sustainability by means of Industry 4.0.*

The comments can generate ideas which can be implemented by practitioners at different levels and open a scientific debate concerning how to design such an implementation pattern.

Originality of the study. *Comparison of the before and after observations reveals interesting and novel results which contribute to the research on the effects of Industry 4.0 on environmental performance.*

Key words: *Industry 4.0, Manufacturing, Environmental performance*

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1. Introduction

The main objective of this paper is to investigate Industry 4.0 tools and how they can help reduce the environmental impacts of manufacturing organisations. The paper is based on empirical observation inside a large Italian company which has implemented Industry 4.0 and an environmental management system.

Industry 4.0 is a new term first coined in Germany and launched in 2011 by the German Federal Government (Kagermann et al. 2011). The well-known term refers to the fourth industrial revolution; the first revolution was based on water and steam-powered machines, the second industrial revolution was based on electricity and the third one was based on electronics and information technology. Industry 4.0 strongly emphasises cyber-physical systems (CPS) and smart technologies with an integration of machinery, factory and business processes, which are capable of autonomously exchanging information, activating actions and making decisions and controlling each other independently (Kagermann et al. 2013).

The environmental impacts of the production and logistics activities of the company were identified and measured before and after the implementation of some Industry 4.0 tools such as: Automated Guided Vehicles, Augmented Reality, Smart Sensors, Smart maintenance, Robot and Cobot, Integration over the internet of Things (IoT). Comparison of the before and after observations reveals interesting and novel results which contribute to the research on the effects of Industry 4.0 on environmental performance.

In this light, this exploratory research contributes to the debate concerning how to improve environmental performance in manufacturing context, answering the research question:
Is there a specific connection between industry 4.0 technologies and the environmental performance?

2. Literature review

The concept of sustainable development first appeared at the UN Conference on the Human Environment held in Stockholm (Rogers et al., 2008). There are several definitions of sustainable development. An interesting definition that insists on maintaining a balance between profit, planet, and community has been given by the EPA (2003): "Sustainability creates and maintains the conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations." In the manufacturing sectors, sustainability aims to create manufactured products which use processes and practices that maximize profits, minimize negative environmental impacts, conserve natural resources and energy, and are safe for employees, consumers, and communities (NACFAM, 2012). Hence, achieving sustainability in manufacturing requires a complete view covering not only the product and the processes involved in its production, but also the entire supply chain and the manufacturing system (Faulkner and Badurdeen, 2014).

Over time, sustainability has been implemented through several systems concerning environmental management, health and safety management as well as social responsibility management (Qi et al., 2013). For this purpose, the Industry 4.0 tools have been analysed as possible way for improving environmental performance. Findings have been collected through a direct observation before and after the implementation of the tool.

Through a first literature review we identified some Industry 4.0 tools which can be investigated for their impacts on environmental performance. Industry 4.0 is a structured and complex model of many technologies connected with each other over the so-called IoT. The number of possible technologies and systems connectable and integrable is uncountable and subject to a rapid and continuous evolution. We tried to categorise them according to the current literature review, especially linked to the possibility of affecting environmental performance in the logistics industry. Hermann et al. (2016) analysed 51 papers dedicated to industry 4.0 and tried to categorise the most important elements of Industry 4.0. According to the authors, the most quoted and studied elements are cyber-technologies, followed by the IoT, Smart Factory, Internet of Services, Smart Products, Machine-To-Machine, Big Data and Cloud.

The consulting firm PwC (2016) carried out the most global survey so far about Industry 4.0 with no less than 2,000 companies in 26 countries involved, collecting data from different kinds of manufacturing industries. According to the results of this research, Industry 4.0 is based on 11 contributing digital technologies which are mobile devices, the IoT platforms, location detection technologies, advanced human-machine interfaces, authentication and fraud detection, 3D printing, smart sensors, bid data analytics and advanced algorithms, multilevel customer interaction and customer profiling, augmented reality/wearable, cloud computing.

Other authors (Jeschke et al., 2017; Dalenogare et al., 2018) classified Industry 4.0 technologies using the three main advantages introduced by Industry 4.0, vertical integration, horizontal integration and end-to-end engineering. According to Dalenogare et al. (2018), the vertical integration is the integration between the production and the management levels, the horizontal integration the integration between production processes and suppliers, while the end-to-end engineering is the integration of product design in the whole value chain from product development until after-sales. In this way, Dalegoner et al. (2018) listed a combination of new and more consolidated technologies such as CAD/CAM, integrated engineering systems, digital automation with sensors, flexible manufacturing lines, Manufacturing Execution Systems (MES) and Supervisory control and data acquisition (SCADA), simulation and

analysis of virtual models, bid data collection and analysis, digital product systems, additive manufacturing, 3D prototyping, cloud service.

There are also authors (Rüßmann et al., 2015; Romero et al., 2016) who, in addition to the above-mentioned technologies, highlighted how Industry 4.0 relies on new autonomous and collaborative robots which can help and assist workers instead of just substituting them like in the past.

In this literature we tried to find some traces of impacts on environmental performance and then we combined the technologies discussed by the different authors creating the below Table 1 where the technologies are grouped avoiding to refer to specific single technological items and apparatuses. In this way technologies can sometimes be considered as a combination of different other technologies creating a more complex system. For instance, we put together the integrated engineering systems and the CAD/CAM creating the Product Data Management and Product Life Management (PDM/PLM) system.

Table 1 – Industry 4.0 technologies and systems (tools)

Technology/System
MES/SCADA
PDM/PLM
Big data collection and analysis
Cloud
3D printing, additive manufacturing
Smart products and customer interaction
Digital automation with sensors and smart sensors
COBOT and AMR/AGV
Augmented Reality (AR) and Smart Human Interfaces (SHI)
Cyber Security

3. Methodology

This qualitative research is based on a case study. We observed the Industry 4.0 implementation within a large manufacturing company which has 800 employees and manufactures pumps. The company has been managing an environmental system for more than 20 years reaching also an ISO 14001 certification. In the last two years the company has implemented some Industry 4.0 technologies as well. Pumps are directly sold to other manufacturing companies and usually they do not have a direct contact with the end-user of the product, who typically is the driver of a lorry, an excavator or an agricultural vehicle.

The observation produced much data, and the practice of coding qualitative data (Lofland and Lofland, 1995) was used to assign labels to classify and assign meaning to parts of the information. An initial coding generated several categories from the direct observation. A second coding known as focused coding was used to reduce the number of initial coded categories by eliminating the less useful ones. Sometimes codes are not mutually exclusive thence the same information could be assigned several codes. In order to avoid these interrelationships in the coding process it is important to review the codes several times, eliminating less useful ones, and grouping smaller categories into larger ones (Lofland and Lofland, 1995).

4. Discussion and findings

With reference with the tools listed in Table 1, we found different levels of effects on environmental performances. Starting from the use of a MES and/or a SCADA, we analysed the situation before and after the implementation and we were not able to find relevant differences. The MES can measure key performance indicators such as the overall equipment effectiveness (OEE), number of failures, stoppages, delays, as well as can trace down products monitoring the quality of the logistic flow. However, unless the MES can be modified for specifically measuring environmental indicators of the shop-floor, it does not affect the possibility of improving environmental performance.

PDM/PLM could affect environmental performance as long as they are designed for this purpose. The PDM/PLM should include features like design to environment, environmental characteristics of the product and end-of-life product management. Especially the PLM should trace down the product once it is in use, monitoring and collecting data and information concerning consumptions, environmental aspects and impacts as well as its interactions with other products or more complex systems.

Data stores in this company have continued to grow exponentially and big data has become increasingly challenging. Now they are realising that Big Data management involves putting the right people, procedures and technologies in place to ensure the accuracy, security and quality of large stores of data. At the beginning the company implemented complex and expensive pieces of software for analytics and cyber-security. They have collected big data from products in the markets and from production processes. However, the data are mainly about product performance, especially

related to reliability, and process performance such as productivity, quality, cycle time and machine parameters. In a second time they understood how important could be collecting data also from sensors and equipment dedicated to environmental performance. For instance, data concerning energy consumptions, raw materials used for the products, waste produced as well as consumptions of water and gas. Big data could also be collected directly from the products in terms of pollution. For each new motorcycle the company could even measure the quantity of CO_2 and other chemicals released in atmosphere. However, the company declared some difficulties in developing a specific software for analysing environmental big data providing environmental patterns and trends.

Strictly connected with big data analysis and cloud storing

3D additive printing is another interesting tool linked to Industry 4.0 which could have a relationship with environmental performance. The company implemented a couple of 3D printers, the first one dedicated to plastic prototypes and second one to metallic components. The 3D printers can help designers in reducing prototyping times, making products and components more customised. However, a part from a saving of raw materials and electricity for making the prototype there are no other relevant savings connected with environmental performance. Moreover, the above-mentioned savings of raw materials and electricity can be considered not so significant from an economic point of view.

Table 2 – Effects of Industry 4.0 technologies and systems on environmental performance

Technology/System	Possible effect on environmental performance
MES/SCADA	Low
PDM/PLM	Moderate
Big data collection and analysis	Moderate
Cloud	Low
3D printing, additive manufacturing	Low
Smart products and customer interaction	High
Digital automation with sensors and smart sensors	High
COBOT and AMR/AGV	Moderate
Augmented Reality (AR) and Smart Human Interfaces (SHI)	Low
Cyber Security	No effect

5. Conclusions

We started this research investigating a case study based on a manufacturing company which has managed for many years an environmental system and in the last two years has also implemented some Industry 4.0 technologies. We found different levels of effects on environmental performance. MES/SCADA and other software are not significantly improving environmental performance. With many difficulties, Big Data collected from sensors and equipment can be dedicated to environmental performance and analysis as well. Moreover, Automated Mobile Robots and Augmented Reality are not particularly affecting environmental performance. While smart sensors can really help in improving environmental performance.

This research has several limits due to its nature. In particular it is based on observations within a manufacturing company using qualitative inquiry and, consequently, cannot be generalized. Therefore, the theory derived from such a qualitative inquiry, including the discussed findings, should be deeper tested leading to further research.

The paper supplies a practical table and comments for improving environmental sustainability by means of Industry 4.0 technologies. Findings can generate ideas which can be implemented by practitioners at different levels and open a scientific debate concerning how to design such an implementation pattern.

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