The Kanban System's Environmental Impacts: A Comparative Study

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Abstract

The increasing customer's environmental conscientious, the strict environmental regulations and the need to keep market competitiveness, is pressuring organizations to reduce their environmental impacts. Hence, organizations are looking for new approaches to achieve sustainability. Several studies discuss the relation between Lean and Green Manufacturing approaches not only to reach Leaner results but also to decrease the environmental footprint of organizations. However, most researchers evaluate the global impact of Lean Manufacturing tools, and so their individual impact is lost. To overcome this gap, this work presents a comparative study of the Kanban system's environmental impacts, evaluating Green KPIs, such as, Energy usage, Material usage, Water usage, Waste, and Air and Water pollution. The analyzed papers showed a positive impact related to the Energy usage, Material usage and Waste, when Kanban and its related practices are applied. Regarding Water usage and pollution, the findings are very scarce. Additionally, the results show that Air Pollution is the most controversial Green KPI. This comparative study allows for a global view on Kanban's environmental impacts to prevent them in advance. Moreover, at the end of the paper a work-in-progress, regarding the practical measurement of the Green KPIs upon the Kanban system's implementation, is presented.

Keywords
Kanban system; Lean Manufacturing; Green Manufacturing, Environmental impacts; Sustainable Manufacturing

1. Introduction

The current globalization trends trigger rapid and continuous changes in the markets, which compels enterprises to search for new ways to enhance productivity and profitability. To this, one can also add, the higher customer demands for quality, shorter time deliveries, lower cost and highly customized products which oblige industries to rethink their production systems in order to make them more efficient and flexible (Alsyouf 2007; Bastos et al. 2009; Varela et al. 2014). Moreover, increased customer environmental awareness and responsibility, and strict environmental regulations, have pressured organizations to consider the environment in management and operations, if they must maintain their competitiveness in the market (Baumer-Cardoso et al. 2020; Cherrafi et al. 2018; Sawhney et al. 2007).

Cherrafi et al. (2018) refer " […] that for organizations to remain competitive, a proper balance of economic, environmental and social priorities needs to be managed in their global operations" (Cherrafi et al. 2018). These three priorities turn companies focus to Sustainable development, in particular, Sustainable Manufacturing which EPA (n.d.) defines as "the creation of manufactured products through economically-sound processes that minimize negative environmental impacts while conserving energy and natural resources. Sustainable manufacturing also enhances employee, community and product safety" (EPA n.d.).

However, sustainability at a manufacturing level, involves the implementation of innovative practices and the adoption of different management and business approaches, which ought to meet the organization's current needs, simultaneously protecting, maintaining, and enhancing, the resources available for future generations. On this note, Sustainable Manufacturing may be achieved by concurrently applications of Lean and Green Manufacturing approaches, as previously stated in the literature (Azevedo et al. 2012; Cherrafi et al. 2018; Dornfeld et al. 2013).

The Lean Manufacturing concept, pioneered by Taiichi Ohno and Shigeo Shingo, has its origins in the Toyota Production System (TPS) and can be defined as an efficiency-based approach focused on flow optimization and non-value-added activities (waste) elimination (Bhamu and Sangwan 2014; Sabadka 2014). On the other hand, Green Manufacturing is defined as a manufacturing approach that induces the constant integration of Green strategies and techniques to eliminate or reduce environmental impacts (Deif 2011).

Several papers in the literature discuss the relationships between these two approaches. Bergmiller and McCright (2009) studied " […] winners and finalists of the Shingo Prize for Manufacturing Excellence […]" (Bergmiller and McCright 2009), to connect Lean and Green Manufacturing practices. In the end, the authors determined that a synergetic relationship exists between these two approaches and, consequently, when companies apply Green objectives are more likely to be Leaner. Various authors reached identical conclusions, that Lean and Green are synergetic, hence applying Lean practices will positively impact Green practices and vice-versa (Dües, Tan, and Lim 2013; Miller et al. 2010; Sabadka 2014). Nonetheless, a variety of scholars underline that, even though they are helpful, not all Lean practices may lead to Greener results (Dornfeld et al. 2013; Herrmann et al. 2008). In fact, Dües et al. (2013) and Dieste et al. (2019) refer that, concerning replenishment frequencies, Lean and Green do not marry, and so, companies have to achieve some kind of trade-off. In their literature review Dieste et al. (2019) specified that 14% of the reviewed papers acknowledged that Lean has a positive effect in environmental performance, and merely 4% recognized a negative relationship.

In spite of the current interest on the environmental impacts of Lean Manufacturing practices, little research has been performed exclusively focusing on the environmental benefits and drawbacks of the Kanban system's implementation, a widely used Lean Manufacturing tool. Most researchers tend to evaluate the impact of a set of Lean Manufacturing practices and, consequently, the exclusive impact is lost. Thus, as the implementation of Lean tools is a progressive process and not a simultaneous one, understanding what would happen environmentally once the system was implemented, would allow organizations to develop, in advance, environmental solutions that go hand in hand with the triggered impacts.

Therefore, to fill this gap, a comparative study on the Kanban environmental impacts will be presented and, at the end of the paper, a brief presentation of an ongoing work in this matter will be presented. This paper is divided in 5 sections. In Section 2 a presentation of important concepts and practical implementation studies will be introduced and in Section 3, the research methodology applied is presented. Section 4 comprehends the results assessed in the literature and compares the analyzed papers' findings. Lastly, Section 5 summarizes the main findings and presents the work that is being done in a Portuguese company to surmount the gap identified above.

2. Lean and Green Concepts

2.1 Lean Manufacturing, Just-in-time Production and Kanban system

According to Tayyab et al. (2018), if one were to analyze any current industry on a global scale, it would be easily verified that Lean Manufacturing is imperative if organizations want to endure in the rising market competition. As Lean is an approach that focuses in higher efficiency when applying Lean Manufacturing tools, it is expected a reduction, or ideally, the elimination of the eight Lean wastes presented in Table 1.

Table 1. Eight Lean wastes (Adapted from Choudhary et al. (2019)).

Type of waste	Description
Overproduction	Producing above the client's needs and before it is needed.
Transportation	Unnecessary movements and handling of products, materials, or Work-In-Progress (WIP).
Inventory	Above-the-needs material or final products in stock, which are waiting to be processed, transported, inspected, etc.
Motion	Nonvalue added movements by people.
Waiting	People, products and material "[…] waiting for information, for machines to finish their automatic cycles, for other people, for materials, etc […]" (Choudhary et al. 2019).
Defects	Production of defected products, which may be considered waste or rework.
Over-processing	Unnecessary processing of a product that do not add value to the product in the clients' perspective.
Skills	Not using employees' talents, skills, and knowledge.

In their review Bhamu and Sangwan (2014) depicted TPS as the sum of two pillars the Just-in-time (JIT) production system and the Respect-for-human system. The JIT production system comes associated with ideas such as Small lot production, Product variability production (mixed model production) and Pull production (or Pull system), and a set of tools such as 5S, Standardized Work, Single Minute Exchange of Dies (SMED), Visual Controls, *Poka-Yoke* and Kanban (Bhamu and Sangwan 2014; Tayyab et al. 2018). The implementation of these tools is well documented in the literature.

Amrani and Ducq (2020) applied Cellular layout, One-piece flow, Visual Control, Standardization, *Poka-Yoke* and SMED in a company operating in the aerospace industry. The results obtained with the implementation of those Lean tools show a 66% reduction in the defect rate, 43% cycle time reduction, waste elimination and the reduction in WIP inventories. Moreira and Pais (2011) also applied the SMED methodology in a Portuguese mold making company, which resulted in the elimination of wastefulness and non-added-value activities worth around 360M€.

Choomlucksana et al. (2015) demonstrated the impact of Lean Manufacturing tools in the efficiency improvement of a sheet metal company. For that, the authors applied 5S, Visual Control and *Poka-Yoke*. The obtained results show a processing time reduction, the elimination of non-added-value activities and cost reduction.

Randhawa and Ahuja (2018) intended to evaluate the benefits strategically of applying the 5S methodology in an Indian automotive parts industry. The benefits obtained go from process performance to safety and employees' morale. The authors observed a 69% reduction in inventory levels, 72% reduction in WIP levels, a 95% decrease in quality rejected products and an enhancement of 96% in productivity per employee. Additionally, the accident frequency rate decreased by 98.5% and the absenteeism had a reduction of 69% after 5S implementation.

Mukhopadhyay and Shanker (2005) implemented a Kanban system, 5S and SMED in a continuous product production line of a tyre factory. The results obtained show a reduction in WIP, defects, lead and setup times, and an increase in machine uptime. The authors also mention an increase in works' responsibility and motivation.

Kanban is referred by Taiichi Ohno (1988) as "the operation method of the Toyota Production System" considered by some authors (Kumar and Panneerselvam 2007; Mojarro-Magaña et al. 2018) as the trademark for JIT and the Pull system. Kanban is a card-based instruction system that transmits to each workstation, what specific part must be produced and when it needs to be produced, to satisfy the customer requirements. The foundation of the Kanban system is the replacement of the strategically defined and controlled stocks (also known as supermarkets). Thus, after the subsequent process pulls what is needed from the supermarket, a signal is sent to the previous process to indicate that it must produce to restore what was consumed ahead (Ohno 1988). When applying Kanban, organizations adopt a Pull system production. This type of production system allows them to gain the flexibility to produce a higher mixed of products (derived from the reduction of lot size), to lessen their inventory and WIP levels, to eliminate overproduction and to reduce waiting times (Mojarro-Magaña et al. 2018; Ohno 1988).

2.2 Green Manufacturing

Green Manufacturing is an approach to production processes that intends to use efficient inputs with small environmental impact, and generate, ideally, no pollution (Ninlawan et al. 2010). Green Manufacturing strives to economize materials, energy and water, to eliminate the use of toxic substances and, eliminate water, air and land pollution (Deif 2011; Hallam and Contreras 2017; Johansson 2009). So, similarly, to Lean, Green Manufacturing is expected to eliminate seven types of wastes (Table 2). Additionally, Azevedo et al. (2012) point out that besides diminishing the environmental impact of manufacturing, Green Manufacturing is also effective for cost reduction.

Table 2. Seven Green wastes (Adapted from Choudhary et al. (2019)).

Type of waste	Description
Energy	Excessive use of energy.
Water	Excessive use of fresh water.
Material	Use "[…] virgin raw materials into products that would end up in the landfill or designing resource expensive non-recyclable product for short lifetime" (Choudhary et al. 2019).
Waste	Pay for products or materials that will eventually be thrown out.
Transportation	Unnecessary movements of products, materials, and people.
Emissions	"Unnecessary paying to create and discharge pollutants on-site, and then being subject to the fines and levies associated with doing this" (Choudhary et al. 2019).
Biodiversity	"Either directly impacting flora and fauna negatively or overharvesting resources faster than they can regenerate themselves Environmental" (Choudhary et al. 2019)

Dief (2011) states that when adopting Green Manufacturing an organization "is aware of its production/product impact on the environment [...] and include such impact in its overall efficiency planning and control". On a manufacturing level, Ninlawan et al. (2010) present different Green activities that have been employed in several Thai electronic companies. For hazardous substance control, these companies replaced substances as bismuth, silver, tin, gold, and copper, and instead of using chemicals to wash parts, they replaced it with clean water and then recycled it. In terms of energy usage, the number of load and unload transports were reduced, machine uptime and downtime were improved and, the product lifespan was enhanced. To reduce the quantity of waste generated concepts like 3R's (Reuse, Reduce and Recycle) were applied. Jayal et al. (2010) present the 6R's (Reuse, Reduce, Recycle, Recover, Redesign and Remanufacturer) concept which goes beyond the 3R's concept stated by Ninlawan et al. (2010).

In a UK Cement plat, Summerbell et al. (2016) examined fuel mix, rate of production, and process airflow to verify the daily variation of fuel-derived CO_2, in order to estimate the potential for operational improvement. The results demonstrated a potential reduction of 10% in CO_2 emissions and a reduction of 7% in energy consumption. Due to the reveal potential two mathematical models were used to examine the factory energy balance and to predict CO_2 emissions based on specific input conditions. The models conclude that that is possible to reduce energy consumption and CO_2 emissions by changing the airflow ratio and fuel mix.

Chahabra et al. (2017) use an Analytical Hierarchy Process to encounter Green alternative practices in the assembly and packing processes of an Indian automotive company. The authors evaluated the alternatives according to green efficiency, safety, and operation effort. To join the metallic and non-metallic components and wires of the assembly processes the Green alternative chosen consisted in the use of Clinch Joints followed by self-piercing rivets. In terms of alternatives for the packaging process the authors opted for a carbon positive packing followed by a mushroom packaging.

3. Research Methodology

In order to understand the implications of applying Lean Manufacturing tools, especially the Kanban system, to obtain positive environmental impacts, a bibliographical research was made. The methodology followed to select the articles and documents for the literature review comprises three different steps. The first step involves the search for papers/documents using the selected keywords and the exclusion of non-English ones. At the end of this step, a list of several papers/documents was available. In the second step, the abstracts of the previously mentioned list were read, in order to eliminate the papers that do not fit with the topic of interest. The third and last step concerns the integral reading of the papers. For this literature review, only the papers that dealt with environmental indicators of Kanban and related practices (such as JIT, Production variability, Small lot production and Pull systems) were selected. It was found that there is a lack of papers in this subject.

Initially articles and documents with the keywords "Kanban" and "Green Manufacturing" were analyzed, however, the reduced number (only one article was selected) forced for a broader research. Several searches were made, and they are described in Figure 1. After this process six different papers were chosen for this study.

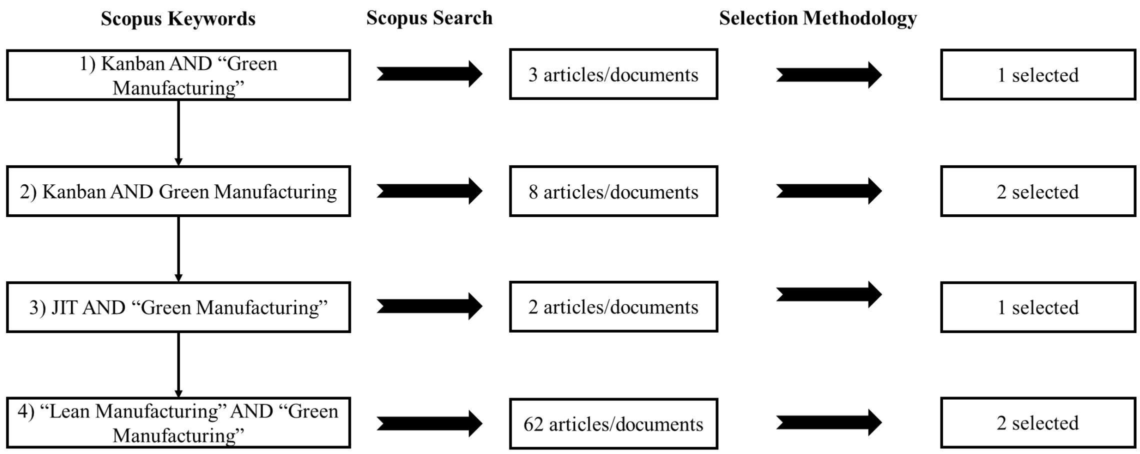

Figure 1 – Paper selection process.

However, throughout the reading of the selected titles, several other papers, that fulfil the selection criteria, were consistently mentioned by the authors. Consequently, some of those papers were also chosen for this study. Nevertheless, after the selection process, nine papers were selected, and it is based on those papers that this study is developed. From these nine papers, three are case studies, three are simulation-based studies, two are literature reviews and, one is a theoretical study, based on Lean and Green experts' opinions.

4. Kanban environmental impacts, a literature review

For the purpose of impacts comparison of the Kanban system and related practices, it is important to define the common performance indicators (KPI) from which the environmental impact will be assessed. According to the selected papers in this work, it was observed that the most used Green KPIs, were:

- Energy usage;
- Material usage;
- Air pollution;
- Waste;
- Water usage;
- Water pollution.

Thus, these will also be the Green KPIs chosen for the papers' comparison.

Baumer-Cardoso et al. (2020) performed a discrete-event simulation (DES), to evaluate the applicability of Kanban and supermarkets in a Brazilian manufacturing company. They also studied the impact of those Lean Manufacturing tools in Green performance. In this study, the authors measured Green performance through three KPIs: Raw material usage, and Energy and Water usage. After analyzing the obtained values, it was demonstrated that the application of Kanban and supermarkets reduced by 13% the raw Material usage and by 14% the Energy usage. Contrarily, the Water usage had an increase which the authors correlated to the setup characteristics. This correlation was based on the need to exchange the water in the injection molding machine upon each setup. Considering that the Kanban system enhances the number of setups needed, the Water consumption increased proportionally.

Similarly, Herrmann et al. (2008) used a simulation-based approach to analyze the environmental impact of Lean Manufacturing tools on a production line. After the study, the authors stated that, "[…] the Kanban System involves more runs to provide the materials […]" (Herrmann et al. 2008), which led to an increase in Energy consumption and, consequently, an increase in Air pollution.

Miller et al. (2010), through discrete-event simulation at a small furniture production company, proved that with the application of Lean tools, such as Standardized work, Kanban, 5S and SMED it was possible to eliminate over and under production and, therefore, avoid unnecessary Energy usage.

In Cherrafi et al. (2018), the environmental impact of Lean Manufacturing tools, such as JIT, SMED, Cellular manufacturing and Waste elimination was evaluated in 374 manufacturing companies. With the obtained results the authors concluded that these tools substantially improve the Green supply chain performance. The application of JIT tools led to a reduction in Material usage, which was achieved through both inventory and defects reduction. The latter also meant a reduction in Waste production. Additionally, producing in Smaller lots allowed for the use of smaller vehicles in material transportation, which, in turn, resulted in a reduction of fuel and emitted CO_2 (Reduction of Air pollution).

Belhadi et al. (2018) presented the impacts of Lean Manufacturing tools on the Green performance in a Small and Medium Enterprise (SME) that produces different types of pumps. Among the analyzed Lean tools, Pull system and Kanban were mentioned to help reduce WIP and prevent overproduction. The obtained results showed a decrease in Energy and Water usage, and also a decrease in raw Material usage. However, the decrease in Water usage was not related to the Kanban system nor related practices, therefore, it is not mentioned in this comparative analysis.

Dieste et al. (2019) analyzed, in a 5 years study, the relationship between Lean Manufacturing and environmental performance in five different manufacturing companies. In their study, evidence was found that Lean tools like Pull and Kanban systems had a positive impact on Material, Water and Energy usage and Waste. However, depending on the company and transportation characteristics the impact on Energy usage could be negative. Regarding Air pollution the authors determined that Pull and Kanban had a negative impact.

In Dües et al. (2013) a systematic review of Lean Manufacturing tool impacts on Green supply chain performance was developed. Here, it is stated that "[…] though the pull system with small batches and JIT deliveries, Lean implies an increase in the replenishment frequency, whereas Green practices aim at reducing transport time and replenishment frequencies" (Dües et al. 2013). Consequently, using tools like JIT, Pull system and Small lot production causes an increase in CO_2 emissions from transport.

Additionally, the extensive literature review performed by Dieste et al. (2019) has unveiled several other papers that support the previous statements. Here, it was stated that "[…] small deliveries might produce additional wastes and emissions" (Dieste, Panizzolo, Garza-Reyes, et al. 2019).

Lastly, Sawhney et al. (2007) developed different matrixes that identify the relation (positive, negative or both) between Lean Manufacturing principles and its environmental impacts. The matrixes were based on the evaluation of different case studies, by several Lean and environmental experts, where various Lean tools were applied.

4.1 Comparative analysis of results

Table 3 summarizes the nine papers found in the literature that evaluate the environmental impacts of the Kanban system or Kanban related practices, such as JIT, Pull system, Small lot production and Product variability. After examining the papers, a summary of the impact of each indicator was made. According to the papers conclusions and discussions a positive (P), negative (N) or both (P/N) environmental impact for each indicator was established. This review is presented in Table 3.

Table 3. Papers' comparison regarding the environmental impact of the Kanban system and related practices.

	(Baumer-Cardoso et al., 2020)	**(Belhadi et al., 2018)**	**(Cherrafi et al., 2018)**	**(Dieste et al., 2019a)**	**(Dieste et al., 2019b)**	**(Dües et al., 2013)**	**(Herrmann et al., 2008)**	**(Miller et al., 2010)**	**(Sawhney et al., 2007)**	**(Sawhney et al., 2007)**	**(Sawhney et al., 2007)**
Lean Tools / **Green KPIs**	Kanban	Pull system Kanban	JIT SMED Cellular manufacturing Waste elimination	Pull System Kanban	JIT Kanban Small lot production	JIT Kanban Small lot production	Pull system Kanban	Standardize work Kanban 5S SMED	Pull system	Small lot production	Mix Products
Air pollution	-	-	**P** Smaller vehicles used for transportation	**N** Transportation increase	**N** Transportation increase, and Inventory and Lean waste reduction	**N** Transportation increase	**N** Transportation increase	-	**P** Overproduction elimination	**N** Transportation and Setups increase	**P/N** Impact influenced by Setup
Water pollution	-	-	-	-		-	-	-	-	**N** Setups increase	-
Waste	-	-	**P** Defects reduction	**P** Defects reduction		-	-	-	**P** Overproduction elimination and Defects reduction	**P** Defects reduction	**P/N** Impact influenced by Setup
Water usage	**N** Setups increase	-	-	**P** Waiting reduction		-		-	**P** Overproduction elimination and Defects reduction	**N** Setups increase	-
Energy usage	**P** Overproduction elimination	**P** Overproduction elimination and Inventory reduction	**P** Inventory reduction	**P/N** Inventory reduction but Impact influenced by Transportation		-	**N** Transportation increase	**P** Overproduction elimination	**P** Inventory reduction	**P/N** Defects reduction, but the Setups increase.	-
Material usage	**P** Overproduction elimination	**P** Defects reduction	**P** Inventory and Defects reduction	**P** Defects, Inventory and Waiting reduction	**P** Inventory reduction	**P** Defects reduction	-	-	-	-	-

Legend: P – Positive Impact | N – Negative Impact | P/N – Positive or Negative Impact

The opinion of each author is very diverse in terms of Air pollution. The majority considered that Kanban has a negative impact on the environment, since lot size reduction causes an increase in the material handling and transportation which, in turn, increases the air pollutants from transportation. In contrast, other authors believe that it has a positive impact. Moreover, Dieste et al. (2019) mentioned that "[…] JIT principles, waste minimization and buffer minimization can conflict with some features of environmental performance, in particular, with the VOC (Volatile Organic Compounds) emissions" (Dieste, Panizzolo, Garza-Reyes, et al. 2019). Cherrafi et al. (2018) highlighted that, in consequence of smaller lots, the transportation frequency increases, but, in contrast, the quantity to be delivered in each transport decreases, enabling the use of smaller vehicles, which increase fuel savings and lessen pollutants emissions. Sawhney et al. (2007) evaluated the Pull system's impact as positive, but, not for the same reasons as the previous authors. They believed that the reduction in Air pollution was only related to producing according to the clients' requirements, which resulted in the elimination of overproduction. Still, when enhanced, the product variability (Mix Products) can cause an increase or a decrease in Air pollution, depending on the machines' setups (Sawhney et al. 2007). For example, in the work presented by Baumer-Cardoso et al. (2020), the setup had a negative impact on the environment. Additionally, Sawhney et al (2007) referred that the Small lot production, promoted by the Kanban system, increases air emissions from machinery, since there will be "[…] more frequent shutdowns and start-ups" (Sawhney et al. 2007).

The negative impact of Small lot production in Water pollution is solely mentioned by Sawhney et al. (2007). According to the authors, its negative value is due to an increase in "intermediate cleaning" (Sawhney et al. 2007), due to more frequent setups, which leads to "more effluents (wastewater) – in the form of sludge, residuals, solvents […]"(Sawhney et al. 2007).

Related to the Waste reduction, the authors agreed that Kanban had a positive impact, since the system helped to eliminate overproduction, and reduce defects in production. Besides, Dieste et al. (2019) stated that, because of Kanban there was a smaller need for packaging, which resulted in less solid Waste generated by it. Yet, depending on the setup Sawhney et al. (2007) stated that an intensification in variability can produce a negative impact in this Green KPI.

Only Baumer-Cardoso et al. (2020), Dieste et al. (2019) and Sawhney et al. (2007) mentioned the Water usage impacts. Although the conclusions of the first study indicated an increase in Water usage, it was due exclusively to the setup, as explained before. The last study concluded that the use of Water decreases since the production is done according to the clients' requirements, but it also mentions an increasing in Water usage due to higher "intermediate cleaning" (Sawhney et al. 2007) in consequence of Small lot production. Contrarily, Dieste et al. (2019) determined that the Pull system caused a reduction in parts waiting times, which provoked a reduction in Water usage.

As can be seen in Table 3, regarding Energy usage the authors' opinions, in a general way, converge. The majority of authors (Baumer-Cardoso et al. 2020; Belhadi et al. 2018; Cherrafi et al. 2018; Miller et al. 2010; Sawhney et al. 2007) agreed that due to a decrease in transportation, defects, WIP and inventory levels, and also the elimination of overproduction, the use of Energy decreased. However, Herrmann et al. (2008) had a different opinion. They stated that Kanban has a negative impact once it applies Small lot production, which increased the need for more frequent transportations. This point was also referred by Dieste et al. (2019). Regarding Small lot production, Sawhney et al. (2007) also stated that Lean Manufacturing practices can have a negative impact on Energy usage. This happens because smaller lots may cause "[…] more frequent shutdowns and start-ups" (Sawhney et al. 2007). Nonetheless, Small lot production can also have the reverse effect, since a small number of defects means less energy consumed.

In terms of Material usage, all authors agreed upon the fact that the Kanban system and related practices have a positive impact. This conclusion was expected because overproduction is eliminated. Upon limiting the production volumes, there will be, consequently, a reduction in WIP and inventory levels. Belhadi et al. (2018), Cherrafi et al. (2018), Dieste et al. (2019) and Dües et al. (2013) also state that this indicator is affected by the reduction in defect rates. Moreover, Dieste et al. (2019) verified that the Pull system application has a positive impact in reducing waiting times, which according to the authors reduces Material usage.

The results allowed the us to withdraw several conclusions. First, the existing literature on this subject is very scarce, as can be seen by the number of papers found and selected.

It was also noted that the impact of the Kanban system and related practices was only studied within a short-term period. Solely, Dieste et al. (2019) came close to a long-term study, by evaluating the Kanban system's environmental impacts within a period of five years. Dieste et al. (2019) also unveiled the same conclusion for the general Lean Manufacturing practices, stating that "Researches present in the literature are often punctual analyses in time while a medium-long term vision is lacking considering the evolution of the process of lean transformation in companies" (Dieste, Panizzolo, Garza-Reyes, et al. 2019).

Furthermore, among the bibliographic analysis carried out, the environmental impact indicators are not consensual, and most authors only use and evaluate a small number of them. As can be confirmed by analyzing Table 2, Sawhney et al. (2007) are the only authors that analyzed all environmental indicators with the exception of Material usage. In contrast, Miller et al. (2010) mentioned only one environmental KPI, which was Energy usage. Nevertheless, Energy and Material usage, and Waste are the only KPIs with which the majority of authors agree. In terms of Energy and Material usage, the authors claim that there is a positive environmental impact with the Kanban implementation. In the case of Waste, and regarding its minimization, the authors that evaluate this indicator mainly recognize that the Kanban system wields a positive impact. Additionally, it was noted that the most divergent KPI is Air pollution, since some authors agree that Kanban enhances the quantity of CO_2 emissions while others have an opposite opinion. The same can be said about Water usage, since according to the studied authors Kanban can have both positive and negative impacts. We can also conclude that Water pollution is the less studied impact in the literature.

It is also important to highlight that the impact of Lean Manufacturing on environmental performance is highly dependent on specific company characteristics (Dieste, Panizzolo, Garza-Reyes, et al. 2019), especially, setup characteristics as seen for example:

- in Baumer-Cardoso et al. (2020), as an increase of Water usage was detected, which was solely related to the machine setup characteristics;
- in Dieste et al. (2019), Company C had a 126% increase, between 2016 and 2017, in Water consumption due to, as mentioned by the authors, "[…] exceptional circumstances […]" (Dieste, Panizzolo, and Garza-Reyes 2019);
- and in Sawhney et al. (2007), where the impact can shift from positive to negative according to the setup characteristics of the company's machines.

5. Conclusions and Future Work

In the present work, we aimed to evaluate the environmental impacts of the implementation of the Kanban system and its related practices in manufacturing companies. For that, an in-depth bibliographical research on the subject, was developed. Immediately, it was possible to conclude that, although being a popular topic, there was little information on it, and that most papers evaluated a reduced number of KPIs, for example Miller et al. (2010) only evaluated Energy usage. Besides, the majority of papers did not analyze the Kanban system's environmental impacts in the long-term (Dieste, Panizzolo, Garza-Reyes, et al. 2019). As referred, Dieste et al. (2019) were the only authors to evaluate the Kanban related practices within a medium to long term period. Moreover, from this study it can also be assessed that the result of the environmental impact (positive or negative) is highly influenced by the company's characteristics, especially, the machine setup characteristics (Dieste, Panizzolo, Garza-Reyes, et al. 2019).

The selected papers were then analyzed, and the relation between Lean Manufacturing tools and environmental impacts was evaluated. This evaluation resulted in a papers classification, according to the Lean tools and Green KPIs. According to this classification, and the conclusions of each work, the majority of the authors agree that Material usage, Energy usage, and Waste produced are all positively affected by the implementation of Kanban or related practices. Contrarily, Air pollution and Water usage are the Green KPIs where most authors disagree. In the first, this controversy is related to the supposed increase in transportation frequencies, which is a result of the Small lot size production and the Kanban system's operating mode (a lot is only sent to the subsequent workstation upon consumption). In terms of Water usage, the main negative impact highlighted is, solely, related to setup increase, which is also a result of Small lot size production. Regarding Water pollution, only one work (Sawhney et al. (2007)) mentioned a negative impact related to an increase in the cleaning process' frequency, which results in more pollutants in the water.

Furthermore, with this study, several doubts regarding the CO_2 emissions increasing, caused by the intensification in transportation frequencies, after the Kanban implementation, arise. These are related to external transportation (to suppliers and clients) and internal transportation inside the factory. The question is: How, does a Lean company implement Kanban, if, with this, it would increase substantially one of the other Lean Wastes that it aims to eradicate?

In terms of external transportation, the vehicle capacity always needs to be maximized. Hence, even if the delivery transportation frequency increases, the company will not send a vehicle unless its full capacity is used. Or, as suggested by Cherrafi et al. (2018) the size of the vehicle can be reduced, which means less Air pollution. In internal transports, the elimination or reduction of transportation wastes is kept. Even when the capacity of the vehicle is limited (forklift, *Mizusumashi*), the Kanban restricts the production to only the necessary parts, which, consequently, reduces the quantity that needs to be transported.

In conclusion, this work allowed for an evaluation of the Kanban and related practices in regard to the specific environmental impacts. This way, when a company applies the referred practices it can prevent, in advance, its negative effects on the environment. For example, a company can introduce a system to reuse water as proposed by Baumer-Cardoso et al. (2020), or "[…] selecting suppliers of the same geographic area that could share truckloads when delivering or, when delivering small amounts, managing the routes in order to supply multiple customers in the same area on one delivery route" (Dües et al. 2013), or even, by using smaller transportations vehicles as proposed by Cherrafi et al. (2018).Additionally, by introducing environmental practices in the company's strategic plan, a reduction in operation costs may also be achieved (Bashkite and Karaulova 2012; Cherrafi et al. 2016; Hallam and Contreras 2017; Tseng et al. 2013).

Therefore, with the present literature review three literature gaps were found:

- There is little information regarding the Kanban system and its related practices' environmental impacts;
- There is little information regarding the Kanban system and related practices' impact in Water pollution;
- There is no long-term analysis of the Kanban system and its related practices.

Summing up, we suggest a more profound study of the Green KPIs on organizations in order to determine and evaluate the impacts that arise from the implementation of a Kanban system. According to these assumptions and conclusions, a case study in an international automobile Portuguese company is currently in progress in the work of Romeira and Moura (2020). In the mentioned study the main objective is to design, digitalize and implement an e-Kanban system to monitor and control not only the production and inventories but also to integrate all support services as well. After the implementation of the intended digital system, the Green impacts will be calculated not only to study and validate the e-Kanban implementation but also to complement the literature related to the environmental impacts.

References

Alsyouf, Imad. 2007. "The Role of Maintenance in Improving Companies' Productivity and Profitability." *International Journal of Production Economics* 105(1):70–78.

Amrani, Aicha and Yves Ducq. 2020. "Lean Practices Implementation in Aerospace Based on Sector Characteristics: Methodology and Case Study." *Production Planning & Control* 1–23.

Azevedo, Susana G., Helena Carvalho, Susana Duarte, and V. Cruz-Machado. 2012. "Influence of Green and Lean Upstream Supply Chain Management Practices on Business Sustainability." *IEEE Transactions on Engineering Management* 59(4):753–65.

Bashkite, V. and T. Karaulova. 2012. "Integration of Green Thinking into Lean Fundamentals by Theory of Inventive Problems-Solving Tools." in *DAAAM International*. Vienna: DAAAM International.

Bastos, Pedro, Rui Lopes, Luis Pires, and Tiago Pedrosa. 2009. "Maintenance Behaviour-Based Prediction System Using Data Mining." Pp. 2487–91 in *2009 IEEE International Conference on Industrial Engineering and Engineering Management*. IEEE.

Baumer-Cardoso, Marina I., Lucila M. S. Campos, Pedro Pfeifer Portela Santos, and Enzo Morosini Frazzon. 2020. "Simulation-Based Analysis of Catalyzers and Trade-Offs in Lean & Green Manufacturing." *Journal of Cleaner Production* 242:118411.

Belhadi, Amine, Fatima Ezahra Touriki, and Said El Fezazi. 2018. "Benefits of Adopting Lean Production on Green Performance of SMEs: A Case Study." *Production Planning & Control* 29(11):873–94.

Bergmiller, Gary G. and Paul R. McCright. 2009. "Are Lean and Green Programs Synergistic?" in *Industrial Engineering Research Conference*.
Bhamu, Jaiprakash and Kuldip Singh Sangwan. 2014. "Lean Manufacturing: Literature Review and Research Issues." *International Journal of Operations and Production Management* 34(7):876–940.
Cherrafi, Anass, Said Elfezazi, Andrea Chiarini, Ahmed Mokhlis, and Khalid Benhida. 2016. "The Integration of Lean Manufacturing, Six Sigma and Sustainability: A Literature Review and Future Research Directions for Developing a Specific Model." *Journal of Cleaner Production* 139:828–46.
Cherrafi, Anass, Jose Arturo Garza-Reyes, Vikas Kumar, Nishikant Mishra, Abby Ghobadian, and Said Elfezazi. 2018. "Lean, Green Practices and Process Innovation: A Model for Green Supply Chain Performance." *International Journal of Production Economics* 206:79–92.
Chhabra, Deepti, S. K. Garg, and Rajesh K. Singh. 2017. "Analyzing Alternatives for Green Logistics in an Indian Automotive Organization: A Case Study." *Journal of Cleaner Production* 167:962–69.
Choomlucksana, Juthamas, Monsiri Ongsaranakorn, and Phrompong Suksabai. 2015. "Improving the Productivity of Sheet Metal Stamping Subassembly Area Using the Application of Lean Manufacturing Principles." *Procedia Manufacturing* 2:102–7.
Choudhary, Sonal, Rakesh Nayak, Manoj Dora, Nishikant Mishra, and Abhijeet Ghadge. 2019. "An Integrated Lean and Green Approach for Improving Sustainability Performance: A Case Study of a Packaging Manufacturing SME in the U.K." *Production Planning & Control* 30(5–6):353–68.
Deif, Ahmed M. 2011. "A System Model for Green Manufacturing." *Journal of Cleaner Production* 19(14):1553–59.
Dieste, Marcos, Roberto Panizzolo, and Jose Arturo Garza-Reyes. 2019. "Evaluating the Impact of Lean Practices on Environmental Performance: Evidences from Five Manufacturing Companies." *Production Planning & Control* 1–18.
Dieste, Marcos, Roberto Panizzolo, Jose Arturo Garza-Reyes, and Anthony Anosike. 2019. "The Relationship between Lean and Environmental Performance: Practices and Measures." *Journal of Cleaner Production* 224:120–31.
Dornfeld, David, Chris Yuan, Nancy Diaz, Teresa Zhang, and Athulan Vijayaraghavan. 2013. "Introduction to Green Manufacturing." *Green Manufacturing: Fundamentals and Applications* 9781441960:1–23.
Dües, Christina Maria, Kim Hua Tan, and Ming Lim. 2013. "Green as the New Lean: How to Use Lean Practices as a Catalyst to Greening Your Supply Chain." *Journal of Cleaner Production* 40:93–100.
EPA. n.d. "Sustainable Manufacturing." *EPA Website*. Retrieved April 15, 2020 (https://www.epa.gov/sustainability/sustainable-manufacturing).
Hallam, Cory R. A. and Carolina Contreras. 2017. "The Interrelation of Lean and Green Manufacturing Practices: A Case of Push or Pull in Implementation." Pp. 1815–23 in *PICMET 2016 - Portland International Conference on Management of Engineering and Technology: Technology Management For Social Innovation, Proceedings*. Institute of Electrical and Electronics Engineers Inc.
Herrmann, Christoph, Sebastian Thiede, Julian Stehr, and Lars Bergmann. 2008. "An Environmental Perspective on Lean Production." Pp. 83–88 in *Manufacturing Systems and Technologies for the New Frontier*. Springer London.
Jayal, A. D., F. Badurdeen, O. W. Dillon, and I. S. Jawahir. 2010. "Sustainable Manufacturing: Modeling and Optimization Challenges at the Product, Process and System Levels." *CIRP Journal of Manufacturing Science and Technology* 2(3):144–52.
Johansson, Glenn. 2009. *Lean vs. Green Manufacturing: Similarities and Differences Chalmers Area of Advance on Sustainable Production View Project ProAct View Project*.
Kumar, C. Sendil and R. Panneerselvam. 2007. "Literature Review of JIT-KANBAN System." *International Journal of Advanced Manufacturing Technology* 32(3–4):393–408.
Miller, Geoff, Geoff Miller, Janice Pawloski, and Charles Standridge. 2010. "A Case Study of Lean, Sustainable Manufacturing." *Journal of Industrial Engineering and Management* 3(1):11–32.
Mojarro-Magaña, María, Jesús Olguín-Tiznado, Jorge García-Alcaraz, Claudia Camargo-Wilson, Juan López-Barreras, and Rubén Pérez-López. 2018. "Impact of the Planning from the Kanban System on the Company's Operating Benefits." *Sustainability* 10(7):2506.
Moreira, António Carrizo and Gil Campos Silva Pais. 2011. "Single Minute Exchange of Die. A Case Study Implementation." *Journal of Technology Management and Innovation* 6(1):129–46.
Mukhopadhyay, S. K. and S. Shanker. 2005. "Kanban Implementation at a Tyre Manufacturing Plant: A Case Study." *Production Planning and Control* 16(5):488–99.
Ninlawan, C., P. Seksan, K. Tossapol, and W. Pilada. 2010. "The Implementation of Green Supply Chain

Management Practices in Electronics Industry." Pp. 1563–68 in *Proceedings of the International MultiConference of Engineers and Computer Scientists 2010, IMECS 2010*.
Ohno, Taiichi. 1988. *Toyota Production System: Beyond Large-Scale Production*. New York: Productivity Press.
Randhawa, Jugraj Singh and Inderpreet Singh Ahuja. 2018. "An Investigation into Manufacturing Performance Achievements Accrued by Indian Manufacturing Organization through Strategic 5S Practices." *International Journal of Productivity and Performance Management* 67(4):754–87.
Romeira, Bárbara and Ana Moura. 2020. "Applicability of an E-Kanban System According to the Industry 4.0 Paradigm: An Applied Practical Study." in *20ª Conferência da Associação Portuguesa de Sistemas de Informação*.
Sabadka, Dušan. 2014. "INNOVATION LEAN PRINCIPLES IN AUTOMOTIVE GREEN MANUFACTURING." *Acta Logistica-International Scientific Journal* 1(4):23–27.
Sawhney, Rapinder, Pamuk Teparakul, Aruna Bagchi, and Xueping Li. 2007. "En-Lean: A Framework to Align Lean and Green Manufacturing in the Metal Cutting Supply Chain." *Int. J. Enterprise Network Management* 1(3).
Summerbell, Daniel L., Claire Y. Barlow, and Jonathan M. Cullen. 2016. "Potential Reduction of Carbon Emissions by Performance Improvement: A Cement Industry Case Study." *Journal of Cleaner Production* 135:1327–39.
Tayyab, Muhammad, Biswajit Sarkar, and Misbah Ullah. 2018. "Sustainable Lot Size in a Multistage Lean-Green Manufacturing Process under Uncertainty." *Mathematics* 7(1):20.
Tseng, Ming Lang, Anthony Shun Fung Chiu, Raymond R. Tan, and Anna Bella Siriban-Manalang. 2013. "Sustainable Consumption and Production for Asia: Sustainability through Green Design and Practice." *Journal of Cleaner Production* 40:1–5.
Varela, Maria Leonilde R., André S. Santos, Ana M. Madureira, Goran D. Putnik, and Maria Manuela Cruz-Cunha. 2014. "Collaborative Framework for Dynamic Scheduling Supporting in Networked Manufacturing Environments." *International Journal of Web Portals* 6(3):19.

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