International Journal of Mathematical, Engineering and Management Sciences
Vol. 6, No. 5, 1214-1229, 2021
https://doi.org/10.33889/IJMEMS.2021.6.5.073

Lean & Green on Industry 4.0 Context – Contribution to Understand L&G Drivers and Design Principles

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(Received on February 24, 2021; Accepted on June 16, 2021)

Abstract
The purpose of this paper is to demonstrate how the implementation of Lean & Green (L&G) in an Industry 4.0 (I4.0) environment can enhance the potential impact of the L&G approach and help manufacturing companies moving towards higher operational and sustainable performances. The research work developed here shows that although a proper definition of L&G is neither exposed worldwide nor explicitly implemented under that name, the current industrial firms are deeply concerned about the demanding challenge of keeping businesses flexible and agile without forgetting strategies to minimize the acceleration of climate change. So, one contribution of this paper is the identification and characterization of L&G drivers and design principles, supporting a robust and well-informed L&G systems implementation. As inferred from the research work, this challenge demands high quality and updated data together with assertive information. Thus, the implementation of L&G in I4.0 contexts is the answer to overcome the identified barriers. Likewise, an L&G system contributes to overcoming the challenges of I4.0 implementation regarding the triple bottom line sustainability concept. Consequently, another contribution of this paper is to depict why an L&G system performs better in the I4.0 context.

Keywords- Lean, Lean & Green, Sustainability, Industry 4.0, Design principles.

1. Introduction

Lean and Green (L&G) is an emerging topic evolving around industrial firms today. The philosophy of Lean explains improvements in the efficiency of the process by identifying and eliminating the non-value-added activities in a process flow. Lean is commonly accepted in the industrial sector as a conventional solution to reduce waste in the supply chain and maintain production processes' productivity (Valamede and Akkari, 2020). Therefore, it is incorporated in almost every operation in most reputed and upcoming industries (Duarte and Cruz-Machado, 2017a). The Green term means that actions are environmental oriented, helping to reduce environmental impacts like reduction of Greenhouse gases and hazardous wastes (Duarte and Cruz-Machado, 2017a). The principle of Lean can be compared to a quote, *"Prevention is better than cure,"* said by the Dutch philosopher (Desiderius Erasmus, 1500), which explains that the idea of Lean is to eradicate the waste entirely and not to minimize it.

Additionally, support from Green principles chips in to add a positive impact on Lean. High customer demand and drastic climate changes around the globe make Lean Manufacturing and Green approaches go beyond the boundaries taking deep Lean thinking and further environmental impact reduction into account (Leong et al., 2019). This pressure on industries made the researchers focus more on sustainable production and operations. Sustainability refers to *"The development which meets the needs of the present without compromising the ability of future generations to meet their own needs"* (World Commission on Environment and Development, 1987). In other words, from an engineering perspective, it can also be termed as optimal use of resources, maximizing efficiency, and progressing a way to be economical. So, acting simultaneously on Lean and Green objectives helps L&G be a pillar for sustainable development by compromising all these requirements. In addition, reducing production and operation waste in the industry is mandatory to remain competitive (Leong et al., 2019).

Recently, Industry 4.0 has arisen, incurring disruptive shifts in development practices based on a technology-driven plan (Valamede and Akkari, 2020). Different countries around Europe have identified the linkage between sustainable manufacturing and I4.0, and their governments have taken responsibility for providing guidelines to implement I4.0 (Machado et al., 2020). It has been noted that Industry 4.0 (I4.0) has a positive impact on all the sustainability dimensions in an integrated way, where sustainability dimensions include economic, environmental and social well beings (Machado et al., 2020). The future requirements of I4.0 can be adapted easily by the characteristics of the Lean and Green supply chain, indicating that both approaches strive for a similar goal (Duarte and Cruz-Machado, 2017a). For almost the last three decades, Lean management is the most widely used business strategy in industrial firms. Currently, industrialists are fond of these strategies and their contribution to the implementation of I4.0 (Valamede and Akkari, 2020). Lean management helps to differentiate waste and value within an organization. By applying this approach, an extensive amount of non-added-value activities is segregated. Eliminating these would promote positive impacts on the environment either directly or indirectly. The Lean approach focuses on reducing waste, instead helps to increase the energy efficiency of a sector. Lack of policy, support, and commitment from the government and industrialists is found in implementing the L&G approach. This lack exists mainly because the benefits owned by the L&G approach are misunderstood (Leong et al., 2019). Despite several studies on L&G approaches and successful case studies, the required drivers for implementing an L&G system are not clear. In addition, there is a gap in the literature regarding the fundamental aims of the L&G system and its relationship with Lean principles and/or sustainability-related objectives. Finally, the available literature does emphasize the potential and dependence of successful L&G system implementation from the availability of reliable, abundant, and updated data.

Therefore, the paper aims to overcome these gaps by identifying and characterizing the L&G drivers by defining and explaining the L&G design principles. These contributions are derived from literature analysis and published case studies interpretation (presented in section 2). The authors believe these contributions support a robust and well-informed L&G systems implementation. In addition, in section 3, a detailed explanation of the L&G design principle has been presented, and at last in section 4, the available literature focusing the potential of L&G on an I4.0 context is assessed, allowing the other contribution of this paper: to depict why an L&G system performs better in I4.0 contexts and what I4.0 components are relevant for L&G systems implementation. These contributions allow a discussion about the high potential and benefits of using L&G in the I4.0 context.

2. Lean & Green: State-of-the-Art

This section begins with an analysis of the existing definitions of the emerging L&G concept, and it assists in identifying the potential benefits of the approach. Then, the approaches proposed in the literature, the integration level of L&G with challenges to overcome are also analyzed. Henceforth, the significant characteristics of L&G approaches are discussed, contributing to understanding how to develop them further.

2.1 Combination of L&G

Lean manufacturing has been gaining a reputation since the 1950s amongst the extensive range of industries. Empirical evidence suggests that it increases competitiveness by improving productivity with a Lean inventory and reducing lead times. The term “Green" emerged from the raising concern on the environment and the new government’s and agency’s regulation that has to be adopted by the industries (Garza-reyes et al., 2014). The Lean concept was initially formulated from eight significant losses, called Wastes or *Muda* – inventory, over-production, defect, waiting, motion, transportation, over-processing, and human resources (Amrina and Zagloel, 2019). Spending resources to create value for the customers is said to be the economic expenditures; any other spending is considered wasteful and zero-valued (Pampanelli, 2015). Identifying and eliminating these losses makes an industry achieve a successful Lean approach. The responsibility of manufacturing industries to address and rectify the negative impacts caused on the environment due to their operation is the core principle of the Green concept (Amrina and Zagloel, 2019).

Researchers typically accept that, while Lean Manufacturing and Green Production vary in their key targets, there is also a common wished outcome: mitigate (ideally eliminate) waste, regardless of what sort of waste they are based on (Mollenkopf et al., 2010). Table 1 represents the definition of "Waste" in both the context of Lean and Green and the similarities between them. While Lean Manufacturing and Green production approaches are not entirely synonymous and vary in their primary emphasis, understanding their similarities and differences contributes to understanding their complementary aspects that potentially strengthen the good practices of both methods (Abualfaraa et al., 2020).

Table 1. Definition of lean manufacturing and green production, with focus on types of waste reduction and/or elimination (Abualfaraa et al., 2020; Johansson and Winroth, 2009; Kurdve and Bellgran, 2021).

	Lean Manufacturing	**Green Production**
Difference	Lean waste • Transportation • Inventory • Motion • Waiting • Over-processing • Over-production • Defect	Green Waste • Solid wastes • Hazardous wastes • Air emissions • Wastewater discharges
Similarity	Non-value-added activities in Lean are majorly linked with energy and resources, relating the seven lean wastes to the wastes described in the sense of green manufacturing.	

Waste types differ in terms of Lean Manufacturing and Green Production, but both agree that minimizing waste will lead to the most critical aspect: resource efficiency and operations systems improvement (Abualfaraa et al., 2020; Johansson and Winroth, 2009; Kurdve and Bellgran, 2021).

Some authors point that the Lean approaches initiate a better atmosphere for the deployment of Green philosophies (Garza-Reyes et al., 2014; Wiengarten et al., 2013). Some indirect advantage of adapting Lean production comes from the fact that it may lower the marginal cost of pollution reduction (King and Lenox, 2001). Even with the substantial contributions of both practices to sustainability, researchers also argued that stand-alone Lean or Green implementation programs are typically not adequate to maintain the balance between the three pillars of sustainability required by the modern global market: the economic, environmental, and social ones (Abualfaraa et al., 2020).

Amrina and Zagloel (2019) refered to the positive impact of incorporating Lean Manufacturing and Green Approach on the organization's sustainability and quality performance. Experimental studies indicate that the synergetic impact of Lean based methods and Green practices supports innovation and reducing the costs of making environmentally sustainable goods (Galeazzo et al., 2014).

Following the referred synergies, a standard definition can be driven by reviewing multiple authors view on the L&G approach (Abualfaraa et al., 2020; Amrina and Zagloel, 2019; Garza-Reyes et al., 2014; Pampanelli, 2015) L&G is a system designed to concurrently and continually increase organizational quality and sustainability in order to dramatically improve the capacity of either an enterprise or a supply chain to produce and provide value to its customers and society as a whole.

Abualfaraa et al. (2020) stated recently that the L&G processing concept is a new notion, awaiting confirmation of its practical use. Campos and Vazquez-Brust (2016) stated, the deployment of L&G in the future will only be possible if the implementing sector has a high degree of confidence because implementing L&G system needs a complete transformation of traditional process chains, that consequently needs thorough knowledge about the consequences. This rigorous knowledge exhibits the confidence level of the implementing sector (Saetta and Caldarelli, 2020). Summing up, when there is a high degree of confidence and risk-sharing tendency and a low level of power differentials between Lean Manufacturing and Green Approaches roles, the capacity for Lean and Green synergy is fully realized (Campos and Vazquez-Brust, 2016).

Section 2.2 investigates L&G implementation in different application areas and confirms the synergy explained by the authors in this section. Additionally, section 2.2 helps to find the challenges of the L&G approach and the factors that have to be incorporated to process the approach.

2.2 The Application Areas of L&G

Despite the emergent development state of L&G described in section 2.1, the potential of the L&G approach has been identified by various authors (Table 2). Their proposals and frameworks call for sustainability, economic profitability, and resilience as the key reasons to apply the L&G approach. The synergy implicated in L&G helps the firm to gain efficiency and reduce risk factors which cannot be easily achieved when either one of them is used separately (Abualfaraa et al., 2020; Amrina and Zagloel, 2019). The scope of L&G is not biased with a single application area; instead, it covers multiple areas which involve various processes (from a commercial firm like container terminals to an agricultural firm), revealing its adaptation to various sectors and business fields.

Table 2. Different application areas and their objectives.

Application Area	Focus	Methodology	Ref.
Aircrafts	Environmental benefits by identifying the joint effect of lean, green, and resilient	Importance-Performance Analysis (IPA) technique and Interpretive Structural Modelling (ISM) approach identifies the relationships' map between lean, green, and resilient supply chains.	(Ruiz-Benitez et al., 2017)
Radial tyre Industry	Performance assessment of L&G	Finding waste using Lean principles and assessing the entire system using System Dynamics model to determine the factors that contribute to overall Lean and Green performance	(Gupta et al., 2018)
Foundry	Change in technology leads to L&G goals	Attaining green production by technological innovations initiated by Lean production	(Saetta and Caldarelli, 2020)
Small and medium-sized farms	Lean training and Lean tool to attain L&G goals	Using Lean training and Lean tool, Lean tool - Value stream mapping is used to increase production, profit, and environmental sustainability.	(Barth and Melin, 2018)
Container terminals	To discover the determinants of green performance using Lean management	Lean-based data collection. Structural equation modelling approach was employed to examine the relationships among lean management, green operations, and green behavior using the data	(Kuo and Lin, 2020)
Automotive Industry	Performance assessment of L&G	Professional institution frameworks are used as a base to regulate the conceptual framework to evaluate the performance.	(Duarte and Cruz Machado, 2017b)
Transport & Logistics	Implement L&G using a customized STVSM	Lean tool VSM – value stream mapping is customized to STVSM – sustainable value stream mapping to attain L&G goals.	(Garza-Reyes et al., 2016)
Manufacturing companies	Assessment of sustainability using Lean cleaner production benchmarking	Combining Lean manufacturing and Cleaner production to propose LCPB – Lean green production benchmarking	(Ramos et al., 2018)

Though L&G goals are similar, there is no standardized method to operate the approach (Duarte and Cruz Machado, 2017b). The focus of this presented literature is majorly categorized into two types: "Assessment based implementation" (Duarte and Cruz Machado, 2017b; Gupta et al., 2018; Kuo and Lin, 2020; Ramos et al., 2018; Ruiz-Benitez et al., 2017) and "Direct Implementation" (Barth and Melin, 2018; Garza-Reyes et al., 2016; Saetta and Caldarelli, 2020). Assessment-based implementation – is performed with a formal approach where authors start to measure the current level of L&G implementation in their particular area, and the results obtained through this assessment are then used to improve the operation to get aligned with the L&G goals. In direct implementation – a Lean/green tool (Barth and Melin, 2018) or a customized tool (Garza-Reyes et al., 2016) is used to initiate L&G in their area directly. The importance of Data Acquisition remains common in both these methods. There is a varied number of deployment tools to handle Lean and Green operations in an industry. Nevertheless, data remains essential to handle the tools successfully.

Data collection is handled with the topmost priority in both implementation methods. The Source of data should be reliable, which eventually increases the effectiveness of the approach. Data are collected by interviewing experts and employees (Barth and Melin, 2018; Duarte and Cruz-Machado, 2017b; Kuo and Lin, 2020; Ruiz-Benitez et al., 2017) or by physically measuring the existing operations (Gupta et al., 2018; Garza-Reyes et al., 2016; Ramos et al., 2018; Saetta and Caldarelli, 2020). Performances are measured through the collected data, which explains the dependency of the approach for appropriate data collection. Additionally, the literature presented some essential vital details. In Barth and Melin (2018) the significance of Lean training to change

the culture of the working environment has been explained. The main takeaway from this article is, Lean is not a state/condition that can be achieved once, but it is a process that needs continuous monitoring and change of work culture to achieve goals. Gupta et al. (2018) explained the significance of Data processing and Data relations. For a complex production environment, the identification of factors required for L&G implementation is tedious. To overcome this challenge, researchers have also used a high-level mathematical tool like SD modelling (Gupta et al., 2018) to help the user improve the process by identifying the trade-offs between factors. The "ready to change" nature and a detailed data gathering/processing system are the two main primary requirements of the L&G approach.

From the analysis, two factors were explained: the synergic nature of L&G and the invaluable work of L&G in different application areas. Another finding is related to the importance of deployment methodologies and the need for fresh and reliable information to support (new) decision-making processes related to L&G for continuous improvement. The need for updated and comprehensive mapping of operational and resource waste (non-added values) is the base of supporting L&G frameworks (i.e., to support Lean principles application and Green inventory records). Data is the fundamental requirement to extract the maximum benefit from the L&G approach. A practical implementation calls for a design principle that has to be standardized to deploy and have a continuous improvement in L&G.

3. Systematic Outlook of L&G - Drivers and Design Principles

By comparing different authors' proposals, it was evident that the implementation of L&G can be done through different approaches, but the main goals are shared. The lack of a complete and uniform approach also reveals the flexible and holistic characteristic of L&G. Nevertheless, the existence of a standardized way to experience the multi-dimensional gains of L&G would contribute to aligning the present and future approached with the fundamental requirements of L&G: one can name it the Design Principles of L&G. Identification of the drivers and procedure to operate them would also lead to an effective design principle implementation. The five proposed Design Principles are defined and explain in the following sub-sections and were derived from the Lean Principles and the revisions of the multiples publication regarding L&G referred to in sections 2 and 3.

3.1 Specifying L&G Value

Specifying the value of the end customer based on economic, operational, and environmental aspects is the primary L&G design principle. Specifying customer-based L&G value at the early stage helps identify the internal factors that simultaneously increase profitability and environmental performance. Most authors (section 2.2) handled L&G implementation with a "problem-driven" strategy by determining the internal problem occurring factors. This problem should be "customer-driven," assuring a higher impact in the organization to satisfy this design principle. To determine the customer-driven process improvement pathway, human expertise and operational data should also be introduced into the L&G system (Leong et al., 2020). Comprehensive and structured data collection is crucial to enhance the information system regarding customer perceived performance and demand profile (Leong et al., 2019; Sony, 2018).

Similarly, to achieve customer L&G value, the relevant data should be sorted out. As the value is specified, data collection and analysis can be performed in a focused manner. Data gathering helps the user to handle the process comprehensively from every dimension. On the other hand, inappropriate data collection leads to a lack or overload of measurements and ineffective metrics,

(Kuo and Lin, 2020; Ruiz-Benitez et al., 2017; Siegel et al., 2019). Therefore, it is possible to conclude that data availability and L&G specific data analytics are crucial drivers to support the Specifying L&G Value design principle.

3.2 Identifying L&G Value Stream

The second design principle is to identify every step and action that consumes unnecessary time and resources (material, energy, consumables, etc.) and causes harmful emissions and/or wastes that cannot be further reused or recycled. The wastes are the ones present in Table 1. The Added Value (AV) activities are identified from applying the first principle – the ones the customer is willing to pay for. The identification of AV and non-Added Value (nAV) activities is crucial to the implementation of this principle, where the Lean tool Value Stream Mapping (VSM) can be used or other L&G specific mapping tools like STVSM (Garza-Reyes et al., 2016). However, mapping resources, emissions, and hazardous wastes value streams together with the Lean wastes stream requires a significant amount of data acquisition and processing, meaning that the traditional pen & paper approach of Lean to build VSM would be limited (Ejsmont et al., 2020; Willsky et al., 2007). So, dedicated data acquisition and data analysis are required to implement this principle.

Identifying the value stream also helps to reduce the resistance to change to improve L&G performance. Merging the AV and nAV stream of operational and green performance makes the company easily measure and prioritize factors that simultaneously increase operational excellence and environmental performance. In addition, the L&G value stream analysis will contribute to overcoming the general defensive attitude of managers against environmental and economic trade-offs (Galeazzo et al., 2014). To quantify the impact of every action that consumes unnecessary time and resources (material, energy, consumables, etc.) and causes harmful emissions and/or wastes, there is the need for performance indicators allowing the L&G approach to understanding what needs to be done to improve the performance.

3.3 Creating L&G Flow

Knowing the value stream makes the possibility to implement the third L&G design principle, consisting of creating an AV process flow that avoids waste, mitigates emissions and non-valuable scrap. The process steps should consist in a sequence allowing the item/product to flow smoothly towards the customer. Changes in traditional operations may entail certain precautions (Saetta and Caldarelli, 2020) therefore, a thorough verification is required before changing. Pilot testing can be done in this phase, e.g., small-scale test casts using both organic and inorganic binders are made to measure the emissions of the casting processes (Saetta and Caldarelli, 2020). As in the second design principle, results must be visible and communicable inside the organization and with customers, so performance indicators are crucial. Additionally, a performance indicator identifies the challenges and the impact of the approach, and it also helps the user reassess the data if required (Gupta et al., 2018; Saetta and Caldarelli, 2020). The use of reliable data is also a critical requirement to support the updated assessment of the impacts and clear identification of the areas or processes requiring more attention.

3.4 Creating an L&G Pull System

As industrial operations are dynamic, they require a system that can easily adapt to the change. Though the latter design principle creates L&G flow based on the customer value, users' expectations and requirements towards environment performance change today. Creating an L&G flow will help the user at the initial stage of L&G implementation, but to maintain the flow and continuous improvement, a system that can handle dynamic changes should be incorporated

(Ejsmont et al., 2020). To overcome this challenge, the fourth L&G design principle shows its relevance: to design a system where customers pull the production, where the product/item produced is precisely what the customer needs when the customer needs, and in what quantity the customer need. This pull system with an integrated L&G approach created a flow made mainly by AV activities and adapted to dynamic requirements from the customers, minimizing wastes by producing what and when is asked. The performance assessment of this system requires permanent data acquisition and analysis to satisfy both manufacturer and customer to see the results of the actions and decisions and identify corrective and pro-active actions. The L&G approach impact can be fully understood and seen when this design principle is implemented.

3.5 Pursuing Perfection

L&G approach is reciprocal and has an excellent scope for continuously enhancing the results (Dhingra et al., 2014; Wiengarten et al., 2013). In fact, the fifth L&G design principle coincides with the fifth Lean design principle, meaning the implementation of a continuous improvement culture, in this case with relevant information about operational and environmental-related performances. So, this design principle helps improve information transparency to enable managers and teams to eliminate other wastes and continuously identify improvements regarding economic, operational, and environmental aspects.

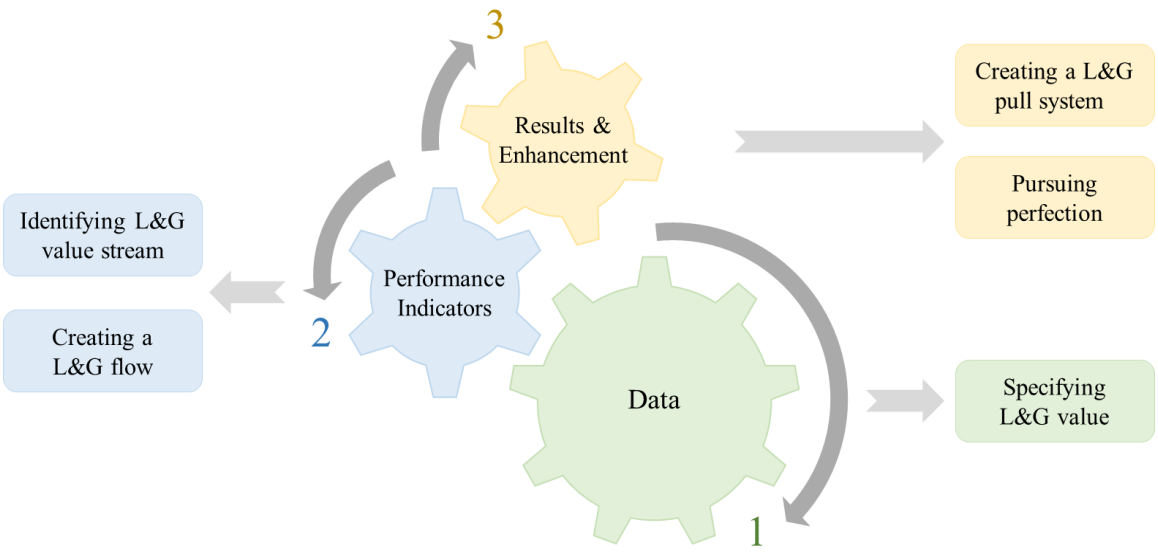

Figure 1. Three drivers and the design principles of L&G.

From the explanation of the proposed design principles, three drivers can be identified. First, the need for data acquisition and data processing dedicated explicitly to supporting L&G assessment, as pointed out (Duarte and Cruz Machado, 2017a; Kuo and Lin, 2020; Leong et al., 2019; Ramos et al., 2018; Siegel et al., 2019; Sony, 2018) the need for performance indicators to monitor the performance of the L&G system, as referred Garza-Reyes et al. (2016), Gupta et al. (2018), Kuo and Lin (2020), Ruiz-Benitez et al. (2017), Saetta and Caldarelli (2020) and a culture and tools for results assessment and their enhancement (Gupta et al., 2018; Kuo and Lin, 2020; Ramos et al., 2018; Saetta and Caldarelli, 2020).

The handling of the process is more crucial than its definition. The approach of L&G evolves around these three drivers; henceforth, a clear understanding and actions are required to implement L&G successfully. Lack of knowledge or data in either one of the drivers will lead to an immutable condition. Reverification of results is done in the last driver, which will be the basis of the further work enhancements. The integration of design principles with the identified drivers is illustrated in Figure 1.

3.6 Limitations and Findings of L&G

L&G has its own limitation and trade-offs when it comes to practical world (Abualfaraa et al., 2020; Campos and Vazquez-Brust, 2016; Ejsmont et al., 2020; Luthra et al., 2020). The continued development in research in L&G aims to address these limitations and trade-offs and represents an evolving pattern for future studies. Several interesting findings are also discussed by authors suggesting paths to overcome the challenges of L&G.

According to Mollenkopf et al. (2010), Lean practices are more complicated to implement and sustain due to high complexities in the growing supply chains. Additionally, they point out that integrating both approaches may lead to certain limitations: Firms that have implemented lean practices do not strategically pursue environmental advantages, and they often fail to identify environmental threats. Green activities, it is widely believed, do not pay off and "erode competitiveness." Green projects are seen as time-intensive and challenging to set up, even though lean processes are often followed for cost savings. They also confirm that the L&G approach requires a change of structure. The findings of Galeazzo et al. (2014) refer to Lean programs encourage only requested volumes to flow through the supply chain (and not the safety inventory). A decreased quantity of inventory can reduce the negative environmental effects of the supply chain. Eventually, Lean techniques using just-in-time (JIT) delivery of small lot sizes can entail additional transport, packing, and handling; these can clash with a Green approach (Mollenkopf et al., 2010). According to Campos and Vazquez-Brust (2016), this limitation can be rectified by "Hybrid sourcing" where the company allocates a space "in house" inside the factory where long-term suppliers will supply the contracted components, with the focal company supplying electricity, water, and a room for the suppliers' equipment to be installed (Campos and Vazquez-Brust, 2016). By doing so, a remarkable positive impact on L&G has been identified.

Nevertheless, this contradiction requires a potential solution for small-scale companies that cannot afford to share "inhouse space." This trade-off can also be reduced by technological advancements where electric vehicles can be used to compromise. Bashkite and Karaulova (2012) proposed creating an integration model by implementing the contradiction-solving matrix between L&G production systems (Bashkite and Karaulova, 2012).

The future of L&G requires a diverse nature and a helpful technology that may assist a firm in adapting to quick changes (Mollenkopf et al., 2010; Wiengarten et al., 2013) stated that the decline of the global economy has made companies invest more in innovative projects that entail sustainability. So that firms can be able to recognize trade-offs or establish strategies that reduce adverse outcomes by understanding this dispute. Additionally, identifying the required technology (including data acquisition and dedicated analysis) increases the "Know-How" of the user while handling L&G operations.

4. L&G and I4.0

To move forward with L&G, it is vital to consider the limitations, current trends, and technological advancements. The world moves towards autonomous systems, where continuous exchange of data and information will be embedded in all components, products, devices, and systems. As referred by John Adair: "*communication is essentially the ability of one person to make contact with another and make himself or herself understood*," so in the context of L&G, communication can be referred to as exchanging of data and information. Therefore, the incorporation of L&G in industries using the I4.0 context will be crucial to overcoming the current challenges of L&G (Kolberg and Zühlke, 2015; Sony, 2018; Taghavi and Beauregard, 2020; Valamede and Akkari, 2020).

4.1 L&G is Better with I4.0

As the world moves towards a sustainable process chain derived from Lean principles and Green approaches, flexible information systems will be crucial (Jastia and Kodali, 2015). High technological development will help to achieve an enhanced communication system (Wang et al., 2016). In order to make processes and goods more environmentally friendly, an L&G supply chain needs reliable and smart data processing technologies allowing it to be effective and efficient as referred by several authors (Jastia and Kodali, 2015; Mollenkopf et al., 2010; Roblek et al., 2016; Wang et al., 2016). Several authors worked on empirical researches linking either Lean or Green with I4.0 (Ejsmont et al., 2020; Felsberger and Reiner, 2020; Luthra et al., 2020; Taghavi and Beauregard, 2020; Willsky et al., 2007). Nevertheless, Duarte and Cruz-Machado (2017a) noted that the methodology of L&G management would evolve to respond to the emerging developments expected by I4.0. Lean application and green approaches will evolve in various ways, but they can still converge on the I4.0 approach. One of those cases regards the higher knowledge of customer-specific wishes and demand over time (Duarte et al., 2020), other regards high levels of information are shared about lean and green supply chains (Mollenkopf et al., 2010). Both cases benefit Lean objectives, and Green targets and are just two among many. The implementation of I4.0 is still in progress; that is why the L&G approach in I4.0 is essential to understand. For example, the implementation of smart factory technologies and connectivity methods facilitates recognizing wastes and harmful factors that affect the environment (Duarte and Cruz-Machado, 2017a).

Another example is the impact of higher accuracy and reliability of the I4.0 based planning and autonomous technologies, contributing to more efficient and effective systems (Stock and Seliger, 2016). These changes will allow a reduction of errors and better management of wastes (or its avoidance), including non-value added activities, but require a redesign of the whole process chain (Dhingra et al., 2014). In addition, the boundary of L&G is not only within the parent industry, but instead, its characteristics extend up to the collaboration with suppliers and customers (Duarte and Cruz-Machado, 2017a). In an I4.0 context, communication with suppliers, producers, and customers by enhanced software and hardware systems will synchronize the data in the whole process chain, where information sharing will be much more frequent than in the past. So, as referred by (Sanders et al., 2016), the limitations in current practices can be addressed by integrated information and communication systems to increase efficiency and reduce waste. In line with the strong positive influence of I4.0 in the increase of the sustainable value of the industry, (Stock and Seliger, 2016) showed how I4.0 could support the permanent monitoring and improvement of the overall life cycle phase (end-to-end solution): (i) the procurement of raw materials, (ii) development, (iii) transport (between all phases), (iv) the process of use and operation, and (v) the phase of end-of-life (containing the re-use, remanufacturing, recycling, recovery, and disposal). The contribution of suppliers and customers will play a vital role in I4.0 (Roblek et al., 2016) through new technological systems, resulting in a better understanding of customer demand.

Customer demand in this context refers to Lean - needs – who's main motive is to lower lead time and price without compromising the quality; Green - needs – who are more environmentally concerned. The systems of I4.0 would transform the whole supply chain and the product life-cycle management - it changes the view of manufacturers and suppliers with more clarity and flexibility and helps streamline the process (Roblek et al., 2016).

Hence, besides the proven convergence of Lean tools and Green practices, there is also the convergence of the I4.0 impacts on operational waste reduction and resource efficiency increasing. The explained advantages make it evident that incorporating I4.0 with the L&G design principle results in a reliable Data Acquisition and Data processing System to determine the optimal way of L&G and also enhances the continuous improvement by monitoring the dynamic changes.

4.2 L&G on Industry 4.0 Context

From previous sections, it is evident to several authors the higher potential of L&G application if under an I4.0 context. So, an effective L&G design principles implementation requires or at least is highly enhanced by an I4.0 context. This streamlining helps L&G to overcome their most significant challenges and to have a robust stand for them. Nevertheless, the understanding by researchers and professionals of the relationship between the L&G design principles and I4.0 components and systems would move organizations also closer to the I4.0 approach resulting in a win-win situation.

Smart Data Acquisition System

Data gathering is the crucial part of satisfying the customer value and initiating the implementation of L&G principles. It is possible to understand customer demands and quickly share demand data through a diverse supply chain using new information and communication technology (GTAI, 2014). I4.0 context allows a comprehensive definition of the path to customer value through digital technology such as the internet of things, cloud computing, cloud-based services, big data analytics, artificial intelligence, and/or virtual reality (Duarte et al., 2020). The path to understanding L&G customer value can be done under an I4.0 context by gathering data and information from various sources and then applying analytics to streamline production processes (Felsberger and Reiner, 2020). This context allows to collect data directly from company/product-related value stream sources and process and forward it simultaneously and organize the stakeholders within the network (Felsberger and Reiner, 2020). Modern technologies like Big data, Data analytics, etc. enables businesses to generate new growth markets and completely new types of businesses by combining and analyzing market data (Duarte et al., 2020). Big data would make it easier to achieve an L&G structure than conventional methods (Ejsmont et al., 2020). The process mapping and operational and environmental-related wastes are streamlined, and problem-solving is facilitated by Big Data and Data Analytics (Ejsmont et al., 2020). In other words, and simplifying, a large amount of structured and unstructured data relevant to L&G can be collected and processed smartly.

Smart Performance Indicators

Identification of the L&G value stream consists of physical and cyber processes, which data, information, and output have to be analyzed to determine the L&G system performance. According to GTAI (2014), the Industry 4.0 model is being ushered in by the convergence of the technological and physical worlds by cyber-physical systems (CPS) and the subsequent integration of technology and business processes. As mentioned by Duarte and Cruz-Machado (2017a), Industry 4.0 will deliver a holistic smart environment where machines, products, processes, and employees will be interconnected. In this type of scenario (called Smart Environment (Duarte and Cruz-Machado,

2017a; Valamede and Akkari, 2020)), instead of being told what to do, operators will be able to optimize themselves by intelligent and informed decision-making. The specified customer value will enter into the system as an input, and the process segregates the value-added and non-value added activities from the customer point of view and delivers the best L&G flow for the company. For a company's efficiency and competition, accuracy and traceability of product and process knowledge based on available data are extremely valuable (Ejsmont et al., 2020). In this way and context, smart performance indicators allow the creation and the permanent improvement of an L&G flow to avoid waste, mitigate emissions, and non-valuable scrap, flowing the item/product smoothly towards the customer.

Smart Results and Enhancements

I4.0 allows customers to incorporate different features and parts to tailor their products rather than choose from a pre-set feature spectrum set by the vendor (GTAI, 2014). In parallel, current manufacturing industries aim to keep a Pull System in their production process, which will help them stay more focused on economic growth (Leong et al., 2019). The biggest challenge of the Pull System is the varying customer demand, affecting L&G system performance, so this system must be flexible and agile to adapt fast and accurately. Additionally, customized product delivery is the key factor for industries to remain competitive in the market, requiring a reliable communication system to sustain the L&G system within performance limits. Under an I4.0 context, the company can benefit from autonomous automation and processes, data-driven MES with smart devices, and

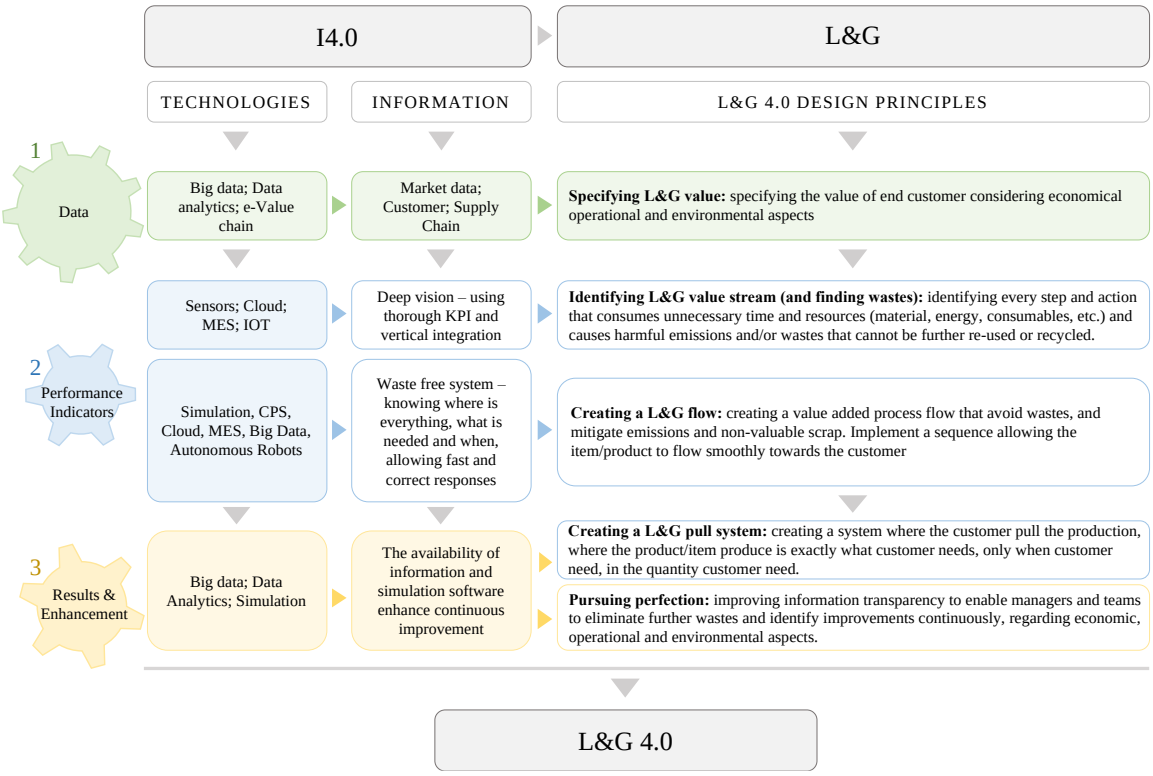

Figure 2. Relation of drivers and design principles of L&G with I4.0 technologies and processes.

cloud computing to apply intelligent algorithms to support decentralized and agile decisions, as well as from simulation and virtual reality technologies (feed with digital twins and real-time data) to continuous understand the impact of alternative solutions. So, pursuing perfection will be facilitated involving both operational and environmental performance to sustain and continuously improve a Pull System that requests, consumes, and produces only what the customer needs, in quantity the customer needs, and when the customer needs (by knowing sooner and by predicting those needs accurately).

Insights about L&G in the I4.0 context are represented in Figure 2. In this way, a well-formulated L&G 4.0 system can be achieved. On the whole, linking L&G with I4.0 overcomes the challenges of both the concepts and explicitly itself with an emerging concept called L&G 4.0.

5. Research Implications and Conclusions

The concept of L&G focuses simultaneously on operational excellence, economic benefits, and environmental well-being. It helps the industry to reduce environmental impacts by using Lean principles and Green approaches also resulting in personal economic benefits. Although L&G was introduced decades ago, it faces a huge barrier to set its strong position amongst industrialists. This barrier is nothing but the "ready-to-change" nature: L&G requires a new process chain that differs entirely from the traditional way. I4.0 is a way to overcome this obstacle: the next industrial revolution enables a myriad of data types and facilitates a faster communication system. Through an I4.0 environment, rapid process changes can be made with a tightly packed information system.

The goals of L&G are within the scope of I4.0: L&G promotes higher time effectiveness and resource efficiency. Along with that, I4.0 enhance L&G: one weak point of L&G is its need for a high level of data confidence and availability. I4.0 addresses both problems, by introducing modern technologies with intensified information systems. This integrated approach leads to L&G 4.0 where Lean principles and Green approaches go beyond boundaries. It changes the way of interaction between the producer and the consumer. This upgraded system assists the user to enlarge their "ready-to-change" nature and shifts the traditional work culture, moving towards continuous improvement.

This work depicts why an L&G system performs better in I4.0 contexts and what I4.0 components are relevant for L&G systems implementation. It proposes design principles to exploit L&G in I4.0 context. It should be followed now by the tuning and validation of the proposed principles through implementation cases and its assessment.

The diverse nature of the L&G approach makes it possible to handle the approach in multiple ways but a standard way of implementation helps the industrialist to achieve maximum benefits. Thus, the work proposes a framework for L&G implementation based on the current literature, so it needs a practical experiment to proceed further in the development. The contribution of this paper lies in three categories, one to identify a way to standardize the L&G approach based on L&G Design Priciples and this identification resulted in the second category: the characterization of the drivers that assist the proposed L&G framework; as the third category, the paper also explains the acceleration of the L&G drivers while working in the I4.0 context.

Conflicts of Interest
The authors declare no conflict of interest.

Acknowledgments
This work was supported by: FCT, through IDMEC, under LAETA, project UIDB/50022/2020; the European Regional Development Fund (FEDER) through a grant of the Operational Programme for Competitivity and Internationalization of Portugal 2020 Partnership Agreement (PRODUTECH4S&C, POCI-01-0247-FEDER-046102) and (PRODUTECHSIF, POCI-01-0247-FEDER-024541). The authors would like to thank the Management Accounting and Control Chair, Faculty of Economics and Business Administration, Chemnitz University of Technology.

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