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Review

A Systematic Literature Review for Better Understanding of Lean Driven Sustainability

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Abstract: Global trends and factors, such as the increased level of globalization, climate change, resource scarcity, and awareness of social and environmental responsibilities, as well as fiercer competition and lower profit margins in all industries, force organizations to act to retain, regain, or sustain their competitive advantages for long-term survival. These trends and factors are historically known to bring about innovations that drive the evolution of industries. Sustainability is considered to be such an innovation to achieve fiscally sound, environmentally conscious, and socially progressive organizations and supply chains. This study reviewed 477 past articles published in five major databases from 1990 to 2018. The purpose of the study was to assess the current state-of-the art in the subject of lean-driven sustainability. Based on the exhaustive descriptive and contextual analysis, synergies, divergences, and the extent of two-way permeability of lean and sustainability concepts from the perspective of intra- and inter-organizational operations were identified along with future research opportunities. Fundamental strengths and weaknesses of both concepts, existing strong synergies and untapped potential, along with their key contributors, the potential-use cases of lean tools to derive sustainable solutions are highlighted in this review.

Keywords: lean philosophy; sustainability; lean supply chain management; triple bottom line

1. Introduction

This study reviewed articles published to address issues occurring in the intersection zone of two impact streams and one target stream, namely, lean manufacturing (LM), lean supply chain management (LSCM), and sustainability (environmental, economic and social). A correlation matrix identifying the research focus of this project is given in Figure 1. The relationship between LM and LSCM has been widely studied by researchers in the past. Therefore, that part of the correlation matrix was excluded from the study. The primary focus area of this review was defined to be the intersection zone of all three concepts to observe joint influence of impact streams on target stream, whereas relationships between LM-sustainability and LSCM-sustainability were set to be secondary focus areas of the study to deepen definitive outcomes of the review process. Although numerous metrics, frameworks, and methodologies were developed to separately measure different aspects of sustainability and lean performance in the context of a supply chain, studies exploring the feasibility of achieving true sustainability through lean philosophy are scarce. This review study was designed to summarize evolution of both lean and sustainability concepts, as well as to determine current state-of-the-art within the context of lean-driven sustainability with a purpose of discovering the extent of untapped potential in the research streams. Moreover, there is yet to be an innovative, versatile, scalable, and practical tool that could enable managers, engineers, and scientists to track, evaluate, and further improve true sustainability performance of organizations and supply chains. Outcomes of this study are expected to contribute development efforts of such a tool by providing comprehensive guidelines on lean and sustainability relationships.

Figure 1. Correlation matrix illustrating the relationships among target research streams.

Global factors, such as the increased level of globalization, climate change, resource scarcity, and increased awareness of stakeholders on social and environmental responsibility, as well as fiercer competition and lower profit margins in all industries, force companies to act to retain, regain, or sustain their competitive advantages for long-term survival. Global factors trigger the birth of new innovations and those innovations determine the direction of industry evolution. Sustainability is the leading concept of the sixth, and latest, innovation wave [1]. As of today, most Fortune 500 companies have Chief Sustainability Officers (CSOs) [2]. Within the last two decades, corporations and, thus, supply chains, have undergone a major change to evolve into more sustainable versions of themselves both to conform to regulations and to meet the expectations of stakeholders, while aiming to protect their profitability undamaged against the cost of compliance [3–7]. The urgency to elevate the environmental and social pillars of the triple bottom line (TBL) along with the economic pillar was mainly due to the fact that companies started to feel more intense pressure from stakeholders than ever before [8–11]. Conditions of long-term organizational survival have shifted to include environmental and social performance in addition to financial excellence [12]. As a function of this pressure, corporations faced the risk of losing competitive advantage. Therefore, they sought compliance with widely-recognized voluntary and enforced regulations, guidelines, and standards developed by national and global organizations such as:

- International Standards Organization (ISO)
    - ISO 14000 series—Environmental Protection Oriented
    - ISO 9000 series—Quality Oriented
    - ISO 45000 series—Health and Safety Oriented
    - ISO 27000 series—Information Security Oriented
- Occupational Safety and Health Administration (OSHA)
    - Occupational Safety & Health Act of 1970—Safety and Health Oriented
- British Standards Institution (BSI)
    - OHSAS 18000 series—Health and Safety Oriented
- US Environment Protection Agency (EPA)

    - Lean and Environment Toolkit—Environment Protection Oriented
    - Lean, Energy and Climate Toolkit—Environment Protection and Resource Preservation Oriented
- European Union (EU) Standards
    - Eco-Management and Audit Scheme (EMAS)—Environment Protection Oriented
    - Health and Safety at Work Act
- Global Reporting Initiative (GRI)
    - GRI Universal and Topic-Specific Standard Series—TBL Oriented

However, in most cases, the scope of integration has not reached satisfactory levels. This lagging passion and dedication of companies is caused by the lack of a holistic sustainability perspective and understanding of inter-dependency of economic, environmental, and social corporate excellence [13–15]. Such an incomplete approach often prevents companies from foreseeing and realizing potential gains presented by sustainability or sustainable development initiatives. True sustainability would simultaneously contribute to economic prosperity of organizations, as well as to natural resource preservation, environmental protection, and the well-being of people and other living things [16]. Moreover, any kind of bias towards any of the three sustainability pillars would be prone to failure since it would not be any different from a trivet that has legs with unequal lengths. Therefore, both professionals and academics should acknowledge that all three pillars of sustainability must be simultaneously handled to achieve meaningful results. According to the National Council for Advanced Manufacturing (NACFAM), from the perspective of manufacturing sectors, the main purpose of sustainability is to ensure that preferred manufacturing practices and processes that lead to maximization of profit also serve the social and environmental responsibilities [17]. Sustainability and Sustainable Development have been evident notions since the 1970s [18]. In 1987, the World Commission on Environment and Development defined sustainability as:

> *"The Development that meets the needs of the present without compromising the ability of future generations to meet their own needs."* [19]

In 1969, U.S. Environmental Protection Agency (EPA) published its own definition of sustainability:

> *"Sustainability creates and maintains the conditions under which humans and nature can exist in productive harmony that permits fulfilling the social, economic and other requirements of present and future generations."* [20]

From the very first day of its introduction, sustainability has been prone to misperceptions. It was evaluated and measured within the scope of either economic or environmental sustainability alone, even though it consists of three pillars, namely environmental, economic, and social [21]. In many sources, the term sustainability was used to define environmental focus and it was occasionally substituted with the notion of "green". However, within the scope of this study, the term "sustainability" is used to comprehend all three pillars.

In 1994, John Elkington came up with new framework named the "triple bottom line", which involves all three pillars of the sustainability concept [22,23]. In some resources, TBL also referred to as "Three P's" or "3P's", which stands for people, planet, and profits [23,24]. Within this study, TBL is used to refer to the triple bottom line, which was designed to serve as a better tool to measure sustainability and sustainable performance. It has also been considered to be an avid aid to create a greater business value. In a short time period, the TBL concept has become quite popular across corporate, non-profit, and government organizations due to its holistic perspective of sustainability. Although the application principles of TBL are the same across any organization, deployment of a sustainable development plan, assessment of outcomes, and perceived importance of each pillar vary from one organization to another. That is why sustainability or TBL is coupled with other management approaches rather than handled as a standalone framework. It needs to be incorporated with other management systems and business strategies to ensure economic, environmental, and social sustainability excellence. Sustainability aims to tackle epidemic issues, such as environmental waste, economic inefficiencies, and potential health and safety threats to humans and living things that could occur as a function of the activities of product and service systems (PSSs). In other words, it tries to ensure that organizations can deliver the desired products and services with effective and efficient resource consumption, while avoiding potential harm to people and environment, as well as other living things.

As of today, the best tool available to academics and professionals, which could aid with "doing more with less", is lean management or lean philosophy. Lean could conveniently accommodate the requirements of TBL as a function of its contingent and comprehensive nature. The harmony of lean with contingency theory provides required versatility to adjust for company/sector-specific drivers, factors, and conditions within each business ecosystem, whereas comprehensiveness ensures that every nook and cranny of organizations or supply chains is addressed in terms of waste elimination.

The roots of lean manufacturing date to the Toyota production system (TPS) developed by Taiichi Ohno during the 1980s in one of the company's manufacturing plants located in Japan. TPS was a product of forced innovative thinking to find a solution to resource scarcity and financial turmoil [25]. It started to become quite popular in the Western world at the beginning of 1990s, after James Womack published his breakthrough book titled "The Machine That Changed the World [26]." Since then, "lean philosophy" has been proven to be a useful and popular approach available to any organization that seeks a way to improve efficiency, effectiveness, and, thus, profitability in any sector, including the service industry. During its evolution, the scope of lean has been widened and it has been given many titles. It was known as "TPS" during the 1970s, it was referred to as "lean manufacturing" towards end of 1980s. In the last decade of the 20th century, it was named "lean thinking or lean philosophy" and, most recently, the notion of "lean management" has been used to emphasize its comprehensive and extensive nature [27–31].

Although each phase of lean evolution delivered a successor with a more complex structure, each stage preserved the fundamentals of predecessors and built upon them. As of today, it is not just a production system. Lean management is a novel management approach which was proven to be effective for performance and human resources management, as well as continuous improvement [27,30,31]. Many companies have already adopted lean, while others are still in a discovery phase. Some of companies that adopted lean, achieved satisfactory results, while others experienced failures or could not sustain the improvements achieved due to the lack of understanding of lean management philosophy. Lean is an evolving methodology which needs to be integrated dynamically, depending on the conditions of a certain scenario, according to contingent theory [32]. Lean aims to achieve the highest possible profitability, quality and customer service level at the lowest possible cost, in a timely manner, through continuous elimination of waste from the perspective of value-added and non-value-added activities [30]. Eight forms of waste, namely, overproduction, inventory, transportation, waiting, defects, over processing, motion, and behavioral waste, were defined within the context of lean management [29,33]. Some scientists argue that the lean management philosophy was designed to perform well where market conditions favor low product variety, predictable demand and supply certainty, while others discuss that lean's versatile nature could also make it useful for market conditions where demand is much more unpredictable and product variety is vast [34–36]. In such environments, lean methodologies can be modified and averted into more agile and resilient systems to accommodate needs of certain conditions [35,37–40].

Due to the inevitable impact of drivers such as expanded business networks, lowered trade barriers, new technologies and evolving customer needs and demand, a need to shift the lean focus to another level has emerged [41–45]. Towards the mid-1980s, supply chains and supply chain management (SCM) had started to become a formal research focus of many researchers along with industry professionals [46]. The rate of publications on SCM rapidly accelerated in the 1990s due to increased interest in the topic [47]. Many definitions and frameworks were delivered by scientists [48]. Both definitions and frameworks were developed into more comprehensive versions along with the supply chains themselves and expanded to include material and information flow, networks of relationships, value-added, creating efficiencies and customer satisfaction, as well as partners and some other internal components [46]. One of the popular definitions of SCM is the one published by the Council of Supply Chain Management (CSCMP) in 2008. CSCMP defines the SCM as:

> *"Encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies."* [49]

New market conditions turned "clash of companies" into "clash of supply chains" since it has become impossible to achieve desired outcomes without collaboration and collective operation of business partners [50]. Some companies preferred to stick to traditional approach and continued to see the picture from the perspective of "clash of companies" [51]. However, later research has proven it to be the common reason of failure to sustain competitive advantage and survive in the long run [27,33,52]. Therefore, the scope of lean management practices has been widened to cover all elements of a supply chain instead of covering all the functions within a single organization. Vonderembse et al. [53] defined the "lean supply chain" as the "*one that employs continuous improvement efforts that focus on elimination of waste and non-value-added activities along the chain*". This approach evaluated the situation from the point of view of supply chain surplus and relative value for the customer rather than the absolute value approach [9,35]. Likewise, from perspective of sustainability, complying with environmental regulations, fulfilling societal duties, sustaining profitability, and enhancing competitive advantages have become both infeasible and impossible without achieving a certain level of collaboration and transparency among supply chain members [54]. Thus, both lean and sustainability concepts have been re-evaluated from a broader perspective to adjust for evolved market conditions. Recently, due to the increased level of social responsibility and environmental awareness, lean started to be linked with sustainability more frequently. Some researchers have indicated that link of lean with sustainability is its new driver which dictates future direction of the concept [55]. This set the direction towards which all companies should work to ensure survival in the ever-evolving business environment. Lean is directly connected to the economic sustainability performance of a firm, while its correlation with environmental and social sustainability performance is more indirect. Moreover, many studies confirm the positive impact of lean initiatives on firms' and supply chains' sustainability performance [56–58]. All these correlations and differences were re-visited while discussing the outcomes of the systematic literature review. Global trends that have direct or indirect influence on the evolution of the supply chain management discipline are dictated by six main drivers, namely globalization, information technology, new technologies and innovations, laws, regulations and standards, increased public awareness, and, finally, evolving needs, habits and expectations of people [19,42,44,59,60]. Current global trends in supply chain management are given in Table 1.

Table 1. Current trends in the field of supply chain management.

Current Trends in Supply Chain Management	References
Green Inbound and Outbound Logistics Environmentally Conscious Design and Manufacturing Sustainable Products or Services Multi-Company Collaborations and More Transparent Information Sharing Increased Level of Outsourcing Increased level of Automation (Industry 4.0—Smart Concepts) Delivery Innovations "Near-Shore" Manufacturing LCA or Closed-Loop SCM Based Management Totally Customer Centric Focus Due to Less Brand Loyalty and Increased Price Sensitivity Further Engagement with Social Media for Marketing and PR Purposes Standardized Certification of SC Professionals Prominence of SCM at the C-Level Integration of IoT and Blockchain Technology with SCM	[33,41,42,44,59,61–76]

Consequently, increasing the ratio of value added to non-value-added activities through continuous improvement while minimizing (if not eliminating) harmful impacts of operational activities on the environment, natural resources, and all living things through waste elimination and responsible resource consumption have become the primary focus for gaining competitive advantages over other supply chains. In other words, it is essential for all corporations to develop a complete understanding of a truly sustainable operations and SCM activities. Common characteristics of companies with sustainable supply chains when compared to others was reported to be the simultaneous employment of best practices in SCM [77,78]. The intrinsic value of integrated SCM practices, such as lean and sustainability, is not only related to definitive similarities or differences, but also to some external factors that are unique to each situation. Therefore, consideration of contingent theory is critical in the current state of operations and supply chain management. To overcome today's fiercer market conditions and lower profit margins, corporations started to acknowledge the importance of collaboration and communication on the path to leaner, greener, and more responsible supply chains that have the potential to generate increased economic, environmental, and social gains [79].

1.1. Problem Definition and Research Question Construction

Endless effort has been, and is being, spent to deepen the knowledge on the interaction of lean, supply chain management, and sustainability, since the focus of the competition shifted to a clash of supply chains from a clash of companies, and sustainable operations has become the new frontier due to changed market conditions and global trends. However, these efforts are often either missing one or more dimension of the TBL concept or are being abraded and deviated from the main purpose due to the complexity of the product and service systems. Moreover, even in the case of the successful development of a proper understanding of sustainability, some efforts and investments are being wasted since they fail to address corporate responsibilities from the perspective of a complete supply chain or "cradle to crave" approach, addressing both intra- and inter-organizational issues.

Underlying reasons associated with failed efforts to achieve truly sustainable operations can be summarized as:

- Focus on "Impact Reduction" instead of "Impact Elimination" + "Impact Regeneration" [80].
- Placing perspective of absolute profits above all other gains in an outdated approach [79].
- Hesitation to discover the new [80].
- Differences among sustainability perceptions of stakeholders [81,82].
- Focusing solely on macro or micro level sustainability initiatives and ignoring the other.
- Cost of compliance [10].
- Lack of sufficient understanding of contingent theory [83].

True sustainability could only be achieved through full transparency, which requires ultimate collaboration of stakeholders throughout a supply chain [84]. Although focusing solely on intra-organizational (within the walls) sustainability has potential to generate favorable outcomes, in the long-term, sustainable improvement will start to stagnate and inefficiencies will reoccur due to a lack of collaboration and transparency. Therefore, placing equal importance on achieving sustainability at functional unit, company and supply chain level is key for success [21]. Therefore, companies that seek ways to stay competitive, should also seek ways to increase their supply chain surplus by steering away from intra-organization focus and by engaging with inter-organizational perspective to leverage the competitiveness level of entire supply chain. Ultimate objective should be achieving global level inter-sectoral sustainability through highest possible transparency and collaboration, as shown in Figure 2. Genealogy of both lean and sustainability seem to be in accordance with requirements of ultimate objective given in Figure 2 [27,85]. However, the extent of wide-spread applicability of an integrated and holistic approach is not mature enough to generate the true value for organizations and supply chains. Therefore, a systematic literature review (SLR) covering studies that combine lean and sustainability was carried out to highlight future research directions, synergies, divergences, and two-way permeability of the two philosophies at micro and macro levels.

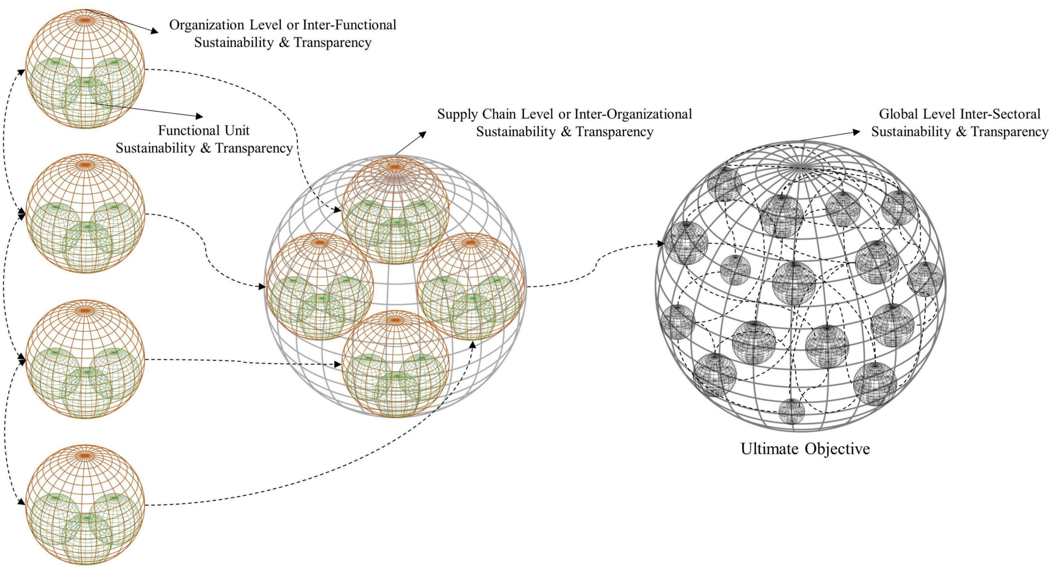

Figure 2. Schematic illustration of the proposed ultimate objective concept.

The objectives of the study can be stated as follows:

(1) To develop a comprehensive understanding of Lean Manufacturing, Lean Supply Chain Management and Sustainability interaction.
(2) To discover key elements that form "Truly Sustainable Operations"
(3) To clearly identify the future direction of research in the field of interest.
(4) To identify areas where Lean and Sustainability overlap and where they cannot be combined.
(5) To establish a foundation for a tool that can be applied to any industry to benchmark "Truly Sustainable Operations".

To achieve these objectives, research questions listed below were constructed and answers to those question were sought through an extensive and systematic literature review.

- *RQ_1: Lean manufacturing and lean supply chain management are mature research streams. However, their relationship with sustainability is relatively new. What is the current state of the literature in the intersection zone of two impact streams and the target stream?*

- *RQ$_2$: Are there any synergies and divergences between lean and sustainability concepts and to which extent do these concepts allow two-way permeability?*
- *RQ$_3$: Is there an untapped potential left in the field of lean driven sustainability. What kind of research gaps exist?*
- *RQ$_4$: To what extent past frameworks could assess and benchmark truly sustainable operations and SCMs?*

2. Systematic Literature Review (SLR) Methodology

A systematic literature review (SLR) methodology was followed to identify and evaluate relevant previous literature addressing inter-relationships among the three research streams. The main purpose of this literature review was to detect and discuss the research gaps and trends in the field of study by fully understanding inter-relationships between impact research streams and sustainability. Each research stream has its own dynamics and it becomes much more complex to deal with when all three are handled simultaneously. Therefore, having a certain level of understanding of dynamics and complexity of formation of relationships had vital importance in achieving desired outcomes.

A literature review is the keystone of any research project since it enables researchers to discover and detect the gaps in the field, as well as to establish a base for the hypothesis under investigation [78,86–88]. A literature review can be conducted in various ways. However, a well-established, systematic and methodical literature review would better serve its purpose to gain a more detailed knowledge on the current state-of-the-art. To ensure replicability, reliability, accuracy, and transparency of the literature review, a systematic literature review (SLR) approach with five phases has been employed for the purposes of this study [86,89]. This approach was altered and adopted from similar methods previously introduced by researchers [10,88,90–92]. The phases of the literature review and the research protocol are given in Table 2. The literature review process was carried out by following five consecutive steps, namely, (1) research question formulation; (2) creation of raw database; (3) refinement of raw database; (4) classification and qualitative/quantitative analyses; and (5) interpretation of de-coded data.

Table 2. Systematic literature review (SLR) phases adapted from Garza-Reyes (2015) [92].

SLR Phases	Objective of the Phase	Preferred Method	Tool	Divergent Mode
Research Question Formulation	Determination of Research Question(s) That Will Lead to Gap Detection	Trend and Opportunity Detection in the field of SCM.	N/A	The need for the literature review.
Creation of Raw Database		Use of 5 Major Online Libraries	Science Direct, Emerald Insight, Springer Link, Taylor&Francis, Wiley Online and Others including but not limited to Ebsco Host, Inderscience, Google Scholar and Purdue Libraries.	Impact and Target Stream Identification Correlation Matrix Construction
Refinement of Raw Database through Selection, Evaluation and Elimination Procedures	Picking, Evaluating and Filtering the raw database to form the final sample of articles	Definition of Time Period to Be Covered Definition of Inclusion/Exclusion Criteria Determination of Keywords	**1990 – February 2018** **Inclusion:** Peer- Reviewed Articles, Proceedings of Conferences containing keywords and addressing Lean and Sustainability (TBL) issues at the level of operations management and supply chain management. **Exclusion:** Books in general, book reviews, book chapters (with some exceptions), editorial articles, articles lacking clear definition of objectives, replication works, articles don't contain keywords. Thesis and Dissertations as well as articles only dealing with sustainability of lean implementation gains are also excluded. **Keywords:** Lean and/or green, Lean and/or environmental management, lean and/or sustainability or Triple Bottom Line, Lean Supply Chain Management and/or Sustainability or Green.	Source, Time Span, Keyword Definition Raw Database Creation Refinement of Raw Database to Final Database Meta Data and Contextual Analysis Focus Channeling Interpretation and Discussion of Outcomes
Qualitative and Quantitative Analysis	Grouping and Analyzing Articles to Visualize Data Distribution	Selection of Qualitative and Visual Analysis Methods De-Coding of Data Through Statistical Analysis	Graphical illustration of data distribution. Decoding through use of Mendeley Desktop. Decoding through use of Nvivo 11 Desktop. Quantitative and Statistical analyses through use of Minitab 17 and Microsoft Excel macros, spreadsheets and pivot tables.	Synergy and Difference Identification Gap Identification and Future Research Direction
Interpretation of De-coded Data	Interpretation of Findings and Further Discussion		N/A	**Convergent Mode**

Main drivers influencing research question formulation have been summarized in the previous section. This research study was born as a product of brainstorming and discussion sessions that were dedicated to interpretation of information collected through expert consultation, industry collaboration, and observation of findings of previous studies [80,91,93,94]. One of the main purposes of this literature review was to test and approve the accuracy and validity of the formulated research questions, which will shape the direction of the continual studies that could be established upon findings of this review.

The objective of the second and third phases of the SLR was to pick, evaluate, and filter the raw database to form the final sample set of articles. This was achieved in four consecutive steps, as can be observed in Table 2. The raw database creation phase of SLR was initiated with determination of online libraries for article search. Five major and well-known publisher databases, namely, Science Direct, Emerald Insight, Springer Link, Taylor and Francis, and Wiley Online were picked to ensure quality and reliability of the content. To include the articles that were milestones in the field, additional databases and search tools, such as Inderscience, Google Scholar, EbscoHost, and Purdue Libraries were also scanned and grouped under "Other Sources" title. The next step was to define the time period to be covered and analyzed. Search results were filtered to cover articles from 1990 to February 2018, since 1990 is the year when lean philosophy was introduced to the Western world. Womack et al. left an inerasable mark on the history of Lean with book titled "The Machine That Changed the World" [28]. Although articles published in 2018 were not meaningful for meta-data analysis, they were still included in the study due to their expected contribution to contextual outcomes and discussions.

Time period definition was followed by the determination of inclusion/exclusion criteria, which have been carefully designed to ensure an effective refinement procedure. Peer-reviewed journal articles, book chapters, and conference proceedings were included, whereas textbooks, in general, book reviews, magazine articles, replication works, articles lacking clear definition of objectives and results, as well as articles that fail to address at least one of the primary and secondary focus areas of the study were excluded to ensure analysis was being performed on a meaningful dataset. Theses and dissertations were also excluded. Inclusion/exclusion criteria were supported by a set of keywords, which were picked based on ability or appropriateness to reflect lean manufacturing, lean supply chain management, and sustainability concepts, were searched for within the context of each article. "Lean" "lean management", "lean manufacturing", "green", "environmental", "social", "economic", "sustainable development" "sustainability", "triple bottom line" and "supply chain management" were the keywords used for article search within the online databases. Keywords were used in combinations with help of Boolean operators to expand and narrow down the search results [95–97]. Articles that had keywords in the title and the abstract, but lacked them in the actual text, were removed from the final database. As the final step of the filtration process, all articles were double-checked for their contextual flow through a detailed reading process to ensure all of the articles included were relevant to primary or secondary focus of this research study within the scope of inter-relationship among lean manufacturing, lean supply chain management, and sustainability. Initial search results yielded 861 articles. At the end of a deliberate refinement and filtration process, a final database with 477 articles was created. A database identification number (DIN) was assigned to each article included in the final database, as can be observed in the Supplementary.

In the fourth phase of the SLR, content classification and data analyses were conducted to visualize the data distribution through use of qualitative and quantitative comparative approaches. Coding of article data was performed in software, namely Mendeley by Elsevier and NVivo 11 by QSR [98–100]. Data classification and some analysis were performed in Minitab 17 by Minitab Inc. and Microsoft Excel spreadsheets using macros and pivot tables. A content classification system has been used, which was adapted and altered from methods used in past studies [10,21,78,88,92,101]. A six-category grouping method was used to extract data for the purposes of descriptive analysis on the articles. The depth of the holistic sustainability perspective and linkage to key concepts were primary concerns of meta-data analysis. These categories were supported by classification groups of geographical contexts, target industry segment, publication year and database origin. Due to the large number of articles in the final database, coding for industry setting category was designed to also include literature reviews and theoretical studies along with empirical articles. For instance, papers that were only conceptual or theoretical, and not specifically addressing an industry segment were coded as "theoretical" while past literature reviews of any sort were classified under the title of "literature review". Classifications based on a journal title and author name were left out since those were not considered essential for the purposes of this study. Graphical illustrations and tables were used for visual representation of data distribution over years, geographical regions, and different industries. Sustainability (TBL) and research stream focus of each article were also visualized. Although qualitative analyses were conducted mainly for detailed contextual data extraction, they were also used to provide discussion support for meta-data analysis. Moreover, statistical methods were employed to generate quantitative analysis of data collected.

The last phase of the SLR was dedicated to interpretation of key findings and further discussion of results to support pre-determined research questions stated in the previous section of the study, and to have a better understanding of potential future research directions in the field. During the interpretation phase, unique contributions of articles with proposed frameworks were also identified.

3. Results and Discussion

3.1. Results of Descriptive Analysis

Inclusion/exclusion criteria and content evaluation of articles has yielded a total number of 477 articles (*n* = 477), all of which simultaneously dealt with lean and sustainability concepts at either the organizational or supply chain level. Based on the observations made throughout the database creation process, this literature review is believed to be the most extensive and comprehensive literature review conducted on the subject matter to date. In the next several sections, meta-data and contextual analysis are presented and discussed in detail.

3.1.1. Distribution of Articles throughout the Defined Time Period

In the first part of descriptive analyses, chronological appearance pattern of the publications throughout the defined time period was analyzed as given in Table 2. Although the beginning date was set to 1990 per the inclusion criteria, the first article caught by the SLR procedure had the publication date of 1993. This was consistent with one of the past studies [10], perhaps due to the fact that SLR procedure was designed to omit the publications with a single concept focus. The number of articles in each research stream had an upward trend across the time span evaluated. However, the publishing rate gained momentum in 2005 and started to follow a parabolic trend as of 2010, as can be observed in Figure 3. The year 2017 is the year where the number of publications had the highest leap from the value of the previous year. Publications released in 2018 were not shown in Figure 3 to ensure accuracy of the trend line since only January and February data were available at the time of data collection.

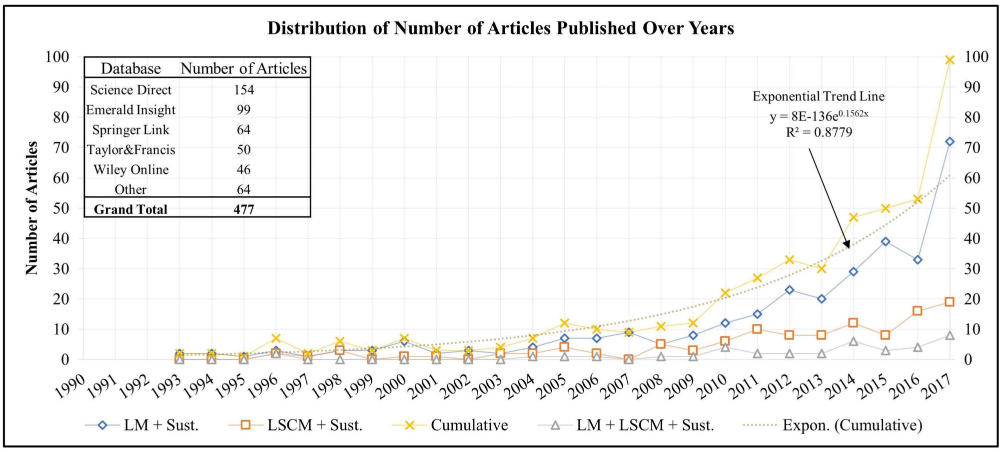

Figure 3. Distribution of articles over years from 1990 to 2017.

Of 477 articles, 430 were published within the period of 2005–2018, which can be seen as an obvious sign of increasing interest from researchers in these research fields. The years of 2017 (99), 2016 (53), and 2015 (50) were the years with the highest number of articles published in a year. Year to date value for 2018 was 15 articles in total as of February. An upward trend in the number of publications over the years could be a reaction to increased pressure placed on industry professionals and academics to deliver solutions to sustainability issues. All stakeholders including, but not limited to, consumers, shareholders of companies, unions, regulators, and authorities, started to be more demanding in terms of corporate and social sustainability outcomes [102,103]. Several journals dedicated some of their issues to sustainability and lean concepts and issued call-for-papers due to the emerging interest in sustainability-related developments [93,104]. Such actions have triggered increased interest by researchers and professionals in discoveries related to synergies, divergences, and two-way permeability between these concepts. Moreover, it is likely that the number of journals that specialize in these topics will substantially increase along with the research projects conducted in these fields. The distribution of articles among target research streams will be discussed in the next sub-section of the article.

3.1.2. Distribution of Articles Based on the Research Stream Focus

Chronological trend analyses of article distribution were carried out to detect perceived importance of each research stream. As stated in previous sub-sections, the articles were preliminarily classified according to three research streams. Preferred classification was aimed to test legitimacy of the proposed argument that "an LM-sustainability focus lacking SC collaboration function would be prone to failure." Moreover, carrying blocks of this research project were built upon the assumption that "a pure sustainability approach with only Supply Chain or only Firm level integration would not be enough to achieve a 'truly sustainable' outcomes". This definition of ultimate objective was expected to contribute towards successful detection of research gaps in the field and believed to help with development of a fully functional lean and sustainability performance assessment and benchmarking. Cumulative trend of publications was evaluated within the context of previous section. Results of converged research stream analyses revealed that both LM—sustainability and LSCM—sustainability (secondary focus areas) have received increased attention from scientists starting in 2005, parallel to trend of cumulative distribution. However, research stream dealing with intersection zone of LM, LSCM and sustainability (primary focus area) has remained silent and scarce during the defined time period. This stream reached an all-time high in 2017 with a total of only 8 articles, followed by 6 publications in 2014. A high majority (67.09%) of articles belonged to LM-sustainability category, while 24.32% were concerned with LSCM-sustainability relationship. LM-sustainability topic received, and is expected to continue to receive more attention from researchers. In addition, results also indicate that potential of LSCM-sustainability stream and importance of spreading Lean and Sustainable practices along the entire supply chain were discovered by scientists and increased its popularity in this decade, as can be seen in Figure 3. Articles belonging to LM-LSCM-sustainability category accounted for only 8.60% of total number of articles included in the study. Therefore, it can be interpreted that this stream is still undiscovered and bears an untapped potential. However, the gap between LM-LSCM-sustainability stream and other two streams, has significantly widened since 2005. This could be interpreted in two ways; (1) researchers have already focused on other directions and ignored Lean path to truly sustainable organizations and supply chains; (2) complexity of product and service systems make simultaneous handling of operations both within and outside the walls infeasible. Discussion of this dilemma is provided within the scope of contextual analysis. Moreover, results of descriptive analysis also revealed that some other concepts such as innovation, resilient, green and agile systems, as well as Total Quality Management (TQM) and Six-Sigma were also evaluated in the articles along with LM, LSCM and sustainability [9,10,38,40,105–108]. This could be part of effort to cover identified weaknesses of lean and sustainability methodologies.

3.1.3. Geographical Distribution

The geographical region-based distribution of articles was evaluated to determine the intensity of interest by researchers located in different parts of the world. Although the continent of Europe ends at the Urals, studies linked to any part of Russia were pooled and the entirety of Russia was marked as part of Europe since it was both impractical to classify based on sub-region and insignificant for the purposes of the study. The relationship of sustainability with lean manufacturing and lean supply chain management varied significantly from one region to another, as can be observed in Figure 4. Geographical classification was generally made based on continents of the World. However, North America was analyzed in segments to better observe the current state-of-the-art in the U.S. For an article to be classified within a specific region, it needed to meet at least one of two criteria; (1) the article had a case study carried out in a company located in that geographical region; or (2) the author(s) of the study were based in that region, if the study was only theoretical/conceptual. Based on the geographical analysis, the contribution of regions to lean and sustainability knowledge followed a descending trend from the developed to developing regions, with an exception of Canada. Canada has contributed to the body of knowledge with only six studies. These results were somewhat contradictory with findings of Singh and Trivedi [109] who studied sustainable green supply chain management trends. In all three streams, a high majority of publications were based in Europe and yielded a total number of 195 studies, which was followed by the US and Asia with 96 and 95 articles, respectively. The underlying reason for Europe's higher contribution could be a collective function of strict environmental and social regulations enforced by the European Union and the high number of clustered countries on the continent. On the other hand, the position of the US could be a product of increased sustainability awareness of government agencies, universities, and large-scale U.S. companies, which encourage and engage with research activities in sustainability-related fields. Although Europe and the U.S. topped the list, only 26.15% of 195 Europe-based studies and 19.79% of 96 U.S.-based articles addressed sustainability issues from a TBL while linking it to lean. The results also revealed that "true sustainability" is yet to receive global attention. In all of the geographical regions, less than 10% of 477 articles contributed to true sustainability from perspective of TBL with both intra- and inter-organizational (holistic) approach. In almost all regions, studies focusing on LM–sustainability relationship outweighed the studies dealing with relationship between LSCM–sustainability or intersection of three research streams. On the other hand, 40 multi-continental studies were identified, which were products of either international collaborations or industry-based studies conducted in multi-national firms and their extensions. However, in contrast with their broader geographical involvement, most of the multi-continental studies failed to target the LSCM concept and limited themselves to studying the LM–sustainability relationship [110–115]. The Middle East (one article) was the region with least number of studies published on the subject matter, followed by Africa (two articles) and Mexico (two articles). Region-specific analyses also revealed that a high majority of papers from each region appeared to have theoretical or conceptual context without any industry specific outcomes. Theoretical/conceptual publications accounted for 32.29%, 27.69%, and 21.05% of the total publications based in the U.S., Europe, and Asia, respectively. Moreover, 32.50% of 40 multi-regional studies have a theoretical or conceptual focus. Consequently, although lean-driven sustainability received some noticeable attention from researchers located in Europe, the U.S., and Asia, it still has plenty of room to grow and potential to attract more researchers from all over the globe.

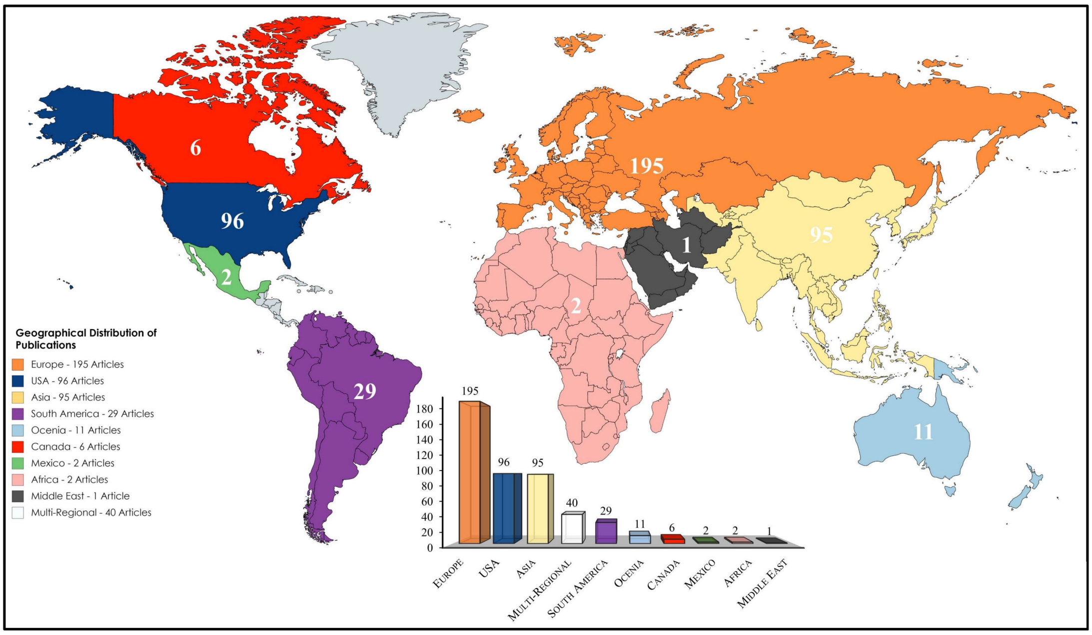

Figure 4. Geographical distribution of SLR articles.

3.1.4. Sectoral Distribution

Sectoral distribution of empirical studies was provided along with a literature review and theoretical studies in Table 3. The source industry segment of some empirical data were undisclosed in various studies due to confidentiality agreements, while some studies referred to only an umbrella sector (I.E. Manufacturing or Service) in partial disclosure. These studies were grouped together under "other manufacturing" and "service/education" titles to simplify classification and to avoid over-diversification. As can be seen in Table 3, theoretical research articles accounted for 27.04% of the total number of papers, while 7.34% of all were literature review papers. Overall, from 1990 to 2018, a strong focus has been directed on theory development as number of studies that were not empirical accounted for 164 (34.38%) publications. The distribution of articles over sectors also showed that 16.35% of 477 targeted more than one sector. These multi-sectoral publications were followed by papers addressing automotive and construction industries with 63 and 32 articles, respectively. Healthcare, metal, electronics, food/agriculture, and service/education categories followed automotive and construction industries. All of these categories had more than 10 articles over the time span being studied. Leasing, leather, mining, and musical instruments sectors drew the least attention, and each sector was represented with only one paper in the SLR database.

Table 3. Sectoral distribution of articles.

	Research Stream						Grand Total	
	LM + LSCM + Sustainability		LM + Sustainability		LSCM + Sustainability			
Industry	**Number of Papers**	**Percentage**	**Number of Papers**	**Percentage**	**Number of Papers**	**Percentage**	**Number of Papers**	**Percentage**
Theoretical/Conceptual	12	2.52%	81	16.98%	36	7.55%	129	27.04%
Multi-Sectoral	12	2.52%	48	10.06%	18	3.77%	78	16.35%
Automotive	2	0.42%	45	9.43%	16	3.35%	63	13.21%
Literature Review	6	1.26%	17	3.56%	12	2.52%	35	7.34%
Construction	2	0.42%	29	6.08%	1	0.21%	32	6.71%
Other Manufacturing	2	0.42%	17	3.56%	4	0.84%	23	4.82%
HealthCare	0	0.00%	12	2.52%	2	0.42%	14	2.94%
Metal	0	0.00%	12	2.52%	2	0.42%	14	2.94%
Electronics	2	0.42%	11	2.31%	0	0.00%	13	2.73%
Food/Agriculture	0	0.00%	7	1.47%	5	1.05%	12	2.52%
Service/Education	0	0.00%	10	2.10%	1	0.21%	11	2.31%
Transportation/Cargo	1	0.21%	2	0.42%	6	1.26%	9	1.89%
Aerospace/Aviation	1	0.21%	3	0.63%	4	0.84%	8	1.68%
Consumer Goods	1	0.21%	3	0.63%	3	0.63%	7	1.47%
Plastic/Rubber	0	0.00%	4	0.84%	1	0.21%	5	1.05%
Wood Products	0	0.00%	4	0.84%	0	0.00%	4	0.84%
Foundry/Casting/Molding	0	0.00%	3	0.63%	0	0.00%	3	0.63%
Retail	0	0.00%	1	0.21%	2	0.42%	3	0.63%
Government	0	0.00%	1	0.21%	1	0.21%	2	0.42%
High Tech	0	0.00%	2	0.42%	0	0.00%	2	0.42%
Maintenance	0	0.00%	1	0.21%	1	0.21%	2	0.42%
Pharmaceuticals	0	0.00%	2	0.42%	0	0.00%	2	0.42%
Software	0	0.00%	2	0.42%	0	0.00%	2	0.42%
Leasing	0	0.00%	1	0.21%	0	0.00%	1	0.21%
Leather	0	0.00%	0	0.00%	1	0.21%	1	0.21%
Mining	0	0.00%	1	0.21%	0	0.00%	1	0.21%
Musical Instruments	0	0.00%	1	0.21%	0	0.00%	1	0.21%
Grand Total	**41**	**8.60%**	**320**	**67.09%**	**116**	**24.32%**	**477**	**100.00%**

Dominance of the theoretical studies was the primary evidence to support the assumption that the proposed techniques and concepts for solutions of lean and sustainability problems are still in the development phase and could be used as a hint to predict the current phase of sustainability innovation on Roger's adoption curve [116]. While there were only one or two studies that dealt with lean and sustainability from a holistic perspective, numerous articles involving elements of the automotive industry have been identified. A higher number of publications for the automotive industry could be associated with the fact that lean was born in this sector and spread across all functions to provoke continues improvement [25,117]. Therefore, sustainability integration was considered as part of a continuous improvement journey and implemented quickly for further advancements. A combination of all manufacturing industry-related articles (including the automotive industry) accounted for almost 50% of papers, while combination of service and education sectors drew limited attention from researchers. This could be due to the high level of pressure from stakeholders of manufacturing industries, which caused a larger reaction from members to take action to deal with sustainability issues earlier and quicker than any other industry group. Moreover, electronics and software industries were expected to be more prominent on the list, however, they collectively had only 15 studies. The underlying reason for this outcome could be the relatively new interrelationship of Lean with issues and concepts of these sectors such as e-waste and reverse logistics, and conflict minerals [46,109,118,119].

Although the LM–sustainability stream was believed to be the most mature stream among the trio under investigation, it still had the highest percentage of theoretical papers with a value of 16.98%. Distribution of multi-sectoral papers among research streams revealed a similar result with findings of a previous study [88]. A total of 61.53% of multi-sectoral papers were concerned with the resolution of intra-organizational sustainability issues, while 23.07% dealt with inter-organizational problems. Only 12 multi-sectoral articles had both intra and inter-organization focus, as shown in Table 3. Articles studying automotive sector led others in terms of intra- or inter-organizational focus with 45 and 16 articles, respectively. However, only two articles out of 63 automotive sector-specific studies used a holistic approach. A high majority of articles (30 out of 40) with a holistic perspective belonged to one of three categories, namely, theoretical studies, multi-sectoral articles, and literature review papers. The dominance of multi-sectoral papers could be due to their experimental design, since many of these studies were survey-based articles that are designed to collect opinions from a broader range of professionals and academics. A similar issue was also observed in literature review articles. These articles intrinsically consisted of studies with various business level focus, which granted them a place in the stream of LM-LSCM-sustainability. Only 8.60% of 477 articles simultaneously dealt with intra- and inter-organizational sustainability and their relationship with each other based on lean principles. This could be interpreted as a holistic perspective, which would lead to the achievement of the ultimate objective (see Figure 2), having an enormous untapped potential in general. Moreover, the LSCM–sustainability stream was observed to be more mature than holistic perspective, however, it carries more unseized opportunities than the LM–sustainability stream.

Consequently, both individual sector studies and multi-sectoral studies paid more attention to either operations within the walls or outside the walls rather than employing a more integrated approach. Finally, there were only three sectors, namely, automotive, construction, and electronics, for which there were more than one empirical paper within the stream of LM-LSCM–sustainability. Most of the industries had zero papers in this stream, as can be seen in Table 3.

3.1.5. Sustainability Focus of Articles from the Perspective of the Three Pillars

SLR procedure also evaluated publications depending on their TBL focus. As shown in Figures 5 and 6, the number of papers concerned with environmental sustainability had a positive trend from 1993 to 2017, while papers with both environmental and economic pillars' emphasis started to gain momentum only after 2005. Articles with a complete TBL approach started to be more prominent after 2005 and had a positive trend since then. Papers with a complete TBL emphasis experienced the most noticeable increase over time as shown in Figure 6. Economic pillar-centric articles followed a continuous upward trend and were determined to have the oldest and most consistent footprint in the time horizon. However, it followed a somewhat flat and stationary pattern for a couple of years between 1996 and 2002.

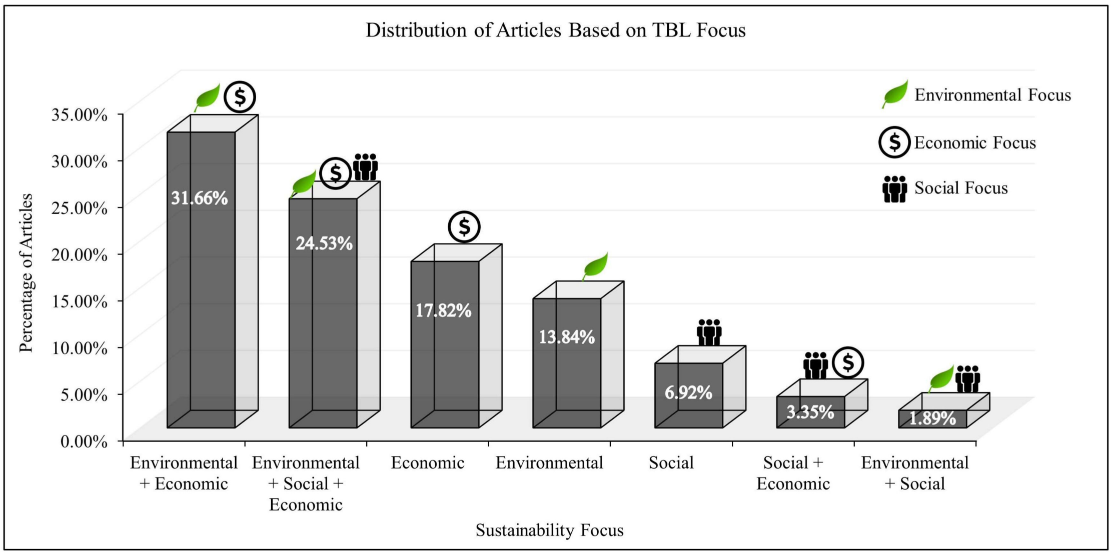

Figure 5. Distribution of articles based on TBL focus.

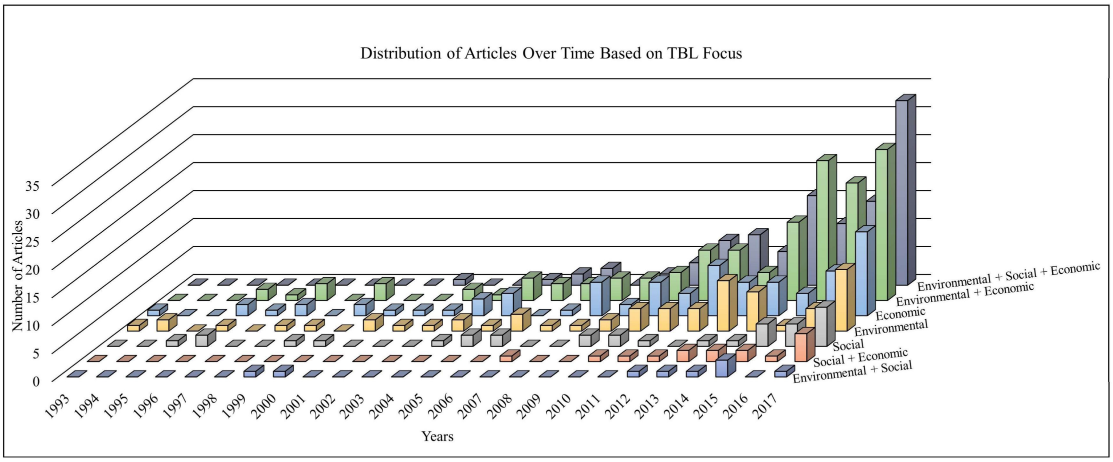

Figure 6. Occurrence rate of articles over time based on TBL focus.

A line of research concerned with the economic pillar at either the individual level or in combination was the strongest line of TBL research. It had the most attention from researchers and was addressed in 77.36% of studies, as can be seen in Figure 5. Results of the analysis also revealed that environmental pillar followed the economic pillar with a value of 71.92%. The social pillar was found to be the weakest pillar with the least attention from researchers, with a value of 36.69%. Moreover, the number of studies addressing the social pillar alone, or along with either environmental or economic pillars, did not show any upward trend until 2017, as shown in Figure 6. Two of the past literature review studies have also determined similar characteristics for research papers concerned with TBL pillars [10,88].

A total of 38.58% of the studies dealt with only one pillar, whereas 36.90% of all papers addressed two pillars of TBL. Only 24.53% of total number of papers shared a complete TBL perspective, most of which were either theoretical papers or literature review articles. This could be an indication of lack of practicality for academic studies concerned with the TBL framework. On the other hand, some previous studies stated that these kinds of outcomes could be due to travails during theory building efforts for any discipline [120,121], while some authors discussed the difficulty of simultaneous integration of all three pillars [8,80]. However, it is not possible to achieve "true sustainability" without giving equal importance to all three pillars. Therefore, the research focus on the entire TBL framework should be enhanced and well researched to achieve the ultimate objective for true sustainability.

3.2. Results of Contextual Analysis

Contextual analysis was performed to meet four objectives:

- To investigate the findings of past literature reviews in detail;
- To extensively discuss synergistic and divergent aspects of lean and sustainability within the scope of ten constructs;
- To discover strengths and weaknesses of previously proposed lean-based sustainability assessment tools; and
- To understand potential sustainability contribution of certain lean tools.

Therefore, not all of the 477 articles were evaluated for contextual contributions to the field. A total of 273 articles were addressed and referred to in the various following subsections. The supplementary (Table S1) can be reviewed for the complete list of articles included in the study.

3.2.1. Past Literature Reviews

The SLR database also included 35 past literature reviews published between 2000 and 2018. More than 90% of these articles appeared in the literature after 2014. Only two articles published prior to 2010 have met the inclusion criteria of the SLR procedure. Researchers have reviewed publications in the main research stream of sustainability and various sub-streams in the past. Conceptualized networks of past literature reviews can be observed in Figure 7. One with the closest objectives to those of this study was published by Martinez-Jurado and Moyano-Fuentes in 2014 [88]. A total of 58 papers were reviewed in detail to identify contributions made by researchers to the research streams addressing lean management-sustainability and lean SCM-sustainability relationships.

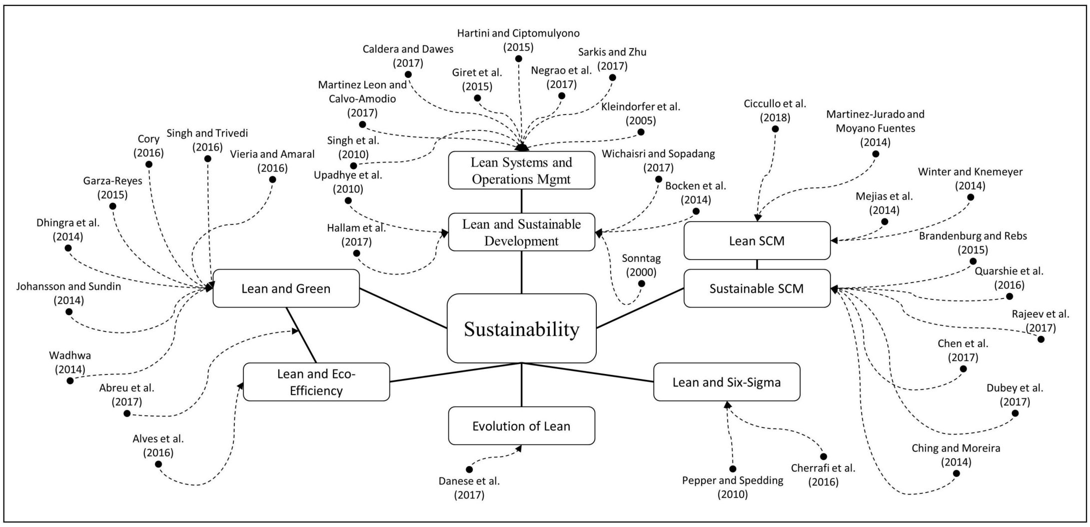

Figure 7. Network of past literature reviews and their link to key concepts.

Based on chronological order, the first review article included in this study was the publication of Sonntag (2000), which evaluated sustainability from the perspective of competitive advantage and identified sustainability as the new frontier [60]. Another early literature review article caught by the SLR inclusion criteria was published by Kleindorfer et al. in 2009 [122]. The researchers evaluated contributions made by the first 50 issues of the Production and Operations Management Journal to the sustainable operations management field. The authors stated that first mover advantage and the relationship between corporate image and profitability are two important elements of competitive advantage. Upadhye et al., (2010) identified 14 potential benefits from lean manufacturing/management practices to shed light onto the path of sustainable development [123]. In the same year, Pepper and Spedding reviewed evolution of lean six-sigma and explored how waste minimization power of lean could be harmonized with quality control competency of six-sigma methodology [124]. Authors also highlighted the lack of a standardized framework for a lean six-sigma implementation.

Winter and Knemeyer (2013) reviewed 456 articles to discover the current state of the integration between SCM and sustainability, as well as to identify future research opportunities [78]. Dhingra et al., (2014) reviewed articles published in a special volume of the Journal of Cleaner Production that was dedicated to the discovery of synergies among lean, green, and sustainability concepts [93]. The articles were concluded with three recommendations, one of which emphasized importance of necessity of assigning a “sustainability champion” in companies for a successful implementation. Johansson and Sundin (2014) conducted a systematic literature review on 102 journal publications to compare lean product development with green product development [90]. The authors came up with seven propositions that are in favor of the synergistic relationship of two different product development concepts in terms of value creation, waste generation, implementation, education/training, tools/techniques, as well as process structures and activities. In another literature review, Wadhwa (2014) discovered synergies among environmental management systems (EMS), lean, and green for manufacturing SMEs [125]. The article highlighted increasing complexity level when these paradigms are combined as one of the barriers in front of the researchers. On the other hand, Bocken et al., (2014) constructed technological, social, and organizational sustainable business archetypes [126]. The authors proceeded with a detailed explanation of each selected archetype to shed light on the business model innovations for sustainability. Similarly, Hallam et al., (2016) reviewed 109 peer-reviewed articles along with data associated with 23 Balridge Award winners to discover correlation between lean and sustainable competitive advantage [127]. The authors emphasized the importance of making lean actions part of business-level strategic plans to achieve meaningful outcomes in the long-term. Wichaisri and Sopadang (2017) observed the current trends in sustainable development and identified lean-driven TBL among the most probable directions for future research [128]. Ching and Moreira (2014) reviewed 40 articles to identify management systems and practices related to Sustainable Supply Chain Management [129]. The study revealed an insufficiency of existing management systems and practices at successfully dealing with issues that occur in the social sustainability pillar. Fortunately, Danese et al., (2017) conducted an SLR on recent lean research and its future direction [130]. The authors identified relationships of lean-green, and lean-social sustainability among issues to be tackled in the future research studies. Furthermore, Negrão et al., (2017) reviewed 83 articles to investigate level of lean adoption across industries and impact of lean practices on operational, financial and environmental performance [131]. Various lean tools were shown to be positively correlated with the overall performance of companies in various sectors.

In 2015, Garza-Reyes (2015) investigated lean-green relationship and identified six research streams addressing issues such as compatibility, integration, development of an assessment mechanism, and impact of lean and green on organizational performance [92]. The author also pointed out untapped potential in the field of lean-green synergies. Another past literature review aimed to discover the relationship between lean and sustainable manufacturing by means of performance outcomes. A total of 58 empirical and conceptual studies were reviewed to identify the current state of the relationship, as well as to determine the extent of the positive impact of lean and sustainable manufacturing on TBL pillars [101]. Brandenburg and Rebs (2015) reviewed 185 articles published between 1994 and 2003 [132]. Their review approached the sustainable SCM concept from the perspective of modeling purposes and presented a seven-step guideline for development of sustainable SCM models. Holistic SCM and a complete TBL focus were among the most emphasized issues. Giret et al., (2015) discussed urgency of delivering solutions to sustainability issues incurred in manufacturing operations [133]. An extensive literature review was conducted to identify the shortcomings of the current literature. Articles were categorized under three titles, namely, input-oriented approaches (proactive), output-oriented approaches (reactive), and hybrid approaches. Highlights of the study also included the importance of having benchmarking tools to evaluate and control input and output parameters for manufacturing scheduling problems and the necessity of more active involvement of universities in the subject matter.

Mejías et al., (2016) tried to answer four research questions related to best practices in the SCM discipline from the perspective of social responsibility [134]. The authors reviewed 194 publications within the study and emphasized the importance of measurement of sustainability performance in logistics operations. Potential research opportunities focusing on the development of TBL performance metrics for logistics operations was also among the recommendations of the authors. Additionally, Hallam and Contreras (2016) conducted a review study covering 60 articles published in the field of the lean-green relationship [91]. The impact of lean wastes and benefits associated with the elimination of these wastes were identified from the standpoint of environmental performance. The authors of the article argued that the achieved lean-green integration is weak and relies upon indirect environmental gains of lean initiatives. The lack of an integrated framework which will trigger direct gains through co-deployment of these two concepts was also pointed out. On the other hand, Alves et al., (2016) conducted an SLR involving a final database of 83 papers to investigate the relationship matrix of sustainability, lean, green, and eco-efficiencies [94]. The outcomes of the study showed an increasing level of lean-green synergies and referred to sustainability as the top item in the agenda of researchers and professionals. In the same year, Quarshie et al. investigated the state-of-the art in sustainability and corporate social responsibility within the context of SCM and business ethics [21]. Even though the identified synergy between SCM and business ethics was determined to be limited, the future research agenda presented in the study was quite inclusive to cover a broad range of topics including, but not limited to, inter- and intra-organizational collaborations, self-regulation policies, downstream SCM issues, and the impact of globalization. Moreover, Singh and Trivedi (2016) provided an insight from the research stream of green SCM by conducting an analysis of 138 articles from 29 journals [109]. The findings confirmed a positive trend for the interest in this stream while revealed various research gaps under categories of responsible manufacturing and logistics activities, supplier relations, HR activities, and IT systems. Vieira and Amaral (2016) worked on a final database of 37 articles and identified internal and external barriers being faced during the implementation of cleaner production principles [135]. The authors discussed various strategies to overcome identified barriers. Enhanced CP knowledge, organizational culture transformation, stakeholder commitment, regulations, and use of quality tools were among the listed strategies, all of which also apply to sustainability methodology. In another study, Cherrafi et al. reviewed 118 articles published between 1990 and 2015 to explore two- and three-way relationship among lean, six-sigma, and sustainability [10]. The researchers identified barriers in front of effective integration of these methodologies in addition to deliberate analysis to understand potential benefits associated with integration and co-deployment of techniques. Contribution of lean and six-sigma tools to environmental and social performance were also discussed to identify the TBL effectiveness of these paradigms. The need for sustainability performance assessment systems, frameworks and models were emphasized along with some limited focus on application of frameworks in SMEs and service industry. Holistic TBL and SCM perspectives were among highlighted concerns. Moreover, Chen et al., (2017) reviewed 90 articles to understand how various levels of supply chain collaboration plays a role in achieving sustainability and presented a future research agenda for this stream [84]. On the other hand, Rajeev et al., (2017) [136] explored evolutionary steps of sustainability in SCM from 2000 to 2015 while Dubey et al., (2015) [137] explored the path to world class sustainable supply chains through the detailed identification and discussion of enablers of sustainable SCM in addition to existing research gaps in the field.

Martínez León and Calvo-Amodio (2017) discussed synergies between lean and sustainability from the perspectives of operations, finance, society, and the environment [138]. The authors stated that there is a need for a consensus on definitions of lean and sustainability to ensure both concepts are working toward aligned purposes for achieving a successful integration. Abreu et al., (2017) reviewed 27 papers (out of 85) with lean-green models to identify commonly used KPIs designed to assess factors, such as time, efficiency, cost, waste, corruption risk, emissions, and supplier selection/relationship [139]. Caldera et al., (2017) focused on the identification of the contributions of lean to sustainability in terms of cost and waste reduction, as well as improvements in environmental performance [140]. Sarkis and Zhu (2017) reviewed articles published in the International Journal of Production Research (IJPR) to identify the current state-of-the-art in terms of sustainability and production research integration [76]. The increased integration of sustainability in production systems was foreseen by authors for days to come. Singh et al., (2017) conducted a review of previous publications with a focus on recycling, reuse and eco-friendly production to clear the path for a zero waste manufacturing (ZWM) framework, which was claimed to be the future of manufacturing industries [141]. The authors supported their claim with outcomes of a case study for aerospace industry. In the most recently published review article, Ciccullo et al., (2018) have evaluated lean-sustainability and agile-sustainability integration under six categories to identify the characteristics of integration within the scope of supply chain performance [142]. They found that the most common characteristic of lean or agile integration with sustainability was as a supporting paradigm followed by their integration characteristic as a precursor to sustainability.

Consequently, many researchers have been conducting review studies to identify the current state of sustainability knowledge and its association with other paradigms. Other common research objectives include, but are not limited to, presenting a future research agenda for sustainable development and establishment of a foundation for sustainability framework development projects. Therefore, it can be concluded that:

> *Researchers are expending substantial effort to discover the path to "true sustainability" by re-visiting findings and proposals of their colleagues who approached the situation from various perspectives.*

3.2.2. Synergies, Divergences, and the Extent of Potential Permeability between Lean and Sustainability Concepts

To successfully incorporate a concept or methodology with another, the extents of synergistic and divergent aspects of the relationship should be well-understood [143]. This becomes much more critical when the concept in question is TBL. Initially, sustainability was perceived as economic prosperity. Later, the environmental pillar was either prioritized over economic and social pillars or it was confused with social sustainability due to a lack of borderlines [144,145]. Prior to Elkington, many researchers and practitioners delivered sustainability definitions and frameworks to deal with it [16]. However, it proved to be a difficult task, since three pillars of sustainability do not have a common measure. There is no universal standard or metrics defined to measure the TBL performance [146]. This could be TBL's strength and weakness, since it gives the concept infinite versatility and flexibility while causing some inconsistencies from one application to another. The environmental pillar promotes the use of environmentally friendly techniques and technologies to deliver harmless products and services while the economic pillar's primary focus is on long-term financial survival, competitive advantage, and profitability [14,147]. On the other hand, the social pillar is the least mature pillar among the trio, which aims to fulfill both individual- and organizational-level responsibilities, such as occupational safety, job satisfaction, and contribution to society [78].

In this sub-section, lean and sustainability concepts are discussed from the perspective of synergies and divergences to determine the extent of potential two-way permeability based on the SLR findings. Motives leading to individual or simultaneous implementation of each paradigm were identified as a starting point. Then, a detailed discussion was provided within the scope of ten constructs as given in Figure 8.

Both concepts strive for and promote competitive advantage, increased performance and value creation [90,91,148,149]. However, they follow slightly different paths to reach their primary targets. These paths could be effectively explored under ten constructs, namely, value creation, quality focus, waste definition, versatility, impact on organizational culture, deployment strategy, key competencies, supply chain integration, KPIs, as well as tools and methods used to achieve objectives. First, a couple of synergies and divergences could be evaluated based on characteristics of two systems. Lean is considered to have intensified focus on the workplace while sustainability concepts stand out with its broader structure [150]. Lean tries to achieve a certain level of efficiency and effectiveness through waste minimization, while sustainability aims to achieve compliance with laws, regulations, standards, and expectations of stakeholders by minimizing negative impacts of processes and activities on the environment, society, and assets [106,151,152].

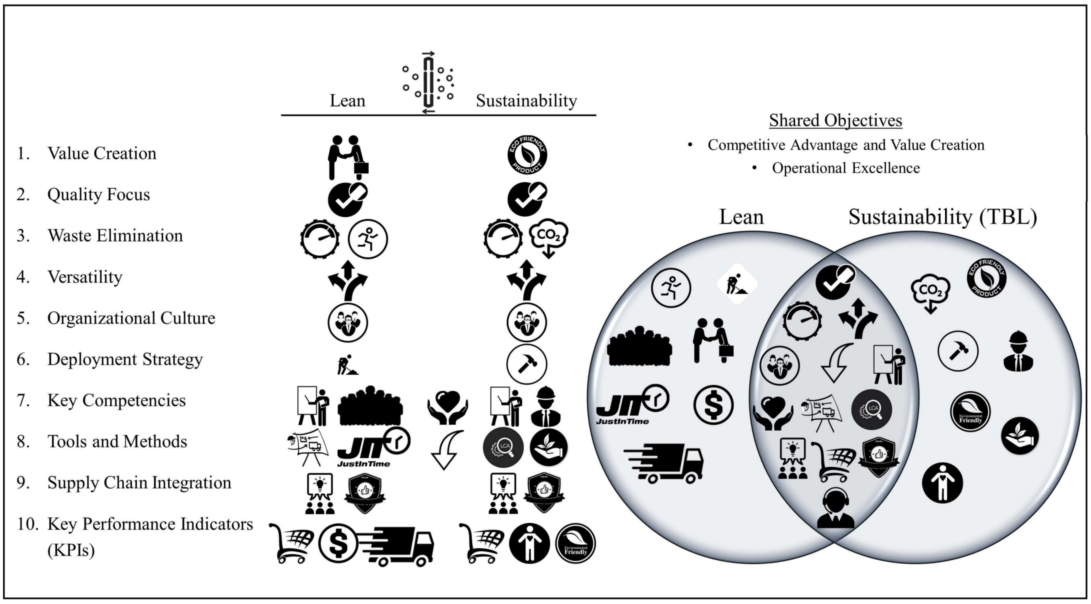

Figure 8. Graphic illustration of synergies and divergences between lean and sustainability.

3.3. Quality Focus and Value Creation Constructs

Quality is an important property, which is directly related to all three pillars of TBL. Performance measures such as customer service level, production cost, employee health and safety, emission levels, and scrap generation are potentially highly correlated with the overall quality of products and service systems. Pil and Rothenberg (2003) found a positive correlation between environmental performance and quality [153]. Quality focus of both concepts remains among the shared goals. Both try to increase the quality of processes and products at all stages through value creation and elimination of waste [148,149,154]. Both concepts were often integrated with six-sigma and TQM methodology to strengthen quality focus of implementation [56,107,155–158]. Integration of six-sigma is truly beneficial since lean and sustainability methodologies could leave some soft spots in terms of technical and statistical analysis tools due to their nature. In a past study, Venkat and Wakeland (2006) observed a positive correlation between six-sigma project implementation and pollution prevention [159].

Value construct is also essential for both concepts. From the lean point of view, value is only achieved if customers are willing to pay for the activity and process in question [30,110,160]. On the other hand, value perception of sustainability is based more on environmental and social friendliness of processes being preferred as well as products/services used and offered [90,147]. Although they approach quality and value creation problems from slightly different perspectives and emphasis, every effort would contribute to sustainable development in a direct or indirect way since all three pillars of TBL are inter-dependent [13,15].

3.4. Waste Elimination Construct

Furthermore, the definition of waste bears some similarities and divergences from the perspectives of each concept. Waste incurred as a function of business practices was listed among the global sustainability issues [147]. Cobra et al., (2015) showed waste as the common gene of lean and cleaner production [26]. Moreover, Moreira et al., (2010) concluded that production wastes could be one of the major causes of environmental wastes and pointed out the potential of lean as a solution to this problem [161]. Lean defines waste as anything that does not add value to the product or service being delivered from the perspective of customers and evaluates it under eight distinct categories, as listed in Table 4 [30,33,162]. Waste definition of lean includes both tangible and intangible factors, such as inefficient machinery and non-value-added movement, respectively, whereas sustainability refers to more tangible issues, such as resource consumption, emission levels, and physical material dumped into landfill [25,91,163,164]. Interpretation of lean wastes in the language of sustainability is provided in Table 4.

Table 4. Eight wastes and their linkages to sustainability. Adapted and altered from U.S. EPA lean and environment toolkit [164–170].

8 Wastes	Examples	Linkage to Sustainability
Defects	Scrap, rework, replacement production, inspection.	• Raw materials consumed in making defective products. • Defective components require recycling or disposal. • More space required for rework and repair, increasing energy use for heating, cooling, and lighting.
Waiting	Stock-outs, lot processing delays, equipment downtime, capacity bottlenecks	• Potential material spoilage or component damage causing waste. • Wasted energy from heating, cooling, and lighting during production downtime.
Over-Processing	More parts, process steps, or time than necessary to meet customer needs.	• More parts and raw materials consumed per unit of production. • Unnecessary processing increases wastes, energy use, and emissions.
Over-Production	Manufacturing items for which there are no orders	• More raw materials consumed in making the unneeded products. • Extra products may spoil or become obsolete requiring disposal.
Inventory	Excess raw material, WIP, or finished goods	• More packaging to store work-in-process. • Waste from deterioration or damage to stored WIP. • More materials needed to replace damaged WIP. • More energy used to heat, cool, and light inventory space.
Unnecessary Transportation	Unnecessary movement of materials within or outside the walls.	• More energy usage. • More emissions are created. • Increased cost factors.
Unnecessary Motion	Human motions that are unnecessary or straining, carrying work in process (WIP) long distances, transport	• More energy use for transport. • Emissions from transport. • More space required for WIP movement, increasing lighting, heating, and cooling demand and energy consumption. • More packaging required to protect components during movement
Under-Utilized Talents	Lost time, ideas, skills, improvements, and suggestions from employees.	• Fewer suggestions of Pollution prevention • Fewer opportunities for waste minimization.

3.5. *Versatility, Organizational Culture, and Deployment Plan Constructs*

The applicability of both lean and sustainability is quite extensive and expandable. Several past studies concluded that both concepts are relevant for, and versatile enough to, accommodate needs of any industry [8,88,130,171,172]. Evidence of both separate [28] and co-deployment [173] of frameworks were prominent in the literature since early 1990s and early 2000s, respectively.

Applications took place in a wide variety of sectors including, but not limited to, automotive, aerospace, education, healthcare, construction, wood products, mining, service and retail sectors [174–183]. For instance, Brown et al., (2014) tested the versatility of Sus-VSM framework for three case studies with different product varieties and product volumes and concluded in favor of sufficient versatility [184]. Moreover, some past studies also highlighted that each paradigm comes with its own sector and organization-specific internal and external barriers that need to be well-understood for successful implementation [11,90,118,185–191]. Barriers include, but are not limited to, factors such as the cost of implementation/transformation, lack of awareness/education/dedication of workforce and partners, intra-/inter-organizational network complexity, and insufficient communication and transparency [5,62,192–195]. These contingent barriers share a similar aspect in their nature when it comes to the level of teamwork and dedication required. For instance, lean requires ongoing dedication of the entire workforce, especially of executives, while sustainability requires a synchronized effort from different strategic teams (design team, quality team, human resources, marketing team etc.) performing different duties from the perspective of the life cycle of a product within the system [168,196–200]. Both concepts require a substantially high level of communication and collaboration among members of their respective supply chains to achieve excellence in lean and sustainability at inter-sectoral levels [54,77,201,202]. Moreover, some researchers claimed that lean could be effectively used to alleviate and eliminate the impact of internal barriers along the sustainable development journey [200,203,204].

Deployment of lean and sustainability noticeably diverges from path of each other. Segmentation of deployment and the amount of changes required in the general structure of the organization were among the identified divergences [172,205]. Lean implementation tackles issues through a systematic approach and progresses towards continuous improvement goals with utilization of available tools while sustainability approaches the situation with a holistic strategy to integrate initiatives into existing structure through smaller alterations. Lean moves forward by making extensive changes in the structure of the organization or supply chain, whereas sustainability progresses with less aggressive changes [62,113].

3.6. Key Competencies Construct

Another synergy between lean and sustainability occurs in the zone where key competencies are considered. Both concepts require a certain level of understanding of the theory and ongoing educational activities to ensure readiness and awareness of associated staff within the organization and throughout the supply chain [8,88,113,206,207]. The only difference between the preferred methods, by which competencies are created, is the level of the target staff in organizational hierarchy. Lean requires contribution and awareness of entire workforce, whereas sustainability is primarily aimed at engineers, sustainability managers, project managers, and other upper-level staff. However, infusion of lean and sustainability competency development strategies along with organizational structure follows a top-down bottom-up hybrid approach in both cases. On the other hand, from a more fundamental approach, educational institutions should develop and offer sustainability curriculums to increase sustainability awareness and competency of future generations [190,208]. Hanna et al., (2000) [209] and Longoni and Cagliano (2015) [196] concluded in favor of the noticeable impact of employee involvement on environmental and social sustainability performance. Employee involvement could be enhanced through lean since its emphasis on intra- and inter-organizational social sustainability is evident [210]. Finally, the significance of human impact on supply chains in terms of both transaction-based (staffing, training, evaluation and compensation) and relationship-based (structure, culture and empowerment) strategies were proven [211].

3.7. Supply Chain Integration

Within the scope of supply chain integration of both concepts, lean and sustainability place extensive importance on collaboration at intra- and inter-organizational levels [106,132,149,151,152].

Thus, both methodologies try to establish an information flow that would aid with spreading best practices across entire supply chain through combined efforts working toward shared goals [90,149,212,213]. Gopalakrishnan et al., (2012) documented essentialities of SSCM under ten main and several other sub-categories for sustainable development [15]. Pagell and Wu (2009) argued that it might be necessary to replace existing best practices with new ones to achieve truly sustainable SCs [77]. Moreover, Dey et al., (2011) stated that logistics is the best place to start integrating sustainability into SCM due to substantial cost and carbon footprint impact of logistics activities [214]. On the other hand, current SCs have been subject to some criticism due to their lack of long-term viability and incapability of creating socially conscious procedures [215]. If lean and sustainability successfully co-deployed, this integrated approach could aid with development of truly sustainable SCs through effective waste elimination.

3.8. Tools and Methods Construct

Tools and techniques used to achieve lean-driven sustainability goals are quite numerous. Especially, shared use of VSM and LCA for lean and sustainability applications was among the factors that strengthened the synergies between concepts [184,216–220]. Sustainability is a strong concept. However, it does not have any practical tools to measure sustainable performance. That is, the underlying reason of its integration with other methodologies such as lean, LCA, six-sigma, and TQM [137,219,221–224]. Many lean tools were used to derive sustainability solutions at both intra- and inter-organizational levels [169,225,226]. The most commonly used lean tools for sustainability purposes were identified to be value stream mapping (VSM), 5S, Kaizen, just-in-time (JIT), cellular manufacturing, single minute exchange of dies (SMED), standardized work, and total preventive maintenance (TPM) as can be observed in Table A2. VSM has been successfully used for many efficiency optimization scenarios across various industries, from service to maintenance [227]. Benefits of VSM for environmental and economic sustainability purposes were also evident in the literature [228–231]. 5S has also been commonly employed to achieve various sustainability outcomes [155,165,169,232,233]. Eventually, 5S evolved into 6S to include the safety element, along with initial housekeeping activities [4,234,235]. Although 5S (6S) was initially designed to serve intra-organizational purposes, the outcomes also contribute to the inter-organizational excellence when the situation is considered from the perspective of the ultimate objective concept (see Figure 2). Kaizen was another Lean tool that has been used within various projects to achieve continuous improvement in TBL pillars [57,200,236]. Kaizen was highlighted for its potential to create substantial opportunities for waste and pollution prevention, as well as emission reduction [199,237]. The strength of the just-in-time (JIT) methodology to provide organizations and supply chains with some competitive edge in terms of TBL was recognized in the literature [7,238,239]. However, Rothenberg et al., (2001) argued that JIT could be conflictive with batch production practices since it is a common practice used to reduce VOCs and emissions in the automotive industry [240]. On the other hand, Sobral et al., (2013) stated that JIT practices could be one of the facilitators that clear the path to obtain ISO 14001 certification [241]. Moreover, Kim et al., (2010) evaluated environmental impacts of a lean supply system [242]. They found that JIT delivery is superior to traditional methods during the construction of high-rise condominiums in Korea, although the fabrication of rebar at a JIT-implemented plant was initially expected to generate slightly more material scrap than the one with batch production. Another common tool of lean is cellular manufacturing, which usually goes hand in hand with JIT principles [8]. In a past study, cellular manufacturing was identified to be positively correlated with environmental performance [169]. Cellular manufacturing could help eliminate wastes of transportation and waiting time [232]. Sertyesilisik (2014) claimed that cellular manufacturing was more useful and was intended for mass production facilities [207]. In another study, pollution generation performance and employee safety and health performance were reported to be better for cellular manufacturing setups when compared to those of a batch-style manufacturing [243]. The relationship of cellular manufacturing to the social pillar was less addressed in the studies and bears an untapped potential.

SMED was shown among the techniques for future state improvement when VSM analysis are conducted [244]. It is also considered a part of TPM practices [245]. As previously discussed, VSM is commonly used to visualize intra- and inter-organizational activities with a purpose of achieving sustainable outcomes. Thus, SMED both directly and indirectly contributes to sustainable development by reducing changeover times and inventory levels [246]. However, some past studies argued that SMED could increase consumption of cleaning materials in addition to the disposal of unused products that could damage environmental and social sustainability performance [149,203]. In another past study, Chiarini (2014) did not observe any environmental gains that could be tied to SMED implementation [169]. Therefore, positive and negative impacts of SMED on environmental and social sustainability should be studied more before reaching a certain conclusion.

Standardized work principles are important part of lean toolkit for achieving streamlined and robust operations at micro and macro levels. Tice et al., (2005) claimed that standardized procedures could be useful to deal with complex, high risk and costly environmental management issues [200]. The tool was also pointed out as the basis for continuous improvement [247] and continuous organizational learning [117], which could lead to increased efficiency, employee satisfaction, and a reduced number of occupational safety incidents as a function of high competency of tasks [210]. In another study, standardized work was linked with reduced material and energy consumption, as well as decreased waste generation levels [10]. Moreover, Soltero and Waldrip (2002) acknowledged the importance of standardized work principles for the lean house and incorporated it with the clean house concept for pollution prevention and waste reduction purposes [248]. Based on this evidence, it could be stated that standardized work is essential for improving operational stability on the way to sustainable development.

TPM is another lean tool that was linked with solutions to some economic, environmental, and social sustainability issues [8,101,225,226]. TPM was often referred as one of the most effective waste elimination tools [142,151,249]. In a past study, TPM was shown to be among ten lean tools that simultaneously help with productivity and environmental efficiency [4]. Reduced defect rate, decreased number of machine failures, and alleviated time inefficiencies were achieved by TPM implementation in a past study [222]. The contribution of TPM to environmental performance due to increased machine life, reduced hazardous leakage, and emissions is also evident in the literature [138,165,169]. There was another case where TPM was part of a model called integrated system of management that was established upon lean manufacturing, sustainability, and organization culture dynamics [172]. TPM was used, along with other lean tools, to create safe and sustainable workplaces [250,251]. Based on the findings of an empirical study, TPM, organizational culture creation, and supplier development initiatives were prioritized over other lean management practices in Indian and Chinese SMEs [252]. Therefore, the proven strength of TPM could be taken advantage of to derive sustainability outcomes along with efficiency gains. Almost all lean tools are capable of delivering direct or indirect sustainability gains. However, their negative impacts on sustainability pillars have been less studied so far.

3.9. Key Performance Indicators (KPIs) Construct

The performance measures of lean and sustainability have both synergies and divergences. The most commonly shared KPIs for lean and sustainability are customer service level, profitability, energy and resource consumption, as well as employee safety and satisfaction [105,113,149,249,253,254]. On the divergent side, KPIs related to supplier selection, logistics, and raw material acquisition have been designed to prioritize different preferences [11,160,171,206,255–258]. Expectations of lean customers and sustainable customers also differ from each other to some extent [92,149]. Lean customers prioritize cost efficiency and shorter delivery times, whereas a high majority of sustainable customers are more interested in environmental and social aspects of the products and services delivered [101,249,259]. However, neither of the customer segments are reported to object to benefits of an integrated system, if initial expectation is unharmed. Such a double-benefit environment would not only strengthen the overall sustainability of any organization and supply chain, but also would ensure a broader spectrum of the customer portfolio as a function of increased ability to meet various customer expectations. It will also help with positioning organizations according to global supply chain trends mentioned in Section 1. Many studies reported that corporate organizations that are hesitant to invest in sustainable operations are prone to fall behind their competitors [8,57,161,236,260–262]. Some composite KPIs were also evident in the literature. For instance, Domingo and Aguado (2015) developed an *"Overall Environmental Equipment Effectiveness"* metric to simultaneously assess equipment utilization and the environmental impact of processes [263]. In three more recent studies, energy saving opportunities were discovered through employment of another composite metric called "value-added energy" [228,264,265]. On the other hand, Taghavi et al., (2014) criticized existing social pillar KPIs for being reactive rather than proactive in generating true value for decision making [266]. Moreover, Closs et al., (2011) stated that organizations could choose to implement one of three leadership approaches (reactor, contributor, and innovator) for different sustainability dimensions to achieve sustainable outcomes [14]. They defined innovator leadership as *" . . . establish sustainability as a strategic priority and often seek best practice performance regarding the manner in which each sustainability dimension is implemented. Such firms seek not just to have a visible sustainability platform, but they apply sustainability to change and positively benefit their stakeholders, industry and communities."* Issues brought up by authors could be pointing out to the necessity for re-tailoring the current performance measures to ensure intra- and inter-sectoral comparability and benchmarking of TBL performance among all organizations and supply chains. It could also be interpreted that the innovator approach should be preferred over reactor and contributor approaches for achieving inter-sectoral level of true sustainability.

Overall, lean and sustainability are neither 100% synergistic nor totally divergent. Some researchers claim that lean and sustainability concepts could work against each other, while some authors documented synergistic effects. For instance, Hallam and Contreras (2016) [91] and Rothenberg et al., (2001) [240] found out that sustainable operations may incur increased operational costs, since they tend to prefer less harmful materials and processes (if not completely harmless). Similarly, lean activities, such as JIT delivery and small batch production, were reported to generate controversial outcomes as a function of increased negative environmental impacts due to frequent deliveries [134,259,267]. On the other hand, Ng et al., (2015) found that carbon-value efficiency can be improved by 36.3% as a function of the 64.7% improvement in production lead time and the 29.9% reduction in carbon footprint [268]. On the other hand, some researchers concluded that lean and environmental performance could be aligned and used for reducing CO_2 emissions, VOC consumption, and pollution rates [4,173,203,269]. Moreover, Chen (2015) concluded that inventory leanness is negatively correlated with carbon intensity levels (both intra- and inter-organizational level) for manufacturers with a high level of outsourcing, but low product diversification [270]. Furthermore, Soltero and Waldrip (2002) listed pollution prevention among potential benefits of Kaizen events [248]. In another empirical study for furniture industry, Miller et al., (2010) concluded in the favor of increased overall operational performance through co-deployment of lean and sustainability [243]. Similar claims were made by Puvanasvaran et al., (2014) [271]. Furthermore, Canon reduced CO_2 emissions in their facilities through SERU (similar to lean's cellular manufacturing) implementation [272]. Fahad et al., (2017) reported not only similar outcomes achieved through cellular manufacturing practices, but also included evidence of increased energy efficiency and reduced energy costs [273].

Past research studies also showed that lean-driven sustainability could be among the best practices to transform companies into corporate structures that are fiscally sound, environmentally conscious and socially progressive. Some researchers emphasize that companies and/or supply chains that implemented either of these philosophies are inherently ready to start working toward the other one as well [148]. When Lean, sustainability, and supply chain management are melted in the same pot, it becomes one broad theory, which covers a range from the product design phase to end-of-product-life management including reverse logistics. This creates a necessity to benchmark lean and sustainable operations to ensure measurement and comparability of truly sustainable performance, as well as establishment of a reward mechanism through a rating scale [274,275]. Some authors discuss that cost of compliance with environmental regulations would damage economic sustainability of an organization, while many studies including EPA's publications conclude that lean and sustainability practices can be combined to strengthen and fill the gaps in each other to achieve truly sustainable outcomes [164,168,276]. Moreover, Hartini, and Ciptomulyono (2015) conducted a study among Shingo Prize (America's most prestigious Lean designation) winners and found that higher environmental performance results were present for corporations with implemented lean systems [101]. To neutralize any sort of potential conflicts and to accurately map the interaction between both paradigms, more effort needs to be put in by all associated parties. Sustainability is here to stay, and sustainability awareness has been increasing recently. There are even banks offering loans with favorable interest rates to support sustainability initiatives [146]. Consequently, in the light of stated opinions from many scientists, it can be concluded that:

Well-established maturity of lean could provide a good foundation for new frameworks and paradigms [277]. Existing gap for lean-X concepts have been highlighted in the literature [130].

Lean philosophy could serve as a catalyst to promote better sustainability performance [90,107,149,188].

Lean and sustainability can co-exist and contribute to financial, environmental and social improvements despite of some inherent differences due to the nature of each philosophy [150,165,203,204,278].

Lean and sustainability integration has some soft spots in terms of technical tools to measure all aspects of TBL concept, which may be covered for through further integration with other methodologies with stronger quantitative toolkits such as Six-Sigma, LCA, etc. Such an integration has also been highlighted by many researchers [161,279–283].

3.9.1. Past Lean-Based Sustainability Assessment Frameworks

As a part of convergent mode of SLR procedure, previously proposed lean-driven sustainability assessment frameworks were also identified. Both regulative bodies and academics have started to release and propose sustainability assessment frameworks involving certain lean methods starting in 2000. Five U.S. EPA publications were reviewed in addition to SLR articles for the purposes of this section. In 75 previous studies, various lean-based sustainability assessment tools were proposed. These tools were evaluated based on three criteria namely, holistic sustainability (TBL) strength, sustainability benchmarking capability, and the involvement of lean tools. Some of these proposed frameworks had macro-level metrics, while others focused on shop-floor-level activities. Moreover, as discussed in descriptive results section, a high majority of articles target either intra-organizational assessment or inter-organizational sustainability performance. Scalability issues have been evident in most of proposed frameworks. Since the lean-based sustainability assessment concept is still relatively immature, many proposed frameworks had partial sets of KPIs for sustainability performance measurement. Moreover, only 13 of 72 past studies had some sort of benchmarking perspective, and only five of them had a well-established benchmarking capability. A complete list of articles that propose sustainability assessment tools/frameworks can be found in Appendix A.

The sustainable value stream mapping (Sus-VSM) tool proposed by Simons and Mason (2002) is one of the very first frameworks in the field [173]. In their study, Simons and Mason tried to measure and assess CO_2 emission levels of logistics activities for the food sector supply chains while keeping the value-added/non-value-added ratio at a high rate. The U.S. EPA has also tried to clear the path towards lean-driven true sustainability by releasing several publications between 2000 and 2011. In 2000, the U.S. EPA released the Lean and Green SCM Framework that consisted of guidelines and examples for reducing cost factors associated with SCM activities while improving environmental performance [201]. In a 2007 publication, the EPA created a foundational framework for environmental sustainability using three lean tools namely, VSM, Kaizen, and 6S (5S + Safety) [164]. This toolkit also consisted of implementation strategies of the proposed framework. Furthermore, the U.S. EPA rolled out two other lean-based frameworks to tackle water and chemicals usage problems, as well as energy consumption inefficiencies and climate change issues in their publications released in 2009 and 2011 [284,285]. Whitman et al., (2006) proposed a framework called the waste stream prioritization method (WSPM) to incorporate an environmental index into VSM to prioritize the harmful impact of various pollutants on air and water [286]. Waste identification and toxicity rating procedures were used within the framework. In 2007, Sawhney et al. came up with the en-lean model to assess the impact of certain lean principles on waste generation and resource consumption, as well as environmental and social sustainability performance [287]. Versatility of the model was proven through a tailored application in the metal cutting sector. In another study, Lai et al., (2008) developed and tested an integrated model called the extended value stream model [288]. The authors tried to track and assess both economic efficiency and environmental impact of packaging process of a U.S. automobile parts manufacturer through use of KPIs designed for division managers. The authors concluded that while integration of economic and environmental impact assessment of manufacturing and logistics operations is feasible, it is very complex due to the interactions among different dimensions of sustainability. The publication of Jr. Torres and Gati (2009) was the last study published prior to 2010 [24]. The authors developed an Environmental VSM (EVSM) and tried to visualize raw water usage and cost associated with production processes in a sugar and alcohol manufacturing plant. Through EVSM implementation, 20,000 cubic meters of water waste has been identified.

All other articles proposing sustainability assessment tools/frameworks were published in between 2010 and 2017, with intensified prominence toward the end of review period, as can be observed in Figure 9. Paju et al., (2010) used a variation of VSM, named sustainable manufacturing mapping, which incorporated discrete event simulation and LCA into traditional VSM structure [220]. Kuriger and Chen (2010, 2011) worked on a modified VSM, named the energy and environment VSM (EE-VSM), to track energy and material consumption, along with other traditional performance measures [223,289]. Although their framework was successful for its intended purposes, it was significantly lacking economic and social metrics. Ho (2010) addressed quality and environmental management concerns, as well as occupational health and safety issues through a 5-S-based integrated lean-TQM model [56,155]. Proposed checklists within the study were designed to measure competitiveness and global sustainability, however, a clear benchmarking methodology was not presented in either publication. Presley and Meade (2010) worked on an enterprise performance management (EPMM) framework to benchmark enterprise level sustainability in construction industry [290]. The framework consisted of various KPIs for TBL dimensions with assigned weights to construct benchmarking matrix. On the other hand, proposed methodology slightly lacked visualization perspective and was designed for a single industry, which weakened its inter-sectoral benchmarking capability. A group of researchers proposed sustainability measures/metrics to be used in a balanced score card procedure for lean and green SCM in two different studies [206,291]. However, how to calculate and document sustainability performance of supply chains remained unexplained throughout the studies. In a more recent study, Duarte and Cruz-Machado (2017) tested an improved version of the previous model in the automotive industry with better performance metrics and benchmarking capability [292].

Kim and Min (2011) developed a framework consisting of two different performance indices, namely, the logistics performance index (LPI) and the environmental performance index (EPI), to focus on the international sustainability analysis of supply chains [293]. Both indices served well for benchmarking purposes but lacked emphasis on the social pillar of sustainability. In another past study, Vinodh et al., (2011) proposed the eco-function matrix incorporated with Sus-VSM, 5S, and Kaizen methodologies [225]. The proposed tool focused on waste detection and elimination by means of material usage and environmental impacts at intra-organization level. Dadashzadeh and Wharton (2012) worked on a version of Green VSM with an intensified focus on the environmental sustainability pillar [294]. The authors focused on both gear manufacturing and service delivery functions of an IT department for waste and environmental impact identification purposes. In the same year, Azevedo et al., (2012) came up with lean and green framework for sustainable development in the context of upstream supply chains [267]. The framework consisted of three performance metrics for each pillar of sustainability and had no clear definition from a benchmarking perspective. On the other hand, the information infrastructure model developed by Lees et al., (2012) was aimed to detect non-productive GHG emission factors, as well as energy consumption inefficiencies in the case of brewing industry [295]. The authors proposed measuring non-productive consumption (NPC) and non-productive GHG (NGE) levels for performance comparison and waste detection purposes. Li et al., (2012) developed a carbon efficiency indicator to evaluate carbon emission performance of products and processes in a printed circuit board manufacturer [296]. The proposed efficiency indicators were incorporated in VSM to visualize and track the data at an intra-organizational level. Smith and Ball (2012) worked on developing guidelines for modelling of material, energy, and waste (MEW) process flows [297]. The model intrinsically leaned towards keeping continuous track of material and energy usage, as well as carbon emissions and waste generation associated with consumption rates. Therefore, holistic sustainability and benchmarking perspectives were not featured. Wang et al., (2013) combined lean, green, and social responsibility practices and created an evidence-based framework called composite practices framework [143]. Three KPIs for each sustainability pillar were selected and tested at a Chinese automotive parts manufacturer for effectiveness. In another intriguing study, Roosen and Pons (2013) developed an environmental impact index and integrated it into VSM from an intra-organizational perspective [298]. This framework had strong visualization features and a decent benchmarking methodology. However, it was slightly biased toward the environmental pillar of TBL.

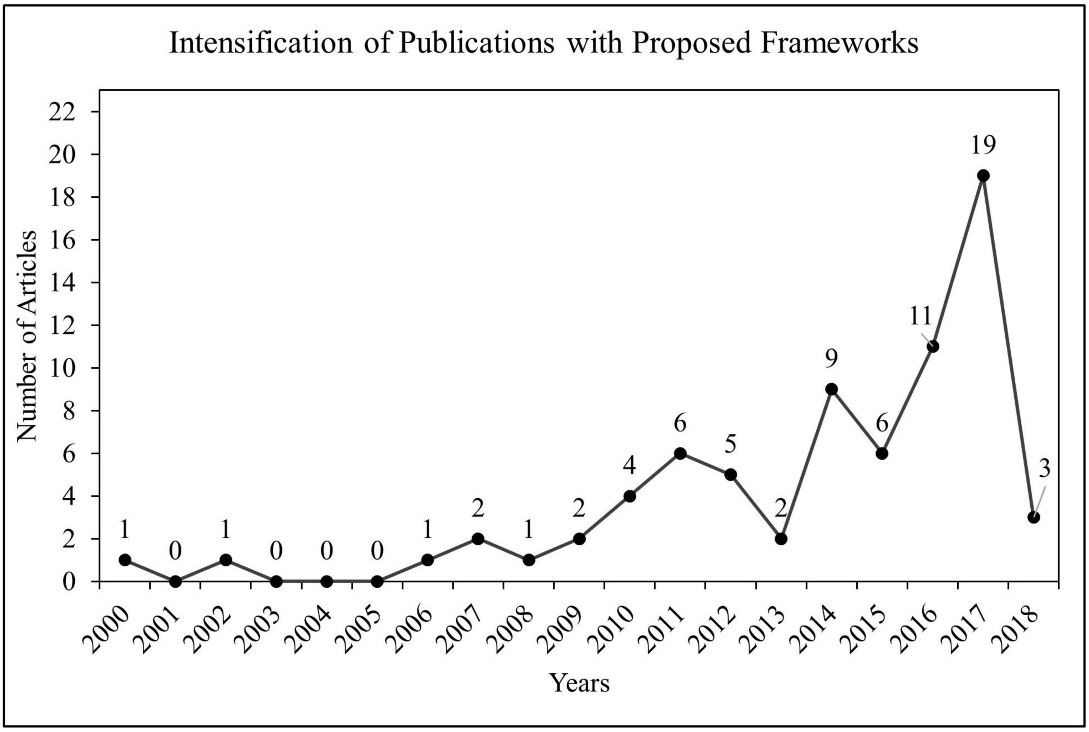

Figure 9. Intensification of publications with proposed frameworks over time.

As can be seen in Figure 9, effort put in by researchers to solve sustainability problems through lean initiatives has intensified starting in 2014. Faulkner and Badurdeen (2014) built upon Sus-VSM of Simons and Mason (2002) and strengthened the concept with better metrics, especially in terms of the social sustainability pillar [216]. Brown et al., (2014) studied applicability of enhanced Sus-VSM concept in three detailed case studies from three different manufacturing firms [184]. Outcomes were in favor of the validity and usefulness of proposed framework. Sus-VSM also appeared in a more recent work published by Helleno et al. in 2017 [299]. The authors conducted a five-year long research study to propose a new set of KPIs with detailed equations for each sustainability pillar. Then, the meaningfulness of the KPI set was tested and ensured in three different manufacturing settings, namely, cosmetics, thermoplastic products, and aluminum kitchen utensils. However, this version of Sus-VSM also lacked a benchmarking capability, similar to its predecessors. Marimin et al., (2014) proposed a green value stream mapping tool (GVS) that relies on the green productivity index (GPI) calculations [229]. GPI was calculated as a ratio of economic indicator and environmental indicator to measure sustainability performance. The study did not have a focus on social sustainability. Therefore, it was able to offer a partial benchmarking perspective with the GPI. Banawi and Bilec (2014) approached the sustainability issues of the construction sector from the combined perspective of lean, green, and six-sigma by proposing a VSM based framework [221]. The framework was designed to take advantage of lean-green synergies, while prioritization of sustainability related issues was ensured by six-sigma tools. More recently, Cherrafi et al., (2017) and Ben Ruben et al., (2017) studied integration of lean, six-sigma, and green methodologies to achieve better sustainability performance [158,300,301]. Cherrafi et al. proposed a green, lean, six-sigma (GL2S) framework to increase efficiency of resource consumption while enhancing economic, environmental, and social sustainability performance of product systems. GL2S was applied to four different organizations and the results of initial data analysis showed up to 40% increased resource consumption efficiency, as well up to 12% as energy and mass stream cost reductions. Ben Ruben et al. initially conducted a study to identify a road map for developing a lean six-sigma framework with environmental focus. Then, the proposed composite framework that was deployed onto an Indian automotive component manufacturing firm. Based on the results of the case study, internal defect rate was reduced to 6000 ppm from 16,000 ppm, along with some meaningful environmental impact reductions [301].

Another model empowered by synergies between lean and green was proposed by Pampanelli et al., in 2014 and 2015 [110,113]. The authors worked on lean and green Business Model in two different studies to improve environmental performance while simultaneously ensuring economic sustainability. Verrier et al., (2014) reviewed the lean and green literature to develop a repository and an indicator for lean and green benchmarking [58]. The study was one of the few studies with a benchmarking perspective. The authors discussed difficulty of finding KPIs with a wide applicability range across different sectors. Mutingi et al., (2014) developed a framework, named the taxonomic performance measurement framework, to measure sustainability performance within the context of SCM [302]. The proposed concept had a strong emphasis on the environmental aspect, but with less focus on the other two pillars. The authors identified and discussed major green supply chain strategies and their impact on SCM activities. White and James (2014) worked on an extension of traditional process mapping with a purpose of identifying green waste [303]. The purpose of the framework was to detect environmental wastes in a manufacturing system by taking advantage of the documentation power of the process mapping tool. Egbue et al., (2014) were among the researchers who combined lean principles with life cycle analysis [304]. The proposed framework aimed to achieve waste identification at different life cycle stages to ensure successful pollution control and prevention.

In 2015, surge rate of proposed frameworks slightly decreased when compared to overall trend as can be interpreted from Figure 9. One of the six models proposed in 2015 was carbon-value efficiency VSM [268]. The lean and green-driven framework could achieve 64.7% carbon-value efficiency and 29.9% lead time reduction in metal stamped parts production, respectively. Bhasin (2015) has approached the sustainability concerns through lean gains from the perspectives of economic and social sustainability [82]. The author compared the strengths and weaknesses of major lean audits, such as Eugene Goodson, Shingo Prize, EFQM Excellence Model, etc. The relationship between lean wastes and pre-identified audit dimensions were also discovered before the development of a lean maturity scoring system. On the other hand, Dubey et al., (2015) have come up with the world-class sustainable manufacturing (WCSM) framework to assess sustainability performance [137]. A conceptual framework evaluated the sustainability pillars under seven constructs to measure firm performance. Reliability and validity of the proposed framework was checked trough survey-based data collection. In another study, Kasava et al., (2015) applied one of the most inclusive frameworks, for which a foundational ground was established by Mohd Yusof et al. in 2013 and was deployed in aircraft maintenance operations [175,305]. The sustainable domain value stream mapping (SdVSM) framework employed KPIs of the Sustainable Manufacturing Repository (SMIR) of NIST and was successful at measuring and benchmarking sustainability performance of maintenance operations through the help of VSM. As an innovative solution to waste detection and management in business systems, Kurdve et al., (2015) proposed waste flow mapping (WFM) and integrated operations management with environmental management practices to contribute to sustainability performance [306]. The focus of the framework was on environmental and economic pillars without any benchmarking concerns. Sproedt et al., (2015) proposed a simulation-based assessment tool involving a component called the environmental value stream map (E-VSM) [307]. Within the scope of this framework, performance evaluation and decision making were based on company specific KPI selection and cost associated with improvement actions. E-VSM had strong emphasis on environmental performance with partial focus on the economic pillar. However, the social pillar and the benchmarking perspective were not discussed in the article.

Edtmayr et al., (2016) proposed an approach to assess and track environmental impact of resource consumption through VSM-based ideal-typical re-utilization cycle tool with a purpose of promoting reuse, recycle and recovery of scrap and other types of production wastes [217]. Scrap rate and waste generation calculations were the backbone of proposed approach, while kgCO_2eq was the main KPI employed. This tool was further improved by Sunk et al., (2017) to include methods-time measurement (MTM) and process management principles along with a limited number of economic and social KPIs [230]. Applicability of the proposed tool was tested in automotive sector and successfully identified 0.42 kg waste per part produced in the system. In another impactful study, Azevedo et al., (2016) developed the derivative of index construction model to assess upstream supply chain sustainability [308]. The model consisted of GRI sustainability KPIs. Index calculations and scalability of the proposed framework were documented throughout the study. This framework was one of the concepts that did not involve a visualization/mapping component. Thanki et al., (2016) worked on a hybrid lean and green system for SMEs to sustain competitive advantage in fiercer market conditions [252]. The authors identified TPM (21%) and ISO 14001 (26.2%) as the most significant Lean and Green initiatives through an analytical hierarchy process (AHP). On-time delivery for lean and emission reduction for green practices were also highlighted as the most critical KPIs. One year later, AlJaberi et al., (2017) employed the AHP methodology to develop a framework for the criteria selection process of sustainability assessment in the healthcare sector [309]. Customer satisfaction level was determined to be the most important criterion, followed by the employee satisfaction rate, continuous improvement, lean management, and corporate social responsibility, consecutively.

Kusi-Sarpong et al., (2016) assessed green supply chain practices in the mining industry and concluded that strategic supplier partnership (SSP) was the most influential GSCM practice leading to sustainable operations [310]. Moreover, based on the feedback received from managers of the firms in the sector, potential of lean and SSP to generate the greatest sustainability returns for organizations was also discussed in the study. Thanki and Thakkar (2016) studied another graphical tool, value-value load diagram (VVLD) to calculate an eco-leanness index and to identify process improvement opportunities with a purpose of efficient use of available resources [233]. The validity of the proposed framework was demonstrated in a manufacturing firm located in India. VVLD was able to help with the identification of resource usage inefficiencies. The tool had a focus on economic and environmental pillars without any benchmarking perspective.

Lean, agile, resilient, and green (LARG) business frameworks and index models were among popular concepts that have been addressed in five publications from 2012 to 2016. Cabral et al.,

(2012) worked on LARG analytic network process to deliver a tool to assist decision-makers with choosing the most appropriate supply chain KPIs for measuring and comparing their performance against industry standards [38]. Duarte and Cruz-Machado (2013) studied the lean and green business model by evaluating the assessment structure of existing awards, standards, and prizes associated with Lean and green performance [235]. The authors also explained the road map for lean and green transformation based on seven criteria. Azevedo et al., (2016) proposed a LARG index to benchmark automotive supply chain performance as a function of weighted KPIs for each management practice [105]. Although the framework lacked a holistic TBL view, it presented a strong benchmarking capability. Govindan et al., (2014) evaluated the same concept and tested its applicability for the automotive sector [311]. The authors concluded that social sustainability was among the limitations of the proposed framework, while observing that waste elimination, supply chain risk management, and cleaner production practices had a significant impact on all pillars of TBL within the context of SCM. Garza-Reyes et al., (2016) proposed the sustainable transportation value stream mapping (STVSM) framework designed to take advantage of lean and green synergies to tackle issues related to economic efficiency and environmental performance of road transport operations [312]. A case application of the proposed tool contributed to reduced CO_2, NO_x, CO, and HC emissions along with some economic performance improvements. Another popular VSM-based framework type that attracted attention of researchers was energy value stream mapping. Müller et al., (2014) [313] and Verma and Sharma (2016) [265] tried to identify value-added and non-value added time and energy consumption in production and logistics settings as a part of waste elimination activities while Cosgrove et al., (2017) [264] focused on the identification of direct, indirect, and auxiliary energy consumption by significant energy users (SEUs) in production facilities. Cost factors associated with consumption rates were also addressed within the scope of lean principles. The authors concluded that auxiliary energy consumption provides the best opportunity to eliminate waste and to achieve savings. However, all three studies had emphasis on energy consumption and lacked a holistic TBL perspective, as well as benchmarking capability. Within the scope of the EVSM concept, Li et al., (2017) integrated a Sankey tool with EVSM methodology to evaluate value stream flows of manufacturing systems in terms of energy, material and time [314]. Usefulness of the proposed tool was tested in an aluminum recycling facility. The tool was successful at identifying process inefficiencies, such as increased gas consumption and prolonged process time in soaking pit processes due to long waiting times and frequent break downs of the hot mill.

LCA integrated VSM frameworks have become more popular and prevalent after 2015. Vinodh et al., (2016) handled TBL from a total life cycle aspect and assessed the sustainability performance of an automotive component manufacturer [315]. The proposed framework had four, seven, and three KPIs for environmental, economic, and social sustainability pillars, respectively. The proposed tool helped with reduced raw material and energy consumption, cycle time, value-added, and non-value-added costs. The future state map also indicated a substantially lower level of air acidification and carbon emissions. In a more recent study, Cheung et al., (2017) incorporated lean and LCA methodologies to reduce the environmental impact of production processes of plastic injection molded parts [222]. Through deployment of the proposed framework, 40% combined performance enhancement in climate change impact, human toxicity, photochemical oxidant formation, acidification, and eco-toxicity was recorded. On the other hand, Fornasiero et al., (2017) proposed a method that combined LCA with a discrete simulation method to measure sustainability of customization strategies in supply chain structures [256]. Lean's involvement with this framework was limited to quantity and quality control metrics within evaluated supply chain management strategies. Fu et al., (2017) studied on a framework named green embedded lean production model (GELPM) to improve the economic and environmental performance of production facilities for increased competitiveness [316]. The framework was deployed onto production processes of a dairy products manufacturer and was able to achieve various benefits in material efficiency, energy savings, pollution reduction, quality improvement, cost reduction, and delivery time.

In an economic sustainability centered study, Dabic et al., (2016) worked on a 20-Keys methodology to ensure sustainable development through continuous cost reduction [317]. The authors highlighted that success of the proposed methodology was strongly correlated with senior management's active participation and leadership, as well as with sufficient resource allocation. On the other hand, Kumar BR et al., (2016) came up with LeGreen framework to enhance green performance of supply chains through sustained lean gains [318]. The framework had an environmental performance focus with limited cost factor optimization. However, social sustainability performance and benchmarking perspective was not discussed within the study.

In an effort to benchmark sustainability performance of manufacturing firms, Latif et al., (2017) developed a model called the overall sustainability index (SI) with a focus on energy efficiency, waste management, and workers' health and safety [319]. Although the index construct was solid, the proposed index could have been improved with stronger emphasis on economic performance assessment. Vimal et al., (2015 and 2017) worked on sustainability frameworks for manufacturing systems in two graph-theory based studies [320,321]. In 2015, environmental performance of a metal arc welding process was improved through the proposed methodology, whereas, in 2017, the authors developed a scoring tool called overall organizational sustainability (OSS). This scoring tool consisted of numerous metrics to assess the sustainability performance of manufacturing organizations in terms of environment, economy, business, and society. However, the complexity of the proposed benchmarking perspective could hinder its wide-spread application across sectors. On the other hand, Yang et al., (2017) approached sustainability theory from the perspective of value captured/uncaptured with a purpose of developing a sustainable value analysis tool [322,323]. In one study, the value uncaptured concept was developed and tested in six case studies to ensure validity of concept, whereas, in the next study, the concept was turned into a sustainable value analysis tool that would aid organizations with identification of value uncaptured along the life cycle of a product. Although theoretical and conceptual frameworks were quite detailed and definitive, no quantitative metrics were addressed across the two studies due to the nature of the proposed framework. In another recent study, Ferrera et al., (2017) provided an overview of MAESTRI total efficiency framework (MTEF) that combines continuous improvement, optimization strategies, and waste minimization theories with an Internet-of-Things infrastructure with a purpose of leveraging efficiency and sustainability of manufacturing industries [75]. The framework had emphasis on economic and environmental pillars of TBL, with an innovative perspective of Internet-of-Things (IOT) to alleviate current scalability issues. Since the framework is a work-in-progress, performance metrics are yet to be announced.

In some studies, environmental consciousness was brought into the game through Eco-Lean perspective. Skornowicz et al. (2017) empirically tested eco orbit view framework in two case studies and concluded in the favor of increased economic and environmental performance with significant improvements in waste generation and resource consumption [324]. In another study, Gomes et al., (2017) worked on multi-layer stream mapping (MSM) to assess economic and environmental performance and efficiency of production systems [325]. Baptista et al., (2017) has built upon work of Gomes et al. and integrated it with eco-efficiency integrated methodology production systems (ecoPROSYS) [326]. The framework has also addressed benchmarking perspective with an integrated efficiency index.

Some of the recent studies dedicated serious amount of effort to benchmark sustainability performance in various TBL pillars. Tomelero et al., (2017) developed a lean environmental benchmarking (LEB) tool to measure environmental performance of cutting tool activities at the strategic planning level [327]. Scalability of the proposed tool was not discussed in detail throughout the study. In another study, Banerjee and Ganjeizadeh (2017) worked on a leagility index for SCM sustainability with strong emphasis on economic pillar [328]. Environmental sustainability was not among the purposes of the proposed framework. Ramos et al., (2018) were also among the researchers who studied sustainability performance benchmarking methodologies [329]. The lean cleaner production benchmarking (LCPB) method was proposed by authors of the study to assess and promote cleaner production to improve mainly environmental performance. The LCPB method was employed in Brazilian manufacturing firms to compare cleaner production performance of 16 different firms and the outcomes confirmed the validity of the proposed tool. In one of the most recent studies, Arce et al., (2018) modified the VSM methodology to accommodate requirements of the ergonomics discipline and introduced ergonomic value stream mapping tool (ErgoVSM) [231]. The purpose of the tool was to improve ergonomic conditions of workplaces. According to the outcomes of a case study conducted in an ISO 9000 certified facility, ErgoVSM was effective at identification of space, workforce capacity, productivity, work-in-process, and mental work load inefficiencies.

Finally, the last study reviewed within the scope of SLR from the perspective of framework development was publication of Souza and Alves (2018) [226]. The authors delivered the lean-integrated management system for sustainability improvement (LIMSSI), which had strong and holistic TBL perspective. This management level tool was aimed at helping organizations with increased competitiveness through improved efficiency in all pillars of TBL. The tool was designed to take advantage of synergistic integration of lean philosophy with other management systems, such as the environmental management system (EMS), the quality management system (QMS), the social responsibility management system (SRMS), and the occupational health and safety management system (OHSMS). However, some sort of scoring index or benchmarking perspective was not addressed within the scope of the study.

Overall, a majority of the proposed frameworks were designed to enhance at least one sustainability performance characteristic with help of lean methodology. Many of them succeeded in measuring performance of product and service systems, to the extent, and business level, of the proposed KPIs. Overall strength of the proposed frameworks included effective visualization of processes and flows, continuous improvement purposes, resource and energy consumption capturing, pollution detection, and value-added/non-value-added analysis. However, some of the proposed tools/frameworks also had some epidemic issues, such as bias toward one of the sustainability pillars, lack of benchmarking capability, incomplete and impractical KPI sets, as well as focusing solely on intra- or inter-organizational assessment. Moreover, some propositions ignored vertical or horizontal scalability issues, while some frameworks were designed to serve a single industry segment. Another shortcoming of some frameworks was the lack of a clear definition of a deployment plan. Finally, a weak social sustainability component of the proposed frameworks was observed for some of the concepts, which is a clear sign of a lack of a holistic TBL perspective. Therefore, it can be concluded that:

> *There is still a lack of an assessment tool and performance measurement system that could simultaneously assess and benchmark both efficiency and true sustainability level of organizations and supply chains. Moreover, any kind of future framework should be proposed along with a deployment plan to ensure clear guidance for practical applications.*

3.9.2. Future Research Opportunities in the Field of Lean Driven Sustainability

In Table 5, identified research gaps and opportunities are presented. The list was compiled based on the interpretation of both SLR outcomes and some supportive documents that were not part of the SLR procedure. This section of the SLR was carried out to discover and describe existing gaps in the literature and the future direction of research in the intersection zone of impact and target research streams. The ultimate objective could be achieved only after existing gaps are filled through future research studies. The puzzle of true sustainability will only be solved following the achievement of the ultimate objective. Moreover, findings of SLR also tested the adequacy of the research questions defined in Section 1.1.

Table 5. Identified future research opportunities.

Research Opportunity	References
• Lack of assessment tools and performance measurement systems to measure efficiency and sustainability of supply chains for specific industries and processes.	[10,78,82,92,101,132,134,136,219,257]
• Limited evidence showing economic, environmental and social impacts of simultaneous deployment of lean and sustainability practices on organizational performance.	[88,90–92,219]
• Scarcity of proposed solutions to macro supply chain issues such as counterfeit food and medicine, hunger relief, disaster response, child labor and conflict minerals.	[14,21,43,46,59,330–333]
• Limited application of lean and sustainability to supply chain of SMEs.	[10,144,218]
• Lack of new holistic models, frameworks and methods for designing and managing global supply chains.	[21,78,82,109,132,257]
• Lack of comprehensive lean-driven sustainability frameworks that could simultaneously generate solutions for various sustainability issues of organizations and supply chains.	[88,140]
• Limited co-implementation of lean-driven sustainability principles in service, healthcare and education sectors.	[10,92,109,261]
• Limited research on social dimension of sustainability. A clear bias towards either economic or environmental performance.	[78,101,128,133,334]
• Lack of a customer-driven culture throughout the supply chain considering contingent theory.	[88,149]
• Lack of evidence that supports implementation feasibility and applicability of integrated tools in underdeveloped countries. Geographical analyses show that implementation only occurred in developed geographical regions.	[10,46,76]
• Limited research on negative impacts of co-implementation of lean and sustainability.	[80,261]
• Limited research on proactive sustainability solutions. Greater focus was channeled toward reactive propositions.	[14,80,91,206,318]
• Necessity to re-evaluate current key performance indicators (KPIs) to ensure comparability and benchmarking across all organizations and sectors.	[134,266]
• Limited research on sustainability curriculum development for higher education.	[93,190,208]
• Limited sustainability research on reverse logistics, closed loop SCs and waste management.	[109]

4. Limitations of the Study

Although this review was conducted with extreme due diligence to ensure the highest level of comprehensiveness and accuracy, it still has some technical and practical limitations. First, the number of major databases scanned were set to 5 due to feasibility and practicality constraints. Second, given the high level of human intervention, the database creation phase could be slightly subjective based on the authors' understanding of lean manufacturing, lean-SCM and sustainability methodologies. The same limitations could be applicable to the industry segment classification. Furthermore, despite systematic characteristics of the literature review procedure, some articles that should have been included in the study might have been left out due to limitations associated with picking and sorting power of search engines. Next, although the highest possible technology engagement was ensured through use of NVivo 11, Excel spreadsheets, and Minitab 17, there could still be some minor unnoticed human errors associated with data coding and the interpretation of coded data. On the other hand, this study only evaluated the relationship of sustainability with lean manufacturing and lean SCM concepts, linking sustainability with other paradigms was beyond the scope of the study. Therefore, the strength of the relationship was not compared with that of other management systems. However, the outcomes of the study are comprehensive enough to contribute to the body of knowledge in this field.

5. Conclusive Remarks

Outcomes of this extensive review are expected to serve as a guide for researchers and practitioners to develop an accurate research agenda for their work without the hassle of "try and fail experience". Based on the research findings, it can be concluded that interest in lean-driven sustainability has gained some momentum recently. Researchers from Europe, USA, and Asia are paying more attention to it than their colleagues in other parts of the world. Currently, a majority of the existing literature is being dominated by theoretical papers that are followed by empirical studies with multi-sectoral focus. Synergies between lean and sustainability are stronger than their divergences. Lean could be successfully used to set the foundation for sustainability frameworks and both methodologies could contribute to true sustainability. However, there are some internal and external barriers associated with integration of lean and TBL philosophies. Ways to control for identified divergences and weaknesses of lean and sustainability concepts should be part of a future research agenda. This could be achieved through the introduction of other methodologies into lean-driven sustainability frameworks whenever possible.

Apparently, lean-driven sustainability still has a great deal of untapped potential which is yet to be discovered. Moreover, the review of past frameworks and tools was not conducted with a purpose of criticizing the previous work of colleagues. The sole purpose of this review was to identify strengths and weaknesses of proposed techniques to set the right direction for future research projects by pointing out existing improvement opportunities. A complete and versatile tool that has the capability to assess and benchmark efficiency and sustainability of organizations and their supply chains is yet to be developed. Researchers and professionals should channel their concentration on the development of new methodologies, frameworks, and tools that could help with the achievement of truly sustainable organizations and supply chains compliant with the proposed ultimate objective concept.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/10/7/2544/s1, Table S1: List of SLR Articles.

Author Contributions: Both C.T. and R.G. contributed to the design of the research and to the writing of final version of the manuscript. C.T. gathered data, created the raw and final database, performed the descriptive and contextual analysis, drafted the manuscript and designed the figures and tables. R.G. supervised the entire work and proofread the drafted manuscript.

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Appendix A

Table A1. List of Articles with Proposed Sustainability Assessment Tools Involving Lean Tools.

Proposed Tool	Year	Economic Metrics	Environmental Metrics	Social Metrics	Benchmarking Perspective	Source(s)
Sustainable Value Stream Mapping (Sus-VSM)	2002	Partial	Partial	–	–	[173]
EPA Lean and Environment Toolkit	2007	–	+	Partial	–	[164]
EPA Lean, Energy and Climate Toolkit	2011	Partial	+	–	–	[335]
EPA Lean and Green SCM Framework	2000	+	+	–	–	[201]
EPA Lean and Water Toolkit	2011	Partial	Partial	–	–	[285]
EPA Lean and Chemicals Toolkit	2009	Partial	Partial	–	–	[284]
Environmental VSM (EVSM)	2009	Partial	Partial	–	–	[24]
Sustainable Manufacturing Mapping (SMM)	2010	Partial	+	Partial	–	[220]
Energy and Environment VSM (EE-VSM)	2010	–	Partial	–	–	[289]
Green VSM	2012	–	+	–	–	[294]
Sustainable Value Stream Mapping (Sus-VSM)	2014	Partial	+	+	–	[216]
Sustainable Value Stream Mapping (Sus-VSM)	2014	Partial	+	+	–	[184]
Green Value Stream Mapping (GVS)	2014	+	+	–	Partial	[229]
Ideal-Typical Re-Utilization Cycle Tool	2016	–	Partial	–	–	[217]
MTM-Sustainable VSM Development	2017	Partial	Partial	Partial	–	[230]
Lean, Green and Six Sigma Framework	2014	–	+	–	–	[221]
Lean and Green Model	2014	Partial	+	–	–	[110,113]
Derivative of Index Construction Model	2016	+	+	+	–	[308]
Framework for Lean-Green System	2016	Partial	Partial	–	–	[252]
Fuzzy-DEMATEL for Green SCM	2016	+	+	+	-	[310]
EPMM for Enterprise Level Sustainability	2010	Partial	Partial	Partial	Partial	[290]
Framework for Lean and Green Mgmt.	2014	+	+	Partial	Partial	[58]
Taxonomic Performance Measurement Framework	2014	Partial	+	Partial	–	[302]
Green-Lean Model for Sustainability	2017	+	+	+	Partial	[292]
Energy Value Stream Mapping	2016	Partial	Partial	–	–	[264,265,313]
En-Lean Model	2007	–	+	Partial	–	[287]
Balanced Score Card for Lean and Green SCM	2011	+	+	Partial	–	[206,291]
P-Mapping for Green Waste	2014	–	Partial	–	–	[303]
Lean and Green Framework for Sust. Development	2012	Partial	Partial	Partial	–	[267]
Information Infrastructure Model	2012	Partial	+	–	–	[295]
Integrated Lean-TQM Model (5S Based)	2010	+	Partial	Partial	–	[56,155]
Carbon-Value Efficiency VSM	2015	Partial	+	–	–	[268]
LARG Business Model Frameworks and Scoring Index	2016	Partial	+	–	+	[37,105,234, 235,311]
Sustainable Transportation Value Stream Map	2016	+	+	–	–	[312]

Table A1. *Cont.*

Proposed Tool	Year	Economic Metrics	Environmental Metrics	Social Metrics	Benchmarking Perspective	Source(s)
Carbon Efficiency Model	2012	–	Partial	–	–	[296]
PMS for Green SCM	2016	+	+	–	–	[318]
Lean Audit System	2015	+	–	+	Partial	[82]
Green Logistics Performance Index	2011	Partial	+	–	+	[293]
Value–Value Load Diagram	2016	+	+	–	–	[233]
Eco-Function Matrix and Sus-VSM	2011	–	+	–	–	[225]
Waste Stream Prioritization Method (WSPM)	2006	–	+	–	–	[286]
Lean-Integrated Management System for Sustainability Improvement	2018	+	+	+	–	[226]
Lean Cleaner Production Benchmarking (LCPB)	2018	–	+	–	+	[329]
Green Embedded Lean Production Model (GELPM)	2017	Partial	Partial	–	–	[316]
LCA Backed VSM Approach	2017	Partial	+	Partial	–	[222]
Sustainability Index	2017	–	+	Partial	–	[319]
Sustainable Value Stream Mapping (Sus-VSM)	2017	+	+	+	–	[299]
LCA Integrated VSM	2016	Partial	Partial	Partial	–	[315]
Lean Life Cycle Framework	2014	–	Partial	–	–	[304]
Lean Six Sigma-Environment Framework	2017	Partial	Partial	–	–	[158,301]
20 Keys Method	2016	Partial	–	–	–	[317]
GL2S Framework	2017	Partial	+	Partial	–	[300]
Analytical Hierarchical Process Framework	2017	Partial	Partial	Partial	–	[309]
Overall Organization Sustainability	2017	Partial	+	Partial	Partial	[320,321]
World-Class Sustainable Mfg. Framework	2015	Partial	+	Partial	–	[137]
Sustainable Domain Value Stream Mapping (SdVSM)	2015	Partial	Partial	Partial	+	[175,305]
Composite Practices Framework	2013	Partial	Partial	Partial	–	[143]
Waste Flow Mapping (WFM)	2015	–	Partial	–	–	[306]
Environmental Value Stream Map (E-VSM)	2015	Partial	+	–	–	[307]
Extended Value Stream Model	2008	+	+	–	–	[228,288]
Material, Energy and Waste Process Flow (MEW)	2012	Partial	Partial	–	–	[297]
Environmental Waste Value Stream Method (EW-VSM)	2013	–	Partial	–	+	[298]
Eco Orbit View	2017	Partial	Partial	–	–	[324]
Multi-Layer Stream Mapping	2017	Partial	Partial	–	–	[325]
MAESTRI Total Efficiency Framework	2017	Partial	Partial	–	–	[75]
Eco-Efficiency Assessment Method (ecoPROSYS)	2017	Partial	Partial	–	Partial	[326]
Ergonomic Value Stream Mapping (ErgoVSM)	2018	Partial	–	Partial	–	[231]
Sustainable Value Analysis Tool	2017	Unclear	Unclear	Unclear	–	[322,323]
Lean Environmental Benchmarking (LEB) Method	2017	Unclear	Partial	–	Partial	[327]
LCA-SCM Model	2017	Partial	+	–	–	[256]
EVSM Sankey Tool	2017	Partial	Partial	–	–	[314]
Leagility Index	2017	+	–	–	–	[328]

Table A2. Common Lean Tools and Their Potential Contributions to Sustainable Development (Adapted and Altered from U.S. EPA [336] and Cherrafi et al. [10]).

Lean Tools	Sustainability Contribution	References
5S	Achieves basic housekeeping activities. Promotes clean and organized work environment. Reduces health and safety risks as well as space requirements of operations. It may also increase the job satisfaction rate.	[10,55,169,225,232,241]
Kaizen (Continuous Improvement)	Creates a collective, creative, and proactive brainstorming opportunity for continuous improvement and waste elimination. Process improvements may lead to reduced environmental impacts and health hazards within or outside the walls.	[110,197,225,232,240,241,243]
Value Stream Mapping (VSM)	Helps with visualization of process flow at any stage for any product group to provide increased communication. Enables professionals to track value added and non-value-added activities along the supply chain. It is also useful for waste elimination. Excessive and unnecessary use of resources/inputs can be avoided through proper employment of VSM. This tool is often referred in LCA studies as well.	[10,164,169,184,216,225,241,262,268]
Kanban (Pull System) and Visual Factory	Employment of Kanban (Pull System) tackles excessive inventory levels, which was reported to be the most damaging form of waste. Facilitates flawless flow of goods and information within factory and outside the factory with upper and downstream operations. However, some past studies argued that it could increase energy and water consumption rates. Nowadays, as a function of new, advanced technologies, Kanban can be modified to accommodate RFID or barcode technologies. Visual Factory refers to use of signs, indicators, displays and controls coded to convenience of visual perspective to promote effective communication of information. VF makes everything visible and easy to understand for everyone. It promotes a safe work environment, and it contributes waste elimination.	[4,10,55,200,240,337]
Visual Management (Andon)	Andon is a sort of feedback system alerts associated parties when an unexpected or undesired situation occurs. It provides real-time communication and thus, problems could be instantaneously resolved before the issues passed on to further processes, which is highly associated with less material and energy use, as well as environmental waste and hazard. Andon systems could be used as a primary alert mechanism for environmental management control along supply chain processes.	[10,170,225,241]
Total Productive Maintenance (TPM)	This is a maintenance approach which aims for increased up-time, reduced cycle times, elimination of defective production, and reduced worker health hazards. TPM also increases production efficiency that promotes effective use of resources to avoid waste generation. Preventive and proactive maintenance ensures increased life span of machinery and equipment used, as well as detection of required technology improvement.	[4,169,225,232,241]
Single Minute Exchange of Dies (SMED)	SMED tackles set-up (changeover) times through process simplification, elimination of unnecessary procedures, and work standardization. It enables system to become more responsive and provides opportunity for use of smaller batch sizes as well as reduced inventory levels. Some authors link gains created by SMED to reduced emissions and reduced use of hazardous chemicals.	[10,94,161,169]
Standardized Work	Standardized work practices establish and document best practices for a specific process for continuous waste elimination. It is a kind of sustainable procedure which is open to future improvements. SW increases utilization while tackling unnecessary resource and time consumption. It also reduced the risk of work-related accidents.	[10,55,101,169,170,243,247,248,338]

Table A2. *Cont.*

Lean Tools	Sustainability Contribution	References
Plan, Do, Act, Check, Act (PDCA)	The PDCA approach is a systematic approach that tries to discover new improvement opportunities for processes. It also eases implementation and performance measurements of certain environmental and social management systems.	[107,232,236,247,339]
Jidoka (Autonomation)	Certain level of automation along with competencies of workers enhances quality of processes and products along the implementation scope. Jidoka may contribute to financial sustainability and waste generation and elimination through reduced labor, material, and energy costs. Both directly and indirectly associated with lower occurrence rates of health and safety issues.	[3,10,168,193,225,236,340]
just-in-time (JIT)	JIT goes hand in hand with Continuous Flow, Kanban Standardized Work and Takt Time to provide reduced inventories, increased liquidity, and reduced space requirements. It can be linked with both environmental and economic sustainability pillars.	[4,149,196,240,278]
Layout Reconfiguration and Cellular Mfg.	Reconfiguration of existing layouts can be performed with several purposes including, but not limited to, improvements in ergonomics design, compliance with occupational safety and environmental regulations, efficient use of capacity, resources and energy, as well as to promote process flow. Cellular manufacturing provides increased specialization, multi-skilled workforce, increased social interactions and teamwork spirit within a facility. It also forms a base for continuous improvement and efficient use of materials and energy. Increased familiarity with the work being performed and with the equipment being used reduces the risk of accidents and the rate of defective production.	[4,10,55,150,169,200,232,243,262,287, 315,341]

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