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Saeed khaled, Mohamed ; Abdelfadeel Shaban, Ibrahim ; Mostafa, Ahmed Karam Abdelfattah; Hussain, Mohamed; Zahran, Ismail; Mamdouh Yusuf Hussein, Mohamed

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Review

An Analysis of Research Trends in the Sustainability of Production Planning

Mohamed Saeed Khaled [1], Ibrahim Abdelfadeel Shaban [1,2,*], Ahmed Karam [3,4,*], Mohamed Hussain [1], Ismail Zahran [1] and Mohamed Hussein [2]

[1] Mechanical Engineering Department, Faculty of Engineering, Helwan University, Helwan, Cairo 11795, Egypt; mohamedsaeed@h-eng.helwan.edu.eg (M.S.k.); Mohamed.hussien@h-eng.helwan.edu.eg (M.H.); ismail.zahran@h-eng.helwan.edu.eg (I.Z.)
[2] Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong 999666, China; mohamed.hussein@connect.polyu.hk
[3] Mechanical Engineering Department, Faculty of Engineering at Shoubra, Benha University, Banha, Cairo 11629, Egypt
[4] Department of the Built Environment, Aalborg University, 9220 Aalborg, Denmark
* Correspondence: ibrahim.shaban@polyu.edu.hk (I.A.S.); akam@build.aau.dk (A.K.)

Abstract: Sustainability has become of great interest in many fields, especially in production systems due to the continual increase in the scarcity of raw materials and environmental awareness. Recent literature has given significant attention to considering the three sustainability pillars (i.e., environmental, economic, and social sustainability) in solving production planning problems. Therefore, the present study conducts a review of the literature on sustainable production planning to analyze the relationships among different production planning problems (e.g., scheduling, lot sizing, aggregate planning, etc.) and the three sustainability pillars. In addition, we analyze the identified studies based on the indicators that define each pillar. The results show that the literature most frequently addresses production scheduling problems while it lacks studies on aggregate production planning problems that consider the sustainability pillars. In addition, there is a growing trend towards obtaining integrated solutions of different planning problems, e.g., combining production planning problems with maintenance planning or energy planning. Additionally, around 45% of the identified studies considered the integration of the economic and the environmental pillars in different production planning problems. In addition, energy consumption and greenhouse gas emissions are the most frequent sustainability indicators considered in the literature, while less attention has been given to social indicators. Another issue is the low number of studies that have considered all three sustainability pillars simultaneously. The finidings highlight the need for more future research towards holistic sustainable production planning approaches.

Keywords: sustainability; production planning; sustainability indicators; sustainability objectives; review; sustainable production planning

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1. Introduction

Production planning is the process of making a set of decisions or a plan to ensure the correct and efficient flow of production processes according to specific objectives. These objectives mostly focus on achieving the desired product quality with the least possible production cost within the planned production schedules [1]. Production planning is a complex task that includes many decision-making problems related to various production stages such as aggregate production planning, lot sizing, and scheduling [2,3]. For example, aggregate production planning aims to match plant capacity with demand while considering lower costs [4,5]. Due to increasing the world population and production capacities, the resources of our planet are excessively consumed. Methods to safeguard these resources from vanishing are necessarily required [6,7]. Furthermore, increase of global temperatures and changes in weather patterns have increased the severity of the issue [8]. In 2015, the United Nations proposed 17 sustainable development goals. Since then, sustainability has become of great interest in many fields, especially in production systems, because the scarcity of raw materials and environmental regulations are continuously increasing. This has made production planning one of the most important research topics to support the three sustainability pillars (3Ps) (i.e., environmental, economic, and social sustainability) [9] as most of the sustainability issues can be found through all production planning stages such as aggregate production planning, scheduling, etc. [10]. In addition, the eruption of COVID-19 has caused several socioeconomic disruptions in the manufacturing and industrial firm sectors [11]. These sectors have adopted several strategies and polices to reduce the undesirable impacts. One of these strategies is to modify their production plans to apply the social distancing [12]. However, these strategies have led to many drawbacks because of the complexity of the production planning process. Moreover, production planning is connected to the product life cycle through process planning, product design, and recycling, and it is also connected with social aspects of employees and customers. Hence, many scholars have studied the production planning problems while considering the 3Ps of sustainability [9,10].

Considering at least one of the sustainability 3Ps in the traditional production planning extends its scope towards sustainable production planning [13], as shown in Figure 1. The 3Ps of sustainability could be achieved by minimizing energy consumption, greenhouse gas emissions, and increasing health and safety or training of employees [13]. For example, a low carbon process design strategy is considered a sustainable production planning objective [14]. Wichmann et al. [15] studied lot-sizing and scheduling operations to improve energy consumption by minimizing the machining time. In addition, it is of great importance that a company makes joint or integrated decisions combining various aspects of a planning process such as pricing, retailer selection, labor time, etc., while considering a more sustainable environment [16]. Some studies have reported difficulties in combining management and planning requirements with the 3Ps of sustainability [17], especially social sustainability. In this regard, it is important to revise the theoretical background of sustainability, sustainable development, production planning, and sustainable production planning.

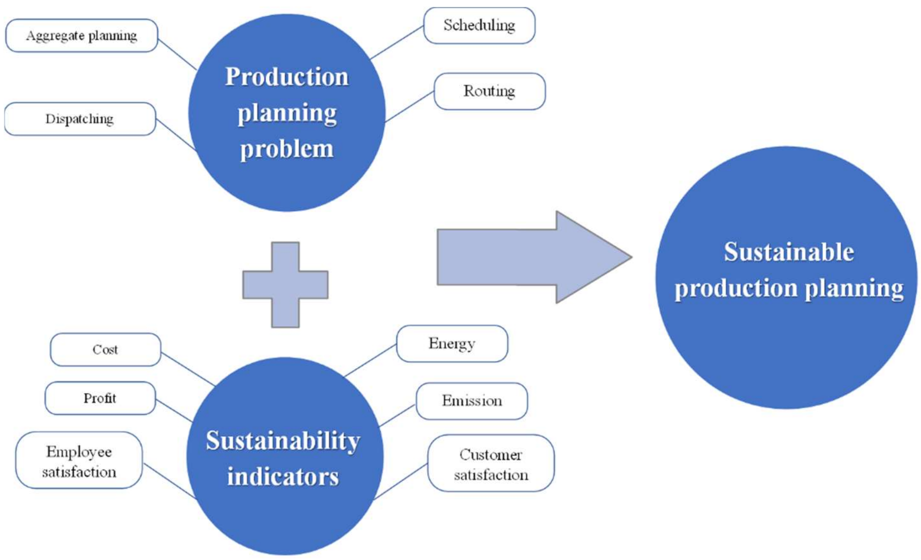

Figure 1. Converting traditional production planning to sustainable production planning.

Gaps in the Existing Reviews and Contributions

In recent years, some scholars have conducted review studies relevant to the sustainability aspects in manufacturing and production processes. Table 1 summarizes the previous reviews and presents the number of papers reviewed, the covered period, and the objective of each review. We found that only three review studies [18] considered production planning as a tool for implementing the 3Ps of sustainability. Giret, et al. [18] covered the period from 2008 to 2014 and considered only one production planning problem, i.e., scheduling. They found that the link between tactical and operational levels wasvery neglected and further studies areneeded, especially for planning activities. As for the objectives of these problems, they reported that the input-oriented energy parameters were the focus of most studies, while less attention had been given to social sustainability. Biel and Glock [19] mainly focused on energy-oriented production planning. They also reported an increase in the research of energy-oriented production planning approaches. Moreover, they concluded that most articles mainly focused on job allocation and sequencing more than any other planning problem. Bóna and Korkulu [20] addressed only one production problem, i.e., lot-sizing and its impact on social sustainability. Thus, the contribution of this work stems from the existing literature gaps. The existing literature lacks a holistic review study that analyzes the relationships among different production planning problems (e.g., scheduling, lot sizing, aggregate planning, etc.) and 3Ps of sustainability. Unlike previous review studies, the present review study focuses on all production planning problems and considers all pillars of sustainability, i.e., economic, environmental, and social sustainability.

Table 1. Classification of previous review studies.

Reference	Focus	Objective	Covered Period	No of Articles
[18]	Sustainable manufacturing operations scheduling	- Addressing sustainable manufacturing from a scheduling perspective - Classifying sustainable operation scheduling according to the orientation of the approach, the method of scheduling, and multi-objective considered	2008–2014	45
[19]	Energy-efficient production planning	- Addressing sustainable production planning but only from the economical perspective, specifical energy - Addressing decision support models that integrate energy considerations - Classifying reviewed articles mainly according to the type of production planning problem	Until 2015	89
[13]	Decision support system for sustainable manufacturing	- Addressing different decision-making methods and different sustainable indicators used in sustainable manufacturing from a product and production life cycle perspective - The resulted papers were categorized by methods, sustainable indicators, and life cycle phase.	2007–2017	23
[21]	Tools available for implementing sustainable development goals	- A scoping methodology was used to address tools available for sustainable development goals. - The review sought three main properties of each tool nature or type of the tool, purpose of the tool, and background to its development. - The resulting studies were categorized based on three main categories: mapping tools, reporting tools, and aligning tools.	2000–2018	50

Table 1. *Cont.*

Reference	Focus	Objective	Covered Period	No of Articles
[22]	Sustainable consumption and production	- Addressing a comparison of sustainable production and consumption considering differences and challenges between developed and developing countries	1998–2018	90
[20]	Social sustainability lot sizing	- Addressing ergonomics as a sustainable social objective in lot-sizing problems	Until 2019	36

The remainder of this paper is organized as follows: In Section 2, we present an overview of the different production planning problems and explain the sustainability pillars used to classify the relevant studies; in Section 3, we discuss the review methodology; in Section 4, we present the results; in Section 5, we suggest implications for future research; in Section 6, we present the conclusions.

2. Production Planning and Sustainability Pillars

2.1. Production Planning Problems

A thriving production process mainly depends on appropriate allocation of available resources [23]. Production planning is the ultimate tool for meeting increasing customer requirements, diversity of products, and a decrease in resources [24,25]. It can also enable utilizing available resources to obtain the desired quality at the least possible cost [26]. Hence, production planning plays a vital role in the production process by increasing its efficiency [27]. Production planning is considered to be a non-isolated function that depends on multiple parameters. Hence, information obtained from procurement and selling or the parameters assumed by manufacturing, engineering, finance, and material management, even marketing functions, are crucial to production planning [28] and are connected with all production stages. These parameters can be divided into multiple steps and various categories [1], as shown in Figure 2., in which we categorized production planning problems into several categories based on a categorization used by [19] and another introduced in [1] to ease the classification of the sampled articles. This does not mean that this is the only existing classification of the production planning problems, but we classified them based on the articles included in this review. For example, aggregate production planning is a more concentrated and compact version of production planning that is only concerned with a shorter period of time [29] and has a specific objective of matching plant capacity with demand while considering lower costs [4,5].

The other production planning problems can be listed as lot-sizing, scheduling, routing, loading, dispatching, and controlling [30]. Some of these steps have substeps that form problems and constraints of their own. Rasmi, et al. [31] stated that aggregate production planning was a primary step in defining other secondary parameters such as production rates, inventory levels, and workforce requirements. Biel and Glock [19] considered scheduling and capacity planning as essential tasks for performing the planning process. In addition, scheduling can have subprocesses such as operation scheduling, order scheduling, and shop scheduling [30].

Consequently, due to its connection with various parameters of a production process, production planning controls the flow of a production process [2] and ensures the smoothness of such a flow to reach the desired product [32]. Kiran [1] considered it to be the brain and the nervous system of the production program. Production planning has also been recognized as the process that ensures the availability of all materials, as well as helps ensure assembly at the right time, at the right place, and in the right quantities [33], in other words, a balance between the required orders (capacity) and the produced units [34]. Consequently, production planning is considered to be an intermediate step that connects the design of a product and its manufacturing to reach the product use and recycling, when described from a product life cycle point of view [35].

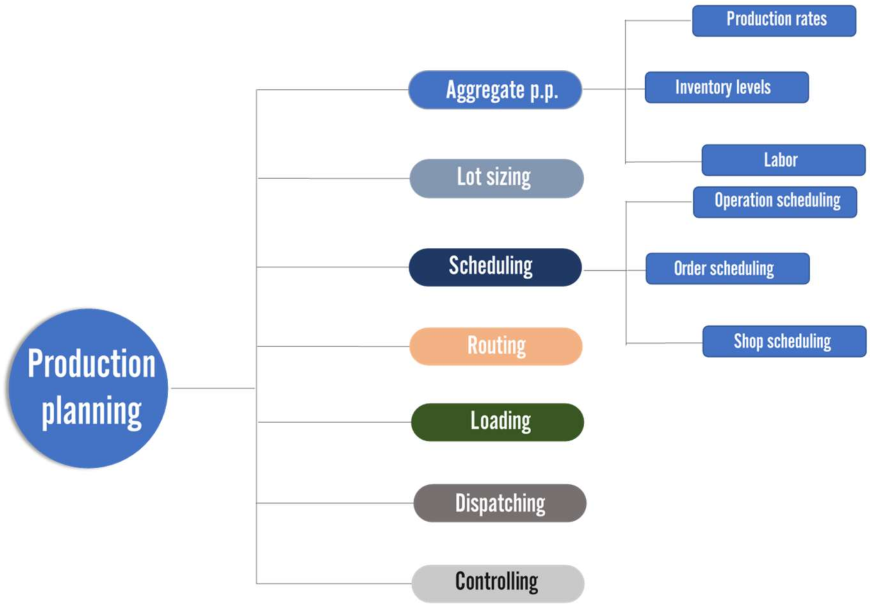

Figure 2. Production planning categorization.

2.2. Sustainability Pillars and Their Indicators

The growth in awareness of environmental consciousness has led sustainability to gain more attention during the last century [36]. Hence, the United Nations has found a specific commission for sustainability issues. This commission was formerly known as the "World Commission on Environment and Development", and then it was renamed as the "Brundtland Commission". The commission focused mainly on studying the capability of the environment to maintain stability through the 21st century. In this connection, the commission wrote a report called "Our Common Future" which established the basis of sustainable development and sustainability. In that report, sustainable development was defined as "the development that fulfils the needs of the present without compromising the ability of future generations to meet their own needs" [37,38]. In 2015, the 2030 agenda of the United Nations for Sustainable Development proposed 17 sustainable development goals, which are shown in Table 2 [39]. This table shows the extent to which sustainability goals have evolved through the years. These goals of sustainability were defined by three main pillars termed the triple bottom line (TBL), i.e., economic, environmental, and social [40], and they were considered to be the foundations to build up the generalized definition of sustainability [41,42]. Hence, this table can be considered to be a listed form of a written explanations for these three pillars. In addition, each pillar contains subterms called indicators that can define each pillar of sustainability [31,43]. Articles by [13,44] provided a similar categorization of indicators for three pillars of sustainability. The present work follows the categorization proposed in [11] and we adapted it for this review. As shown in Figure 3, the sustainability pillars are considered in production planning problems in two ways: Either a production planning problem that tackles a single sustainability pillar or a production planning problem that tackles at least two integrated pillars. For more details, each pillar contains some indictors which can be addressed in production planning problems. For example, the economic pillar addresses only two indicators, i.e., cost and profit, neglecting the investment subpillar which was not found in the sample studies of sustainable production planning problems. The environmental pillar includes three indicators, i.e., material, energy, and greenhouse gases [45]. The social well-being pillar addresses three responsibilities towards the customer, the employee, and the whole community [46]. Furthermore, at least two of these pillars are integrated.

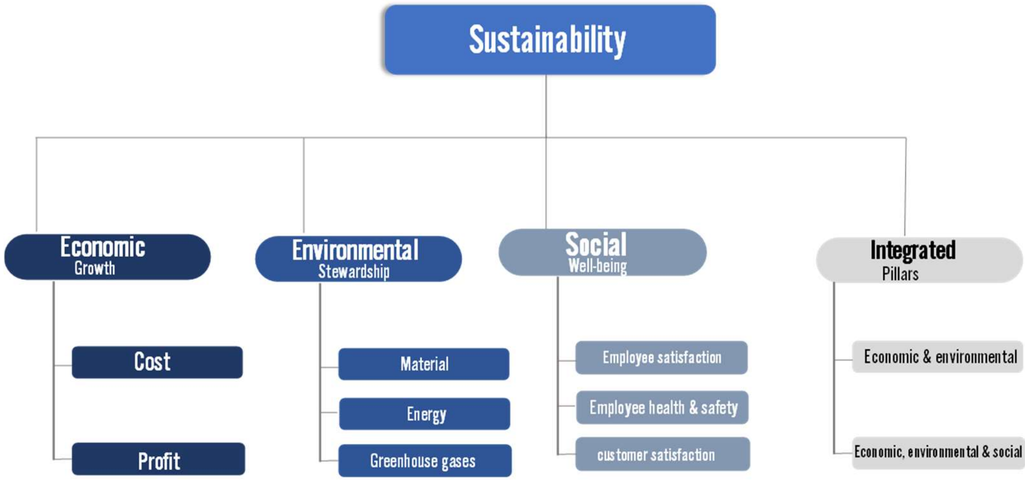

Figure 3. The categorization of sustainability indicators.

Based on the above understandings, sustainable production planning aims at decreasing the negative environmental impact while preserving energy for less consumption and a safer economic impact for stakeholders [47]. The indicator categorization shown in Figure 3 is used to classify and discuss the existing literature on sustainable production planning, which enables providing a clear and better understanding of trends and possible shortcomings in the existing literature.

Table 2. United Nations proposed 17 goals in the 2030 agenda for sustainable development [39].

Goal 1.	End poverty in all its forms everywhere
Goal 2.	End hunger, achieve food security and improve nutrition and promote sustainable agriculture
Goal 3.	Ensure healthy lives and promote well-being for all at all ages
Goal 4.	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
Goal 5.	Achieve gender equality and empower all women and girls
Goal 6.	Ensure availability and sustainable management of water and sanitation for all
Goal 7.	Ensure access to affordable, reliable, sustainable, and modern energy for all
Goal 8.	Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all
Goal 8.	Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation
Goal 10.	Reduce inequality within and among countries
Goal 11.	Make cities and human settlements inclusive, safe, resilient, and sustainable
Goal 12.	Ensure sustainable consumption and production patterns
Goal 13.	Take urgent action to combat climate change and its impacts
Goal 14.	Conserve and sustainably use the oceans, seas, and marine resources for sustainable development
Goal 15.	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
Goal 16.	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all, and build effective, accountable, and inclusive institutions at all levels
Goal 17.	Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

3. Research Methodology

In this research, a systemic literature review was conducted on sustainable production planning studies using a methodology adapted from [13] with the following steps:

Step One, define the research scope The main scope and objective of this review mainly focused on the application of production planning approaches to achieve sustainable goals. **Step two, select the search keywords** This step aimed at finding the most suitable keywords for the required review. Two sets of keywords were used. The first set included three keywords: production planning, production control, and planning, while the second set considered two keywords: sustainable and sustainability. These two sets resulted in six different combinations of search keywords. The authors used the Scopus database to perform the search, because it has one of the widest search library [13]. The search process resulted in identifying 560 articles.

Step three, define the inclusion and exclusion criteria This step aimed at identifying the most relevant articles among the identified 560 articles. Hence, the following inclusion and exclusion criteria were used:

- Only peer-reviewed articles published in English were considered.
- Only engineering, decision, and environmental sciences were considered.
- A time frame condition from 2011 to 2021 was added.
- The production planning problem needed to have at least one sustainable objective.
- Any framework related to production planning was considered, such as joint production planning and pricing or hybrid manufacturing remanufacturing systems addressing production planning.

Step four, screen the identified articles This step applied the inclusion and exclusion criteria and reduced the number of related articles to 36 articles. Then, a backward review for the resulted articles is conducted to find any missing articles. The final set of the identified articles included 45 articles and three review articles. Then, the 45 research articles were categorized into a two-dimensional classification based on production planning problems and sustainability pillars. In addition, the problems' solution methods were discussed.

4. Results and Discussions

In this section, the identified studies are discussed. Their classification is based on a two-dimensional classification, i.e., sustainability indicators (see Figure 3) and production planning problems, as illustrated in Figure 2.

Table 3 presents an overview of the identified articles. In addition, each article is assigned to its corresponding sustainability indicator and production planning problem used. Figure 4 reflects the analysis in Table 3 and shows the percentage of studies using the sustainable pillars. For example, Satyro et al. [48] considered the economic pillar in a holistic production planning approach, whereas Xiao et al. [49] integrated the economic and environmental pillars while solving a routing problem. For more details, the 45 articles were classified as follows: 9 articles addressed economic sustainability indicators, 12 articles addressed environmental indicators, and only 1 article addressed social indicators [50], while the remaining 23 articles used integrated indicators of two or more sustainability pillars. Three of these articles used the integration of social, economic, and environmental indicators [2,30,49], while 20 articles used economic and environmental indicators together.

In Table 3, the identified articles were also categorized according to the type of production planning problems. For example, the 12 articles addressing environmental indicators addressed different production planning problems as follows: Three articles considered scheduling problems [51–53], five articles considered hybrid methods of integrating more than one production planning problem [14,54–57], and two articles considered the lot-sizing problem [7,58].

In the following sections, we thoroughly discuss the identified articles shown in Table 3.

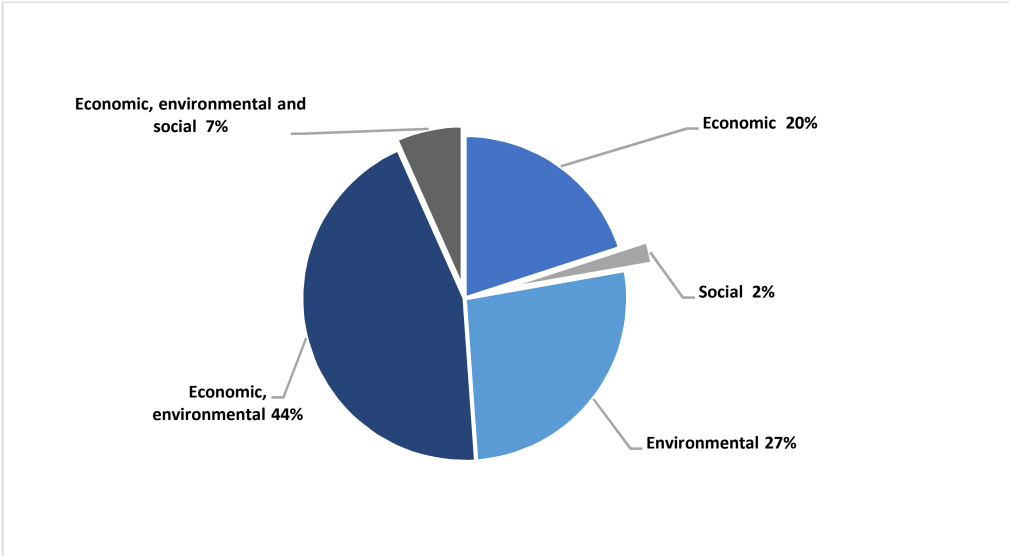

Figure 4. Percentage of studies that considered each sustainability pillar or an integration of various pillars.

Table 3. The classification of the identified articles.

Reference	Sustainability Pillars and Indicators								Production Planning Problem
	Economic			Environmental			Social		
	Cost	Profit	Investment	Material	Energy	GHG	Employee Satisfaction	Customer Satisfaction	
[48]	✓		✓						Holistic approach
[59]	✓								* Hybrid
[60]		✓							Hybrid
[61]	✓								Hybrid
[62]	✓								Hybrid
[63]		✓							Scheduling
[64]	✓								Hybrid
[65]	✓								Routing
[66]	✓								** Other
[54]						✓			Hybrid
[14]						✓			Hybrid
[51]					✓				Scheduling
[58]						✓			Lot sizing
[55]				✓					Hybrid
[56]					✓	✓			Hybrid
[52]					✓				Scheduling
[57]					✓				Hybrid
[67]					✓				Other
[68]					✓				Other

Table 3. *Cont.*

Sustainability Pillars and Indicators	**Economic**			**Environmental**			**Social**		**Production Planning Problem**
Reference	**Cost**	**Profit**	**Investment**	**Material**	**Energy**	**GHG**	**Employee Satisfaction**	**Customer Satisfaction**	
[53]					✓				Scheduling
[7]				✓					Lot sizing
[50]							✓		Other
[2]	✓				✓		✓		Scheduling
[49]	✓				✓				Routing
[16]	✓	✓				✓			Hybrid
[69]	✓				✓				Hybrid
[70]	✓				✓				Dispatching
[71]	✓				✓				Scheduling
[47]	✓				✓	✓			Hybrid
[15]	✓				✓				Hybrid
[72]	✓				✓	✓			Hybrid
[31]	✓	✓			✓	✓	✓	✓	Aggregate production planning
[73]	✓					✓			Hybrid
[74]	✓				✓				Hybrid
[75]	✓				✓	✓			Dispatching
[76]		✓				✓			Hybrid
[77]		✓				✓	✓		Hybrid
[78]	✓				✓				Hybrid
[79]	✓				✓				Holistic approach
[80]		✓				✓			Holistic approach
[81]		✓			✓				Other
[82]	✓				✓				Scheduling
[83]	✓				✓				Scheduling
[84]	✓					✓			Scheduling
[85]	✓				✓	✓			Other

* Hybrid, more than one production planning problem used, and production planning problem combined with other planning processes; ** Other, other planning operations such as energy planning and shipment planning.

4.1. Economic Sustainability Pillar

In this section, we discuss the identified studies that considered any production planning problem with an economic objective, i.e., minimizing the cost or maximizing the profit. The economic pillar is the second most studied objective after the environmental objective, specifically the energy indicator. Energy is also the most studied single indicator [11] and is mostly driven by cost. As presented in Table 3, nine papers addressed the economic perspective using different production planning approaches.

The most recent study was by Satyro, et al. [48] who used a multi-correspondence analysis to find the production planning variables with the most affect over achieving economic sustainability. Their study used a systematic questionnaire to analyze the whole production planning process of six companies. They found that the effect of production planning could vary according to the size of the industry. With industries of more than 9000 employees, the implementation of production planning was not on an operational level as compared with that of smaller companies that varied from 400 to 5000 employees. However, their analysis was based on a small number of companies, and thus, the findings could not be generalized to any company, therefore, more confirmation and a wider set of companies was needed. Lage Junior and Godinho Filho [59] integrated two different production planning stages, i.e., scheduling and routing in a remanufacturing system. Their proposed model determined the optimum number of products to be disassembled to reduce the total cost expected from stochastic routing. However, their proposed model did not consider the number of products to be disassembled, which would affect the material recovery rate. Farahani and Rahmani [60] proposed a hybrid system in which they used production planning process, distribution planning process, and facility location-allocation of a crude oil network, while using net present value as a sustainable objective. The model was formed as mixed-integer linear programming solved by IBM LOG CPLEX. In addition, Yildirim and Nezami [64] developed a hybrid model that used lot sizing and preventive maintenance to decrease machine degradation over time, electrical cost, and operational cost. The proposed model determined lot sizes while satisfying the demand to determine the suitable preventive maintenance plan based on the machine up-and-down time. They introduced a coherence between production planning presented by lot-sizing and preventive maintenance.

4.2. Social Sustainability Pillar

Social sustainability is the most neglected pillar among the 3Ps of sustainability [2,13]. Zarte, et al. [13] conducted a review on addressing sustainable objectives through different decision-making methods. They found that regardless of the decision-making method used, the social sustainability pillar was always the least addressed pillar among the 3Ps. In a similar context, but from another point of view, the human factor has been shown to be the most neglected factor in planning objectives [86], which also proves that the social pillar has been neglected. Relatively, as shown in Figure 4, social sustainability is the least addressed sustainability pillar, either as a single objective or integrated with economic and environmental objectives. Cattaruzza, et al. [50] introduced a packaging and shipping problem that used production planning, workforce, and demand peaks to achieve the ideal number of employees who could process a set of orders to enhance employee satisfaction and development.

4.3. Environmental Sustainability Pillar

The environmental pillar is the most frequent sustainability pillar considered in the literature. As shown in Figure 4, the energy indicator specifically has the most attention. Energy, as an environmental sustainability indicator, can be addressed in two different ways, either as a cost where the objective is to minimize the overall cost or as a resource consumption [15].

Zheng, et al. [54] introduced a lagrangian algorithm to solve a production planning problem with stochastic demands. The proposed lagrangian algorithm could obtain nearly the same optimal solution with less than a 1% difference as compared with the solution calculated by the CPLEX solver. They conducted their research on a real-life case study facing issues with inventory and customer demand. The model considered customer demand as a stochastic demand, because the product was a special order product since different customers could order special requirements in different periods that needed to be met.

A joint production planning with pricing model was introduced by Zhang, et al. [16], who used pricing, production planning, and retailer selection to develop a model. Their model could help firms in making optimal joint decisions. In this study, the Stackelberg game theory was used to formulate the model in which the manufacturer was a leader, and the retailers were followers. Additionally, the model considered an emission control constraint. A nested genetic algorithm and the Stackelberg game model were used to solve the problem. However, the model did not consider that the retailers might be more influential than the manufacturers with respect to refusing the proposed solutions and pricing. In addition, they ignored the influence of other competitors.

In [58], the authors discussed another joint production planning model that considered the supplier and manufacturer as two separate parties, each of whom had revenue preferences. The proposed model assumed a centralized system where the supplier was considered to be a subsidiary to the manufacturer, having a single profit function for the whole system. The model was very informative about the influence of reducing carbon emissions on profitability. Nevertheless, the problem did not consider stochastic demand rates and dealt with only one supplier, which was not the most applicable case.

Rubaiee and Yildirim [51] introduced a fully sustainable framework using a scheduling problem to reduce total completion time to reduce energy costs. The reduction of total completion time was achieved by simply changing the on-off modes of machines to produce more energy-efficient machine scheduling. The developed model was solved using different methods, i.e., the weighted sum method and two different ant colony-based algorithms.

Another study used scheduling problems to achieve environmental sustainability [87]. This study introduced a framework to enable the decision-maker to decide on the best schedule that was less time consuming and more energy efficient. The on-off mode of machines was also used by Liu, et al. [52]. However, instead of working on total completion time for less energy consumption, the objective was to decrease the machine non-processing time; they integrated the problem of scheduling and the on-off modes of machines which resulted in a multi-objective model. The objective was to switch off under-utilized resources. The study proposed a novel genetic algorithm based on a non-sorted genetic algorithm (NSGA II) to solve the resulting model. Nevertheless, the model was not tested in a broader set of job shop cases, therefore, it could not be generalized on every job shop instance.

4.4. Integration of Economic and Environmental Sustainability Pillars

The reduction of total energy consumption always results in a decrease in greenhouse gas emissions [2]. Thus, most economic-oriented problems have an additional environmental objective of reducing greenhouse gas emissions with the increase in the interest of simultaneously addressing economic and environmental pillars [76]. Hence, most of the identified articles that focused on energy consumption considered greenhouse gas emissions while solving the model [19,57]. In order to have a clearer view over each specific indicator such as energy, greenhouse gas, profit, etc., Figure 5 was constructed, which shows the percentage of production planning problems used to solve each indicator either when combined with other indicators or when addressed as a single indicator. Hence, we found that most of studies were energy-oriented studies.

Banasik, et al. [74] proposed an analytical study to prove that implementing uncertainty measures could reduce the difference between actual and expected planning solutions. Their study used a real case to compare the actual results of using a deterministic model versus a two-stage stochastic model. The comparison showed a decrease in the difference between expected and actual results, and also showed a decrease in environmental impact and an increase in profit from using a deterministic model. Another approach for achieving both the economic pillar and the environmental pillar was presented in [56]. The authors used intelligent data collection and processing to simulate future energy consumption situations and used it in production planning and decision making. Similarly, the work in [81] introduced an approach to determine energy consumption values using energy measurement methods and reference cycles. Afterwards, these consumption values were employed to calculate the energy demands for better and efficient planning. Medini and Boucher [80] aimed at balancing forecasted sales and volumes produced in a diverse manufacturing environment while considering environmental and economic sustainability indicators. Thus, they introduced the impact of product diversity on environmental and economic sustainability indicators. Total completion time is an interesting area of research. Liu, et al. [84] introduced a mathematical model that could simultaneously decrease total completion time and greenhouse gas emissions. However, their study assumed that arrival times were deterministic parameters which practically is not the case.

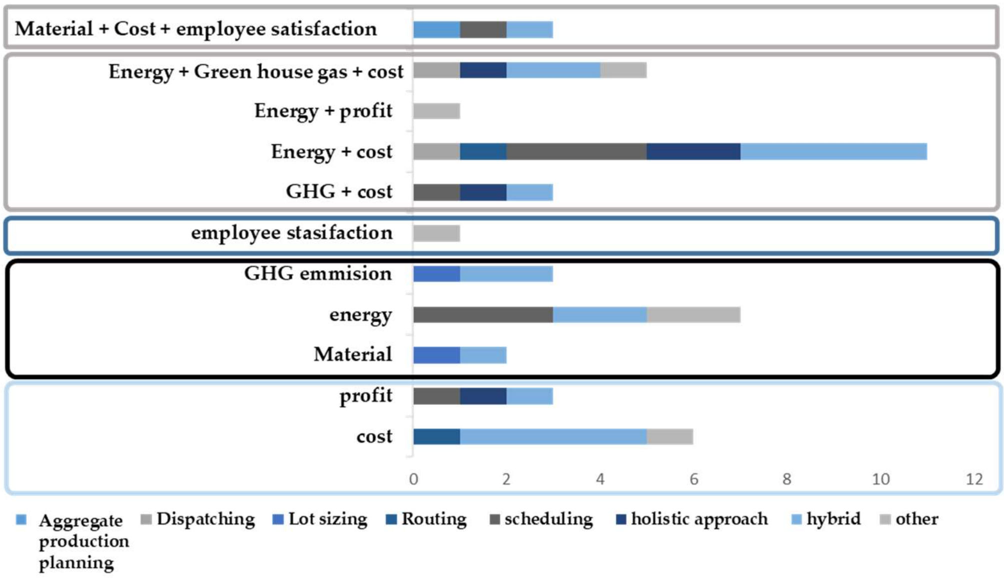

Figure 5. The number of production planning problems' studies and their consideration of various sustainability indicators.

4.5. Integration of Economic, Environmental, and Social Sustainability Pillars

In addition to environmental and economic pillars, Dal Borgo and Meneghetti [73] addressed the social sustainability pillar by considering the learning forgetting phenomena of the working personnel. They could form learning forgetting curves to be used as a framework to develop a production and shipment plan. The results showed that the consideration of the learning forgetting phenomenon could decrease the excessive overtime and stress that workers faced addressing the social sustainability pillar. In addition, this could achieve a full load transport by determining the panels that could be stacked together and then produced consecutively. This led to a decrease in greenhouse gas emissions indirectly and a decrease in shipping costs directly.

Zarte, et al. [2] used a fuzzy optimization to consider all the three main pillars of sustainability in production planning. The authors proposed a fuzzy interference model that combined multiple qualitative and quantitative input variables. This model could assess production sustainability, contrary to a traditional mathematical approach that required input and output measurements to validate the model. However, their proposed model neglected some production planning tasks such as inventory management maintenance, quality control, and product refurbishment.

4.6. International Cases in Production Planning for Sustainability

In this subsection, we consider the international cases which applied production planning for sustainability, as shown in Table 4. The table consists of four columns; the first column presents the study, the second column includes the country case, and the third and the fourth columns describe the targeted sustainability pillar in a production problem. For example, China was involved in most of the literature with seven articles. Four articles aimed at integrating the economic and environmental sustainability pillars [49,70,85,86], while three articles were aimed at the environmental sustainability pillar [12,47,57]. The case of Germany was referred to in four articles. Two articles considered integration of economic, environmental, and social sustainability pillars, one article used scheduling problems [2] and the other article used a hybrid method of integrating between APP and routing problems [77]. Regarding the two remaining articles that referred to Germany, one article used the economic objective [56], and the other article integrated the economic and environmental sustainability pillars while using energy planning [81]. In addition, different production planning problems integrated with different sustainability pillars were implemented in several studies and were implemented in many other countries, such as a hybrid production planning model with the environmental pillar Korea [55], and other production planning problems with integrated sustainability pillars in France [50], Italy [70], Turkey [31], and others.

Table 4. The classification of the identified articles based on each article.

Reference	Country	Sustainability Pillar	Production Planning Problem
[48]	Brazil	Economic	Holistic approach
[66]	Germany	Economic	Other
[61]	Canada	Economic	Hybrid
[54]	China	Environmental	Hybrid
[14]	China	Environmental	Hybrid
[58]	China	Environmental	Lot sizing
[55]	Korea	Environmental	Hybrid
[7]	Germany	Environmental	Lot sizing
[50]	France	Social	Other
[2]	Germany	Integration (economic, environmental and social)	Scheduling
[49]	China	Integration (economic and environmental)	Routing
[69]	China	Integration (economic and environmental)	Hybrid
[70]	Italy	Integration (economic and environmental)	Dispatching
[71]	Ireland	Integration (economic and environmental)	Scheduling
[31]	Turkey	Integration (economic, environmental and social)	Aggregate P.P.
[76]	U.S.A.	Integration (economic and environmental)	Hybrid
[77]	Germany	Integration (economic, environmental and social)	Hybrid
[78]	U.A.E.	Integration (economic and environmental)	Hybrid
[80]	France	Integration (economic and environmental)	Holistic approach
[81]	Germany	Integration (economic and environmental)	Other
[84]	China	Integration (economic and environmental)	Scheduling
[85]	China	Integration (economic and environmental)	Other

5. Implications for Future Research

In this section, we introduce an analysis of the identified sample articles and the fields that require further research and need more attention. Figure 6 summarizes the analysis of the identified articles, which was genuinely created based on the data extracted from the studied articles in each sustainability pillar and its corresponding production planning problem. The chart in Figure 6 provides a summary of the different production planning problems and outlines the extent to which these studies are mixed with sustainability pillars. Hence, we can see that aggregate production planning was the least used production planning problem either as a single problem or in a hybrid system. In contrast, scheduling received the most attention from scholars. This implies a requirement for using aggregate planning in achieving sustainability goals. In addition, existing studies [31,88] on aggregate production planning have addressed multiple sustainability pillars because aggregate production planning enables determining the levels of both workforce and production. Hence, aggregate production planning can be useful in applying multiple sustainability pillars, especially the social sustainability pillar, as it is directly connected with the workforce.

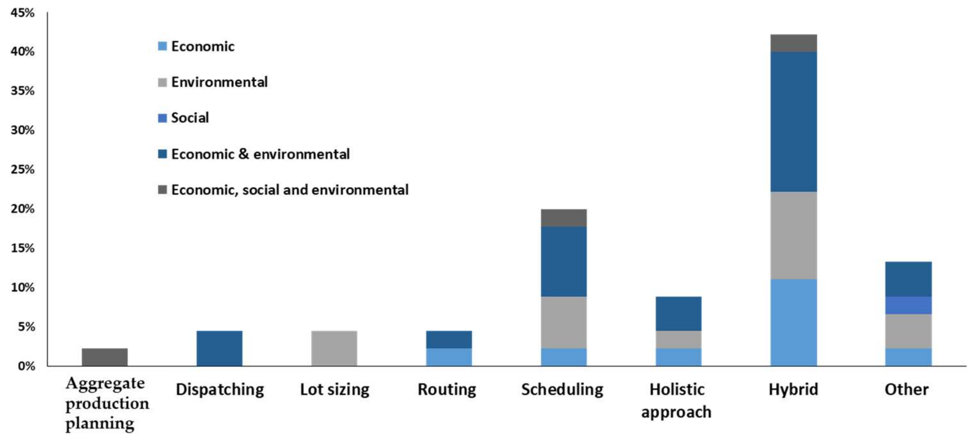

Figure 6. Production planning problems concerning sustainability pillars.

Regarding sustainability indicators, as shown in Figure 5, since the identified studies were relatively few, no studies were carried out on investment as a sustainability indicator for the economic pillar. Almost all of the studies that considered the economic pillar used the cost indicator, while neglecting both of the indicators of profit and investment. In addition, the studies in the existing literature lacked methods for measuring the impact of various sustainability pillars. For example, environmental life cycle assessment was used to measure the environmental impact, and social life cycle assessment was used for measuring social impact [85], while life cycle assessment was integrated between both [89]. Magrassi, et al. [90] developed an optimization model that integrated a proposed decision support system with life cycle assessment to measure environmental impact. Such research and models need to be integrated into production planning for a quantitative measure of sustainable impacts. Another noticeable issue was the reason behind choosing a sustainable indicator. Choosing sustainable indicators through production planning studies was mainly based on the addressed objective function of the problem, which was mostly decreasing energy costs. Because decreasing cost is mostly accompanied by fewer emissions, the economic pillar, thus, was mostly accompanied by the environmental pillar. This identifies another gap in the research, since this connection between energy consumption and harmful emissions is a point of debate.

Zarte, et al. [2] reported that it was useless to add emissions as an indicator to an energy reduction model as long as consuming more energy produced more emissions. In comparison, Biel and Glock [19] found that the relation between CO_2 emissions and energy consumption needed to be more realistic and could not always be considered to be linear. The stochastic modeling techniques in the identified articles found in this review are very scarce [55,74,75], but have more promising and actual values than deterministic models. Hence, this debate needs more attention and research. In a similar context, the reason for choosing a specific production planning problem for a specific sustainability pillar was not defined in most of the articles, but, as mentioned earlier, choosing a sustainable pillar was based on the problem and the required objective. Therefore, more research is needed on finding and assigning the suitable production planning problem with the suitable sustainability pillar.

Social sustainability was the least addressed sustainability pillar either as a single pillar or integrated with other pillars. Economic and environmental sustainability received much more attention. This issue needs more attention because some production planning problems are suitable for addressing the social pillar, such as aggregate production planning, which is concerned with the workforce. Thus, sustainable production planning should give more attention to considering social indicators such as customer satisfaction and employee health and safety.

Another interesting area for future research is integrating sophisticated computational tools into physical production systems which can be called cyber-physical systems [91].

Simply put, systems with embedded computers that enable a real-time connection between workstations and decision support systems, which can be used in various applications such as monitoring systems for intelligent consumption monitoring and smart electrical grids. An interesting study by Rossit, et al. [91] aimed at improving scheduling problems used these systems but did not consider a sustainable objective. Future research might also benefit from the findings of other research fileds with respect to the social sustainability pillers. For example, considering the flexibility in the use of human resources as proposed in the recent literature on the project managemen [92].

On the practical level, the findings provide an easy-to-understand guideline for practitioners to better understand the different pillars of sustainability and their inherent challenges, and how they can be realized in different production planning problems. In addition, the findings can show practitioners how to align their production systems with the 17 goals proposed by the United Nations, in order to gain a competitive advantage over their competitors. Furthermore, practitioners are recommended to develop integrated solutions of different production planning problems in order to achieve a production system in which sustainability pillars are accounted for at every stage.

Lastly, this research introduced a full review considering all sustainable production planning problems in addition to considering all sustainability pillars. The classification showed that the most used solving method among the identified sample articles was genetic algorithms. Nonetheless, this review lacked an inclusive study on each optimization method and its relation with a sustainable objective and the optimization method used. Sustainable production planning is already a complex problem with many parameters. As a result, there is a need for future research to address various optimization methods considering sustainable production planning and the suitability of sustainable objectives.

Although there were some review articles in the literature on sustainable production planning [18–20], each one of them was dedicated to addressing specific production planning problems and their integration with certain indicators of the 3Ps. For instance, Giret, et al. [18] reviewed studies on the production scheduling problem and their consideration of economic and environmental sustainability indicators. Biel and Glock [19] investigated studies related to energy consumption (as an environmental sustainability indicator) in different production planning problems. Recently, Bóna and Korkulu [20] discussed the consideration of ergonomic issues, as a social sustainability indicator, in previous studies on the lot-sizing production planning problem. Unlike previous review studies, this research contributes to the theoretical knowledge by providing a more holistic and comprehensive review of sustainable production planning. This study explores the consideration of various indicators of the sustainability 3Ps when solving different production planning problems that has not been observed well by extant literature. Moreover, this study highlights some theoretical research gaps that the current literature has not yet addressed properly and has ignored some of their critical aspects, as discussed in this section. This research provides researchers, research and development (R&D) centers, and policymakers with a holistic reference on sustainable production planning. First, researchers and R&D centers could benefit from the identified research gaps and the updated overview of the sustainability issues in the production planning field. In addition, the information provided in this research could guide sustainability policymakers to the critical areas that require more efficient policy formulation to further promote sustainable production.

6. Conclusions

This review addresses the studies that considered the three sustainability pillars in production planning. This review considers all production planning stages, sustainability, and indicators of 3Ps in a time frame from 2011 to 2021. The review shows that most of the studies implemented more than one sustainability pillar simultaneously; however, the addressed dual sustainability pillars are always considered to be connected. Another issue is the low number of studies that considered all three sustainability pillars, which shows the need for more attention towards holistic sustainable production planning. In addition, the literature analysis indicates an increasing inclination towards integrating multiple production planning problems with the objective of providing comprehensive production planning solutions. The consideration of the social pillar is still limited either as a single pillar or when integrated with other sustainability pillars. The review shows that few studies considered the 3Ps of sustainability in cyber-physical systems. These applications could assist in multiple sustainable production planning problems. Hence, more attention is required to study the contributions, success factors, and barriers to using cyber-physical systems for more sustainable production planning.

The study results should be considered in light of some limitations. Firstly, some articles related to the study topic might be missed. Secondly, the classification of the included articles based on the production planning problems and the three sustainability pillars depended on the authors' subjective judgements. To mitigate the impact of subjective opinions, recent text mining techniques could be used in the future. However, such techniques cannot provide an in-depth analysis and classification of the included documents.

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