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Impact of Industry 4.0 and Lean Manufacturing on the Sustainability Performance of Plastic and Petrochemical Organizations in Saudi Arabia

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Abstract: Plastic and petrochemical industries are lagging behind in terms of environmental sustainability performance because of the nature of these industries. Although plastic and petrochemical industries have adopted lean manufacturing and/or Industry 4.0 technologies, more efforts are needed to enhance sustainable development. The purpose of this study is to explore the integrated impact of Industry 4.0 technologies and lean manufacturing on the sustainability performance of plastic and petrochemical industries in Saudi Arabia. Moreover, it investigates the casual relationship between Industry 4.0 technologies and sustainability performance as well as the direct linkage between Industry 4.0 and lean manufacturing. A questionnaire is used as the primary instrument for collecting data from 112 plastic and petrochemical organizations. A hypothesized relationship is formulated and then analyzed using the structural equation modeling (SEM) approach. The outcome of the analysis shows that Industry 4.0 and lean manufacturing have a positive impact on sustainability performance. The study also presents a list of valid constructs for Industry 4.0 technologies, lean manufacturing, and sustainability performance. Furthermore, the study shows that the plastic and petrochemical industries in Saudi Arabia acknowledge and recognize the contribution of Industry 4.0 technologies and lean manufacturing principles to the protection of the environment as a dimension of sustainability performance.

Keywords: Industry 4.0 technologies; sustainability performance; lean manufacturing; Saudi Arabia

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1. Introduction

Sustainability is defined as "meeting the needs of the present generation without compromising the ability of future generations to meet their own needs" [1]. Sustainability focuses on the "triple bottom line" (3BL), which comprises social, economic, and environmental dimensions. Social sustainability means a commitment to providing everyone access to healthcare, education, food, water, and shelter. It also means maintaining a stable and peaceful global community of nations. Economic sustainability means being prepared for economic recessions, investing money with a long-term view, regulating the financial industry, and reducing the national debt. Environmental sustainability is about climate change, global warming, human coexistence, ocean acidification, ecosystem collapse, air pollution, and ozone depletion. Solutions in this dimension include renewable energy, protecting endangered species, reducing emissions, and recycling. With a commitment to the sustainability dimensions in all industries and activities, the world can make a big transition to an exciting and thriving future.

There is a conflict between the sustainability concept and the aims of the plastic and petrochemical industries. For instance, the plastic and petrochemical industries play a pivotal role in economic growth and contribute significantly to the GDP of many countries. However, the operations of these industries negatively and diversely impact environmental aspects, which lead to resource depletion, high GHG emissions, and global warming. All these issues endanger the social and environmental dimensions of sustainability [2]. In fact, plastic and petrochemical industries are responsible for consuming a large amount of energy, releasing GHG emissions to the atmosphere, generating wastewater and hazardous wastes, and releasing toxic gases [3]. Additionally, plastic and petrochemical facilities use non-renewable feedstock and store a large amount of flammable and toxic materials, which may pose a high risk to the surrounding population, assets, and environment [4]. In fact, a large fraction of plastics ends up in landfills, and ultimately, in the environment; only 9% of all the plastic has been recycled [5]. Most plastics do not degrade, and some plastics, after being discarded, stay in the environment for a long time because their decomposition rates are very low. Serious incidents in plastic and petrochemical industries have been reported, including chemical spills, chemical fires, and explosions, which caused deaths, injuries, and major damage to assets. Hazards associated with petrochemical industries include air pollutants, groundwater and surface water contamination as well as soil contamination, acid rain, ozone layer depletion, etc. Ideally, these types of pollution should compel these industries to exert massive efforts to balance their operational and financial performance in order to ultimately improve their sustainability performance. New promising technologies such as Industry 4.0 technologies, lean manufacturing, machine learning, and the circular economy have been created and are practiced nowadays to help the world foster sustainability. Moreover, these technologies are capable of confronting and withstanding problems and difficulties faced by the plastic, petrochemical, and other industries. Lean manufacturing principles are now being used widely by many industries, and these tools have been recognized in different countries as successful operational frameworks for reducing waste, increasing productivity, and continuous improvement [6–8]. Lean manufacturing is "a set of management principles and techniques geared towards eliminating waste in the manufacturing process and increasing the flow of activities that, from the customers' perspective, add value to the product" [9,10]. Many researchers have studied the linkage between sustainability and lean manufacturing practices in different industries, including pharmaceutical, automotive, leather, etc. Lean manufacturing helps in minimizing waste and costs, thereby improving productivity and increasing profits [11]. It has been proven that lean manufacturing principles are essential for any organization to achieve sustainability goals [12,13]. In the environmental aspect, the role of lean manufacturing in improving the quality of products and minimizing stored materials has led to the decrease of pollutant levels and the slowing down of resources depletion [14]. Value stream mapping is a lean manufacturing tool that helps to map raw materials, energy, and water, thereby minimizing waste and contributing to the protection of the environmental [15]. With regard to the economic aspect, lean manufacturing provides tools that contribute to minimizing waste, thereby increasing market share and profits [16]. From a social perspective, lean manufacturing contributes to minimizing waste and improving occupational health and safety, thus improving the living conditions of society [17,18]. Several studies have been conducted to examine the impact of lean manufacturing on sustainability performance. For instance, Iranmanesh et al. [19] studied the impact of lean manufacturing practices on the sustainability performance of different industries, including plastic. Their findings support the hypothesis that lean manufacturing practices positively influence sustainability, with the existence of lean culture as a moderator. Similarly, ref.[20] considered the impact of lean manufacturing implementation on organizational performance across various industries in Zimbabwe. Garza-Reyes et al. [21] studied the quality practices of European pharmaceutical companies to explore how ready they were to implement lean manufacturing. A survey questionnaire was prepared and given to 310 European pharmaceutical companies. The findings of this study showed that the participating companies' lean readiness was insufficient. Simultaneously, it was determined that factors such as ISO 9000 certification, type of supplier relationships, and company size had no impact on the quality practices of European pharmaceutical manufacturing organizations, and thus on their level of lean readiness.

The competition to acquire more market shares has put pressure on organizations to upgrade their current manufacturing operations and practices to more advanced levels by exploiting the emerging technologies of Industry 4.0. The new manufacturing systems are now smarter, more intelligent, flexible, digital, agile, and well-equipped to confront market volatility and keep up with the evolution of international markets [22,23]. Global manufacturing industries have seen a huge change with the advent of Industry 4.0 technologies such as cloud computing, big data analysis, robotic systems, and the Internet of Things. Industry 4.0 technologies play a critical role in manufacturing industries and their sustainability performance, bringing about enhanced machineries, improved communication technology, reduced lead times, improved working environments, and product quality [24,25].

Industry 4.0 technologies are expected to significantly improve the three dimensions of sustainability performance of any organization. In the economic dimension, Industry 4.0 technologies positively enhance manufacturing flexibility and the quality of products. The digitalization features of Industry 4.0 technologies contribute to low production time, reduces lead time, minimizes production and transportation costs, which then lead to high customer satisfaction, ultimately increasing the organization's market share and profits [26,27]. Regarding the environmental aspect, the availability of real-time data and data sharing between supply chain stakeholders contribute to the allocation of raw materials, water, energy, and workforce time effectively [27,28], which help to minimize resource depletion, GHG emissions, and waste generation [29]. From the social perspective, implementing Industry 4.0 technologies in organizations improves work conditions, provides safe working conditions for workers, and offers new technologies for people, thereby enhancing motivation and morale [24,30].

Taken together, Industry 4.0 technologies and lean manufacturing are significantly improving the sustainability of organizations. Moreover, their combination helps to reduce waste and cost in areas where it is impossible to use only lean manufacturing. Additionally, the integration of Industry 4.0 technologies and lean manufacturing contributes to the reduction of the implementation costs of Industry 4.0 technologies as it is more costly to implement them without advancing in lean manufacturing principles [31]. Few studies have addressed the relationship between the two in different manufacturing industries [32–34]. Lean manufacturing offers new innovative and automation technologies for organizations [31]. The integration of Industry 4.0 technologies with lean manufacturing helps to remove or minimize some barriers that hinder the implementation of lean manufacturing [32]. The availability of real-time data provided by digitalization and Industry 4.0 technologies is useful for analyzing the current problems with the use of value stream mapping [35]. Nara et al. [36] studied the impact of Industry 4.0 technologies on the sustainability of the plastic industry in Brazil. The study outcome revealed that the IoT, sensors, and big data would enhance the sustainability of the plastic industry.

The literature indicates that there is a lack of research on the integrated impact of Industry 4.0 technologies and lean manufacturing principles on the sustainability performance of organizations. To the best of our knowledge, there is only one study that investigated the relationship between lean manufacturing, Industry 4.0, and the sustainability performance of Indian manufacturing organizations. The scarcity of information regarding this relationship despite the unfavorable and negative impacts of the plastic and petrochemical industries on sustainability performance only exposes the need for further research in this area.

In this regard, the novelty of this study is its exploration of the casual relationship between Industry 4.0 and sustainability performance, between lean manufacturing and Industry 4.0, and the joint impact of Industry 4.0 technologies and lean manufacturing on the sustainability performance of the plastic and petrochemical industries in Saudi Arabia. Additionally, the paper ascertains whether lean manufacturing has a mediating impact on the relationship between Industry 4.0 and sustainability performance. This study offers a new insight into the impact of Industry 4.0 technologies and lean manufacturing on the environmental, economic, and social performance of the plastic and petrochemical industries. In addition, it highlights managerial implications and theoretical contributions to the selected industries. Although Saudi Arabia is one of the world's largest producers of petrochemicals and plastics, many of the enterprises are still implementing Industry 3.0 and have not yet adopted Industry 4.0 technologies extensively. Furthermore, there is a lack of research on these two areas within Saudi Arabian organizations. Thus, this study can assist decision makers in moving towards the adoption of Industry 4.0 and lean manufacturing, similar to their counterparts in other countries. Likewise, the study findings could serve as a foundation of knowledge for decision makers and enterprise managers as they build strategies and policies that will allow their organizations to excel in Industry 4.0 technologies and lean manufacturing. Most of the previous studies surveyed experts from different industries, which might have given inaccurate results. Comparatively, this study is carried out on specific industries, which will create a more generalized understanding of the relationship between Industry 4.0, lean manufacturing, and sustainability performance.

To achieve the study aims, a conceptual framework is developed and a set of hypotheses based on literature review is established. Then, the required data collected from 112 Saudi plastic and petrochemical industries are analyzed using structural equation modeling (SEM) in order to validate the suggested model empirically. Finally, theoretical contributions and managerial implications are highlighted and drawn from the obtained results.

The remaining parts are organized as follows. Section 2 provides a background on lean manufacturing, Industry 4.0 technologies, and sustainability performance. Section 3 provides the proposed hypothesis and framework. Section 4 provides the materials and methods used to conduct this research. Section 5 analyzes the results of this study. The main findings are discussed in Section 6. Section 7 concludes the work and provides directions for further research.

2. Background

2.1. Lean Manufacturing

The primary focus of lean manufacturing is to make the manufacturing process more reliable, efficient, and capable. It looks to develop a well-defined process that enhances the productivity of the organization by meeting customer needs with minimum wastage [8,37,38]. In recent decades, organizations have implemented lean manufacturing, and in many cases, there have been big improvements in their performance and competitiveness [39–41]. There are ten dimensions of lean manufacturing that have been identified in previous literature. These are supplier feedback, just in time, supplier development, customer involvement, pull system, continuous flow, setup time reduction, total preventive maintenance, statistical process control, and employee involvement [42,43]. The ten dimensions and their associated descriptions are summarized in Table 1.

Table 1. Lean manufacturing dimensions.

Dimension	Description
Supplier Feedback (SF)	Supplier feedback is an important lean manufacturing measure as it continuously evaluates and improves supplier correlation and performance. In this practice, all important information from the customers is forwarded to the supplier. SF evaluates communication channels with the supplier such as during feedback on quality and delivery performance, and during the continuous efforts to build long-term relationships [42].
Just in Time (JIT)	Just in time evaluates factors associated with material availability in the manufacturing process by assessing if the required material is available in the desired quantity and time. These measures are analyzed by evaluating supplier involvement in new product development, minimal variance in the desired product time delivery, and a formal supplier certification program [44].

Table 1. *Cont.*

Dimension	Description
Supplier Development (SD)	This is another crucial measure that analyzes the continuous improvement of suppliers' performance by measuring supplier competencies and addressing key concerns. Supplier development is assessed by material cost reduction, lead time and travel duration, supplier communication system, selective suppliers, inventory management with supplier, and total material cost analysis [43].
Customer Involvement (CI)	Customer involvement is an essential measure that determines if customer requirements have been met and if their satisfaction has been achieved. This measure analyzes the close relationship between the organization and the customer by addressing customer involvement in the continual product improvement and new product development processes, and if customer demand information is continuously being collected and monitored [45].
Pull System (PS)	Pull system is an important measure that analyzes how a production schedule is formulated and the essential criteria used to prioritize the activities. To evaluate the production system, the following factors should be assessed: schedule dependency on finished goods, production dependent on continuous demand of successive workstations, deployment of pull production system, and the use of Kanban [35].
Continuous Flow (CF)	Continuous flow measures if there is a smooth continuous flow on the production floor, which would ensure no major halts or downtime. CF is measured by analyzing the proper grouping of production items, the proper grouping of equipment and workstations, and if the factory layout is product-specific [46].
Setup Time Reduction (STR)	Setup time reduction is an essential indicator that measures the flexibility of a production setup such that it can easily accommodate variations in the resources and plans. STR measures how much setup time can be reduced prior to the beginning of production. STR is assessed by analyzing employee capabilities in setup time reduction, a firm dedication to a contingent production system, and equipment types that accommodate setup time reduction [42].
Total Preventive Maintenance (TPM)	This involves the appropriate preventive measures, procedures, and schedule in order to ensure a smooth production floor with minimal breakdown time. TPM evaluates the planned equipment maintenance activities, regular timely maintenance, proper documentation and records of downtime and maintenance activities, and the communication of maintenance activities across the production floor [42].
Statistical Process Control (SPC)	Statistical data and inference are used to control and detect the effectiveness and efficiency of a process such that no further repercussions are seen in the process flow. SPC assesses statistical process control measures such as the statistical process control for reducing process variance, the evaluation of defect rate charts, statistical tools for measuring quality, and a process capability study prior to the launch of new material [42].
Employee Involvement (EI)	Employee Involvement is an essential measure that evaluates the involvement of the employee in the continuous improvement of the process and the product by empowering and developing their competencies. EI measures employee problem solving competencies, employee suggestion management, employee involvement in product/process improvement, and cross-functional competencies training programs [42].

The lean manufacturing dimensions were further grouped into four latent factors, as summarized in Table 2 [32,47].

Table 2. Lean manufacturing latent factors.

Factor	Description
Supplier factors	These include just in time, supplier feedback, and supplier development. These accumulatively measure the major practices that are critical for a manufacturing organization.
Customer involvement factors	Customer involvement signifies how much the customer participates in the organization's processes in order to meet his needs and product expectations.
Process factors	These include continuous flow, pull system, and setup time reduction. Manufacturing industries are heavily dependent on efficient processes. Their objective is continual improvement in processes to improve efficiency and objectivity. Setup time reduction, continuous flow, and the pull system comprise the process factors in the structural equation modelling (SEM).
Control and human factors	These include statistical process control, employee involvement, and total productive maintenance. An effective control of the process and manpower is critical for a manufacturing organizations.

These second-order latent factors were used to measure the correlation of lean manufacturing (third order) with Industry 4.0 technologies and sustainable organization performance. Several authors have examined the lean manufacturing approach in various industries. For example, Alhasan and Zu'bi [48] investigated the relationship between radical product innovation and the dimensions of lean manufacturing in Jordan's pharmaceutical sector. These dimensions include continuous improvement, waste reduction, lean job characteristics, and employee participation. A survey-based questionnaire was conducted in the study to collect data. The results showed that waste minimization and continuous improvement have no impact on radical product innovation. On the other hand, employee involvement and lean job characteristics have a significant effect. Boppana et al. [49] used a lean manufacturing approach to improve the pharmaceutical industry's manufacturing operations. To achieve the study's goal, the authors conducted an extensive survey. The findings revealed that using a lean approach in manufacturing can help reduce cycle times, work-in-process inventory, and lead times.

Sieckmann et al. [50] identified the lean approach's barriers and success factors. The authors proposed a method for implementing a lean production system in a pharmaceutical company that takes into account the characteristics of a small business. The results indicated that the limitation in the applicability of the tools and methods of the lean approach to manufacturing processes is a major impediment to the implementation of a lean production system in the pharmaceutical industry. Gebauer et al. [51] also explored the impact of lean practices on operational performance in the pharmaceutical industry. The findings showed that typical contextual factors such as company type and plant size have an impact on the degree to which lean practices are implemented. Furthermore, the findings suggested that operational performance is connected to the performance of the company. Kumar and Mukherjee [52] proposed a model for connecting the pharmacy supply chain and projecting waste. A lean approach was taken to investigate waste by modeling an inventory control system for the disposal and remanufacturing of the pharmaceutical closed-loop supply chain, with system dynamics as a tool. Pull inventory was used to implement the remanufacturing system. Several observations were made on changes in the level of company incentives and their effects of on customer behavior and residence time by analyzing total inventory costs. The main finding is that companies engaged in the remanufacturing process can improve their management efficiency. Moreover, it was noticed that remanufacturing companies can improve inventory management efficiency by reducing residence time and increasing company incentives, which leads to better customer behavior. Nassereddine and Wehbe [53] investigated the plastic manufacturing production system in Lebanon and focused on the lean system's implementation and the associated barriers. Their findings exposed a number of challenges and obstacles that prevent Lebanese plastic manufacturing companies from implementing lean practices. It was revealed that the lean system is widely misunderstood in businesses. Furthermore, the findings showed that several companies are unknowingly employing some aspects of lean manufacturing.

2.2. Industry 4.0 Technologies

Industry 4.0 technology is an amalgamation of production processes, with new advancements in information technologies and techniques for enhanced manufacturing practices. The aim of the Industry 4.0 technologies is to enhance the "productivity and responsiveness" of manufacturing systems in a manufacturing organization [54], which is driven by the exchange of data in real time, in between various stakeholders [55]. Industry 4.0 technologies are categorized into IoT—Internet of Things, big data analysis, additive manufacturing, robotic system, augmented reality, and cloud computing. Industry 4.0 technologies and their associated descriptions are summarized in Table 3.

Table 3. Industry 4.0 technologies.

Technology	Description
Internet of Things (IOT)	Internet of Things (IOT) is defined as a network in which objects are linked with each other over the internet, where the data is transferred from one object to the other. Data transfer takes place in real time. With the commissioning of 5G communications, Internet of Things has become even more popular [56].
Big Data Analysis (BDA)	As organizations grow exponentially, so do data. Big data analytics examines large data to uncover hidden patterns, correlations, and other insights that could be converted into meaningful information. With an increase in the number of customers and increased global exposure, big data analysis is an integral part of any sustainable organization [57].
Additive Manufacturing (AM)	Additive manufacturing delivers a perfect trifecta of improved performance, complex geometries, and simplified manufacturing. It has two subsets in the form of 3D printing and rapid prototyping. It uses data from a computer aided design (CAD) software or a 3D object scanner to direct hardware to deposit material, layer upon layer, in precise geometric shapes [58].
Robotic System (RS)	A robotic system provides intelligent services and information by interacting with their environment, including human beings, via the use of various sensors, actuators, and human interfaces. The robotic system transforms mass production facilities by optimizing redundant work with efficiency and accuracy [59].
Augmented Reality (AR)	Augmented reality is defined as the combination of virtual and real worlds through a computer-generated software and advanced hardware technology. Augmented reality is transforming the manufacturing industry by enabling organizations to virtually prepare for real-world issues prior to practical implementation [60].
Cloud Computing (CC)	Cloud computing is the on-demand availability of data storage (cloud storage) and computing power. Cloud computing enables manufacturing industries to focus more on their core objectives and outsource data storage and computing power to a location that is well-secured and well-computed, with ease of accessibility [61].

These factors have been well-studied in the literature and are found to play a significant role in promoting the full adoption of Industry 4.0 technologies in manufacturing industries [24,62]. Studies have indicated that these factors have a positive impact on manufacturing industries, which lead to improved sustainability performance [63–66]. The literature lacks some research on the implementation of Industry 4.0 technologies in the plastic and petrochemical industries. Arden et al. [67] presented a vision of pharmaceutical manufacturing in the future as well as some regulatory, technical, and logistical challenges that must be overcome for society to fully benefit from Industry 4.0. According to the findings, the implementation of Industry 4.0 technologies has the potential to significantly improve the flexibility, efficiency, agility, and quality of pharmaceutical manufacturing. Yuan et al. [68] presented several applications of Industry 4.0 in the petrochemical industry. Zhdaneev et al. [69] studied the drivers and challenges of adopting Industry 4.0 in the Russian oil refining and petrochemical industries.

2.3. Sustainability Performance

The primary goals of manufacturing industries is to maximize economic benefits and enhance social welfare within the organization, while maintaining the environment for sustainable performance. Manufacturing organizations need to meet the expectations of its customers, vendors, statutory organizations, and to satisfy government necessities. There are various objectives that have to be met; these objectives can be broadly classified into social, economic, and environmental [70]. To achieve the varying objectives, the organizations need to perform on all the three sustainable dimensions, which are cumulatively known as the triple bottom line [71]. The three sustainability dimensions with their associated descriptions are summarized in Table 4.

Table 4. Sustainability dimensions.

Dimension	Description
Sustainable Social Performance (SP)	For an organization to perform consistently over a long period of time, it needs to perform well socially. Sustainable social performance requires good working conditions, workplace safety, employee health, labor relations, improved morale, and decreased work pressure. It is a critical factor that ensures the organizations' overall performance.
Sustainable Economic Performance (EP)	The primary objective of any organization is to maximize profit and minimize cost; a manufacturing organization is no exception. Sustainable economic performance is an essential factor that ensures the vitality of the organization. It dictates various decision making processes that directly or indirectly affect other factors.
Sustainable Environmental Performance (EVP)	Apart from economic and social performance, the organization has a responsibility towards the environment it operates in. A sustainable environment ensures longevity for the organization. In addition to establishing statutory rules and regulations, an organization needs to safeguard the environment for sustainable performance.

In this study, we will focus on the three types of sustainable performance. Various studies have been conducted to confirm the relationship between lean manufacturing and sustainability performance [72,73], as well as the influence of Industry 4.0 technologies on sustainability performance [24,26,27,74,75]. However, their cumulative effect has not yet been studied in the context of manufacturing industries in Saudi Arabia.

3. Hypothesis Development

Following the discussions in Sections 1 and 2, the framework shown in Figure 1 was developed to assess the integrated impact of Industry 4.0 technologies and lean manufacturing on the sustainability performance of the plastic and petrochemical industries in Saudi Arabia. Moreover, the framework explored the indirect influence of Industry 4.0 technology on sustainability performance via lean manufacturing.

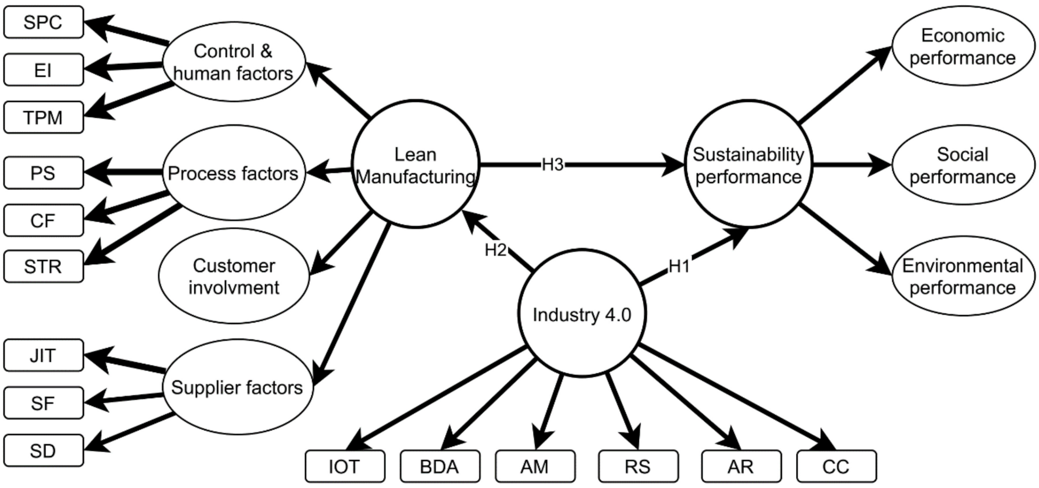

Figure 1. Proposed research framework.

This assessment can be performed by establishing the following three hypotheses:

Hypothesis 1 (H1). *Industry 4.0 technologies directly and positively influence the sustainability performance of plastic and petrochemical industries in Saudi Arabia.*

Hypothesis 2 (H2). *Industry 4.0 technologies directly and positively influence lean manufacturing.*

Hypothesis 3 (H3). *The indirect relation between Industry 4.0 technologies and sustainability performance is significantly mediated by lean manufacturing.*

The three hypotheses were explored and assessed through a questionnaire distributed to targeted plastic and petrochemical organizations in Saudi Arabia, which will be discussed in the subsequent sections.

4. Materials and Method

Based on the aforementioned literature, a questionnaire-based survey was conducted across Saudi Arabia to explore if adopting Industry 4.0 in the presence of lean manufacturing will have positive effects on the sustainability performance of plastic and petrochemical organizations in Saudi Arabia. The questionnaire used in this study was adopted from a study conducted on Indian manufacturing companies [76]. To achieve the study aims, the developed survey was refined and validated via discussion with experts from the industry and academic sectors in Saudi Arabia. Then, the questionnaire was employed in a pilot study, with 15 experts who were aware of the Industry 4.0 technologies and lean manufacturing concepts. The pilot study aimed to ensure good validity and reliability of the developed questions. The Cronbach alpha (α) test was used to check the data reliability. The reliability test helped in excluding the outlier respondents and relied on the precise set of data. The Cronbach's alpha formula that was used to assess the data reliability [77] is the following:

$$\alpha = \left(\frac{n}{n-1}\right)\left(\frac{\overline{V} - \sum V_i}{\overline{V}}\right) \quad (1)$$

where $\overline{V}$ is the sum of variance of overall points, V_i is the variance of values for each point, and n is the number of points. The Cronbach's alpha coefficient has a scale range from 0 to 1. The higher the coefficient, the more reliable the data. The acceptable coefficient range starts from 0.7 up to 1.0. Therefore, any indicators with scores lower than 0.7 were revised and rephrased. The final survey was then distributed to over 600 organizations. A Likert scale of five points was utilized to measure the responses of the respondents [78].

Finally, the analysis was performed using structural equation modeling (SEM) and the SPSS-AMOS26 software.

4.1. Data Collection

In order to collect accurate and precise data, the scope of this study focused on plastic and petrochemical organizations in Saudi Arabia. As per the latest official data provided by the General Authority of Statistics in Saudi Arabia (Statistics, 2021), there is a total of 108,815 registered manufacturing firms within Saudi Arabia, out of which 623 firms are plastic and petrochemical manufacturing organizations. Hence, our population size was assumed to be about 623 firms. The following equation was used to calculate the appropriate sample size [79]:

$$x = Z\left(\frac{c}{100}\right)^2 r(100-r) \tag{2}$$

$$n = N\frac{x}{((N-1)E^2+x)} \tag{3}$$

$$E = \sqrt{\frac{(N-n)x}{n(N-1)}} \tag{4}$$

where N is the total number of manufacturing firms, r is fraction of responses (50%—conservative approach), $Z(c/100)$ is the critical value of the confidence level (95%), E is margin of error (considered to be 9%), and n is the sample size. A sample size of 100 firms, with a margin of error of about 10%, and a confidence interval of 95 was considered to be sufficient for structural equation modeling [80]. Industrial cities were given higher priority. A total of 112 organizations out of the 623 responded within a time frame. All respondents were invited with a covering letter, explaining the purpose, scope, and objectives of the research. Then, there were two eligibility (filtering) questions to be answered; if it was answered negatively, the survey results were not considered. The first question checked whether the respondent had at least one year of experience in the manufacturing organization. The second question checked whether the respondent was aware of the role of Industry 4.0 and lean manufacturing practices in the manufacturing industry. If any of the respondents answered any of the above questions negatively, the survey would not be considered. The questionnaire was divided into 2 sections. The first section asked for general information about the respondent's background and their organizations. The second section asked respondents to answer questions regarding constructs using a five Likert scale. The final sample size for the study represents plastic and petrochemical companies (plastic: 68% and petrochemical: 32%). The sample size varied on the type of manufactured products (final products: 57%, components: 21%, and raw materials: 22%). The 112 respondents varied on their role (operations manager: 11%, supply chain manager: 26%, plant manager: 18%, logistics manager: 22%, procurement manager: 23%).

4.2. Structural Equation Modeling (SEM)

The structural equation model (SEM) is a multivariate technique for analyzing complex relationships between observed and latent variables [81]. The SEM is more powerful than a regression analysis in that it examines the causal relationship between variables while taking into account measurement errors. SEM has been extensively employed in several applications. SEM is a data analysis method that systematically consists of confirmatory factor analysis and path analysis. The measurement model is used for confirmatory factor analysis and the structural model is used to model relationships among variables to be tested [82]. The proposed SEM model used to measure the relationship between lean manufacturing, Industry 4.0, and sustainability performance consisted of 17 latent factors, including lean manufacturing dimensions and Industry 4.0. Each of these latent factors were measured by a set of questions called constructs. The complete model was created from sixty-seven constructs. Before analyzing the model implications, convergent and discriminate validity tests were used to check the validity and reliability of the proposed framework.

4.3. Data Analysis

Various analytical tools were used to verify the model and data before analyzing their implications. First, the common method bias or Harman's single-factor methodology [83] was used to measure variations in the responses due to the instrument, i.e., the survey itself, rather than the respondent's predispositions. As per Harman's single-factor methodology, single factor variance should be less than 50%. Another test checked for data normality, which analyzes if the received data follows a normal distribution. This was evaluated by measuring the kurtosis and the skewness of the data for each measure [84]. As a general rule of thumb, kurtosis should be less than 2 and skewness should be less than 7 [85]. Then, the convergence validity test, which determines how closely the new scale is related to other variables and other measures of the same construct, the average variance extracted (AVE), and the composite scale reliability (CSR) tests were conducted. Not only should the construct correlate with related variables, but it should not correlate with dissimilar or unrelated ones. To analyze convergence validity, as a general rule, CSR should be greater than 0.7 [86,87] and AVE should be greater than 0.5 [88,89]. If there are convergent validity issues, then the variables do not correlate well with each other within their parent factor; i.e., the latent factor is not well-explained by its observed variables. The three formulated hypotheses were examined using the structural equation modeling (SEM) approach. The analysis was conducted on the SPSS-AMOS26 software.

It is essential to measure the model fit of the SEM and to analyze how the data formulate with each other by analyzing convergent and discriminant validity. Then, as per the guidelines proposed by [87,90], the hypothesized measurement model was confirmed by evaluating the chi-square test (χ^2), degree of freedom, and standardized root mean square residual (SRMSR) obtained from the SEM modeling.

5. Results

5.1. Measurement Model

The average values of the constructs were examined utilizing the Kolmogorov–Smirnov test [91]. The data were analyzed for common method bias. The results show a net variance of 48%, just by a single factor. This indicates that the data were not largely affected by common method bias as the variance was lower than 50%, which is the accepted margin. The maximum absolute value of skewness was found to be 1.23, with a standard error of 0.24, which is within the accepted limit (i.e., skewness < 2). Likewise, the absolute maximum value of Kurtosis was found to be 1.65, with a standard error of 0.48, which is also within the established threshold limits (i.e., Kurtosis < 7). Hence, these values confirm that there are no significant deviations and the data have an acceptable normal distribution. The factor loading values confirm that all variables have a factor loading of about 0.50 or more, and hence has no convergent validity issue.

Furthermore, the composite reliability (CSR) readings for each latent factor were above 0.70, with an average variance greater than 0.50, which confirms that there is no convergent validity issue, as summarized in Table 5. While analyzing discriminant validity, it was found that there was a discriminant validity issue with some factors. In order to overcome the discriminant validity issues, the factors were removed from the analysis after carefully analyzing their cross factor loadings. It was noticed in the cross factor loading calculations that the last six variables were loading closely with other factors, with a very minor difference. This could be due to the fact that the respondents found these variables similar to the other variables in the SEM model. Since the majority of the respondents were from various manufacturing sectors, the respondents most likely overlapped these variables with the other variables in the questionnaire. Since the survey targeted various types of manufacturing industries, some of the measuring factors were redundant in their measures, leading to discriminant validity issues. After removing the factors above, the former locker criterion showed no discriminant validity issues, as seen in Table 5.

Table 5. Results of convergent and discriminant factors.

Factors	CSR	AVE	CF	CI	ES	EI	EVS	IOT	JIT	PS	STR	SP	SPC	SD	SF	TPM
CF	0.91	0.72	0.85													
CI	0.86	0.67	0.66	0.82												
ES	0.92	0.63	0.70	0.62	0.79											
EI	0.91	0.77	0.70	0.72	0.70	0.88										
EVS	0.93	0.68	0.64	0.67	0.73	0.70	0.83									
IOT	0.92	0.65	0.64	0.59	0.57	0.62	0.61	0.81								
JIT	0.90	0.76	0.75	0.70	0.73	0.71	0.68	0.80	0.87							
PS	0.91	0.77	0.79	0.70	0.76	0.74	0.64	0.66	0.76	0.88						
STR	0.89	0.72	0.73	0.64	0.63	0.63	0.69	0.66	0.67	0.66	0.85					
SP	0.92	0.71	0.72	0.63	0.65	0.68	0.75	0.61	0.69	0.64	0.77	0.84				
SPC	0.90	0.65	0.78	0.72	0.72	0.77	0.73	0.66	0.73	0.74	0.79	0.75	0.80			
SD	0.91	0.68	0.69	0.68	0.75	0.71	0.65	0.73	0.77	0.78	0.64	0.60	0.74	0.82		
SF	0.91	0.76	0.61	0.69	0.62	0.73	0.71	0.70	0.77	0.69	0.64	0.70	0.71	0.71	0.87	
TPM	0.88	0.72	0.70	0.62	0.74	0.76	0.77	0.50	0.68	0.68	0.64	0.74	0.74	0.60	0.66	0.85

The findings in Table 5 confirm that the square root value of the AVE of a specific construct is better in comparison to the other constructs; hence, there are no major discriminant validity concerns. In order to measure the model fit of SEM, chi-square, degree of freedom (df), and standardized root mean square residual (SRMSR) were also evaluated. The model measurement had a reasonable model fit of 1924 degrees of freedom, χ = 2548.49, and SRMR value of 0.050, i.e., less than 0.06, indicating a good model fit.

5.2. Hypothesis Testing

The complete model comprises of 17 latent factors out of which twelve were first order, four were second levels, and one was third-order level. The model was created from sixty-seven constructs. The structural equation modeling (SEM) was then analyzed to evaluate the hypothesis in affirmative or negative. In order to confirm the mediating impact of lean manufacturing on Industry 4.0 and sustainability performance, it was essential to analyze its effect as it could indicate: no mediation, partial, and full mediations. No mediation happens if both the direct and indirect effects are unsubstantial. Partial mediation occurs if both the direct and the indirect effects (of Industry 4.0 technologies on sustainability performance, through lean manufacturing) are substantial. Full mediation happens when the direct effects (of Industry 4.0 technologies on sustainability performance) in the presence of lean manufacturing is not substantial, while the indirect effects of Industry 4.0 technologies on sustainability performance is substantial. Based on the above criteria, the model is evaluated for mediation effects using the SMART PLS3. Employing bootstrapping methodology, the direct and indirect influence of Industry 4.0 technologies were analyzed.

5.2.1. Direct Impact of Industry 4.0 Technologies

In order to analyze the direct effects of Industry 4.0 technologies on sustainability performance (H1) and lean manufacturing (H2) for the plastic and petrochemical industries in Saudi Arabia, the bootstrapping method of the structural equation modelling (SEM) was utilized. It was found that the previously stated hypothesis "H1: the Industry 4.0 technologies positively influence the sustainability performance" is significant, with values of (β = 0.666, p = 0.000), a T = 11.435 for dependent variable sustainability performance, as shown in Figure 2.

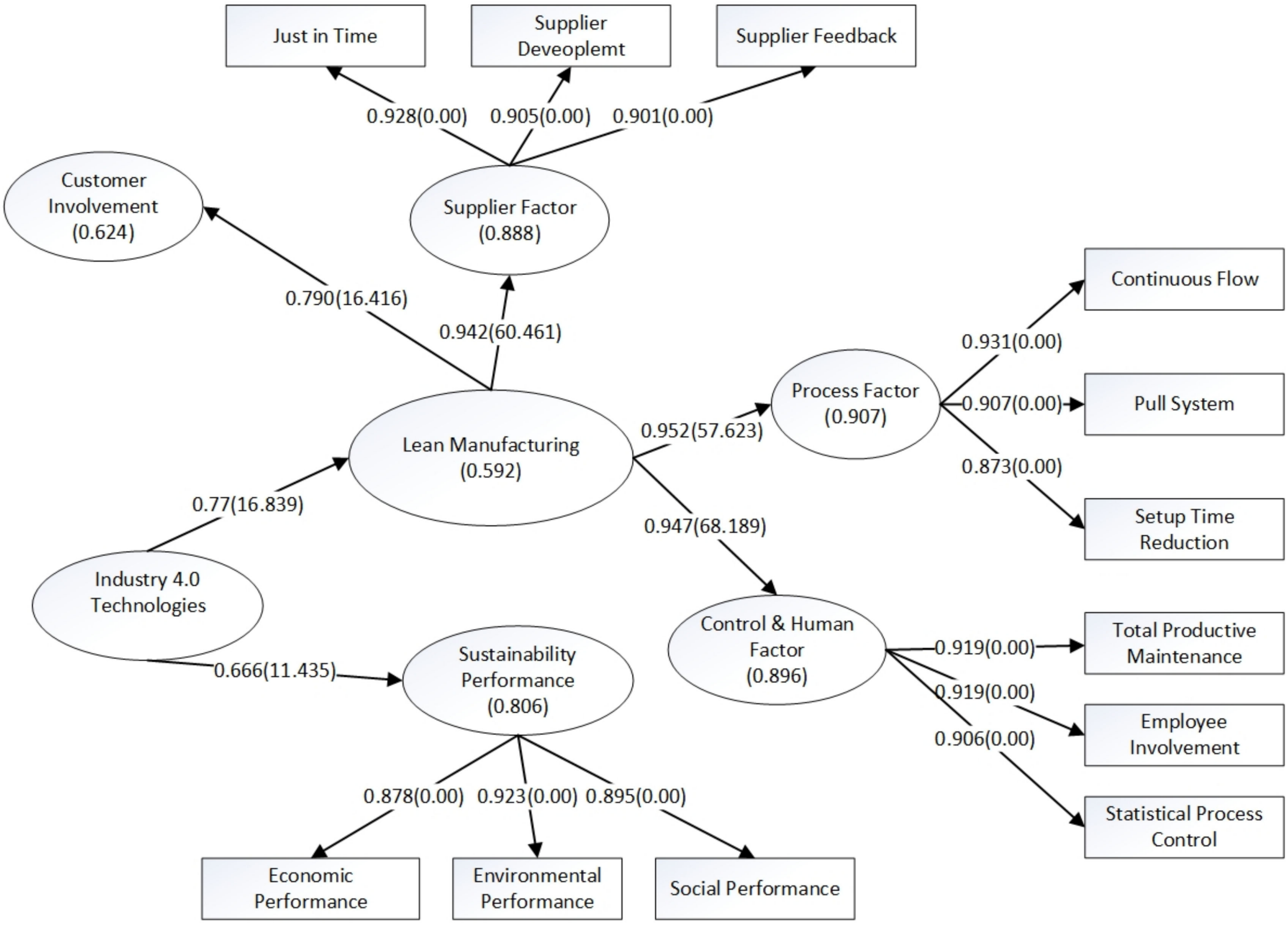

Figure 2. Latent model with no mediation.

Similarly, the second hypothesis "H2: Industry 4.0 technologies positively influence lean manufacturing" was proven to be supported with parameter values of (β = 0.77), a value of T = 16.839 for the dependent variable, and a significant value of R2 = 0.59 for lean manufacturing.

5.2.2. Mediating Effect of Lean Manufacturing

As can be seen from the values in Figure 2, there is a substantial correlation of Industry 4.0 technologies with the performance of organizations with β = 0.666; however, in the presence of lean manufacturing as a mediation variable, the β value is negative (β = −0.061), as shown in Figure 3, suggesting no substantial correlation. According to the "no mediation" criterion, it can be concluded that a full mediation exists in the correlation of Industry 4.0 technologies, lean manufacturing, and sustainability performance. On the other hand, a direct positive effect of Industry 4.0 technologies on lean manufacturing can be seen, with the value of β = 0.769, shown in Figure 3. The R2 values of the dependent variables of lean manufacturing (R2 = 0.592) and sustainability performance (R2 = 0.806) are considered substantial.

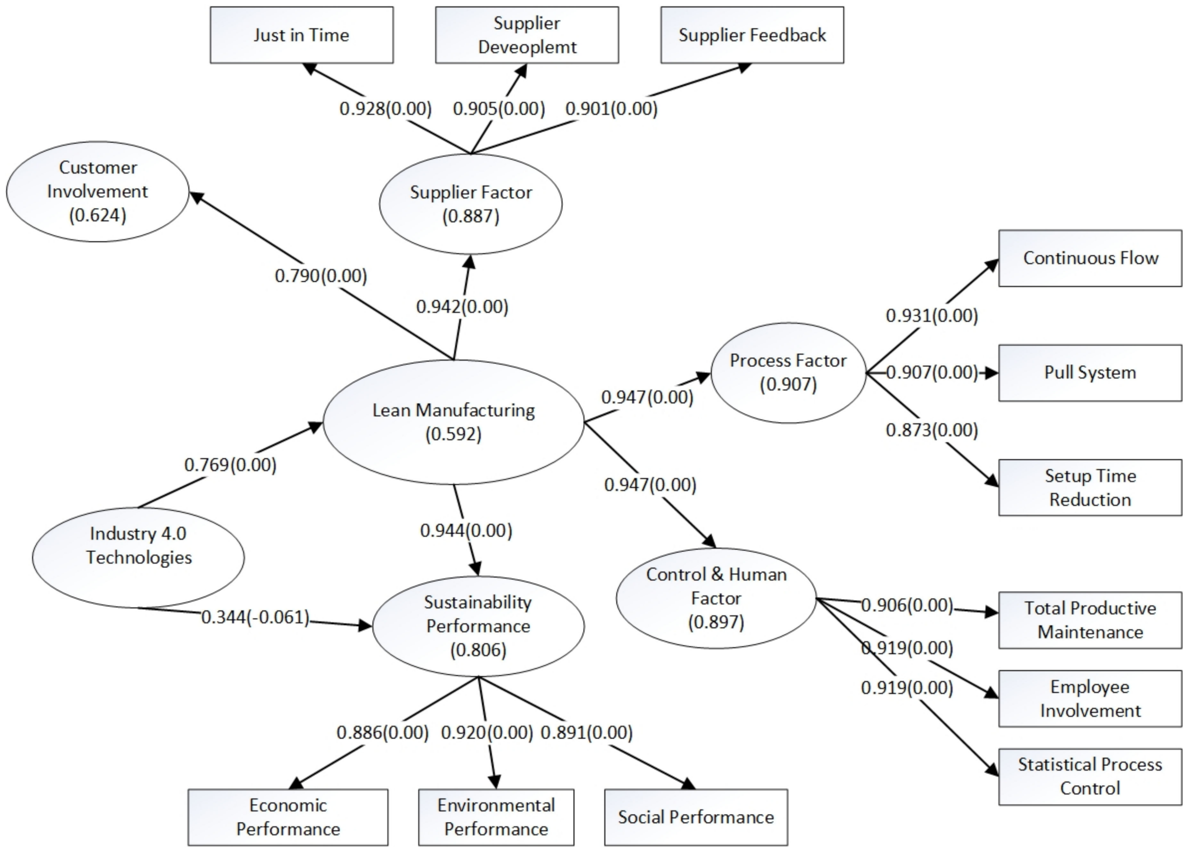

Figure 3. Latent model with mediation.

Additionally, it is worth noting that lean manufacturing loaded on process factors with β = 0.952, control and human factors with β = 0.947, supplier factors with β = 0.942, and customer factors with β = 0.79. The sustainability performance was strongly loaded on the environmental dimension with β = 0.92, on the social with β = 0.891, and the economic performance with β = 0.886, as shown in Figure 3. Table 6 below summarizes the hypothesis test results of this study. These results confirm the mediated effects of lean manufacturing on the relation between Industry 4.0 technologies and sustainability performance, with β = 0.727 at $p < 0.001$.

Table 6. Hypotheses results.

Hypothesis	β	Result
H1	0.666	Validated
H2	0.769	Validated
H3	0.727	Full mediation exists

6. Discussion

Plastic and petrochemical industries play a significant role in economic growth, minimize unemployment, and enhance living conditions in Saudi Arabia. However, plastic and petrochemical industries are lagging behind in their environmental and social sustainability performance, which has put a huge burden on society and the environment. New emerging technologies such as Industry 4.0 and lean manufacturing practices have gained increasing attention from researchers and industries in major economies, which has helped the plastic and petrochemical companies to confront and mitigate the abovementioned issues.

This paper investigated the direct impact of Industry 4.0 technologies and lean manufacturing on sustainability performance, and the integrated impact of Industry 4.0 technologies and lean manufacturing on the sustainability performance of plastic and petrochemical industries in Saudi Arabia. Moreover, it analyzed the mediating impact of lean manufacturing on the relation between Industry 4.0 technologies and sustainability performance. This study indicated that plastic and petrochemical industries in Saudi Arabia are on the verge of implementing Industry 4.0 technologies, and revealed that Industry 4.0 technologies directly and positively influence sustainability performance (H1), confirming that Industry 4.0 technology can have a substantial impact on the sustainability performance measures in Saudi plastic and petrochemical industries. The findings are consistent with previous studies that claimed the existence of a relationship between Industry 4.0 and sustainability performance [24,92,93]. The findings indicated that Industry 4.0 technologies have attracted the interest of Saudi Arabia's plastic and petrochemical industries as a practical solution for improving organizational performance. It can be concluded that the Internet of Things was given the highest priority among all technologies in Industry 4.0, followed by big data analysis and cloud computing. However, robotic systems, augmented reality, and additive manufacturing were given less priority for sustainability performance. Many of the industries in Saudi Arabia, especially the small and medium enterprises, are still implementing Industry 3.0 and have not adopted Industry 4.0 technologies. The digitalization feature of Industry 4.0 technologies will contribute to lower plastic and petrochemical production time, reduce lead time, minimize production and transportation costs, leading to high customer satisfaction and ultimately increasing the organizations' market share. The availability of real-time information would help to allocate resources efficiently, which would minimize resource depletion, the GHG emissions, and reduce plastic waste generation.

This study found that the impact of Industry 4.0 technologies on sustainability performance is magnified with the presence of lean manufacturing as a mediating variable. This implies that adopting Industry 4.0 technologies without lean manufacturing may not have a noticeable and swift impact on sustainability performance since lean manufacturing concentrates on developing the human aspect, which has a substantial influence and drives organizational sustainability [13]. The findings of this paper encourage the plastic and petrochemical industries to adopt Industry 4.0 technologies in order to enhance their sustainability performance, with lean manufacturing as part of the organizations' core process strategy. Jointly, Industry 4.0 technologies and lean manufacturing are expected to help plastic and petrochemical companies to reduce waste and costs in areas where it is impossible to use either lean manufacturing or Industry 4.0 technologies solely. For instance, the effectiveness of suppliers' feedback and just-in-time on enhancing the sustainability of the plastic and petrochemical industries can be improved significantly through the use of big data, sensors, and Internet of Things [94–96]. Both Industry 4.0 and lean manufacturing concentrate on leading industries towards a linked and data-driven environment in which manufacturing systems and supply chains can be improved through real-time and customer-oriented integration. Industry 4.0 technologies and lean manufacturing provide advanced instrumentation technologies, adjustable big data analytics for process optimization, advanced hardware and software platforms, and predictive modeling and simulation technologies.

Similarly, the findings of this paper indicate that Industry 4.0 technologies directly and positively enhance lean manufacturing practices (H2). This is in line with previous studies that claimed the direct and positive impact of lean manufacturing and Industry 4.0 technologies [14,97–99]. This paper further confirms that claim in Saudi Arabia's plastic and petrochemical industries. Moreover, these research findings are more important and relevant than the previous works because Industry 4.0 technologies and lean manufacturing were shown to have a positive and greater association with the enhancement of the environmental dimension of sustainability performance, which is relevant to the plastic and petrochemical industries. These findings imply that the respondents perceive the joint and the significant impact of Industry 4.0 and lean manufacturing on the environment. This means that adopting lean manufacturing and Industry 4.0 technologies in the plastic and petrochemical industries would significantly protect environment. In addition, it demonstrates the statistical significance of all Industry 4.0 technologies and lean manufacturing principles, implying that Saudi Arabian industries acknowledge and recognize the contribution of these principles and tools to the enhancement of sustainability performance, which implies that adopting Industry 4.0 technologies in the presence of lean manufacturing helps to upgrade lean manufacturing to digital lean manufacturing, allowing material and information sharing among all supply chain parties [32]. Moreover, Industry 4.0 technologies can enhance the customer involvement, which would bring the voice of the customer to the early stages of production [100].

In conclusion, lean manufacturing was found to be a substantial mediating variable that is required for the successful implementation of Industry 4.0 technologies. Moreover, the paper introduced a list of valid constructs for Industry 4.0 technologies, lean manufacturing, and sustainability performance from the perspectives of the plastic and petrochemical industries in Saudi Arabia. These constructs and the model were tested for convergence and divergence validity.

7. Conclusions

The study values the role of Industry 4.0 technologies and lean manufacturing as powerful tools for advancement in achieving sustainably in the plastic and petrochemical sectors. This study primarily focused on investigating the direct impact of Industry 4.0 technologies and lean manufacturing on sustainability performance, and the integrated impact of Industry 4.0 technologies and lean manufacturing on the sustainability performance of plastic and petrochemical industries in Saudi Arabia. The results revealed a solid relationship between Industry 4.0 technologies and sustainability performance, and confirmed the casual relationship between lean manufacturing and Industry 4.0 technologies. Moreover, this relationship is strengthened with the presence of lean manufacturing as a mediating variable. Thus, organizations should be committed to adopting Industry 4.0 technologies in order to make the manufacturing process digital, lean, and smart.

These findings could provide decision makers in the plastic and petrochemical industries with the means and insights into the importance and necessity of adopting both Industry 4.0 technologies and lean manufacturing in their organizations, which will jointly enhance sustainability performance. Moreover, the study findings will serve as a foundation of knowledge for decision makers and enterprise managers as they build strategies and policies to excel in Industry 4.0 technologies and lean manufacturing. In addition, the study outcome introduces a list of valid constructs for Industry 4.0 technologies, lean manufacturing, and sustainability performance from the perspectives of the plastic and petrochemical industries in Saudi Arabia. These construct will provide support to the decision makers in adopting Industry 4.0 technologies and lean manufacturing by convincing the supply chain stakeholders. Additionally, the research output provides a roadmap to practitioners and stakeholders by highlighting the relevance of Industry 4.0 technologies and lean manufacturing to the economic, social, and environmental success of their organizations. The research outcomes also show that Industry 4.0 technologies have attracted the interest of Saudi Arabia's plastic and petrochemical industries. It is revealed that the Internet of Things scored the highest among other technologies, followed by big data analysis and cloud computing. On the other hand, robotic system, augmented reality, and additive manufacturing were given less priority in sustainability performance.

Some assumptions made in this research need to be further considered in future research. For example, Industry 4.0 technology is relatively new to Saudi Arabian industries, so the respondents' knowledge on Industry 4.0 is limited. Thus, the answers of the respondents to this part might not be based on their expertise in this field. Therefore, it is recommended to further explore the maturity, awareness, drivers, and challenges of Industry 4.0 technologies in Saudi Arabia. Moreover, as the majority of the industries have not yet implemented both Industry 4.0 technologies and lean manufacturing, the views expressed by the respondents might not be accurate. We therefore recommended to examine the level of integration of both technologies in Saudi Arabian industries. This study is limited to the petrochemical and plastic industries in Saudi Arabia and can be extended to other gulf countries. It can also be implemented in different industries such as small and medium manufacturing enterprises, automobile, oil, leather, etc. Another direction is addressing a large sample size. This study can additionally be extended to different dimensions, for instance, the study of the impacts of other mediating variables such as the circular economy.

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