An Overview of Sustainable Manufacturing in the Algerian Industry Context: Practices, Barriers, Enablers, and Opportunities

نظرة عامة على التصنيع المستدام في سياق الصناعة الجزائرية: الممارسات والعوائق والعوامل التمكينية والفرص

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Abstract:

In response to limited resources and increasing energy costs, many innovative strategies have been introduced in the manufacturing systems. These approaches include lean manufacturing, environmentally friendly practices, agility, and sustainable manufacturing. Sustainable Manufacturing (SM) requires simultaneous consideration of economic, environmental, and social impacts linked to the creation and distribution of products. Currently, manufacturers bear the responsibility of producing products sustainably. However, many companies struggle to adopt SM strategies due to the insufficient integration of various enablers of SM. In this paper, we contribute to a better understanding and holistic approach for SM. The scientific values of this paper are to (1) increase the knowledge on SM concepts (2) identify various barriers and enablers for SM (3) familiarize researchers and practitioners with the SM tools and practices (4) enhance Algerian industrial ecology through sustainability gain (5) provide quantitative insights of SM indicators in Algeria (6) identify of associated future research directions.

Keywords:sustainable manufacturing; manufacturing sustainability; sustainability in production; green manufacturing; triple bottom line; enablers; barriers; opportunities

JELClassificationCodes:L6, L60, Q01, Q56

ملخص:

نظرًا لندرة الموارد وارتفاع أسعار الطاقة، تم إدخال العديد من الاستراتيجيات المبتكرة في أنظمة التصنيع. وتشمل هذه الأساليب التصنيع الخالي من الهدر، والممارسات الصديقة للبيئة، التصنيع المرن والأخضر والرشيق، والتصنيع المستدام. يتطلب التصنيع المستدام دراسة متزامنة للآثار الاقتصادية والبيئية

والاجتماعية المرتبطة بإنتاج المنتجات وتوزيعها. حاليًا، يتحمل المصنعون مسؤولية إنتاج المنتجات بشكل مستدام. ومع ذلك، فإن العديد من الشركات تكافح من أجل اعتماد استراتيجيات التصنيع المستدام بسبب عدم وجود تكامل بين مختلف عوامل تمكين. في هذه الورقة، نساهم في فهم أفضل بنهج شمولي للتصنيع المستدام. تتمثل القيم العلمية لهذه الورقة في (1) زيادة المعرفة بمفاهيم التصنيع المستدام (2) تحديد مختلف العوائق والعوامل التمكينية للتصنيع المستدام (3) تعريف الباحثين والممارسين بأدوات وممارسات التصنيع المستدام (4) تعزيز البيئة الصناعية الجزائرية من خلال مكاسب الاستدامة (5) تقديم رؤى كمية لمؤشرات التصنيع المستدام في الجزائر (6) تحديد اتجاهات البحث المستقبلية.

كلمات مفتاحية: التصنيع المستدام؛ استدامة التصنيع؛ الاستدامة في الإنتاج؛ التصنيع الأخضر؛ الحصيلة ثلاثية؛ عوامل التمكين؛ الحواجز؛ التحديات؛ الفرص؛

تصنيفاتJEL : L6، L60، Q01، Q56

1. INTRODUCTION

New environmental issues and concerns including biodiversity loss, resource depletion, and climate change gained significant attention on the political agendas in the 1990s and early 2000s. In fact, these widespread environmental issues are more complex and differ in intensity compared to earlier environmental challenges. While initial environmental problems have been addressed through advancements in clean technologies, new ecological issues require more profound transformations in the coming decades. These transformations will necessitate substantial changes in transportation, energy generation, and agricultural systems due to the severity of the impending environmental challenges (Qureshi, et al., 2020). The manufacturing industry is essential for the worldwide economy. It provides goods and services that significantly impact the economies and societies of both developing and developed countries (Jamwal, Agrawal, Sharma, & Kumar, 2020).Therefore, the manufacturing sector is the most resource-intensive part of the economy. As a result, manufacturing operations consume a significant amount of energy and natural resources (Qureshi, et al., 2020). As an example, based on a report from the IEA in 2015, manufacturing industries alone account for 36% of carbon dioxide emissions (CO2) and use roughly one-third of the world's energy. Moreover, manufacturing sectors are well-known for their high use of materials and the generation of waste (Shankar, Kannan, & Kumar, 2017). With increasing environmental worries, growing public expectations, and more stringent regulations, manufacturers are making efforts to establish

and meet sustainability-focused objectives (Haapala, et al., 2013). These problems can be addressed by embracing environmentally-friendly manufacturing practices in industries (Jamwal, Agrawal, Sharma, & Kumar, 2020) Hence, there have been notable advancements in sustainable manufacturing (SM) during the last ten years (Haapala, et al., 2013).

Sustainable Manufacturingis one such effort that combines environmental and economic considerations within a business. SM doesn't just focus on protecting the environment but also adopts practices that benefit customers, employees, the environment, and the wider community(Malek & Desai, 2020). Implementing SM practices in a company can enhance resource efficiency, decrease waste, and save energy (Jamwal, Agrawal, Sharma, & Kumar, 2020).

Hence, this study seeks to explore SM and to provide a better understanding and holistic approach for SM in an Algerian industry context. The paper is structured as follows.Section 2 presents a background on SM, definitions, indicators, and relevant concepts are explained. Section 3 provides a literature review of SM studies related to Algeria.Section 4 discusses practices, barriers and enablers, challenges and opportunities of SM.Section 5 analyses quantitative insights for SM in Algeria.Finally, section 6 summarizes the discussion and provides several recommendations for future research in this area.

2. Background on Sustainable Manufacturing

2.1. Defining Sustainable Manufacturing

Various definitions have been suggested for SM, but as of now, there is no widely accepted definition (Haapala, et al., 2013). While different researchers have defined SM from various angles, all agree on its three core dimensions: economic, environmental, and social. Furthermore, they concur on its positive impact on human development (Ngu, Lee, & Bin Osman, 2020)**.** Since there is no universally accepted definition for SM among scholars and in the literature, in this article, we will examine the most pertinent definitions. It is important to note that there exists a distinction between the definitions of sustainable development and sustainable manufacturing.

The notion of sustainability gained prominence following a series of meetings and reports during the 1970s and 1980s, largely prompted by environmental crises, concerns about chemical contamination, and fears of resource depletion. Consequently, sustainability calls for a level of performance that may run counter to humanity's natural inclination for continuous progress and expansion. This distinction is evident in the term

"sustainable development," as defined by the Brundtland Report, which describes it as " development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Haapala, et al., 2013).

Recent investigations have brought to light a notable absence of consensus among researchers regarding the fundamental comprehension of SM. This lack of agreement spans a spectrum, encompassing diverse interpretations of the overarching concept of "sustainability" and variations in the specific terminologies employed to delineate and pinpoint the domains for the application of SM(Alayón, Säfsten, & Johansson, 2022).Sustainable manufacturing is an integral component of the broader concept of sustainable development. (Jasiulewicz-Kaczmarek & Saniuk, 2015)Following sustainability principles, SM involves the creation of industrial products through a process that mitigates adverse environmental impacts, conserves energy, and utilizes natural resources efficiently. Consequently, it is imperative for the business sector to surpass mere financial considerations in order to attain ecological objectives (Qureshi, et al., 2020).According to the U.S. Department of Commerce (DOC), SM is characterized as "the production of manufactured goods employing processes that mitigate adverse environmental effects, preserve energy and natural resources, ensure safety for employees, communities, and consumers, and are financially viable"(Haapala, et al., 2013).

(Quinn, Kriebel, Geiser, & Moure-Eraso, 1998) define SM as “systems of production that integrate concerns for the long-term viability of the environment, workers health and safety, the community, and the economic life of a particular firm”.(De Ron, 1998) defined sustainable manufacturing as “an industrial activity that generates products which meet the needs and wishes of the present society without sacrificing the ability of future societies to meet their needs and wishes”. (Mihelcic, et al., 2003) proposed a definition relevant to engineering contexts as the “design of human and industrial systems to ensure that humankind's use of natural resources and cycles do not lead to diminished quality of life due either to losses in future economic opportunities or to adverse impacts on social conditions, human health, and the environment”. Since there is no universally accepted definition for sustainable manufacturing, (Jawahir & Dillon Jr., 2007) describes it as a process that leads to: improved environmental friendliness, reduced cost, reduced power consumption,

reduced wastes, enhanced operational safety, and improved personnel health.

A more technical characterization, as proposed (Rachuri, et al., 2010), defines SM as a "systematic approach to designing, producing, and distributing innovative products and services within the supply chain. This approach aims to minimize resource consumption, encompassing materials, energy, water, and land. It also seeks to eliminate toxic substances and achieve zero waste generation, resulting in reduced greenhouse gas emissions, specifically lowering carbon intensity throughout the entire life cycle of products and services". In the study conducted by (Alayón, Säfsten, & Johansson, 2022), SM is defined within the context of the triple bottom line framework, which takes into account the three dimensions of sustainability: environmental, social, and economic. In this framework, SM practices are defined as "the actions, initiatives, and techniques that have a positive impact on the environmental, social, or economic performance of a manufacturing company. These practices assist in managing or reducing the effects of manufacturing operations on the triple bottom line" (Hariyani & Mishra, 2022).

2.2. Indicators for Sustainable Manufacturing

Sustainable manufacturing indicators(see **Fig.1)** can be categorized on five dimensions**:**

Environmental Stewardship: This dimension pertains to addressing environmental impacts stemming from emissions, resource consumption, and harm to ecosystems resulting from manufacturing processes and products.

1) ***Economic Growth***: Economic growth emphasizes the financial aspects, including costs, profits, and benefits, as well as investments made by the manufacturing organization.
2) ***Social Well-being***: Social well-being takes into account the impacts on employees, customers, and the community. It involves factors such as health and safety programs, satisfaction assessments, and initiatives related to career and educational development.
3) ***Technological Advancement***: Technological advancement assesses a manufacturer's ability to foster technological progress. This can be achieved through investments in research and development (R&D), staffing, and the development of high-tech products.
4) ***Performance Management***: Performance management focuses on the implementation of sustainability programs and policies and ensuring

compliance with relevant regulations (Joung, Carrell, Sarkar, & Feng, 2012).

Fig.1. Sustainable manufacturing indicators

Source: Prepared by the author, adopted from (Joung, Carrell, Sarkar, & Feng, 2012)

3. Literature Review

There are few useful studies in the literature on SM in Algerian context. Therefore, we reviewed all literature indirectly related to SM, such as sustainable development or green economy in Algeria manufacturing companies.

- ***Sustainable manufacturing***

In (Keddari, Kherbachi, &Benkhider, 2021) study, SM practices are derived from literature and expert input. The study employs a random walk method, utilizing the Policies Design Structure Matrix to depict policy dependencies. The research reveals that innovation policies promote the adoption of SM practices more than trade and industrial policies.

The objective of the article by (Bey & Sami, 2021) is to examine the status of sustainable development in Algeria between 2008 and 2018 by analyzing various economic, social, and environmental indicators. The study utilized a descriptive analytical approach and a selection of statistical indicators.The study's main conclusion is that Algeria has not yet reached the objectives of sustainable development, and it faces several challenges in this regard. However, the research highlights that Algeria possesses the capabilities and resources necessary to compete with developed nations in the realm of sustainable development.

In the research conducted (Azaizia, 2019), the primary focus was on investigating the influence of implementing lean manufacturing principles

as a means to enhance sustainable environmental performance. This was achieved through the organization of the work site, reducing preparation and processing times, adopting cellularmanufacturing, implementing total productivity maintenance, practicing total quality management, and applying series processing principles.The study's findings revealed that the utilization of lean manufacturing principles had a significant impact, contributing to a 5% improvement in sustainable environmental performance.

In the study conducted by (KNOUCH & ÇETİN, 2022), they examined therelationship between green supply chain management (GSCM), environmentalcollaboration (EC), and a firm's sustainable performance (FSP). Additionally, they investigated how environmental collaboration serves as a mediator in this relationship.The results of the study revealed several key findings:GSCM has a positive impact on both FSP and EC, EC also has a positive effect on FSP.The study provided support for the mediating role of environmental collaboration in the relationship between GSCM and firm sustainable performance. This implies that environmental collaboration plays a crucial role in enhancing the impact of GSCM on a firm's sustainable performance.

The aim of (Harouache, et al., 2021) studyis to enhance the implementation of green supply chain practices within the construction industry sector in Algeria. The study specifically focuses on various stakeholders in this sector, including suppliers, managers, and contractors.To achieve this goal, the paper has put forth a conceptual framework that involves assessing and improving all facets of the supply chain within the construction industry. This includes the analysis, redesign, and coordination of the entire supply chain, with particular emphasis on the degree to which green supply chain management practices are being implemented in the Algerian construction industry sector.

- ***Sustainable development and green economy***

The study conducted by (laouar&Benabbes, 2022) seeks to underscore the significance of Algerian Small and Medium-sized Enterprises (SMEs) in realizing sustainable development and, in turn, making a meaningful contribution to the state's economy.

The article authored by (Kaddour&Teba, 2022) delves into the significance of environmental assessment methods in promoting green architectural practices across various climatic zones within the country. The study examines the pillars of sustainable development and conducts a

critical analysis and evaluation of past sustainability development approaches in Algeria.

On the other hand, the paper by (Stambouli, Koinuma, Flazi, Khiat, & Kitamura, 2013) outlines a long-term vision and strategy aimed at fostering the conceptualization and advancement of the Sahara Solar Breeder (SSB) project. This project envisions sustainable solar energy solutions in the Sahara region.

4. Sustainable Manufacturing: Practices, Barriers, Enablers, and Opportunities

4.1. Sustainable Manufacturing Practices

In the present time, SM practices are being embraced by diverse manufacturing sectors in both developed and developing nations. The extent to which SM practices are adopted varies and is influenced by factors including the industry's nature, its size, and the type of products it produces. In developing nations, the concept of environmentally conscious manufacturing, which takes into account sustainability dimensions, is relatively new compared to well-established adoption in developed nations such as the USA, UK, and Germany (Jamwal, Agrawal, Sharma, & Kumar, 2020)

According to (Gupta, Dangayach, Singh, Meena, & Rao, 2018), the literature has classified SM practices in to mainly five dimensions: (1) Sustainable Product Process Design (SPPD), (2) Lean Practices (LP), (3) Agile Practices and Customization (APC), (4) Sustainable Supply Operation and Distribution (SSOD), (5) Product Recovery and Return Practices (PRRP).While a better categorization was conducted by (Shankar, Kannan, & Kumar, 2017) according to three dimensions: Economic, Environment, and Safety. **Table 1** shows the common SM practices with indicators prepared by the author and adopted from (Gupta, Dangayach, Singh, Meena, & Rao, 2018) and (Keddari, Kherbachi, &Benkhider, 2021).

Table 1. Common sustainable manufacturing practices

Dimensions	Practices	Indicators
Economic	Responsive product strategy	- Reducing non-value-added activities in long term business activities. - Tracking company's environmental management system. - Greenhouse gas measurement. - Technological advancement.
	Development of bill of materials	
	Quality improvement tools	
	Supply chain restructuring	
	Advanced product design	
	Enterprise level system integration	
	Improved process performance	
	Resource utilization and economy	
	Reduction of manufacturing cost	
	Reduction of product development time	
Environment	Energy saving	- Saving materials and energy in short-term business operations. - Ordering, capital, warehousing, and replenishment costs. - Prevent, remove or repair the damage caused by business activities.
	Using advanced material and manufacturing techniques	
	Water consumption	
	Promoting 6R (reduce, reuse, recycle, recover, redesign, remanufacture) concepts	
	Improve effectiveness of environment policy	
	Sustainable material and design selection	
Social	Developing education and training	- Profit created per worker. - Employee discontent and turnover rate reduction - Product life cycle assessment. - Employee motivation - Fair public image and employee morale establishment
	Awareness creation	
	Guarding	
	Accident investigation	
	Motivation of workers and safety personnel	
	Personal protective equipment	

Source: Prepared by the author, adopted from (Gupta, Dangayach, Singh, Meena, & Rao, 2018) and (Keddari, Kherbachi, &Benkhider, 2021)

4.2. Sustainable Manufacturing Barriers and Enablers

A logical starting point for examining how companies embrace SM practices, and how to provide support to thesecompanies, is to deepen our comprehension of the obstacles and facilitators that influence their adoption of such practices. Gaining a deeper insight into the barriers and enablers that impact companies serves two primary purposes.Firstly, it equips

companies with the knowledge and insights needed to attain fundamental sustainability objectives.This involvesunderstanding how to overcome obstacles to sustainability by effectively harnessing sustainability enablers. Secondly, this enhanced understanding of the barriers and enablers associated with the adoption of SM practices contributes to the development of frameworks aimed at promoting proactive environmental behavior among companies. In turn, this encourages the adoption of more robust and SM practices (Alayón, Säfsten, & Johansson, 2022)**.**Based on (Alayón, Säfsten, & Johansson, 2022) and (Abdullah, Saraswat, & Talib, 2023) studies, the author created **Table 2** that shows barriers and enablersfor the adoptionof SM, taking into consideration the Algerian industry context.

4.3. Sustainable Manufacturing Opportunities

In the age of Industry 4.0, there's a push towards creating manufacturing processes that are both efficient and environmentally friendly. This means finding ways to make high-quality products while using fewer resources, generating less waste, and reducing harm to the environment. SM makes it easier to embrace the concept of a circular economy. This means designing systems where resources are reused and recycled instead of being discarded. It's a sustainable approach that minimizes waste and promotes long-term resource use.

Industry 4.0 technologies, like sensors and data analysis, allow us to be more transparent in our manufacturing processes. This transparency can lead to significant reductions in waste. By closely monitoring and optimizing how we make things, companies can cut down on both material and energy waste.Furthermore, we can connect data and processes, making it possible to intelligently manage how we use energy. This translates to

Table 2. Barriers and enablers for the adoption of sustainable manufacturing

Categ.	Barriers	Enablers
Organizational & managerial	Manager´s lack of awareness about the company's environmental impact.	Managerial support and effective leadership toward sustainability.
	Organizational culture not aligned with sustainability values.	Inclusiveness of workers toward a more participatory culture.
	Resistance to change.	More efficient routines and practices.
	Imbalance between short term and long term goals.	Long-term strategy.
Governmental	Inefficient legal framework	Government regulations fostering sustainability adoption.
	Lack of local guidance for adopting sustainable manufacturing	Government provided information and knowledge on sustainable manufacturing.
	Lack of governmental incentive policies; subsidies, taxes.	Providing financial incentives to foster sustainable manufacturing practices and the company´s growth.
	Lack of promotion of sustainable practices and products	Institutionalize rewards recognizing the adoption of sustainable manufacturing
	Ineffective controlling and monitoring system	Provide government sponsored platforms.
Financial	Insufficient financial resources.	Providing financial accesses.
	Uncertain and intangible benefits.	Increased awareness of the economic benefits of sustainable manufacturing practices.
	High investment costs and low returns of environmentally sustainable technologies.	Reducing manufacturing costs.
Market and business context	Lack of awareness of international trends related to environmental sustainability.	Increased support from large customers.
	Low energy prices.	High energy prices.
	Competition with less-expensive products.	Adoption of lean manufacturing and product innovation strategies.
	Lack of awareness of role on social capital.	External cooperation.
Techno-logical	Use of outdated technology.	Pressure from market and clients.
	Need for additional infrastructural modifications.	Pressure from supply chains to adopt sustainable manufacturing practices.
	Unavailable technology.	Technical support from technology suppliers.
Training & skills	Low skilled labour.	Education and training systems to improve operations.
	Shortage of technical expertise and training.	Skill enhancement and knowledge improvement of workers and society members.
	Lack of investment in environmental education and training.	Invest in Research and development facilities.

Source: Prepared by the author, adopted from (Alayón, Säfsten, & Johansson, 2022) and (Abdullah, Saraswat, & Talib, 2023)

better energy efficiency, a crucial factor in sustainable practices. In addition, technologies like 3D printing have the potential to significantly reduce waste in manufacturing and maintenance. They can also boost productivity. These technologies help in developing equipment and processes that use energy and resources more efficiently. Strategies like process hybridization and cleaner technologies contribute to sustainability by using resources wisely.

Sustainable manufacturing offers a wealth of opportunities. These opportunities include efficient processes, circular economy principles, waste reduction, energy efficiency, and innovative business models.Industry 4.0 also transforms the workforce and supports the TBL sustainability concept (Sartal, Bellas, Mejias, & Garcia-Collado, 2020)**.**

5. Quantitative Insights for Sustainable Manufacturing in Algeria

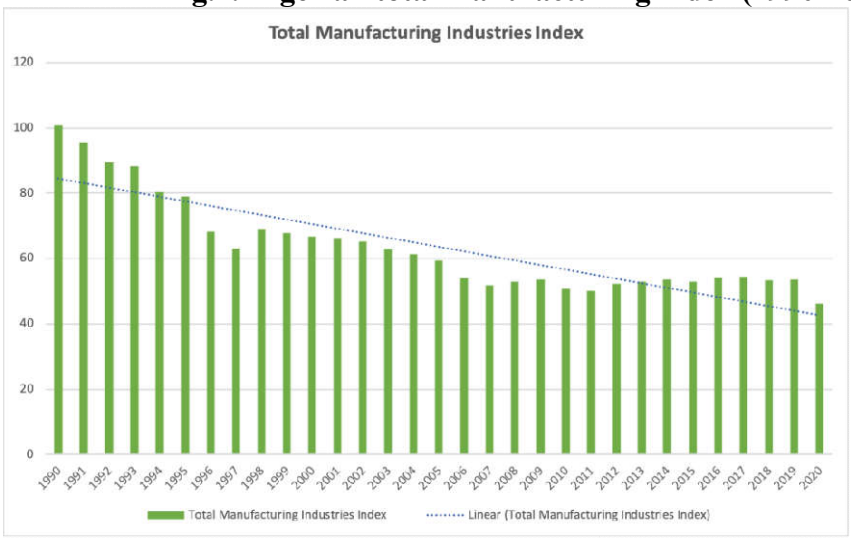
The study on SM in Algeria involved an analysis of economic, social, and environmental indicators spanning from 1990 to 2020. This analysis followed a descriptive analytical method, which focuses on collecting and scrutinizing statistical data to assess the performance of key indicators within Algeria's economy. Economic indicators underexamination included the Total Manufacturing Industries Index and the Hydrocarbons Industries Index, shedding light on the economic aspects of manufacturing and resource-intensive sectors. In the social dimension, we considered Employment in Industry as a vital indicator, providing insights

into employment dynamics within the industrial sector and its social implications. Regarding the environmental aspect, we assessed CO2 emissions and Annual freshwater withdrawals. These indicators offer crucial information on the environmental impact and resource utilization associated with manufacturing activities. By scrutinizing these indicators over the specified period, the study aimed to provide insights into the state of SM in Algeria.

5.1. Analysis of Economic Indicators

The first graph **(Fig.2)** displays the trend in the Algerian Total Manufacturing Index from 1990 to 2020.This index includes the following

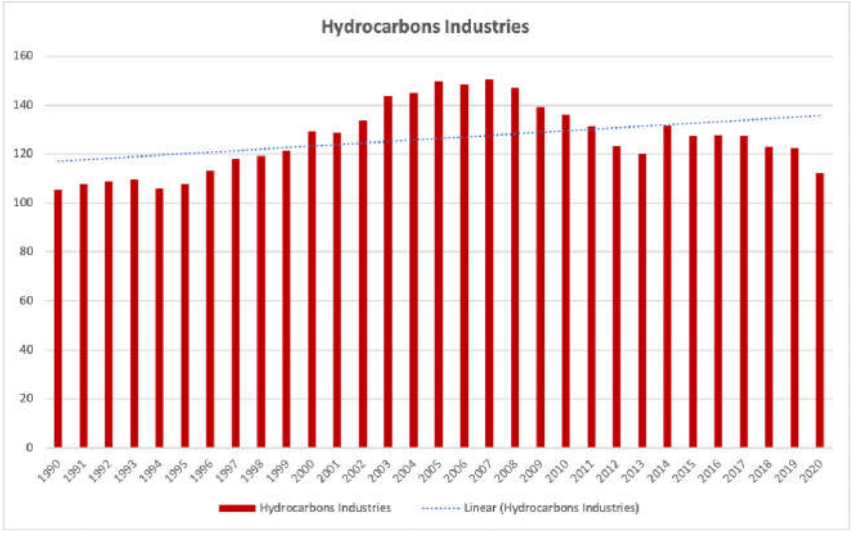
Fig.2. Algerian total manufacturing index (1990-2020)



Source: Prepared by the author according to (National Statistics Office)

industries: S.M.M.E.E. industries (Steel, Metallurgical, Mechanical, Electrical and Electronic); materials of construction industries; ceramic/glass, chemistry, rubber/plastics industries; agro-food/tobacco/matches industries; textile industries; leather/footwear industries; wood/cork/paper industries; and other divers' industries.

Fig.3. Algerian hydrocarbons industries (1990-2020)



Source: Prepared by the author according to (National Statistics Office)

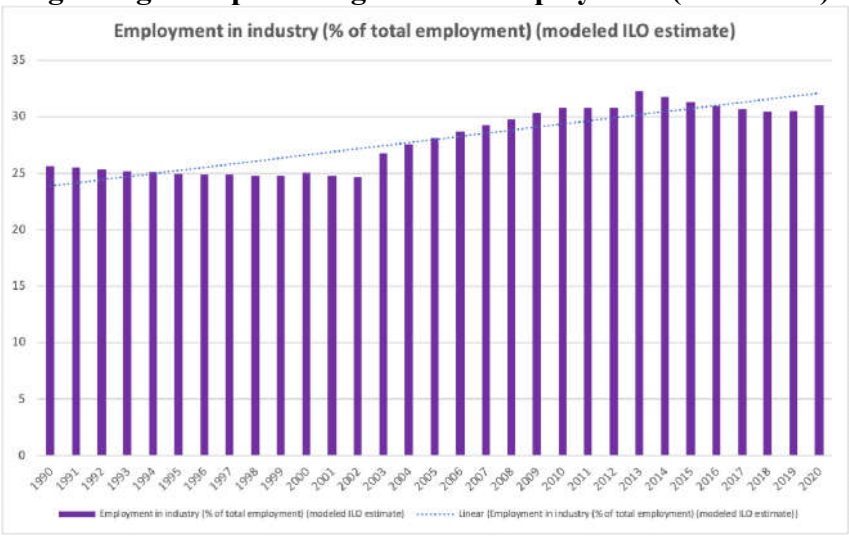
From 1990 to 2020, there was a noticeable decrease in the Total Manufacturing Index. The observed trend could be related to the fact that Algerian economy rely on hydrocarbons production.

The graph in **Fig.3** illustrates the trajectory of Algerian Hydrocarbons Industries Index, encompassing the oil and gas sector, from 1990 to 2020. Between 1990 and 2007, the Hydrocarbons Industries in Algeria experienced increase from 105,4 in 1990 to 150,6 in 2007. Notably, in the early 2008, there was a significant decrease in this sector, corresponding to the global recession in that period.

5.2. Analysis of Social Indicators

Fig.4 graph displays the percentage of total employment in Algeria in the industry sector from 1990 to 2020. Over the past three decades, the Algerian percentage of total employment has increased a little, it is almoststable. The small change is logical since the manufacturing sector didn't prosper since the 90s.

Fig.4. Algerian percentage of total employment (1990-2020)

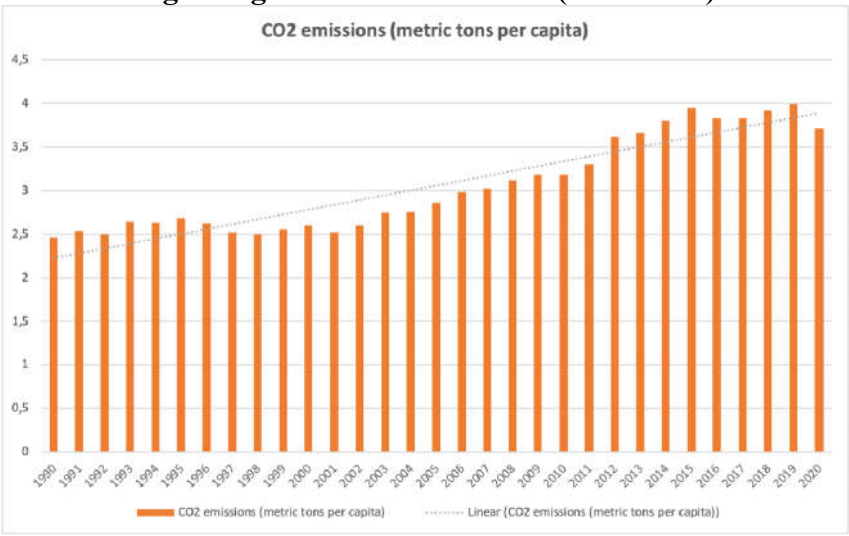


Source: Prepared by the author according to (Worldbank)

5.3. Analysis of Environmental Indicators

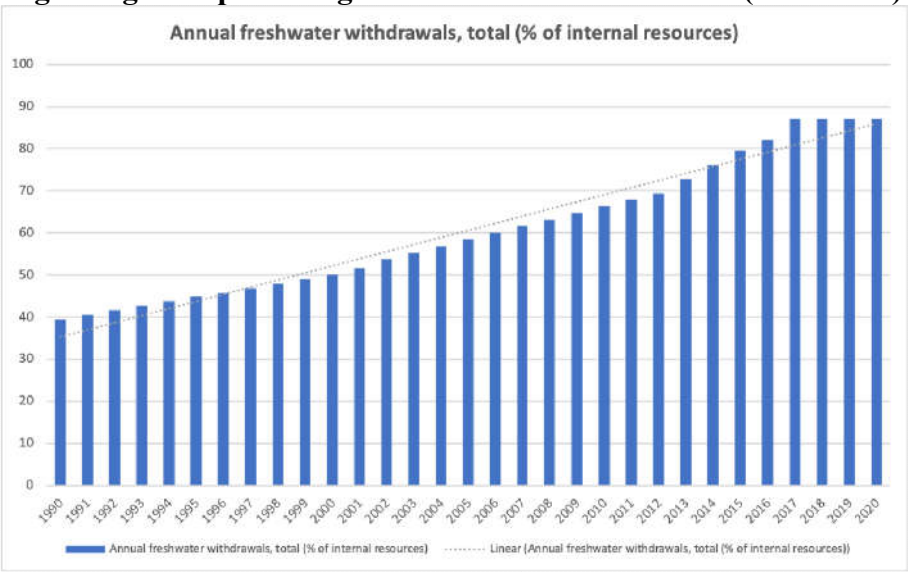
The graph in **Fig.5** portrays the trajectory of CO2 emissions metric tons per capita in Algeria from 1990 to 2020. Particularly noteworthy is thesubstantial increase in emissions. This trend in CO2 emissions may be connected to oil and gas production, the increase of cars in the national park, and other factors.

Fig.5. Algerian CO2 emissions (1990-2020)



Source: Prepared by the author according to (Worldbank)

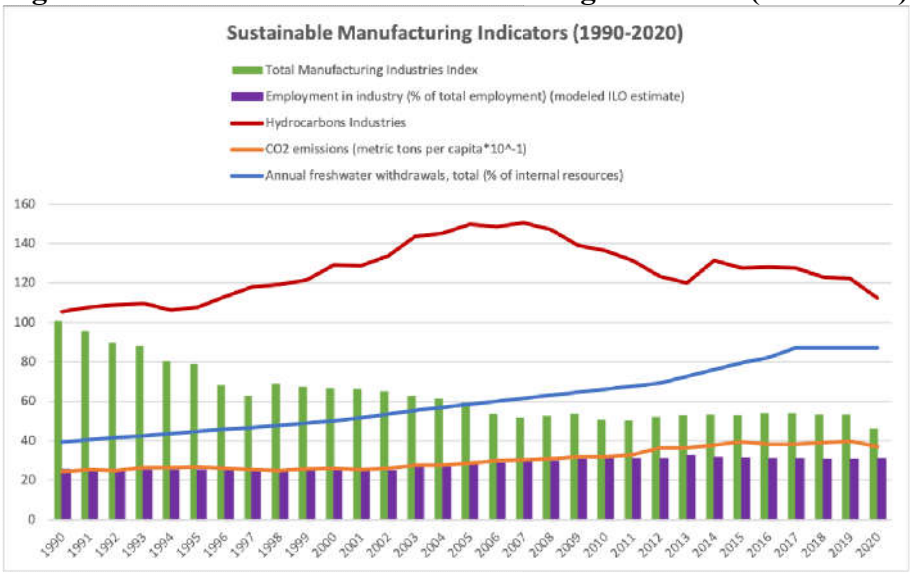
Fig.6. Algerian percentage of freshwater withdrawals (1990-2020)



Source: Prepared by the author according to (Worldbank)

While **Fig.6** presents the percentage of freshwater withdrawals from internal resources in Algeria from 1990 to 2020. The graph reveals the clear increase trend in freshwater withdrawals. This graph underscores the need for strategies to ensure the responsible use of freshwater resources.

Fig.7. Combo of sustainable manufacturing indicators (1990-2020)



Source: Prepared by the author

6. Conclusion and Further Research

In developing nations, particularly in countries like Algeria, there is mounting pressure to elevate economic standards and maintain their global competitiveness. Given this imperative, the adoption of sustainable strategies across all sectors, including manufacturing, has become a necessity. However, Algerian industries are currently encountering challenges in fully embracing green manufacturing, and their transition toward SM is still at a nascent stage. Nevertheless, driven by the global shift towards environmentally conscious policies, they are increasingly inclined to incorporate green strategies into their manufacturing operations. Conversely, there are relatively few policies in place with a dedicated focus on sustainability. Therefore, it is opportune for policymakers to revisit and reorient their policies with a stronger emphasis on sustainability. In this context, this study serves as a valuable resource for policymakers, aiding them in recognizing the significance of implementing SM practices.

Algerian manufacturing companies are encouraged to undertake several key initiatives to advance SM. These initiatives include:

- Algerian manufacturing companies should aim to minimize waste generation and promote material recycling wherever possible.
- There should be a concentrated effort to conserve energy, restrict the use of hazardous substances and chemicals, and reduce air emissions.

- Ensuring a safe and healthy work environment throughout the entire plant is paramount for achieving excellence in environmental, occupational health, and safety management.
- Safe work practices and standards must be developed, maintained, and continuously improved to protect the environment, employees, contractors, and the community.
- Regular monitoring and reviews of the environmental, occupational health, and safety management system, as well as working conditions, should be conducted to drive ongoing improvements.

In addition to these initiatives, there are several issues in the realm of sustainable manufacturing that warrant further research exploration, including:

- Research should examine how individual enablers impact firm financial, environmental, sustainable, economic, and operational performance using structural equation modeling.
- Investigate the combined effects of enablers to address barriers specific to manufacturing units in various sectors.
- Study benchmarking practices in the context of sustainable manufacturing to identify best practices and areas for improvement.
- Explore benchmarking practices for the development of new enablers that can enhance sustainable manufacturing efforts.

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