EAI Endorsed Transactions
on Industrial Networks and Intelligent Systems Research Article EAI.EU

Multi-objective optimization model for sustainable production planning in textile MSMEs

Pablo Flores-Siguenza[1], Jose Antonio Marmolejo-Saucedo[2] and Rodrigo Guamán[1, *]

[1]Department of Applied Chemistry and Systems of Production, Faculty of Chemical Sciences, Universidad de Cuenca, Cuenca, Ecuador
[2]Facultad de Ingenieria, Universidad Nacional Autonoma de Mexico, Ciudad de Mexico, Mexico

Abstract

Textile micro, small and medium-sized enterprises (MSMEs) are characterized by their great influence on the economy of the countries, both for their contribution to the gross domestic product as well as for the generation of employment. In recent years, the complexity of their operations, instability and lack of balance between economic, environmental and social factors, axes of sustainable development, stand out. Therefore, it is necessary to implement approaches such as sustainable manufacturing and production planning, which seeks the creation of products with minimal environmental impact, under safe conditions for workers, and economically robust. In this context, this study aims to develop a multi-objective optimization model that enhances sustainable production planning in textile MSMEs. The methodology is based on two phases, the first one focused on the acquisition of information and the second one dedicated to the mathematical formulation of the model, where three objective functions focused on economic, environmental and social factors are proposed. The model is validated with real data from a textile MSME in Ecuador and different production alternatives are generated by proposing the implementation and use of photovoltaic energy as well as a greater use of personal protective equipment. One of the relevant outcomes of the study is a sustainable decision support tool aimed at the textile industry, where different scenarios for production planning and their respective economic, environmental and social consequences are shown.

Keywords: Sustainable Production Planning, MSMEs, Textile Industry, Multi-objective Optimization

Received on 19 September 2023, accepted on 25 September 2023, published on 27 September 2023

doi: 10.4108/eetinis.v10i3.3752

1. Introduction

One of the most critical business sectors with a long supply chain is the textile and apparel industry, since it is considered one of the most polluting activities in the world [1]. The textile sector has great economic relevance for countries, due to its economic contribution to the Gross Domestic Product (GDP) and employment generation [2].

In Ecuador, the textile sector is the industry with the second largest number of dependent workers and interacts with other 33 productive sectors in the country [3]. It is the third largest industry within the manufacturing sector, which represents about 11.83% of Ecuador's GDP. In addition, the Ecuadorian textile industry is made up of more than 47 thousand micro, small and medium-sized enterprises (MSMEs) [4].

Industrial globalization, technological advances, environmental restrictions, and the recent COVID19 pandemic have generated substantial changes in the manufacturing processes and commercialization of goods in different industries [5]. An example of this reality can be seen in textile MSMEs, where the instability and complexity of their operations has increased. Therefore, most textiles MSMEs are trying to remain in the market by focusing only on economic factors without considering environmental or social aspects [6].

This lack of a sustainable approach in the production process of industries is detrimental to their continuity [7], since there are increasing pressures from customers, as well as stricter government legislation and international agreements that promote the manufacture of less polluting and socially responsible products [8].

The current challenge for organizations, and especially for MSMEs, is to achieve a balance between the three axes of sustainability, i.e., economic, environmental and social factors, to enable them to manufacture quality products and remain competitive in the market [9]. A recent approach to achieve this, is sustainable manufacturing and production planning, as it procures the creation of products with processes that minimize environmental impacts and energy use, and the resulting products are economically robust [10].

To address all these variables and objectives involved in strategic production planning decisions with a sustainable approach, quantitative mathematical programming models are a convenient tool. These models employ optimization techniques seeking to maximize economic and social benefits while minimizing environmental impacts [11].

In this context, the objective of this study is to develop a multi-objective optimization model that enhances sustainable production planning in textile MSMEs. The objective functions (OF) of the model focus on economic, environmental and social factors such as profitability, carbon footprint and work accident rate. The model is validated with real data from a textile MSME in Ecuador and serves as a sustainable decision support tool to the textile sector by showing different scenarios in production planning and their respective consequences.

For a better understanding of the document, it is structured as follows: Section 2 focuses on a brief literature review on production planning and optimization models. Section 3 describes the methodology used to achieve the objective of the study. Section 4 shows the mathematical formulation of the proposed model. Section 5 discusses the results obtained by applying the model in a textile MSME along with a discussion of the main findings. Finally, Section 6 presents the main conclusions of this study.

2. Related research

First, a brief literature review on the integration of sustainability in manufacturing processes and production planning in different industries is carried out in order to analyse the approaches applied in similar studies. One of the studies identified is Hahn and Brandenburg [12], where the authors develop a sustainable production planning model for the chemical industry involving multiple production modalities. Müller et al. [13] instead perform a CO_2-based assessment for sustainable production planning in the metal processing industry, addressing the entire life cycle of the product. The results of the study are compared with other possible production techniques and processes. Yousefi et al. [14] generate a decision support framework for sustainable production planning of paper recycling systems, through the design of multiple feasible production plans.

Regarding the textile industry, the study of Hosseini et al. [15] evaluate the use of solar energy to drive cleaner production and sustainable planning. Chourasiya et al. [16] develop a framework to analyze the effect of adopting sustainable manufacturing in Indian textile industries, through direct interviews and questionnaires based on a sample of 64 companies. Ozturk et al. [17] conduct a series of studies for assessing cleaner production in a textile mill, resulting in the identification of 92 points for improvement. Finally, other articles compile the problems of sustainable development in textile companies together with the main technologies currently applied [18, 19].

Similarly, a complementary review was performed in order to analyze the state of the art in terms of optimization models used to enhance sustainability in production processes. As result, the work of Yazdani et al. [20] was identified, where a multi-objective optimization model was developed for process planning in a sustainable environment. On the other hand, Ozturk et al. [21] design a water use minimization model for a textile factory based on a multicriteria method for decision-making.

In these reviews, no studies related to the design of optimization models to promote sustainable production planning in textile MSMEs could be found. It is also evident that there are scarce applications integrating sustainability in the operational environment of MSMEs, which highlights the importance of this type of research, since the aim is to contribute to a sector with great economic relevance in countries such as Ecuador [3].

The studies reviewed and cited in this section serve as a basis for the development of the proposed model, taking as an example initiatives presented by Hahn and Brandenburg [12], Müller et al. [13] and Yousefi et al.[14] to simulate the use of photovoltaic energy in production in order to analyze its economic and environmental consequences.

3. Methodology

The development of the proposed model is based on a two-phase framework, which is shown in Figure 1. The details of each phase are explained below.

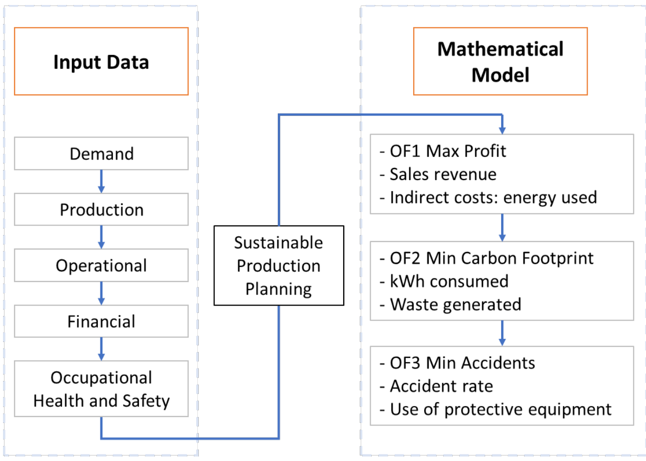

Figure 1. Phases to develop the proposed optimization model

1) Input Data: This first phase is responsible for collecting all the information necessary to plan production in a sustainable manner. The following information must be obtained: demand, raw material characteristics, operations diagrams, production times, installed capacity, resource capacity, waste generated, machinery used, energy input, accident rate, production costs, sales prices of the products, carbon footprint generated in the production process (mass of CO_2 equivalent).

2) Mathematical Model: The second phase consists of the development of a multi-objective optimization model to obtain the number of units to produce for each product analyzed, which is represented in three OF based on the three pillars of sustainability. The first OF maximizes profit by considering the revenue generated minus indirect manufacturing costs. The second OF minimizes the carbon footprint generated by the type of energy used in the production plant (considering hydraulic or photovoltaic sources) and the raw material waste generated. Finally, the third OF, which refers to the social area, minimizes the number of worker accidents by considering accident rates and percentages of use of personal protective equipment (PPE).

4. Model Formulation

The indexes, parameters, decision variables, objective functions and restrictions included in the proposed model are presented in detail.

Indexes:

m	product model manufactured, $m = 1, 2, 3, 4 \ldots M$
e	type of energy used, $e = 1, 2 \ldots E$

Parameters:

PV_m	Sales price per model m
$CUP_{m,e}$	Unit production cost per model m using energy type e
Mp_m	Raw material required per model m
Mpd_m	Raw material available per model m
CTB	Total capacity of the warehouse
FCR	Conversion factor from waste to kg CO_2
R_m	Waste generated per model m
FCE_e	Conversion factor from Energy to kg CO_2 according to type of energy e
$kW_{m,e}$	Kilowatts used per model m according to type of energy e
EC	Capacity of solar panels
P_m	Acceptable percentage of waste according to the company policy for model m
TP_m	Production time per model m
Ia	Accident rate in MSMEs
$TaEpp$	Accident rate based on PPE use
SH	Cost of hours lost due to injury
Pd	Days lost due to accidents
CH	Cost per Hour
Hd_m	Hours available per model m
He	Overtime hours per month
Up_m	Total units produced per model m

Variables:

$Up_{m,e}$	Units produced per model m using type of energy e

Objective Functions:

1) Max Profit = Revenues - Costs

$$Max\ U = \sum_{m=1}^{M}\sum_{e=1}^{E}\left(Up_{m,e} * PV_m\right) - \left(CUP_{m,e} * UP_{m,e}\right) \tag{1}$$

The first OF (Eq. 1) maximizes the profit generated by manufacturing and selling a certain number of units per model minus its production cost. This cost considers among other items the type of energy used in manufacturing, either hydro or photovoltaic energy.

2) Min CO_2 = sum of CO_2 generated by the waste and type of energy used

$$Min\ CO_2 = \sum_{m=1}^{M}(Up_m * R_m) * FCR + \sum_{m=1}^{M}\sum_{e=1}^{E}\left(Up_{m,e} * kW_{m,e}\right) * FCE_e \tag{2}$$

The second OF (Eq. 2) minimizes the carbon footprint emission rate generated by producing a given number of units, considering the KWh consumed and the waste generated according to the model of the product and energy source used.

3) Min Accidents = units produced * Accident and PPE rate

$$Min\ Acc = \sum_{m=1}^{M}(Up_m * TP_m * \mathrm{I}a * TaEpp) \tag{3}$$

The third OF (Eq. 3) related to the social factor, minimizes the number of accidents that can occur when manufacturing a certain number of units, based on a historical accident rate in the textile industry and the effect of the use of PPE in MSMEs.

Restrictions:

The restrictions considered refer to the available raw material (Eq. 4), the capacity of the warehouse (Eq. 5), the allowable percentage of waste according to internal policy (Eq. 6), the installed capacity of the solar panels (Eq. 7), the number of available overtime hours per month (Eq. 8) and the available production hours (Eq. 9).

$$\sum_{m=1}^{M}(Up_m * Mp_m) \leq \sum_{m=1}^{M}(Mpd_m) \tag{4}$$

$$\sum_{m=1}^{M}(Up_m) \leq CTB \tag{5}$$

$$\sum_{m=1}^{M}(Up_m * R_m) \leq \sum_{m=1}^{M}(Mp_m * P_m) \quad (6)$$

$$\sum_{e=2}\sum_{m=1}^{M}(UP_{m,e} * kWE_{m,e}) \leq EC \quad (7)$$

$$\sum_{m=1}^{M}(Up_m * Tp_m) \leq \sum_{m=1}^{M}(Hd_m + He) \quad (8)$$

$$He \leq 48 * mes \quad (9)$$

The structure of the proposed model allows to determine the number of units to produce of each type of product, considering the installed capacity and the available raw material. The model also selects the type of energy source to use, either hydraulic or photovoltaic, taking into account the energy available in the panels and their batteries along with the kWh required for production.

5. Results and Discussion

In order to validate the functionality of the developed model, data from a textile MSME of the Ecuadorian Austro region is used. The textile MSME manufactures leisure clothing and its two best-selling products are analyzed within the period of 30 days. The implementation of solar panels is proposed to generate photovoltaic energy as an alternative to hydraulic energy. An accident rate in textile companies in Ecuador for the year 2022 [22] is applied. Finally, scenarios of PPE use and their influence on the probable number of accidents generated are established based on Baldeon [23].

The results are generated with GAMS software through individual runs of each OF, using the Mixed Integer Programming (MIP) function of the Cplex solver, which uses the Branch and Bound method. The simultaneous runs of the first two OFs (Max Profit and Min CO_2) are executed with the "Epsilon constrained method", which iteratively solves a single objective problem by constraining the other objective. On the other hand, for the general run, which combines the three OFs, the weighted sum approach is used. Therefore, each OF is associated with a weight coefficient, in this case, 0.5 for profit maximization, 0.3 for carbon footprint minimization, and 0.2 for accident minimization.

The analyzed MSME currently operates only with hydraulic energy, for this reason only this type of energy is considered in the first run of the model. Also, a value of 33% is applied as rate of PPE use among workers in the development of their activities. The results obtained from the first run of the model are summarized in Table 1.

The results of the first run show that 89% of the raw material available was used, the waste generated is 7% of the total allowable, the demand is 100% met, and there is still available capacity in the warehouse for 20 additional units. Assuming that 33% of the employees use PPE, we obtain a probable number of accidents of less than one, which generates a projected cost of $567.94. This cost refers to the average prorated cost of the number of hours lost by employees in case that the estimated number of accidents is met [23].

Table 1. Results of the first model run - utilization of hydropower for 100% of the products

Category	Unit	Run 1 - 100% Hydraulic
Raw materials used	m	1090.45
Waste generated	Kg	9.04
Units produced	Unidad	380
Production hours	Hr	145.27
Profit	$	5010.35
CO_2	Kg eq.	128.51
Accidents	Unidad	0.88
Accident Cost	$	567.94

Runs two and three of the model simulate scenarios in which a photovoltaic energy system is implemented to cover 50% (Run 2) and 100% (Run 3) of the total energy required in the production of the two best-selling products in a 30-day period. The condition that 33% of the employees are using PPE is maintained. The results obtained are summarized in Table 2.

Table 2. Results of the second and third model runs - hydro and photovoltaic power utilization

Category	Run 2 – Photovoltaic 50%	Run 3 – Photovoltaic 100%
Raw materials used (m)	1090.45	1090.45
Waste generated (Kg)	9.04	9.04
Units produced - hydroelectric power	210	0
Units produced - photovoltaic energy	170	380
Photovoltaic energy used (KWh)	114.8	205.46
Production hours	145.27	145.27
Profit ($)	**5001.85**	**4991.35**
CO_2 (Kg eq.)	**61.00**	**7.68**
Number of Accidents	0.88	0.88
Accident Cost ($)	567.94	567.94

Table 2 indicates that the number of units produced to meet the demand, the waste generated, the hours of production, the number of accidents calculated and their costs are the same for run 1, 2 and 3. The difference lies in the CO_2 emitted as a consequence of the units produced with hydraulic or photovoltaic energy. In this manner, run two shows a reduction in CO_2 of 52.53% with respect to the first run, causing a decrease in profit of 0.17%. While run 3 generates a reduction in CO_2 of 94.02% and a reduction in profit of 0.38% with respect to the first run.

The decrease in profit is due to the fact that the cost of production increases by \$0.05 per unit when using photovoltaic energy compared to the use of hydraulic energy.

For this reason, in the first run the model takes into consideration only the economic factor, in the second and third runs, the model prioritizes the environmental factor by trying to reduce CO_2 emissions as much as possible.

In the fourth run, the first two OFs are considered simultaneously, while in the fifth run the three OFs are combined. In both cases, the assumption that the photovoltaic energy covers 100% of the energy required for production is maintained. The results of runs four and five, together with the data from the first and third runs are summarized in Table 3.

Table 3. Results of the first, third, fourth and fifth runs of the model

Category	Run 1 - 100% Hydraulic	Run 3 – Photovoltaic 100%	Run 4 – Bi-objective Profit / CO_2	Run 5 – Multi-objective
Raw materials used (m)	1090.45	1090.45	1090.45	1059.75
Waste generated (Kg)	9.04	9.04	9.04	8.80
Units produced - hydroelectric power	380	0	**220**	**210**
Units produced - photovoltaic energy	0	380	**160**	**160**
Photovoltaic energy used (KWh)	0	205.46	123.70	123.70
Production hours	145.27	145.27	145.27	141.45
Profit (\$)	5010.35	4991.35	**5002.35**	**4970.85**
CO_2 (Kg eq.)	128.51	7.68	**69.95**	**65.38**
Number of Accidents	0.88	0.88	0.88	**0.82**
Accident Cost (\$)	567.94	567.94	567.94	503.40

Table 4. Results of the sixth run of the model - OF Min Accidents

Category	Optimistic Scenario PPE – 90%	Standard Scenario PPE – 33%	Pessimistic Scenario PPE – 0%
Units produced - hydroelectric power	220	220	220
Units produced - photovoltaic energy	160	160	160
Profit (\$)	5128.56	5002.35	4938.83
CO_2 (Kg eq.)	69.95	69.95	69.95
Number of Accidents	**0.68**	**0.88**	**0.97**
Accident Cost (\$)	**441.73**	**567.94**	**631.46**

As expected, Table 3 shows that the bi-objective problem between the OF of maximizing profit and minimizing carbon footprint seeks an intermediate point between runs one and three [20], generating a profit value of \$5002.35 and CO_2 emissions of 69.95 kg eq. during run 4. In the fifth run, one particularity is observed, since a smaller quantity of products is produced (360 units), resulting in a reduction of 10 units less than in every other case, this is due in particular to the third OF since the model tries to minimize the number of accidents by sacrificing the production time employed and consequently the number of units produced. If we compare run 5 with run 4, we observe a decrease in profit (0.6%), a lower amount of raw material used (2.8%), lower CO_2 emissions (6.5%) and the non-compliance of demand by 2.6%.

Finally, a sixth run is executed maintaining the conditions of run 4 but increasing three scenarios of PPE use, which directly influences the third OF (Accident Minimization). The scenarios presented refer to the percentage of workers using PPE, which varies from optimistic (90% use of PPE), normal (33% use of PPE) and pessimistic (0% use of PPE). The results of the sixth run are shown in Table 4.

Table 4 shows how the greater use of PPE among workers generates a decrease in the number of possible accidents, resulting in a lower cost associated and in turn an increase in profitability. This profit increase is 3.7% when 90% of the workers use PPE compared to the pessimistic scenario in which no worker uses PPE.

All the runs have allowed validating the functionality of the proposed model. In the same manner, the use of real data from a textile company has allowed the model to present more clearly the consequences of considering environmental or social aspects in production planning. By simulating environmental manufacturing alternatives such as photovoltaic energy and scenarios based on the use of PPE, the model also provides configuration alternatives along with the consequences that these decisions entail when implementing sustainability factors in production planning.

6. Conclusions

A multi-objective optimization model has been developed to enhance the sustainable planning of production in Textile MSMEs. The model was validated with data from an Ecuadorian company dedicated to the manufacture of leisurewear, demonstrating the applicability of the model in this type of textile organization.

The incorporation of three objective functions in the model developed allows the three aspects of sustainability to be analyzed individually and simultaneously. The results of the model generated the following production planning alternatives:

- Use of hydraulic energy for the production of 100% of the products.
- Use of photovoltaic energy with an installed capacity that covers 50% of the kWh necessary to cover the demand.
- Use of photovoltaic energy with an installed capacity that covers 100% of the kWh necessary to cover the demand.
- Combined use of hydro and photovoltaic energy.
- Compliance with the production plan when PPE is used by 90% of workers.
- Compliance with the production plan when PPE is used by 33.33% of workers.
- Compliance with the production plan when PPE is used by 0% of the workers.

In all these alternatives at least 97% of the demand is met and the difference between all of them lies in the value of the total profit generated, the CO_2 generated and the probable number of accidents caused. There is no alternative that can be considered best since the choice depends on the managers of the analyzed company, who will decide which production plan to follow. The decision must also consider the business strategy of the company. In other words, a choice will have to be made between prioritizing the economic factor or sacrificing a percentage of profit in order to achieve better environmental and social results.

Promoting sustainability within businesses does not always generate economic losses [24], the first years it may seem that way because of the investments required, but over time, once the cost of the facilities required for installing a photovoltaic system have been amortized, the production cost per unit of product will decrease. This means that in addition to achieving better environmental results with this type of energy, the company's profit will improve in this same area over time.

However, there are some limitations in this study, since the model has been focused on MSMEs in the textile sector, for this reason, future research could focus on broadening the scope of the model and generalizing it to other manufacturing sectors. Also, additional variables and restrictions could be included to make the proposed model more robust.

References

[1] Jia F, Yin S, Chen L, et al. The circular economy in the textile and apparel industry: A systematic literature review. *J Clean Prod* 2020; 259: 120728.

[2] Gutierrez LAB, Escobar CR, Toledo MR, et al. Análisis de los factores de competitividad para la productividad sostenible de las PYMES en Trujillo (Perú). *Rev Métod Cuantitativos Para Econ Empresa* 2020; 29: 208–236.

[3] Yamuca JLB, Bravo JAL, Carpio WTM, et al. Factores económicos y sociales asociados a la creación y evolución de las MIPYMES en el Ecuador: Economic and social factors associated with the creation and evolution of MSMEs in Ecuador. *LATAM Rev Latinoam Cienc Soc Humanidades* 2023; 4: 4327–4341.

[4] Urco CC, Salinas JG, Castillo D. Aproximación del modelo CAGE para la internacionalización de los productos textiles del Ecuador. *Estud Gest Rev Int Adm* 2019; 9–37.

[5] Acioli C, Scavarda A, Reis A. Applying Industry 4.0 technologies in the COVID–19 sustainable chains. *Int J Product Perform Manag*; ahead-of-print. Epub ahead of print 1 February 2021. DOI: 10.1108/IJPPM-03-2020-0137.

[6] Luna-Altamirano KA, Sarmiento-Espinoza WH, Calle-Masache OR, et al. Modelo de sustentabilidad para la reactivación de las Mipymes textiles de la ciudad de Cuenca-Ecuador. *Dominio Las Cienc* 2021; 7: 325–337.

[7] Malek J, Desai TN. A systematic literature review to map literature focus of sustainable manufacturing. *J Clean Prod* 2020; 256: 120345.

[8] Özsevinç A, Alkan C. Polyurethane shell medicinal lavender release microcapsules for textile materials: An environmentally friendly preparation. *Ind Crops Prod* 2023; 192: 116131.

[9] Chan FTS, Li N, Chung SH, et al. Management of sustainable manufacturing systems-a review on mathematical problems. *Int J Prod Res* 2017; 55: 1210–1225.

[10] Valaei N, Rezaei S. Job satisfaction and organizational commitment: An empirical investigation among ICT-SMEs. *Manag Res Rev* 2016; 39: 1663–1694.

[11] Flores-Sigüenza P, Marmolejo-Saucedo JA, Niembro-Garcia J, et al. A systematic literature review of quantitative models for sustainable supply chain management. *Math Biosci Eng* 2021; 18: 2206–2229.

[12] Hahn GJ, Brandenburg M. A sustainable aggregate production planning model for the chemical process industry. *Comput Oper Res* 2018; 94: 154–168.

[13] Müller R, Loster M, Volk R, et al. CO_2-based assessment for sustainable production planning in the metal processing industry. *Procedia Manuf* 2018; 21: 289–296.

[14] Yousefi S, Baqeri M, Tosarkani BM, et al. A decision support framework for sustainable production planning of paper recycling systems. *Comput Ind Eng* 2023; 183: 109500.

[15] Hosseini Dehshiri SS, Hosseini Dehshiri SJ, Firoozabadi B. Evaluation of using solar energy in Iran’s textile industry towards cleaner production: Sustainable planning and feasibility analysis. *J Clean Prod* 2023; 421: 138447.

[16] Chourasiya R, Pandey S, Kumar Malviya R. Developing a framework to analyse the effect of sustainable manufacturing adoption in Indian textile industries. *Clean Logist Supply Chain* 2022; 4: 100045.

[17] Ozturk E, Koseoglu H, Karaboyaci M, et al. Sustainable textile production: cleaner production assessment/eco-efficiency analysis study in a textile mill. *J Clean Prod* 2016; 138: 248–263.

[18] Tomaney M. Chapter 22 - Sustainable Textile Production. In: Sinclair R (ed) *Textiles and Fashion*. Woodhead Publishing, pp. 547–560.

[19] Islam MdS, Ahmed S, Azady MdAR. 18 - Sustainable technologies for textile production. In: Mondal MdIH (ed) *Fundamentals of Natural Fibres and Textiles*. Woodhead Publishing, pp. 625–655.

[20] Yazdani MA, Khezri A, Benyoucef L. A Linear Multi-Objective Optimization Model for Process and Production Planning Generation in a Sustainable Reconfigurable Environment. *IFAC-Pap* 2021; 54: 689–695.

[21] Ozturk E, Koseoglu H, Karaboyacı M, et al. Minimization of water and chemical use in a cotton/polyester fabric dyeing textile mill. *J Clean Prod* 2016; 130: 92–102.

[22] IESS. IESS Seguro General de Riesgos de Trabajo I Principal, https://sart.iess.gob.ec/DSGRT/portal/index.html (2022).

[23] Baldeón M. *Análisis estadístico de accidentalidad laboral del Ecuador y comparación con la accidentalidad laboral de Colombia del año 2013*. bachelorThesis, Quito: USFQ, 2014, http://repositorio.usfq.edu.ec/handle/23000/3549 (2014, accessed 18 August 2023).

[24] Tumpa TJ, Ali SM, Rahman MdH, et al. Barriers to green supply chain management: An emerging economy context. *J Clean Prod* 2019; 236: 117617.