ISSN 1980-5411 (On-line version)
Production, 32, e20220011, 2022
DOI: 10.1590/0103-6513.20220011

Research Article

A system dynamics model for sustainable corporate strategic planning

Mauricio Becerra-Fernandez[a]*, Liliana Elizabeth Ruiz-Acosta[a], David Andres Camargo-Mayorga[a], Mario Andrés Muñoz[b]

[a]Universidad Militar Nueva Granada, Facultad de Ciencias Económicas, Bogotá, Colombia

[b]The University of Melbourne, School of Mathematics and Statistics, Parkville, Victoria, Australia

*mauriciobecerrafernandez@gmail.com

Abstract

Paper aims: This paper presents a manufacturing process model for assessing the effects on economic, social, and environmental targets, given variations on corporate strategies of production, innovation, marketing, and demand for final goods.

Originality: The model integrates economic, social, and environmental dimensions that are validated through three main scenarios: Business as Usual (no strategic application), Business as Investment (strategic application), and Business as Vision (changes in demand).

Research method: The model estimates the social, environmental, and economic performance through time based on the System Dynamics methodology.

Main findings: The results demonstrate the model's suitability as a decision-support tool for sustainability planning in a corporate environment.

Implications for theory and practice: The model facilitates the analysis of the effects of resource allocation on corporate strategy.

Keywords

Corporate strategic planning. Sustainability. System dynamics. Modeling.

How to cite this article: Becerra-Fernandez, M., Ruiz-Acosta, L. E., Camargo-Mayorga, D. A., & Muñoz, M. A. (2022). A system dynamics model for sustainable corporate strategic planning. *Production*, *32*, e20220011. https://doi.org/10.1590/0103-6513.20220011.

Received: Feb. 4, 2022; Accepted: July 2, 2022.

1. Introduction

Since the inception of Corporate Social Responsibility (CSR), sub-classifications derived from, dependent on, or related to the concept have been presented (Lockett et al., 2006). Its theoretical roots are in management, and it is based on theories such as stakeholder, agency, institutional, legitimacy, resource-based view, and transaction cost economics, among others (Frynas & Yamahaki, 2016). CSR is an efficient management philosophy that can be fundamental to the achievement of organizational goals and performance (Dartey-Baah & Amoako, 2021a). CSR has become highly relevant in the last three decades (Feng et al., 2017), with more stakeholder groups, such as employees, providers, NGOs, and government, pressuring management to increase their CSR related activities (McWilliams et al., 2006).

Society has evolved with economic, social and environmental challenges. Therefore, coming with more complex problems such as climate change, unemployment, poverty, migration, and demographic changes (Ahmad et al., 2020; Dartey-Baah & Amoako, 2021b). To show organizational commitment to ecological and social issues (Aßländer, 2011; Matten et al., 2003) many companies have implemented CSR programs that engage stakeholders to achieve corporate sustainability (Tworzydło et al., 2021), create conditions for a balance between stakeholders (Bian et al., 2021), and work to improve society (Pinillos et al., 2019; Sari et al., 2020). Companies undertake CSR due to internal factors such as top management commitment and ethical corporate culture, and external factors such as socio-political factors, environmental responsibility, and globalization (Dartey-Baah & Amoako, 2021a).

In the last decade, the Global Reporting Initiative (GRI) reports have become the *de facto* international standard for disclosure of CSR activities, becoming an essential decision-making tool by these stakeholder groups (McPherson, 2019; Olanipekun et al., 2021). However, CSR's quantitative measurement is still limited despite broad interest in academic and practitioner circles (Antolín-López et al., 2016; Halkos & Nomikos, 2021).

A Sustainability Performance Measurement System (SPSM) (Morioka & Carvalho, 2016) is a decision-support tool that measures CSR while promoting organizational learning and strengthens the commitments with stakeholder groups (Schneider & Meins, 2012). SPSM modeling focuses on conceptual, qualitative, frameworks, and concept review models (Wood, 2019). Many of these models apply statistically based techniques, e.g., linear and multiple regression, experimental design, fixed and random effects, meta-analysis, econometric and structural equations (Rezaee & Tuo, 2019), or apply mathematical methods and optimization, e.g., Markov-based models, analytical network process, fuzzy logic, and multi-criteria decision analysis (Bilbao-Terol et al., 2018). However, the results from these systems may not be comparable (Crane et al., 2017), due to the complexity of multifaceted nature of business performance evaluation (Kong et al., 2020). Moreover, most of them use indicators that are measured statically at the end of a period; hence, precluding the ability to project into the future and plan a longer-term. Because organizations are dynamic entities, their real-time operations affect their short- and long-term sustainability performance, raising the question: *What are the effects over time that a corporate strategy has on a company's environmental, social and economic performance, considering demand changes and systemic interactions and feedbacks?* To answer this question, a dynamic approach towards CSR measurement is needed.

System dynamics (SD) is a methodological modeling framework that combines quantitative and qualitative analysis, to understand the transformations that a complex system goes through time, due to interactions, feedback and delays (Zhao & Zhong, 2015; Martínez-Fernández et al., 2013; Rasmussen et al., 2012). Through the simulation of diverse *scenarios*, SD enables the visualization and comparison of the outcomes of a variety of decisions, actions, policies, and strategies (Banos-González et al., 2016). As such, SD facilitates long-term planning and reduces uncertainty, as the intended and unintended consequences of the management team's actions become observable. Hence, SD modeling is an ideal approach for the analysis of CSR performance and planning.

This paper presents an SD model of a manufacturing process that provides estimates of its social, environmental, and economic performance through time. Hence, it enables the analysis of the impacts on the performance that resource allocation has at different levels of the system. With this knowledge, decision-makers can prioritize investment that will lead to better outcomes. The model is based on the Key Performance Indicators (KPI) by (Pavláková Dočekalová & Kocmanová, 2016) and uses data from publicly available GRI reports and government agencies. This previous research provides a method for calculating the KPI indicators based on statistics for corporate sustainability. The model is validated through diverse scenarios, demonstrating its suitability as an SPMS for a corporate environment.

The remainder of this paper is organized as follows: Section 2 provides context and background to this paper by discussing related CSR models and SD applications. Section 3 presents the SD model architecture and describes the experimental validation approach based on scenario and sensitivity analyses. Section 4 presents the results of the validation and discusses the findings. Finally, Section 5 presents conclusions from this study, including its limitations and further avenues for work.

2. Literature review

System dynamics has been widely used in social, political, health, environmental and, related to this research, in the study of industrial systems (Forrester, 1997). Stakeholders in supply chains are studied, through the flow of materials and information with a dynamic approach, from the arrival of raw materials, manufacturing processes, storage and delivery fulfillment to the final consumer (Sterman, 2000). System Dynamics is applied to sustainability to be used in different sectors and processes. It is used to understand feedback from the behaviours in ecological-social systems (Nabavi et al., 2017), to determine the scope of the problem, and to analyse the policies in environmental, social (Videira et al., 2010) and economic decision-making as well as to develop and graphically represent partial models (Abdelkafi & Täuscher, 2016).

Dimensions such as the technological, which is beyond those in the triple bottom line (economic, environmental and social) in the SD models, are discussed in the research of Kim et al. (2014); Joung et al. (2013); and Musango et al. (2012). Furthermore, the political dimension is discussed in the research of Bautista et al. (2019) and quality and environmental management accounting (EMA) in Petry et al. (2020).

To develop SD models applied to industry, Zhang (2019) considered that manufacturing processes are holistic as there are sustainability problems with characteristics such as behaviour, interconnectedness, boundaries, delays, perspectives, uncertainty, and resilience. Identification of these characteristics can then aid the derivation of 9 relationships from relationships between economic, social, environmental, and quality factors (Felicetti et al., 2022). The integration of these relationships serves for an analysis of the risk and uncertainty in these relationships. To map the system relationships, an SD model is used to incorporate the system's behaviours and the assessment of its sustainability. This understanding consequently facilitates decision-making (Zhang et al., 2021).

Abdelkafi & Täuscher (2016) showed from the perspective of value creation, integrate four partial models: the firm, the environment, decision making, and the client and their relationships with value creation. Furthermore, decision makers' beliefs and standards regarding sustainability are included, wich are capable of eliciting behavioral changes in both the business model and the way it feeds on the environment and customers.

Harik et al. (2015) studied a sustainability index composed of environmental, social, economic, and manufacturing variables is developed from a holistic perspective; the latter includes direct and indirect manufacturing management. Orji & Wei (2015) simulated supplier behavior in a diffuse environment, taking into account two sustainability criteria: green design and disclosure of information in order to determine the best possible sustainable supplier. In that regard, four suppliers' investment budget is taken into account.

For manufacturing SMEs, Zhang et al. (2021) considered that decision-making in sustainable production is improved when there is an understanding of the interconnections between technical, environmental, social, and economic performance metrics. Marcelino-Sádaba et al. (2015) added aspects such as operation, plant levels, products and internal processes and Nicoletti Junior et al. (2021) also included marketing and finance.

Concerning energy production industries, Bautista et al. (2019) included environmental aspects such as land use, water demand, energy ratio, GHG emission savings, and emissions affecting air quality. Furthermore, Musango et al. (2012) added the community's perception of social aspects and the amount of glycerol accumulated as a result of biodiesel production within environmental aspects. Jin et al. (2019) considered the use of cellulosic fuels, including N_2O emissions from nitrogen as a fertilizer and CO_2 emissions from cellulosic ethanol emissions.

Ansari & Seifi (2012) analysed the effects of subsidies on energy prices with low, moderate, and high energy efficiency scenarios on the iron and steel industry. Kim et al. (2014) developed the DS model is geared to GHG mitigation through technology by comparing BAU and TECH scenarios (use of technology), concluding that the introduction of technologies reduces CO_2 emissions.

In order to reduce the carbon footprint, Thirupathi et al. (2019), used DS to determine sustainable areas in the automotive industry. The elements taken into account were learning and growth, technological growth, market and customer growth, and financial growth.

Similarly, there has been academic research to lead measurement and evaluation tools of sustainability practices (Reverte et al., 2016), most of them focusing on relating social and financial or environmental and financial performances. Waddock & Graves (1997) identified positive, negative, and neutral relationships between social and financial performance. Dobre et al. (2015) analyze the financial impact of environmental and social disclousure indicators in exchange-listed corporations. Reverte et al. (2016) analyzed CSR practices by considering financial and non-financial indicators and the importance of innovation as link between social and financial performance.

Rintala et al. (2022) considered it essential to develop ambidexterity in logistics to improve the relationship between environmental and financial performance, promoting the simultaneous exploitation of existing competencies and explorimg new opportunities to increase organizational performance. Throughout Environmental, Social and Governance research, looking for new alternatives to mitigate environmental and social risks such as climate change and human rights and governance to obtain long-term investment returns in the long term. It operates in the financial domains, focusing on risk and financial return, while CSR operates in the corporate fields (MacNeil & Esser, 2022; Siew, 2015).

Acknowledging the multidimensional character of sustainability, develop a framework for measuring environmental performance that considers the production processes, the qualitative nature of the indicators, and the complexities in developing a synthetic indicator. Shokravi et al. (2014) proposed a model for environmental performance evaluation based on Markov chains, which simulate the operational aspects of an industrial process. This model was later extended to include all sustainability dimensions within a supply chain (Shokravi & Kurnia, 2014). These latter two studies are noteworthy as they consider the dynamical character of an organization in measuring CSR performance.

CSR practices are also influenced by marketing and innovation strategies (Chaudhri, 2016; Padilla-Lozano & Collazzo, 2021; Revuelto-Taboada et al., 2021). For example, Pergelova & Angulo-Ruiz (2013) considered that green marketing and socially responsible consumption have a weak correlation with corporate performance. Singh (2016) studied the effect that an alliance between companies with similar ethical identities have consumer perceptions about social responsibility. Brower & Mahajan (2013) identified 35 variables related to social performance based on a study of the factors that affect demand from stakeholder groups, including marketing intensity, brand strategy, investment in research and development, among others. Broadstock et al. (2020) determined that innovation activities positively affect social performance. Veronica et al. (2020) considered that an organization's orientation towards sustainable innovation depends on both its tangible and intangible stakeholder capabilities. However, none of these studies examined marketing and innovation strategies considering the dynamic nature of an organization.

System Dynamics modeling has been employed to analyze the sustainability of a project. For example, Ozcan-Deniz & Zhu (2016) analyzed the effect that changing conditions affected the sustainability of a construction project. Duran-Encalada & Paucar-Caceres (2009) used a model to simulate the sustainability dimensions in urban development projects. Fang et al. (2017) modeled the economic, population, waste, and energy components. Jin et al. (2009) incorporated the concept of an ecological footprint into an SD model. Finally, Xu & Coors (2012) proposed a model for the analysis of residential development using sustainability indicators. However, none of these models analyzed the impacts on CSR performance over time of a corporate strategy. In the next section, a model is presented aiming to breach this gap.

3. Methods

System Dynamics methodology has been widely used for prospective models, this methodology includes analysis of the model components, development of the dynamic hypothesis in the causality analysis, computational modeling in the flow and level diagram, model validation, scenario runs and analysis of results. Several applications are developed for making decisions under controlled simulation scenarios in supply chain management, energy, environment, society, finance, and public policies. This paper presents a novel model of the manufacturing supply chain, as references for application in the corporate resources planning process considering combined sustainability elements.

3.1. Model design, causal loop and stock-flow diagrams

The structure of the model includes the main sectors in a typical company, such as transformation and support processes proposed by Sterman (2000), through problem articulation (see section 1), formulation of dynamic hypothesis (see Figure 2), formulation of simulation model (see Figure 3), testing (see section 3.2) and, policy desing and evaluation (see section 4). This can be adapted to other manufacturing processes, industrial, commercial, and services sectors. Figure 1 illustrates the main elements of the proposed model, which is based on a manufacturing system.

These are: (a) The *direct* and *indirect production materials*. The former refers to those raw materials necessary for manufacturing the finished product, and of greater volume or cost; while the latter refers to complementary elements such as packaging. Indirect materials are subclassified into purchased and recycled indirect materials. (b) The *manufacturing process* produces the final products to meet the demands of the end consumer, which is stimulated through innovation and marketing strategies. It comprises the materials, workers, and machines. (c) The *Complex Performance Indicator* (CPI) measures the system's performance system from social, environmental, and economic perspectives. Social performance is calculated from the worker sector. Economic performance is calculated from the results of the manufacturing process, the machine sector, and the demand of the final consumer. Finally, environmental performance is calculated from the result of the manufacturing process and the production materials used.

Figure 2 shows the Causal Loop Diagram (CLD) developed using SD methodology to answer the question posed in Section 1. It has three main negative feedback loops.

The first two are the *direct* and *indirect materials loops* that control the essential and auxiliary elements for manufacturing the products. An increase in the desired production results in increased orders of either or both groups of materials, subject to revision of inventory levels and safety stock. After delays due to delivery, the inventory of either or both groups of materials increases. These loops affect the behavior of the environmental

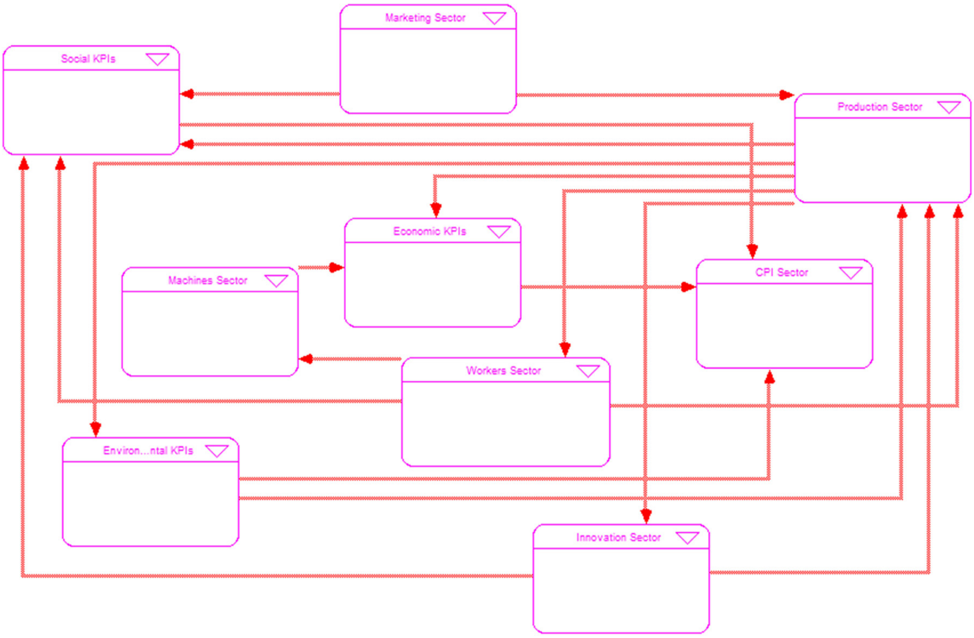


Figure 1. Relations between the sectors of the model.

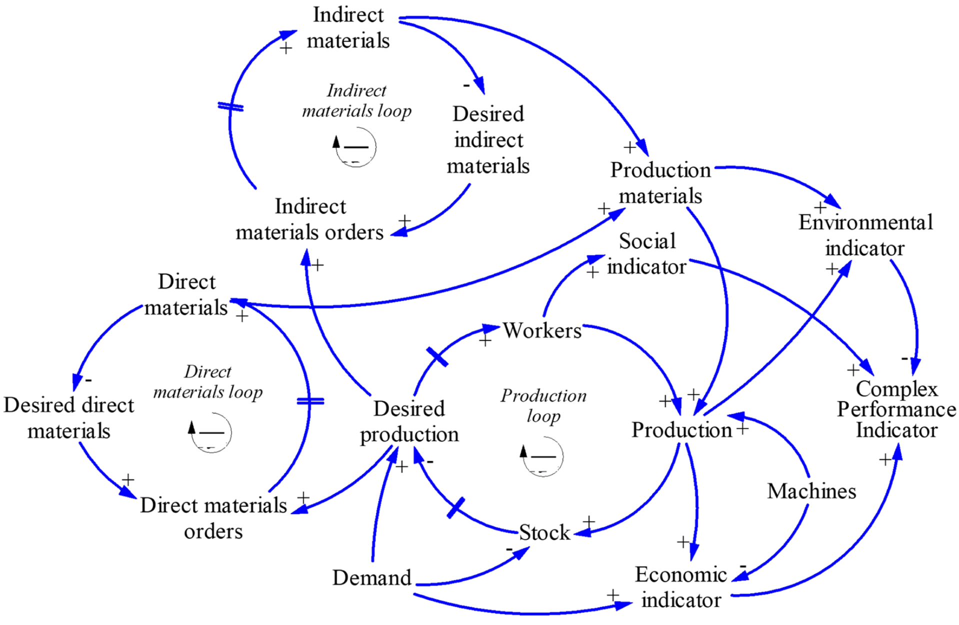


Figure 2. Causal loop diagram.

indicator. The third loop is the *production loop* that controls increases in the desired production. An increase in demand increases the desired production, subject to inventory levels and safety stock, which in turn triggers a request to modify the number of workers hired within a time frame. The production volume is related to each worker's productivity, and it is measured as the number of units produced per unit of time. Production volume increases the stocks of the final product, which decreases as orders are dispatched. This loop affects the social indicator through the workers' behavior and the economic and environmental indicators through the dynamics of production.

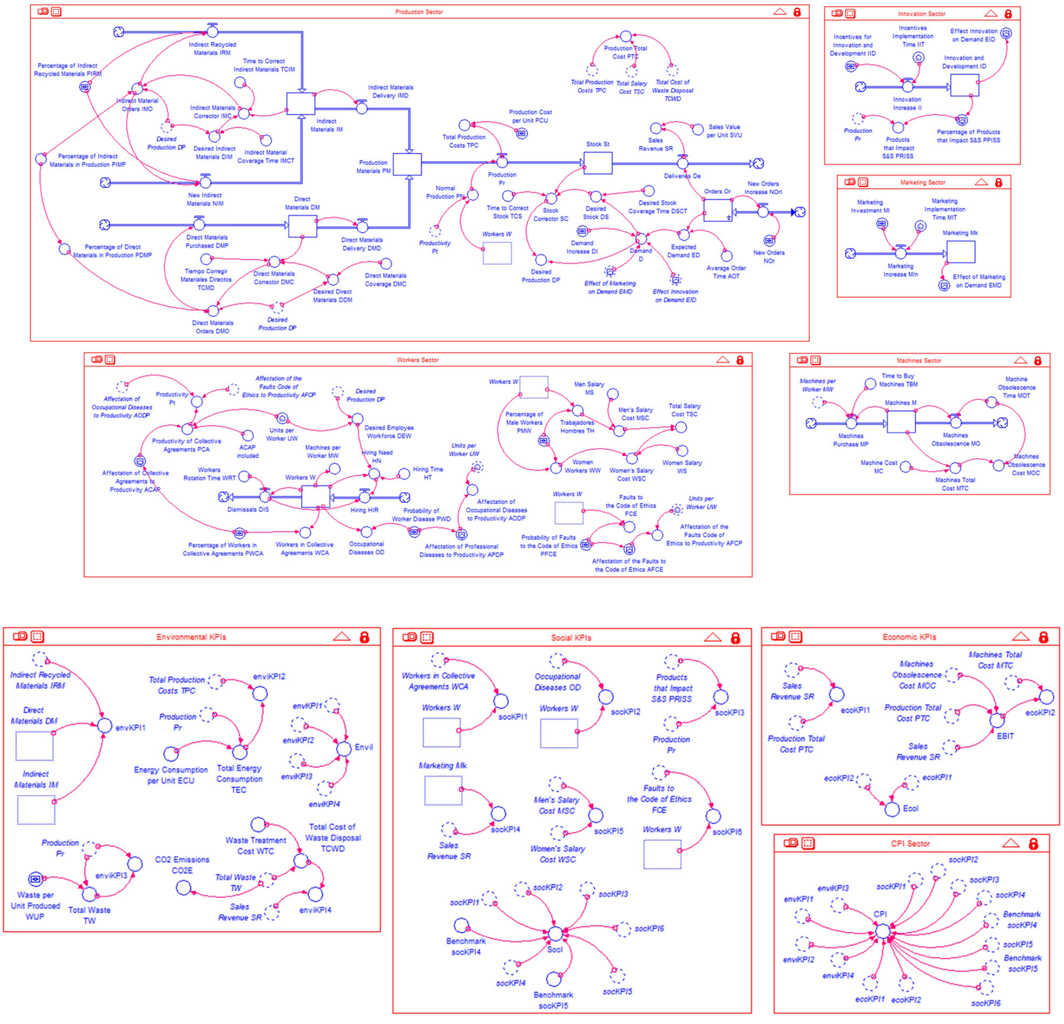


Figure 3. Stock and flow diagram of the corporate social responsibility model.

The model is divided into interconnected *physical* and *information flow sectors* as illustrated in Figure 1, whose individual structure is illustrated in the Stock and Flow Diagram (SFD) in Figure 3. The physical flow sectors are those that simulate the actions within the process that result in the manufacture of finished products. These are:

- The *Worker Sector* (*W*) simulates the changes in the production staff according to production needs, through hiring and dismissal. This sector also simulates the effects of occupational diseases, beaches of ethical conduct, and changes in wages;
- The *Innovation Sector* (*I*) simulates the company's innovation strategy. It aims to model the effect that innovation incentives have on product improvements affecting health and safety;
- The *Marketing Sector* (*M*) simulates the company's marketing strategy. It aims to model the effect that marketing investments have on the demand for the finished product;
- The *Machinery Sector* simulates the acquisition and disposition of machinery, depending on the needs of the manufacturing process;
- The *Production Sector* (*P*) simulates the manufacturing process. Its inputs are the direct and indirect materials, and its output is the stocks of the finished products, as required by market demand;
- The information flow sectors calculate the Key Performance Indicators (KPI) derived from physical flows. The KPIs are based on those proposed by Pavláková Dočekalová & Kocmanová (2016), which are:

- *Environmental KPIs (EnvI)* measures material and energy consumption, waste production, CO_2 emissions and other environmental costs, based on the equations from Table 1;
- *Social KPIs (SocI)* measures the proportion of workers in collective agreements, the frequency of professional illnesses, products that impact safety and health, identification of client needs, salaries, and failures in the code of ethics, based on the equations from Table 1;
- *Economic KPIs (EcoI)* measures cash flows and return on investment, based on the equations from Table 1;
- *Sector CPI* calculates the consolidated indicator derived from the three above, based on the equations from Table 2;

Table 1. Key performance indicators equations.

Sector	KPI	Equation		Variables or parameters used
Environmental	Consumption of recycled materials and raw materials	$envKPI1 = \left[\frac{(IRM + DM)}{(IM + DM)}\right] \times 100$	(1)	*IRM:* Indirect Recycled Materials *DM*: Direct Materials *IM*: Indirect Materials
	Fuel consumption	$envKPI2 = \left[\frac{TEC}{TPC}\right] \times 100$	(2)	*TEC:* Total Energy Consumption *TPC:* Total Production Costs
	Waste production	$envKPI3 = \left[\frac{TW}{Pr}\right] \times 100$	(3)	*TW:* Total Waste *Pr:* Production
	Environmental costs	$envKPI4 = \left[\frac{TCWD}{SR}\right] \times 100$	(4)	*TCWD:* Total Cost of Waste Disposal *SR:* Sales Revenue
Social	Percentage of employees covered by a collective agreement	$socKPI1 = \left[\frac{WCA}{W}\right] \times 100$	(5)	*WCA:* Workers in Collective Agreements W: Workers
	Occupational diseases	$socKPI2 = \left[\frac{OD}{W}\right] \times 100$	(6)	*OD:* Occupational Diseases
	Products which impact on the health and safety of customers	$socKPI3 = \left[\frac{PRISS}{Pr}\right] \times 100$	(7)	*PRISS:* Products that Impact the Health and Safety *Pr:* Production
	Expenditures on identifying and ensuring customer satisfaction	$socKPI4 = \left[\frac{Mk}{SR}\right] \times 100$	(8)	*Mk:* Marketing *SR:* Sales Revenue
	Wage discrimination	$socKPI5 = \left[\frac{MSC}{WSC}\right] \times 100$	(9)	*MSC:* Men's Salary Cost *WSC:* Women's Salary Cost
	Violations of the Code of Ethics	$socKPI6 = \left[\frac{FCE}{W}\right] \times 100$	(10)	*FCE:* Faults to the Code of Ethic
Economic	Cash Flow	$ecoKPI1 = \left[\frac{PTC}{SR}\right] \times 100$	(11)	*PTC:* Production Total Cost *SR:* Sales Revenue
	Return on Assets	$ecoKPI2 = \left[\frac{\mathrm{EBIT}}{MTC}\right] \times 100$	(12)	*EBIT:* Earnings Before Interest and Taxes *MTC:* Machines Total Cost

Table 2. CPI equations.

KPI	Equation	
Environmental performance indicator	$EnvI = (0.186 \times envKPI1) - (0.265 \times envKPI2) - (0.279 \times envKPI3) - (0.27 \times envKPI1)$	(13)
Social performance indicator	$SocI = (0.095 \times socKPI1) - (0.245 \times socKPI2) + (0.109 \times socKPI3) - (0.169 \times \lvert benchmark\ socKPI4 - socKPI4 \rvert) - (0.157 \times \lvert benchmark\ socKPI5 - socKPI5 \rvert) - (0.225 \times socKPI6)$	(14)
Economic performance indicator	$EcoI = (0.708 \times ecoKPI1) + (0.292 \times ecoKPI2)$	(15)
Complex Performance Indicator	$CPI = (0.062 \times envKPI1) - (0.09 \times envKPI2) - (0.094 \times envKPI3) - (0.091 \times envKPI4) + (0.048 \times socKPI1) - (0.123 \times socKPI2) + (0.056 \times socKPI3) - (0.084 \times \lvert benchmark\ socKPI4 - socKPI4 \rvert) - (0.079 \times \lvert benchmark\ socKPI5 - socKPI5 \rvert) - (0.114 \times socKPI6) + (0.112 \times ecoKPI1) + (0.047 \times ecoKPI2)$	(16)

Each of these consolidated indicators consider weights defined as a result of the research by Pavláková Dočekalová & Kocmanová (2016) and detailed in Table 2. Corporate KPIs are calculated through the benchmark studies in Pavláková Dočekalová & Kocmanová (2016), but are not considered in the model developed in this paper. Due to the case study scope and the availability of the information.

The model was constructed using the software iThink. A detailed list of equations of the model is provided in the Appendix A, whereas the parameters used are provided in Appendix B. These parameters were collected from the public databases of Colombian governmental entities, such as the National Administrative Department of Statistics (DANE), the National Planning Department (DNP), the Superintendence of Industry and Commerce (SIC), the National Association of Entrepreneurs of Colombia (ANDI), and the Federation of Colombian Insurers (Fasecolda).

3.2. Model validation through scenario and sensitivity analyses

The model's consistency, confidence, and robustness were validated following a multipronged approach. Initially, the structure and behavior of the model were checked for dimensional consistency and sensitivity as defined by Barlas (1996) and Qudrat-Ullah & Seong (2010). For the former, using the "Check Units" tool included in iThink, the equations' units of measurement are verified for consistency. For the latter, the upper and lower bounds for each variable are defined. This upper and lower bounds represent significant changes in the behavior of the model, added to the adjustment capacity in the planning of corporate strategies, which shows, on the one hand, the robustness of the model's behavior, and on the other hand, the viability in the implementation of the actions to be executed. Then, the model is tested using these extreme conditions. The model presented is a proposal for the sustainability analysis in the manufacturing planning processes, considering the main data collection of the Colombian manufacturing sector, for this reason, the validation is not focused on the historical data of a particular company.

Once these tests were successful, the model was checked for robustness and sensitivity using *scenario analysis*. A *scenario* is defined as a broad set of initial conditions and changes applied during a simulation to observe the responses of the model, a *corporate strategy* is defined as a percentage change made to the initial values of one or more variables of the model, and an *option* is defined as the individual settings of each variable, which are used to observe the behavior over-time of the system KPIs. The analysis focuses on the effects that a corporate strategy implemented by management has on the behavior of the Environmental Indicator (*EnvI*), Social Indicator (*SocI*), Economic Indicator (*EcoI*) and Complex Performance Indicator (*CPI*), during a five-year planning horizon (in manufacturing planning, a five-year time is considered a long-term period for the decision-making process), assuming initial conditions corresponding to the Colombian manufacturing sector, as mentioned in Section 3.1. The results are reported as the accumulated average of each KPI, aiming to observe convergence at the end of the planning horizon. Moreover, the results are also indicators of the viability of the strategy under those conditions. Table 3. shows three global scenarios and its strategies, which include both increases in investment levels and optimistic and pessimistic changes in demand.

Through the system dynamics methodology, scenarios are analyzed, ranging from the base scenario or the current situation, scenarios that evaluate investment possibilities, to scenarios with changes in the future behavior of the environment (Becerra-Fernandez et al., 2020). The scenarios included in this research are:

Table 3. Scenarios combination for the system dynamics corporate social responsibility model.

Strategy	Model Sector	Variable Modified ID	BAU	BAI-P	BAI-W	BAI-PM	BAI-I	BAI-M	BAI-IMM	BAV-OP-PM	BAV-OP-IMM	BAV-OP-AS	BAV-PE-PM	BAV-PE-IMM	BAV-PE-AS
No Strategy Implementation	All	-	•												
Production Management (PM)	Production (P)	PIRM		•		•				•		•	•		•
		PCU		•		•				•		•	•		•
	Workers (W)	UW			•	•				•		•	•		•
		PMW			•	•				•		•	•		•
Innovation and Marketing Management (IMM)	Innovation (I)	IID					•		•		•	•		•	•
		IIT					•		•		•	•		•	•
	Marketing (M)	MI						•	•		•	•		•	•
		MIT						•	•		•	•		•	•
Optimistic (OP)	Production (P)	NOr								•	•	•			
Pessimistic (PE)	Production (P)	NOr											•	•	•

- *Business as Usual (BAU)* is the base-case scenario, where average growth in demand is experienced but none of the proposed strategies are implemented;
- *Business as Investment (BAI)* considers increased levels of investment through *production management* (PM) and *innovation and marketing management* (IMM) strategies. Figure 4 illustrates the variables in the system modified in this scenario. PM strategies affect both the Production (P) and Workers (W) sectors. For sector P, *Percentage of Indirect Recycled Materials* (PIRM) increases by 5% per option, and *Production Cost per Unit* (PCU) decreases by 2.5%. For sector W, *Units per Worker* (UW) increases by 2.5%, and *Percentage of Male Workers* (PMW) decreases by 2.5%. IMM strategies affect both the Innovation (I) and Marketing (M) sectors. For sector I, *Incentives for Innovation and Development* (IID) increases by 5% and *Incentives Implementation Time* (IIT) decreases by 5%. For sector M, *Marketing Investment* (MI) increases by 5% and *Marketing Implementation Time* (MIT) decreases by 5%;

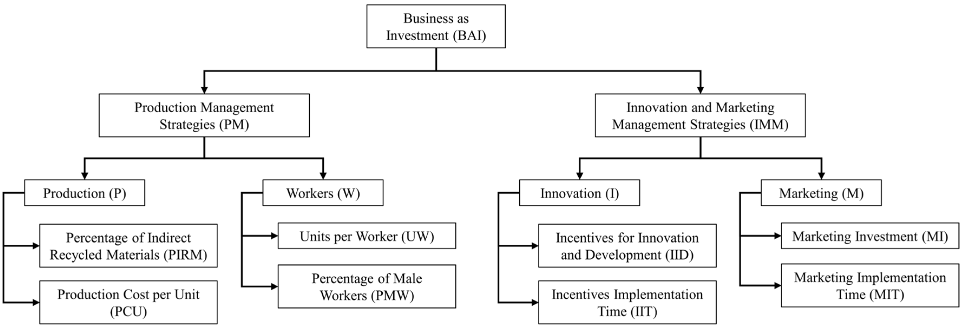


Figure 4. Variables modified by strategy in the Business as Investment scenario.

- *Business as Vision (BAV)* considers *optimistic* (increasing at 8.7% per year) and *pessimistic* (decreasing at 0.4% per year) (Hickel et al., 2021; Hickel & Kallis, 2020; Latouche, 2012; Lehmann et al., 2022; Petschow et al., 2020) demand of the finished product, with one, both or none of the PM and IMM strategies implemented. Percentual changes in demand were based on the annual growth rate of the industrial value-added of the OECD national accounts historical data. Figure 5 illustrates the variables in the system adjusted in this scenario.

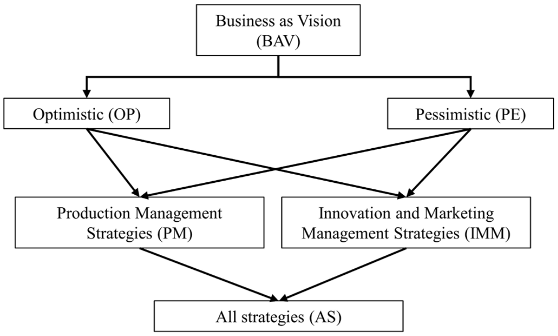


Figure 5. Strategies combination in the Business as Vision scenario.

Once these scenarios were completed, those options that resulted in the highest change in the cumulative average *CPI* are taken as reference for further analysis of the model results.

4. Results

4.1. Outcomes of the sensitivity analysis

Sensitivity analysis is performed for the relevant variables of the model, the detail is not presented but the result is expanded through the following section. Sensitivity analysis allows to observe the behavior of the model sectors in response to changes in the defined variables. The resources of the processes are finite and changes in their allocation represent economic efforts for the companies. In the results section, the amount of variation that significantly impacts the sustainability indicators, allows prioritizing the allocation of resources.

In the following section, the best results from the sensitivity analysis are analyzed during the sixty-month planning horizon, where for each KPI is presented as a percentage increase from the BAU conditions.

4.2. Analysis of the best options during the planning horizon

Figure 6 illustrates the results of the BAU scenario, where no strategies have been implemented and demand growth is based on historical performance. As such, BAU is used to compare the results of all other strategies. At the end of the planning horizon, *EnvI* reaches a value of 5.5, *SocI* reaches a value of -4.3, *EcoI* reaches a value of 73.1, and *CPI* reaches a value of 11.3.

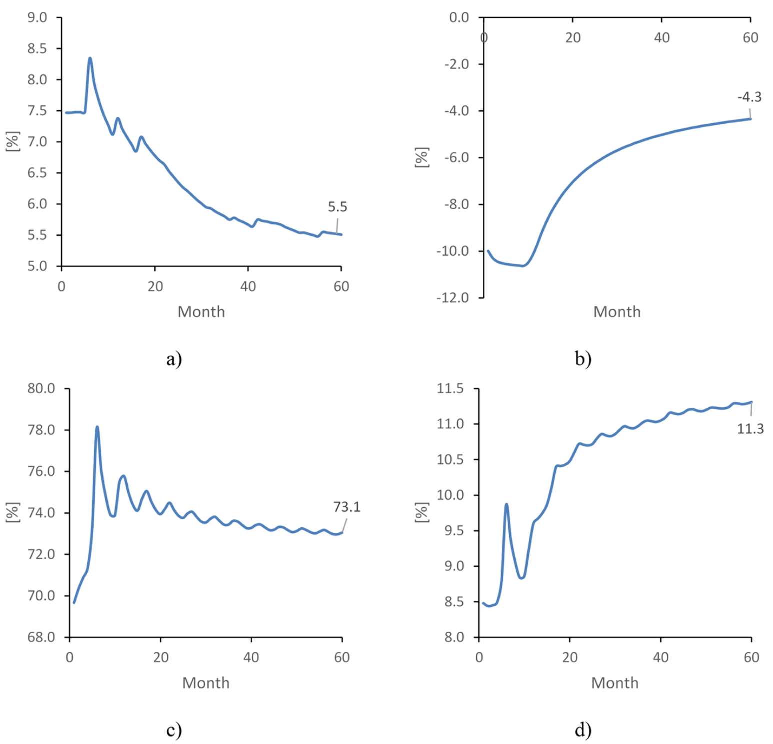


Figure 6. Behavior of (a) EnvI; (b) SocI; (c) EcoI: and (d) CPI under BAU scenario.

Figure 7 shows the results for the best options for the production management strategies in the BAI scenario. At the end of the planning horizon, *EnvI* improves 5.1% (from 5.5 to 5.79) when Sector W variables are modified; *SocI* improves 138% (from -4.3 to 1.65) when Sector W variables are modified or with the combined PM strategies. *EcoI* improves 2.6% (from 73.1 to 77.21) with the combined PM strategies. Finally, *CPI* improves 30.6% (from 11.3 to 15.7) with the combined PM strategies. Worker-related strategies have the highest effect on *CPI*, with minor improvements when combined with production-oriented strategies.

Figure 8 shows the results for the best options for the innovation and marketing management strategies in the BAI scenario. *EnvI* improves 6.9% (to 5.89) when Sector I variables are modified. *SocI* improves 12.4% (to -3.80) when Sector I variables are modified or with the combined IMM strategies. *EcoI* improves 0.3% (to 73.25) when Sector W variables are modified. Finally, *CPI* improves 3.4% (to 11.7) when Sector I variables are modified, meaning that implementing innovation strategies alone has the necessary effect, and a combination with marketing strategies have a minor additional effect.

Figure 9 shows the results for the best options for the BAV scenario, considering an optimistic growth in demand. *EnvI* improves 11.1% (to 6.12) when IMM strategies are implemented. *SocI* improves 150.7% (to

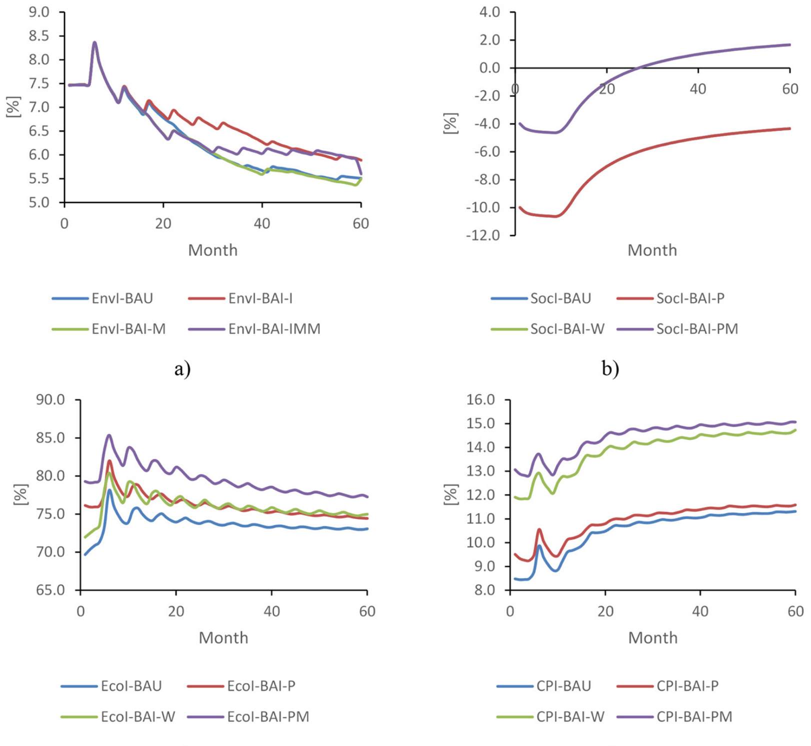


Figure 7. Behavior of (a) EnvI; (b) SocI; (c) EcoI; and (d) CPI indicators under PM strategies implementation.

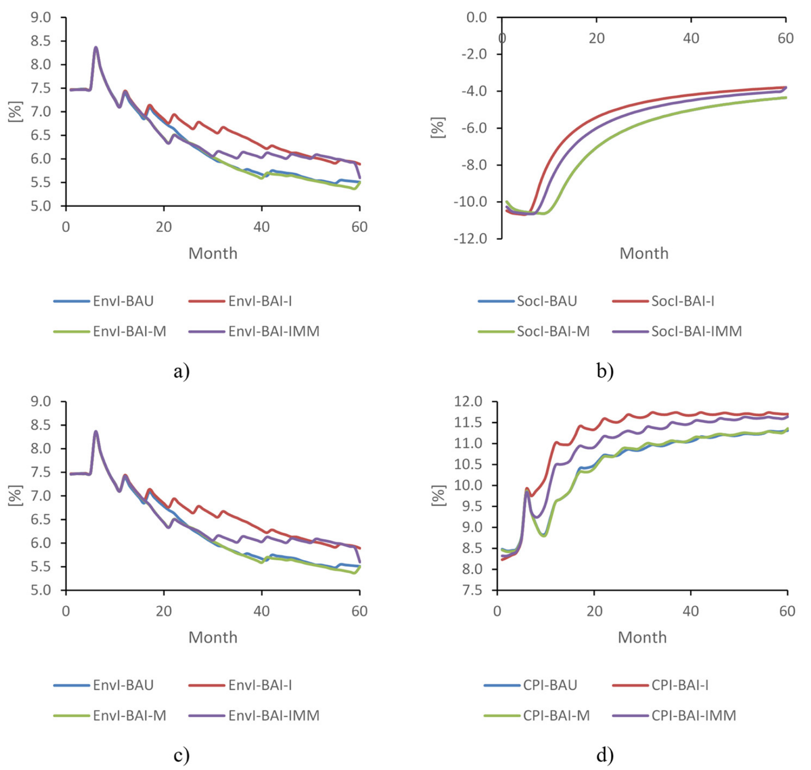


Figure 8. Behavior of (a) EnvI; (b) SocI; (c) EcoI; and (d) CPI indicators under IMM strategies implementation.

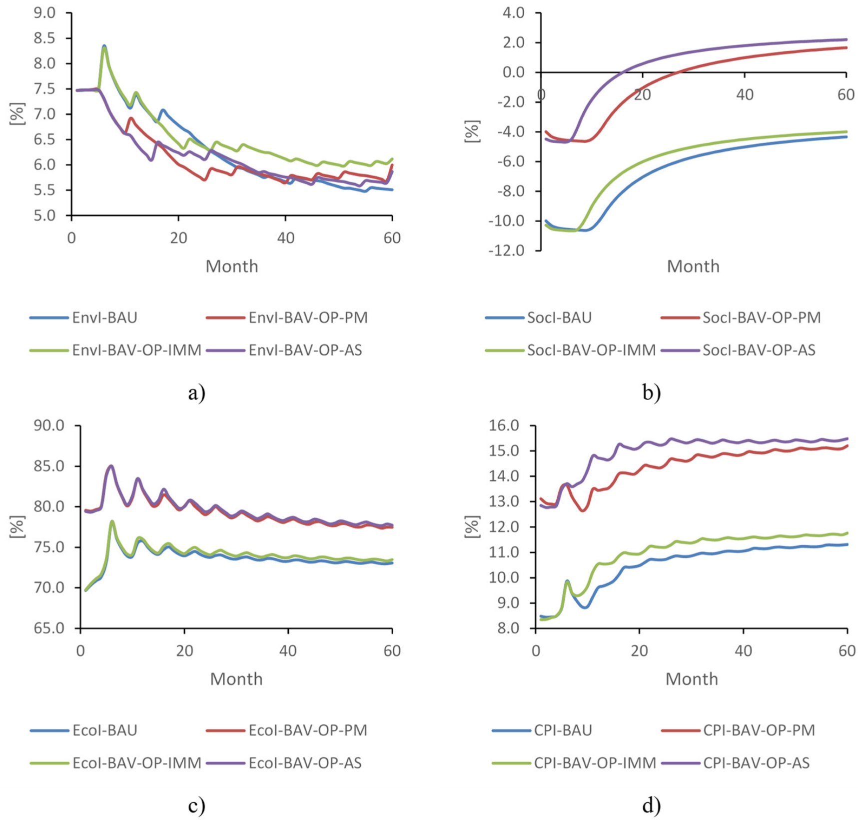


Figure 9. Behavior of (a) EnvI; (b) SocI; (c) EcoI; and (d) CPI indicators under BAV scenario and an optimistic demand increase.

-2.2), *EcoI* improves 6.4% (to 77.72) and *CPI* improves 37% (to 15.49) when AS strategies are implemented, meaning that significant effects on *CPI* are obtained with production management strategies only. Contrary to expectations, innovation and marketing strategies did not significantly improve *CPI*.

Figure 10 shows the results for the best options for the BAV scenario considering a pessimistic growth in demand. *EnvI* improves 6.4% (to 5.86), *SocI* improves 150.7% (to 2.2) and *CPI* improves 33.7% (to 15.12) when AS strategies are implemented. Meanwhile, *EcoI* improves 4.2% (to 76.12) when PM strategies are implemented. As observed in the optimistic demand scenario, *CPI* improves mainly due to production management strategies.

4.3. Consolidated results by indicator

Table 4. shows the consolidated results by KPI according to the changes by sector and the implementation of strategies. In boldface are the results with the highest values, which are obtained for the BAV scenario by combining strategies and optimistic demand growth, and for the BAI scenario by applying the PM strategies.

Figure 11 show the best results for each KPI depending on the implemented strategy. Figure 11a corresponds to *EnvI*, whose best result of 6.12 is obtained with the IMM strategies with an optimistic growth in demand, representing a 3.9% increase compared to modifying the Sector I variables in the BAI scenario (a value of 5.89), and an 11.1% increase compared to the BAU scenario. These results indicate that implementing innovation initiatives always improves *EnvI*; however, marketing actions are required in conditions of growing demand, and production initiatives are required in conditions of falling demand.

Figure 11b corresponds to *SocI*, whose best result of 2.2 is obtained by implementing all strategies in both optimistic and pessimistic demand scenarios. This represents a 33.3% increase compared to modifying the Sector W variables or implementing the PM strategies in the BAI scenario (a value of 1.65 in both cases), and an increase of 150.7% compared to the BAU scenario. These results indicate that *SocI* remains stable with changes in demand. Improvements can be obtained by combinations of production, innovation, and marketing initiatives, and to a lesser extent with worker-related initiatives.

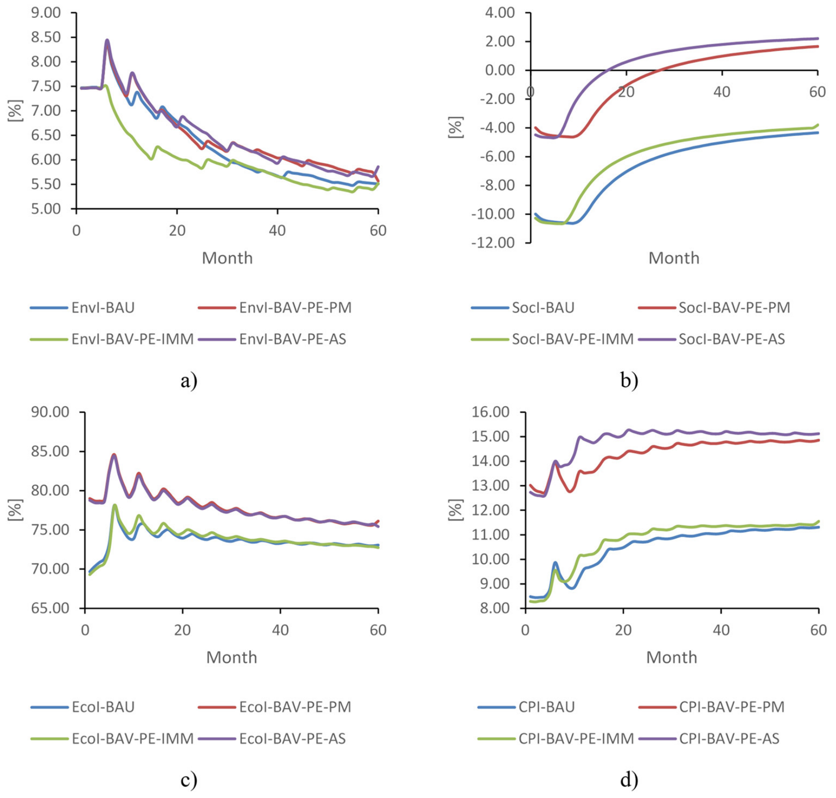


Figure 10. Behavior of (a) Envl; (b) Socl; (c) Ecol; and (d) CPI under BAV scenario and pessimistic demand decrease.

Table 4. Consolidated results by strategy and indicator.

Scenary	Sector or strategy	Envl	Socl	Ecol	CPI
BAU	-	5.51	-4.34	73.06	11.31
BAI	P	5.65	-4.34	74.44	11.59
	W	5.79	**1.65**	74.99	14.73
	PM	5.66	**1.65**	**77.27**	**15.07**
	I	**5.89**	-3.80	72.97	11.70
	M	5.50	-4.34	73.26	11.36
	IMM	5.60	-3.80	73.19	11.64
BAV-OP	PM	6.00	1.65	77.47	15.21
	IMM	**6.12**	-3.99	73.48	11.76
	AS	5.87	**2.20**	**77.72**	**15.49**
BAV-PE	PM	5.57	1.65	76.12	14.86
	IMM	5.52	-3.80	72.76	11.55
	AS	5.86	2.20	75.44	15.12

Figure 11c corresponds to Ecol, whose best result of 77.72 is obtained by implementing all strategies with an optimistic growth in demand, representing an increase of 0.6% compared to implementing the PM strategies in a BAI scenario (a value of 77.27), and an increase of 6.4% compared to the BAU scenario. These results indicate that *Ecol* improves with production initiatives, even when demand for finished products drops. Increases in demand require the combination of these initiatives with innovation and marketing ones to obtain better performance.

Finally, Figure 11 d) corresponds to *CPI*, whose best result of 15.49 is obtained by implementing all strategies with an optimistic growth in demand, representing an increase of 2.8% compared to implementing the PM strategies in a BAI scenario (a value of 15.07), and an increase of 37% compared to the BAU scenario. These results indicate that *CPI* improves with higher levels of investment in production strategies in conditions of growing demand. Moreover, production initiatives have a positive impact on all indicators, including CPI.

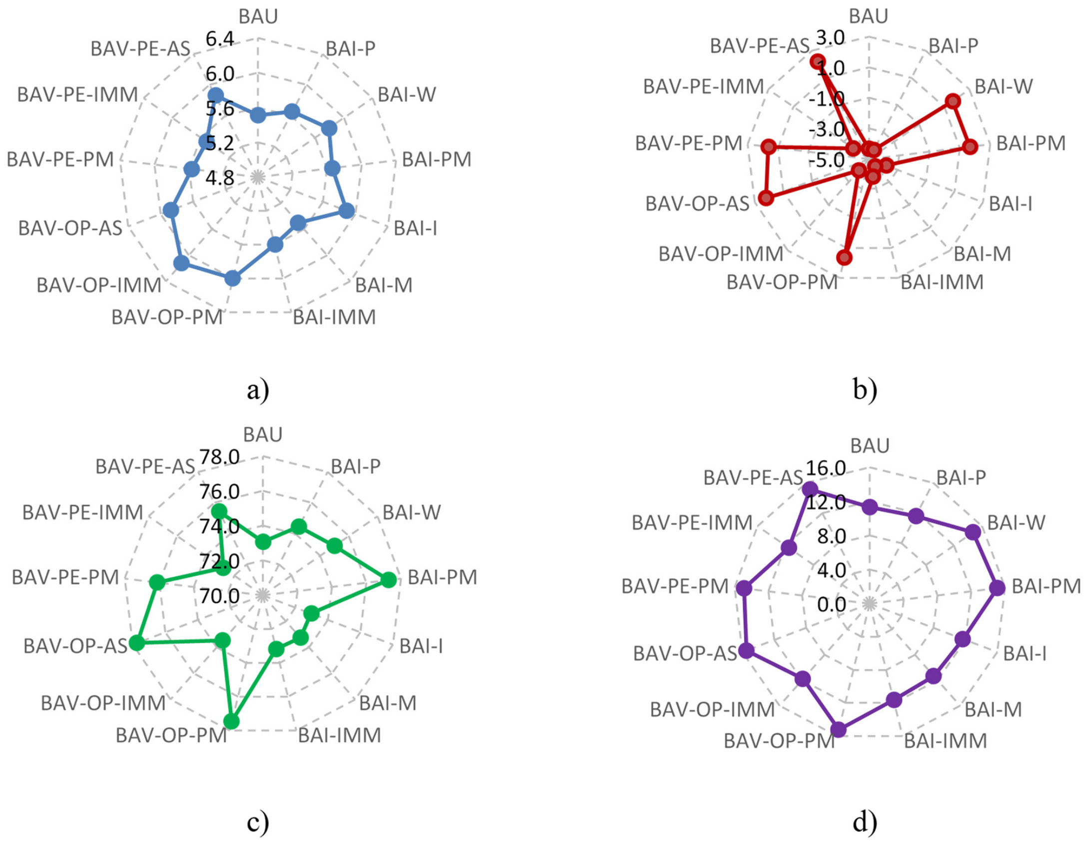


Figure 11. Consolidated results for (a) EnvI; (b) SocI; (c) EcoI; and (d) CPI indicators.

5. Discussion

The contribution of this research focuses on a model with feedback that interrelates the dimensions of sustainability with strategy planning supports decision making in prospective, multidimensional, and sometimes counter-intuitive ways. For example, contrary to expectations, both innovation and marketing strategies did not significantly improve *CPI* in an optimistic demand growth trend. These observations coincide with similar SD models applied in supply chain (Sterman, 2000), sustainability (Bockermann et al., 2005), organizational performance management (Bianchi & Rua, 2017), applications in the mitigation of emissions in the energy supply (Cardenas et al., 2016), among others. As such, decision-makers can establish investment priorities or halt proposed changes, if modeling shows undesirable and unexpected results.

6. Conclusions

This paper presented a System Dynamics based model for assessing strategies of production, (with 39 variables), innovation (with 7 variables), and marketing (with 5 variables), accounting for the demand for final goods, by measuring their impact on the sustainability of a manufacturing process, measured through environmental, social, and economic performance indicators. The model was validated through several scenarios, considering changes in demand and strategy. The results demonstrate the suitability of the model as a decision-support tool for sustainability planning in a corporate environment. The model proposes a support tool for decision-making in manufacturing companies with similar characteristics; the proposed structure provides a reference for its application in service companies. That is, it allows the designers to observe the behavior of the performance indicators over time, and decide investment priorities, changes to be scaled back, or contingency plans to be implemented, given the available resources, the business vision of the company, and optimistic and pessimistic changes in the market.

Through the model, given some initial conditions, planning horizon, and average demand growth, it was observed that environmental performance can be improved through the implementation of innovation strategies. If demand is growing at an above-average rate, environmental performance can be improved through the combination of innovation and marketing strategies. On the other hand, social performance can be substantially improved under diverse conditions by implementing strategies that increase worker welfare and equity in hiring both men and women. Production strategies, such as lowering costs and increasing the usage of recycled materials improved the economical performance under average demand growth conditions. However, with above-average growth, the implementation of production, marketing, and innovation strategies did not provide a substantial increase in economic performance. Finally, analyzing the sustainability performance in aggregate, the improvement of working conditions, and reduction of waste had the most impact throughout the planning horizon. However, with above-average growth, the implementation of production, marketing, and innovation strategies had the largest effect on aggregate performance.

Nevertheless, the model has some considerations. Firstly, the weights used for each indicator, as presented in Table 2., are the same as those proposed by Pavláková Dočekalová & Kocmanová (2016). These weights were based on the Czech manufacturing sector and may require adjustments for new conditions. Secondly, the model does not implement the corporate governance indicator proposed by Pavláková Dočekalová & Kocmanová (2016), as some of the data required was not available on the GRI reports or the systems were hard to model. Thirdly, the model places low emphasis on energy consumption and emission levels, which are deemed to have a significant impact on the environmental performance of a corporation. These important limitations will be tackled in further work, along with further analysis of the variables on the model that could be exposed to the decision-makers' control. Moreover, multi-criteria optimization methods could be used to automatically determine the best strategy, given the existing conditions. Besides, the model can be adapted to corporations with other characteristics, such as service providers. Additionally, concepts such as regenerative capitalism can be included to broaden the perspective of the model (Elkington, 2020).

Acknowledgements

This research is the result of the project INV-ECO 2969 "A dynamic indicator of social responsibility based on GRI reports" funded by the Vice-Rector's Office of Research of the Universidad Militar Nueva Granada. M.A. Muñoz is funded by the Australian Research Council through grant FL140100012.

References

Abdelkafi, N., & Täuscher, K. (2016). Business models for sustainability from a system dynamics perspective. *Organization & Environment*, *29*(1), 74-96. http://dx.doi.org/10.1177/1086026615592930.

Ahmad, R., Ahmad, S., Islam, T., & Kaleem, A. (2020). The nexus of corporate social responsibility (CSR), affective commitment and organisational citizenship behaviour in academia: a model of trust. *Employee Relations: The International Journal*, *42*(1), 232-247. http://dx.doi.org/10.1108/ER-04-2018-0105.

Ansari, N., & Seifi, A. (2012). A system dynamics analysis of energy consumption and corrective policies in Iranian iron and steel industry. *Energy*, *43*(1), 334-343. http://dx.doi.org/10.1016/j.energy.2012.04.020.

Antolín-López, R., Delgado-Ceballos, J., & Montiel, I. (2016). Deconstructing corporate sustainability: a comparison of different stakeholder metrics. *Journal of Cleaner Production*, *136*, 5-17. http://dx.doi.org/10.1016/j.jclepro.2016.01.111.

Aßländer, M. S. (2011). Corporate Social responsibility as subsidiary co-responsibility: a macroeconomic perspective. *Journal of Business Ethics*, *99*(1), 115-128. http://dx.doi.org/10.1007/s10551-011-0744-x.

Banos-González, I., Martínez-Fernández, J., & Esteve-Selma, M. A. (2016). Using dynamic sustainability indicators to assess environmental policy measures in Biosphere Reserves. *Ecological Indicators*, *67*, 565-576. http://dx.doi.org/10.1016/j.ecolind.2016.03.021.

Barlas, Y. (1996). Formal aspects of model validity and validation in system dynamics. *System Dynamics Review*, *12*(3), 183-210. http://dx.doi.org/10.1002/(SICI)1099-1727(199623)12:3<183::AID-SDR103>3.0.CO;2-4.

Bautista, S., Espinoza, A., Narvaez, P., Camargo, M., & Morel, L. (2019). A system dynamics approach for sustainability assessment of biodiesel production in Colombia: baseline simulation. *Journal of Cleaner Production*, *213*, 1-20. http://dx.doi.org/10.1016/j.jclepro.2018.12.111.

Becerra-Fernandez, M., Cosenz, F., & Dyner, I. (2020). Modeling the natural gas supply chain for sustainable growth policy. *Energy*, *205*, 118018. http://dx.doi.org/10.1016/j.energy.2020.118018.

Bian, J., Liao, Y., Wang, Y.-Y., & Tao, F. (2021). Analysis of firm CSR strategies. *European Journal of Operational Research*, *290*(3), 914-926. http://dx.doi.org/10.1016/j.ejor.2020.03.046.

Bianchi, C., & Rua, R. S. S. (2017). Applying dynamic performance management to detect behavioral distortions associated with the use of formal performance measurement systems in public schools: the case of Colombia. In *APPAM 39th Annual Fall Research Conference*. Washington: APPAM.

Bilbao-Terol, A., Arenas-Parra, M., Cañal-Fernández, V., & Obam-Eyang, P. N. (2018). Multi-criteria analysis of the GRI sustainability reports: an application to Socially Responsible Investment. *The Journal of the Operational Research Society*, *69*(10), 1576-1598. http://dx.doi.org/10.1057/s41274-017-0229-0.

Bockermann, A., Meyer, B., Omann, I., & Spangenberg, J. H. (2005). Modelling sustainability: Comparing an econometric (PANTA RHEI) and a systems dynamics model (SuE). *Journal of Policy Modeling*, *27*(2), 189-210. http://dx.doi.org/10.1016/j.jpolmod.2004.11.002.

Broadstock, D. C., Matousek, R., Meyer, M., & Tzeremes, N. G. (2020). Does corporate social responsibility impact firms' innovation capacity? The indirect link between environmental & social governance implementation and innovation performance. *Journal of Business Research*, *119*, 99-110. http://dx.doi.org/10.1016/j.jbusres.2019.07.014.

Brower, J., & Mahajan, V. (2013). Driven to be good: a stakeholder theory perspective on the drivers of corporate social performance. *Journal of Business Ethics*, *117*(2), 313-331. http://dx.doi.org/10.1007/s10551-012-1523-z.

Cardenas, L. M., Franco, C. J., & Dyner, I. (2016). Assessing emissions-mitigation energy policy under integrated supply and demand analysis: the Colombian case. *Journal of Cleaner Production*, *112*, 3759-3773. http://dx.doi.org/10.1016/j.jclepro.2015.08.089.

Chaudhri, V. (2016). Corporate social responsibility and the communication imperative: perspectives from CSR managers. *International Journal of Business Communication*, *53*(4), 419-442. http://dx.doi.org/10.1177/2329488414525469.

Crane, A., Henriques, I., Husted, B. W., & Matten, D. (2017). Measuring corporate social responsibility and impact: enhancing quantitative research design and methods in business and society research. *Business & Society*, *56*(6), 787-795. http://dx.doi.org/10.1177/0007650317713267.

Dartey-Baah, K., & Amoako, G. K. (2021a). A review of empirical research on corporate social responsibility in emerging economies. *International Journal of Emerging Markets*, *16*(7), 1330-1347. http://dx.doi.org/10.1108/IJOEM-12-2019-1062.

Dartey-Baah, K., & Amoako, G. K. (2021b). Global CSR, drivers and consequences: a systematic review. *Journal of Global Responsibility*, *12*(4), 416-434. http://dx.doi.org/10.1108/JGR-12-2020-0103.

Dobre, E., Stanila, G., & Brad, L. (2015). The influence of environmental and social performance on financial performance: evidence from Romania's listed entities. *Sustainability*, *7*(3), 2513-2553. http://dx.doi.org/10.3390/su7032513.

Duran-Encalada, J. A., & Paucar-Caceres, A. (2009). System dynamics urban sustainability model for Puerto Aura in Puebla, Mexico. *Systemic Practice and Action Research*, *22*(2), 77-99. http://dx.doi.org/10.1007/s11213-008-9114-8.

Elkington, J. (2020). *Green swans: the coming boom in regenerative capitalism.* New York: Fast Company Press.

Fang, W., An, H., Li, H., Gao, X., Sun, X., & Zhong, W. (2017). Accessing on the sustainability of urban ecological-economic systems by means of a coupled emergy and system dynamics model: a case study of Beijing. *Energy Policy*, *100*, 326-337. http://dx.doi.org/10.1016/j.enpol.2016.09.044.

Felicetti, A. M., Ammirato, S., Corvello, V., Iazzolino, G., & Verteramo, S. (2022). Total quality management and corporate social responsibility: a systematic review of the literature and implications of the COVID-19 pandemics. *Total Quality Management & Business Excellence*. In press. http://dx.doi.org/10.1080/14783363.2022.2049443.

Feng, Y., Zhu, Q., & Lai, K.-H. (2017). Corporate social responsibility for supply chain management: a literature review and bibliometric analysis. *Journal of Cleaner Production*, *158*, 296-307. http://dx.doi.org/10.1016/j.jclepro.2017.05.018.

Forrester, J. W. (1997). Industrial dynamics. *The Journal of the Operational Research Society*, *48*(10), 1037-1041. http://dx.doi.org/10.1057/palgrave.jors.2600946.

Frynas, J. G., & Yamahaki, C. (2016). Corporate social responsibility: review and roadmap of theoretical perspectives. *Business Ethics)*, *25*(3), 258-285. http://dx.doi.org/10.1111/beer.12115.

Halkos, G., & Nomikos, S. (2021). Corporate social responsibility: trends in global reporting initiative standards. *Economic Analysis and Policy*, *69*, 106-117. http://dx.doi.org/10.1016/j.eap.2020.11.008.

Harik, R. E. L., Hachem, W., Medini, K., & Bernard, A. (2015). Towards a holistic sustainability index for measuring sustainability of manufacturing companies. *International Journal of Production Research*, *53*(13), 4117-4139. http://dx.doi.org/10.1080/00207543.2014.993773.

Hickel, J., & Kallis, G. (2020). Is green growth possible? *New Political Economy*, *25*(4), 469-486. http://dx.doi.org/10.1080/13563467.2019.1598964.

Hickel, J., Brockway, P., Kallis, G., Keyßer, L., Lenzen, M., Slameršak, A., Steinberger, J., & Ürge-Vorsatz, D. (2021). Urgent need for post-growth climate mitigation scenarios. *Nature Energy*, *6*(8), 766-768. http://dx.doi.org/10.1038/s41560-021-00884-9.

Jin, E., Mendis, G. P., & Sutherland, J. W. (2019). Integrated sustainability assessment for a bioenergy system: A system dynamics model of switchgrass for cellulosic ethanol production in the U.S. midwest. *Journal of Cleaner Production*, *234*, 503-520. http://dx.doi.org/10.1016/j.jclepro.2019.06.205.

Jin, W., Xu, L., & Yang, Z. (2009). Modeling a policy making framework for urban sustainability: incorporating system dynamics into the Ecological Footprint. *Ecological Economics*, *68*(12), 2938-2949. http://dx.doi.org/10.1016/j.ecolecon.2009.06.010.

Joung, C. B., Carrell, J., Sarkar, P., & Feng, S. C. (2013). Categorization of indicators for sustainable manufacturing. *Ecological Indicators*, *24*, 148-157. http://dx.doi.org/10.1016/j.ecolind.2012.05.030.

Kim, K.-S., Cho, Y.-J., & Jeong, S.-J. (2014). Simulation of CO2 emission reduction potential of the iron and steel industry using a system dynamics model. *International Journal of Precision Engineering and Manufacturing*, *15*(2), 361-373. http://dx.doi.org/10.1007/s12541-014-0346-5.

Kong, Y., Antwi-Adjei, A., & Bawuah, J. (2020). A systematic review of the business case for corporate social responsibility and firm performance. *Corporate Social Responsibility and Environmental Management*, *27*(2), 444-454. http://dx.doi.org/10.1002/csr.1838.

Latouche, S. (2012). Can the left escape economism? *Capitalism, Nature, Socialism*, *23*(1), 74-78. http://dx.doi.org/10.1080/10455752.2011.648841.

Lehmann, C., Delbard, O., & Lange, S. (2022). Green growth, a-growth or degrowth? Investigating the attitudes of environmental protection specialists at the German Environment Agency. *Journal of Cleaner Production*, *336*, 130306. http://dx.doi.org/10.1016/j.jclepro.2021.130306.

Lockett, A., Moon, J., & Visser, W. (2006). Corporate social responsibility in management research: focus, nature, salience and sources of influence. *Journal of Management Studies*, *43*(1), 115-136. http://dx.doi.org/10.1111/j.1467-6486.2006.00585.x.

MacNeil, I., & Esser, I. (2022). From a financial to an entity model of ESG. *European Business Organization Law Review*, *23*(1), 9-45. http://dx.doi.org/10.1007/s40804-021-00234-y.

Marcelino-Sádaba, S., González-Jaen, L. F., & Pérez-Ezcurdia, A. (2015). Using project management as a way to sustainability. From a comprehensive review to a framework definition. *Journal of Cleaner Production*, *99*, 1-16. http://dx.doi.org/10.1016/j.jclepro.2015.03.020.

Martínez-Fernández, J., Esteve-Selma, M. A., Baños-González, I., Carreño, F., & Moreno, A. (2013). Sustainability of Mediterranean irrigated agro-landscapes. *Ecological Modelling*, *248*, 11-19. http://dx.doi.org/10.1016/j.ecolmodel.2012.09.018.

Matten, D., Crane, A., & Chapple, W. (2003). Behind the mask: revealing the true face of corporate citizenship. *Journal of Business Ethics*, *45*(1), 109-120. http://dx.doi.org/10.1023/A:1024128730308.

McPherson, S. (2019, January 14). *Corporate responsibility: what to expect in 2019.* Forbes.

McWilliams, A., Siegel, D. S., & Wright, P. M. (2006). Corporate social responsibility: strategic implications. *Journal of Management Studies*, *43*(1), 1-18. http://dx.doi.org/10.1111/j.1467-6486.2006.00580.x.

Morioka, S. N., & Carvalho, M. M. (2016). Measuring sustainability in practice: Exploring the inclusion of sustainability into corporate performance systems in Brazilian case studies. *Journal of Cleaner Production*, *136*, 123-133. http://dx.doi.org/10.1016/j.jclepro.2016.01.103.

Musango, J. K., Brent, A. C., Amigun, B., Pretorius, L., & Müller, H. (2012). A system dynamics approach to technology sustainability assessment: The case of biodiesel developments in South Africa. *Technovation*, *32*(11), 639-651. http://dx.doi.org/10.1016/j.technovation.2012.06.003.

Nabavi, E., Daniell, K. A., & Najafi, H. (2017). Boundary matters: The potential of system dynamics to support sustainability? *Journal of Cleaner Production*, *140*, 312-323. http://dx.doi.org/10.1016/j.jclepro.2016.03.032.

Nicoletti Junior, A., Oliveira, M. C., de, Helleno, A. L., & Campos, L. M. (2021). The organization performance framework considering competitiveness and sustainability: The application of the sustainability evaluation model. *Production Planning and Control*. In press. http://dx.doi.org/10.1080/09537287.2020.1857873.

Olanipekun, A. O., Omotayo, T., & Saka, N. (2021). Review of the use of Corporate Social Responsibility (CSR) tools. *Sustainable Production and Consumption*, *27*, 425-435. http://dx.doi.org/10.1016/j.spc.2020.11.012.

Orji, I. J., & Wei, S. (2015). An innovative integration of fuzzy-logic and systems dynamics in sustainable supplier selection: A case on manufacturing industry. *Computers & Industrial Engineering*, *88*, 1-12. http://dx.doi.org/10.1016/j.cie.2015.06.019.

Ozcan-Deniz, G., & Zhu, Y. (2016). A system dynamics model for construction method selection with sustainability considerations. *Journal of Cleaner Production*, *121*, 33-44. http://dx.doi.org/10.1016/j.jclepro.2016.01.089.

Padilla-Lozano, C. P., & Collazzo, P. (2021). Corporate social responsibility, green innovation and competitiveness: causality in manufacturing. *Competitiveness Review*, *32*(7), 21-39. http://dx.doi.org/10.1108/CR-12-2020-0160.

Pavláková Dočekalová, M., & Kocmanová, A. (2016). Composite indicator for measuring corporate sustainability. *Ecological Indicators*, *61*, 612-623. http://dx.doi.org/10.1016/j.ecolind.2015.10.012.

Pergelova, A., & Angulo-Ruiz, F. (2013). Marketing and Corporate Social Performance: steering the wheel towards marketing's impact on society. *Social Business*, *3*(3), 201-224. http://dx.doi.org/10.1362/204440813X13778729134282.

Petry, M., Köhler, C., & Zhang, H. (2020). Interaction analysis for dynamic sustainability assessment of manufacturing systems. *Procedia CIRP*, *90*, 477-482. http://dx.doi.org/10.1016/j.procir.2020.01.114.

Petschow, U., Lange, S., Hofmann, H., Pissarskoi, E., aus dem More, N., Korfhage, T., Schookfs, A., & Ott, H. (2020). *Social well-being within planetary boundaries: The precautionary post-growth approach* (23 p.). Dessau-Roßlau: Federal Environment Agency.

Pinillos, A. A., Fernández-Fernández, J.-L., & Mateo, J. F. (2019). Pasado, presente y futuro de los objetivos del desarrollo sostenible (ODS): la tecnología como catalizador (o inhibidor) de la Agenda 2030. *icade. Revista de la Facultad de Derecho*, (108), 1-60. http://dx.doi.org/10.14422/icade.i108.y2019.001.

Qudrat-Ullah, H., & Seong, B. (2010). How to do structural validity of a system dynamics type simulation model: the case of an energy policy model. *Energy Policy*, *38*(5), 2216-2224. http://dx.doi.org/10.1016/j.enpol.2009.12.009.

Rasmussen, L. V., Rasmussen, K., Reenberg, A., & Proud, S. (2012). A system dynamics approach to land use changes in agro-pastoral systems on the desert margins of Sahel. *Agricultural Systems*, *107*, 56-64. http://dx.doi.org/10.1016/j.agsy.2011.12.002.

Reverte, C., Gómez-Melero, E., & Cegarra-Navarro, J. G. (2016). The influence of corporate social responsibility practices on organizational performance: evidence from eco-responsible Spanish firms. *Journal of Cleaner Production*, *112*, 2870-2884. http://dx.doi.org/10.1016/j.jclepro.2015.09.128.

Revuelto-Taboada, L., Canet-Giner, M. T., & Balbastre-Benavent, F. (2021). High-commitment work practices and the social responsibility issue: interaction and benefits. *Sustainability*, *13*(2), 459. http://dx.doi.org/10.3390/su13020459.

Rezaee, Z., & Tuo, L. (2019). Are the quantity and quality of sustainability disclosures associated with the innate and discretionary earnings quality? *Journal of Business Ethics*, *155*(3), 763-786. http://dx.doi.org/10.1007/s10551-017-3546-y.

Rintala, O., Laari, S., Solakivi, T., Töyli, J., Nikulainen, R., & Ojala, L. (2022). Revisiting the relationship between environmental and financial performance: the moderating role of ambidexterity in logistics. *International Journal of Production Economics*, *248*, 108479. http://dx.doi.org/10.1016/j.ijpe.2022.108479.

Sari, W. P., Ratnadi N.m.d., Lydia, E. L., Shankar, K., & Wiflihani, W. (2020). Corporate social responsibility (CSR): Concept of the responsibility of the corporations. *Journal of Critical Reviews*, *7*(1). http://dx.doi.org/10.31838/jcr.07.01.43.

Schneider, A., & Meins, E. (2012). Two dimensions of corporate sustainability assessment: towards a comprehensive framework. *Business Strategy and the Environment*, *21*(4), 211-222. http://dx.doi.org/10.1002/bse.726.

Shokravi, S., & Kurnia, S. (2014). A step towards developing a sustainability performance measure within industrial networks. *Sustainability*, *6*(4), 2201-2222. http://dx.doi.org/10.3390/su6042201.

Shokravi, S., Smith, A. J. R., & Burvill, C. R. (2014). Industrial environmental performance evaluation: a Markov-based model considering data uncertainty. *Environmental Modelling & Software*, *60*, 1-17. http://dx.doi.org/10.1016/j.envsoft.2014.05.024.

Siew, R. Y. J. (2015). Predicting the behaviour of Australian ESG REITs using Markov chain analysis. *Journal of Financial Management of Property and Construction*, *20*(3), 252-267. http://dx.doi.org/10.1108/JFMPC-03-2015-0009.

Singh, J. (2016). The influence of CSR and ethical self-identity in consumer evaluation of cobrands. *Journal of Business Ethics*, *138*(2), 311-326. http://dx.doi.org/10.1007/s10551-015-2594-4.

Sterman, J. D. (2000). *Business dynamics systems thinking and modeling for a complex world* (1st ed.). Boston: McGraw-Hill.

Thirupathi, R. M., Vinodh, S., & Dhanasekaran, S. (2019). Application of system dynamics modelling for a sustainable manufacturing system of an Indian automotive component manufacturing organisation: a case study. *Clean Technologies and Environmental Policy*, *21*(5), 1055-1071. http://dx.doi.org/10.1007/s10098-019-01692-2.

Tworzydło, D., Gawroński, S., & Szuba, P. (2021). Importance and role of CSR and stakeholder engagement strategy in polish companies in the context of activities of experts handling public relations. *Corporate Social Responsibility and Environmental Management*, *28*(1), 64-70. http://dx.doi.org/10.1002/csr.2032.

Veronica, S., Alexeis, G.-P., Valentina, C., & Elisa, G. (2020). Do stakeholder capabilities promote sustainable business innovation in small and medium-sized enterprises? Evidence from Italy. *Journal of Business Research*, *119*, 131-141. http://dx.doi.org/10.1016/j.jbusres.2019.06.025.

Videira, N., Antunes, P., Santos, R., & Lopes, R. (2010). A participatory modelling approach to support integrated sustainability assessment processes. *Systems Research and Behavioral Science*, *27*(4), 446-460. http://dx.doi.org/10.1002/sres.1041.

Waddock, S. A., & Graves, S. B. (1997). The corporate social performance-financial performance link. *Strategic Management Journal*, *18*(4), 303-319. http://dx.doi.org/10.1002/(SICI)1097-0266(199704)18:4<303::AID-SMJ869>3.0.CO;2-G.

Wood, D. J. (2019). Corporate social performance revisited. *Academy of Management Review*, *16*(4), 691-718. http://dx.doi.org/10.2307/258977.

Xu, Z., & Coors, V. (2012). Combining system dynamics model, GIS and 3D visualization in sustainability assessment of urban residential development. *Building and Environment*, *47*, 272-287. http://dx.doi.org/10.1016/j.buildenv.2011.07.012.

Zhang, H. (2019). Understanding the linkages: a dynamic sustainability assessment method and decision making in manufacturing systems. *Procedia CIRP*, *80*, 233-238. http://dx.doi.org/10.1016/j.procir.2019.01.064.

Zhang, H., Veltri, A., Calvo-Amodio, J., & Haapala, K. R. (2021). Making the business case for sustainable manufacturing in small and medium-sized manufacturing enterprises: a systems decision making approach. *Journal of Cleaner Production*, *287*, 125038. http://dx.doi.org/10.1016/j.jclepro.2020.125038.

Zhao, R., & Zhong, S. (2015). Carbon labelling influences on consumers' behaviour: a system dynamics approach. *Ecological Indicators*, *51*, 98-106. http://dx.doi.org/10.1016/j.ecolind.2014.08.030.

Appendix A. Equations of the model.

Orders_Or(t) = Orders_Or(t - dt) + (New_Orders_Increase_NOrI) * dt

INIT Orders_Or = 1,000

INFLOWS:

New_Orders_Increase_NOrI = Orders_Or*New_Orders_NOr

Direct_Materials_DM(t) = Direct_Materials_DM(t - dt) + (Direct_Materials_Purchased_DMP - Direct_Materials_Delivery_DMD) * dt

INIT Direct_Materials_DM = 100

INFLOWS:

Direct_Materials_Purchased_DMP = Direct_Materials_Orders_DMO

OUTFLOWS:

Direct_Materials_Delivery_DMD = Direct_Materials_DM

Indirect_Materials_IM(t) = Indirect_Materials_IM(t - dt) + (Indirect_Recycled_Materials_IRM + New_Indirect_Materials_NIM - Indirect_Materials_Delivery_IMD) * dt

INIT Indirect_Materials_IM = 200

INFLOWS:

Indirect_Recycled_Materials_IRM = Indirect_Material_Orders_IMO*Percentage_of_Indirect_Recycled_Materials_PIRM

New_Indirect_Materials_NIM = Indirect_Material_Orders_IMO*(1-Percentage_of_Indirect_Recycled_Materials_PIRM)

OUTFLOWS:

Indirect_Materials_Delivery_IMD = Indirect_Materials_IM

Innovation_and_Development_ID(t) = Innovation_and_Development_ID(t - dt) + (Innovation_Increase_II) * dt

INIT Innovation_and_Development_ID = 0.294

INFLOWS:

Innovation_Increase_II = Incentives_for_Innovation_and_Development_IID/Incentives_Implementation__Time_IIT

Machines_M(t) = Machines_M(t - dt) + (Machines_Purchase_MP - Machines_Obsolescence_MO) * dt

INIT Machines_M = 5

INFLOWS:

Machines_Purchase_MP = IF(Machines_M<Machines_per_Worker_MW)

THEN((Machines_per_Worker_MW-Machines_M)/Time_to_buy_machines_TBM)

ELSE(0)

OUTFLOWS:

Machines_Obsolescence_MO = Machines_M/Machine_Obsolescence_Time_MOT

Marketing_Mk(t) = Marketing_Mk(t - dt) + (Marketing_Increase_MIn) * dt

INIT Marketing_Mk = 0.0153

INFLOWS:

Marketing_Increase_MIn = Marketing_Investment_MI/Marketing_Implementation_Time_MIT

Production_Materials_PM(t) = Production_Materials_PM(t - dt) + (Indirect_Materials_Delivery_IMD + Direct_Materials_Delivery_DMD - Production_Pr) * dt

INIT Production_Materials_PM = 100

INFLOWS:

Indirect_Materials_Delivery_IMD = Indirect_Materials_IM

Direct_Materials_Delivery_DMD = Direct_Materials_DM

OUTFLOWS:

Production_Pr = Normal_Production_PN

Stock_St(t) = Stock_St(t - dt) + (Production_Pr - Deliveries_De) * dt

INIT Stock_St = 1,000

INFLOWS:

Production_Pr = Normal_Production_PN

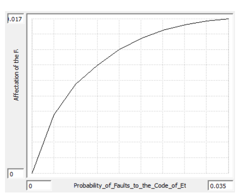
OUTFLOWS:

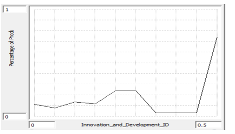
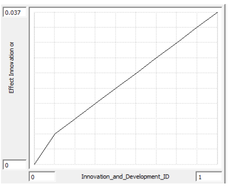
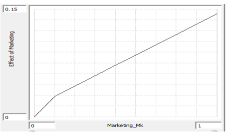
Deliveries_De = Orders_Or
Workers_W(t) = Workers_W(t - dt) + (Hiring_HIR - Dismissals_DIS) * dt
INIT Workers_W = 50
INFLOWS:
Hiring_HIR = Dismissals_DIS+Hiring_Need_HN
OUTFLOWS:
Dismissals_DIS = Workers_W/Workers_Rotation_Time_WRT
ACAP_included = 0
Affectation_of_Collective_Agreements_to_Productivity_ACAP = GRAPH(Percentage_of_Workers_in_Collective_Agreements_PWCA)
(0.00, 0.99), (0.111, 0.986), (0.222, 0.931), (0.333, 0.873), (0.444, 0.766), (0.556, 0.653), (0.667, 0.533), (0.778, 0.385), (0.889, 0.234), (1.00, 0.00687)
Affectation_of_Occupational_Diseases_to_Productivity_AODP = Affectation_of_Professional_Diseases_to_Productivity_APDP*Units_per_Worker_UW
Affectation_of_Professional_Diseases_to_Productivity_APDP = GRAPH(Probability_of_Worker_Disease_PWD)
(0.00, 1.00), (0.111, 0.999), (0.222, 0.998), (0.333, 0.997), (0.444, 0.996), (0.556, 0.995), (0.667, 0.994), (0.778, 0.994), (0.889, 0.993), (1.00, 0.992)
Affectation_of_the_Faults_Code_of_Ethics_to_Productivity_AFCP = Affectation_of_the_Faults_to_the_Code_of_Ethics_AFCE*Units_per_Worker_UW
Affectation_of_the_Faults_to_the_Code_of_Ethics_AFCE = GRAPH(Probability_of_Faults_to_the_Code_of_Ethics_PFCE)
(0.00, 0.00), (0.00389, 0.00642), (0.00778, 0.00981), (0.0117, 0.0119), (0.0156, 0.0136), (0.0194, 0.0149), (0.0233, 0.0158), (0.0272, 0.0163), (0.0311, 0.0168), (0.035, 0.017)
Average_Order_Time_AOT = 12
Benchmark_socKPI4 = 0.0004
Benchmark_socKPI5 = 100
CPI = (0.062*envKPI1)-(0.09*enviKPI2)-(0.094*enviKPI3)-(0.091*enviKPI4)+(0.048*socKPI1)-(0.123*socKPI2)+(0.056*socKPI3)-(0.084*(ABS(Benchmark_socKPI4-socKPI4)))-(0.079*(ABS(Benchmark_socKPI5-socKPI5)))-(0.114*socKPI6)+(0.112*ecoKPI1)+(0.047*ecoKPI2)
Demand_Increase_DI = 1
Demand__D = (Expected_Demand_ED*(1+(Effect_Innovation_on_Demand_EID+Effect_of_Marketing_on_Demand_EMD)))*Demand_Increase_DI
Desired_Direct_Materials_DDM = Desired_Production_DP*Direct_Materials_Coverage_DMC
Desired_Employee_Workforce_DEW = Desired_Production_DP/Units_per_Worker_UW
Desired_Indirect_Materials_DIM = Desired_Production_DP*Indirect_Material_Coverage_Time_IMCT
Desired_Production_DP = Demand__D+Stock_Corrector_SC
Desired_Stock_Coverage_Time_DSCT = 1
Desired_Stock_DS = Demand__D*Desired_Stock_Coverage_Time_DSCT
Direct_Materials_Corrector_DMC = (Desired_Direct_Materials_DDM-Direct_Materials_DM)/Tiempo_Corregir_Materiales_Directos_TCMD
Direct_Materials_Coverage_DMC = 1
Direct_Materials_Orders_DMO = (Desired_Production_DP*Percentage_of_Direct_Materials_in_Production_PDMP)+Direct_Materials_Corrector_DMC
EBIT = Sales_Revenue_SR-Production_Total_Cost_PTC-Machines_Obsolescence_Cost_MOC
ecoKPI1 = (Production_Total_Cost_PTC/Sales_Revenue_SR)*100
ecoKPI2 = (EBIT/Machines_Total_Cost_MTC)*100
EcoI = (0.708*ecoKPI1)+(0.292*ecoKPI2)
Effect_Innovation_on_Demand_EID = GRAPH(Innovation_and_Development_ID)
(0.00, 0.00), (0.2, 0.0074), (0.3, 0.0111), (0.4, 0.0148), (0.5, 0.0185), (0.6, 0.0222), (0.7, 0.0259), (0.8, 0.0296), (0.9, 0.0333), (1.00, 0.037)

Effect_of_Marketing_on_Demand_EMD = GRAPH(Marketing_Mk)
(0.00, 0.00), (0.2, 0.0287), (0.3, 0.043), (0.4, 0.0574), (0.5, 0.0717), (0.6, 0.086), (0.7, 0.1), (0.8, 0.115), (0.9, 0.129), (1.00, 0.143)
Energy_Consumption_per_Unit_ECU = 17.21
EnvI = (0.186*envKPI1)-(0.265*enviKPI2)-(0.279*enviKPI3)-(0.270*enviKPI4)
enviKPI2 = (Total_Energy_Consumption_TEC/Total_Production_Costs_TPC)*100
enviKPI3 = (Total_Waste_TW/Production_Pr)*100
enviKPI4 = (Total_Cost_of_Waste_Disposal_TCWD/Sales_Revenue_SR)*100
envKPI1 = ((Indirect_Recycled_Materials_IRM+Direct_Materials_DM)/(Indirect_Materials_IM+Direct_Materials_DM))*100
Expected_Demand_ED = SMTH1(Orders_Or,Average_Order_Time_AOT)
Faults_to_the_Code_of_Ethics_FCE = IF(INT(Probability_of_Faults_to_the_Code_of_Ethics_PFCE)-(Probability_of_Faults_to_the_Code_of_Ethics_PFCE*Workers_W)>0)
THEN(INT(Probability_of_Faults_to_the_Code_of_Ethics_PFCE*Workers_W)+1)
ELSE(INT(Probability_of_Faults_to_the_Code_of_Ethics_PFCE*Workers_W))
Hiring_Need_HN = (Desired_Employee_Workforce_DEW-Workers_W)/Hiring_Time_HT
Hiring_Time_HT = 1
Incentives_for_Innovation_and_Development_IID = 0.1244
Incentives_Implementation__Time_IIT = 8
Indirect_Materials_Corrector_IMC = (Desired_Indirect_Materials_DIM-Indirect_Materials_IM)/Time_to_Correct_Indirect_Materials_TCIM
Indirect_Material_Coverage_Time_IMCT = 1
Indirect_Material_Orders_IMO = (Desired_Production_DP*Percentage_of_Indirect_Materials_in_Production_PIMP)+Indirect_Materials_Corrector_IMC
Machines_Obsolescence_Cost_MOC = Machines_Total_Cost_MTC/Machine_Obsolescence_Time_MOT
Machines_per_Worker_MW = Workers_W/10
Machines_Total_Cost_MTC = Machines_M*Machine_Cost_MC
Machine_Cost_MC = 20,000
Machine_Obsolescence_Time_MOT = 120
Marketing_Implementation_Time_MIT = 4
Marketing_Investment_MI = 0.0544
Men's_Salary_Cost_MSC = Trabajadores_Hombres_TH*Men_Salary_MS
Men_Salary_MS = 298
New_Orders_NOr = 0.00344881
Normal_Production_PN = Workers_W*Productivity_Pt
Occupational_Diseases_OD = IF(INT(Probability_of_Worker_Disease_PWD*Workers_W)-(Probability_of_Worker_Disease_PWD*Workers_W)>0)
THEN(INT(Probability_of_Worker_Disease_PWD*Workers_W)+1)
ELSE(INT(Probability_of_Worker_Disease_PWD*Workers_W))
Percentage_of_Direct_Materials_in_Production_PDMP = 1-Percentage_of_Indirect_Materials_in_Production_PIMP
Percentage_of_Indirect_Materials_in_Production_PIMP = 0.1
Percentage_of_Indirect_Recycled_Materials_PIRM = 0.0975
Percentage_of_Male_Workers_PMW = 0.59
Percentage_of_Products_that_Impact_S&S_PPISS = GRAPH(Innovation_and_Development_ID)
(0.00, 0.113), (0.0556, 0.079), (0.111, 0.134), (0.167, 0.117), (0.222, 0.24), (0.278, 0.24), (0.333, 0.03), (0.389, 0.03), (0.444, 0.03), (0.5, 0.74)
Percentage_of_Workers_in_Collective_Agreements_PWCA = 0.0916
Probability_of_Faults_to_the_Code_of_Ethics_PFCE = RANDOM(0, 0.03)
Probability_of_Worker_Disease_PWD = RANDOM(0, 0.015)
Production_Cost_per_Unit_PCU = 518.97

Production_Total_Cost_PTC = Total_Production_Costs_TPC+Total_Salary_Cost_TSC+Total_Cost_of_Waste_Disposal_TCWD
Productivity_of_Collective_Agreements_PCA = IF(ACAP_included=0)
THEN(Units_per_Worker_UW)
ELSE(Affectation_of_Collective_Agreements_to_Productivity_ACAP*Units_per_Worker_UW)
Productivity_Pt = (Productivity_of_Collective_Agreements_PCA+Affectation_of_Occupational_Diseases_to_Productivity_AODP+Affectation_of_the_Faults_Code_of_Ethics_to_Productivity_AFCP)/3
Products__that_Impact_S&S_PRISS = Production_Pr*Percentage_of_Products_that_Impact_S&S_PPISS
Sales_Revenue_SR = Deliveries_De*Sales_Value_per_Unit_SVU
Sales_Value_per_Unit_SVU = 653.9
SocI = (0.095*socKPI1)-(0.245*socKPI2)+(0.109*socKPI3)-(0.169*(ABS(Benchmark_socKPI4-socKPI4)))-(0.157*(ABS(Benchmark_socKPI5-socKPI5)))-(0.225*socKPI6)
socKPI1 = (Workers_in_Collective_Agreements_WCA/Workers_W)*100
socKPI2 = (Occupational_Diseases_OD/Workers_W)*100
socKPI3 = (Products__that_Impact_S&S_PRISS/Production_Pr)*100
socKPI4 = (Marketing_Mk/Sales_Revenue_SR)*100
socKPI5 = (Men's_Salary_Cost_MSC/Women's_Salary_Cost_WSC)*100
socKPI6 = (Faults_to_the_Code_of_Ethics_FCE/Workers_W)*100
Stock_Corrector_SC = (Desired_Stock_DS-Stock_St)/Time_to_Correct_Stock_TCS
Tiempo_Corregir_Materiales_Directos_TCMD = 2
Time_to_Buy_Machines_TBM = 1.5
Time_to_Correct_Indirect_Materials_TCIM = 0.15
Time_to_Correct_Stock_TCS = 0.05
Total_Cost_of_Waste_Disposal_TCWD = Total_Waste_TW*Waste_Treatment_Cost_WTC
Total_Energy_Consumption_TEC = Production_Pr*Energy_Consumption_per_Unit_ECU
Total_Production_Costs_TPC = Production_Pr*Production_Cost_per_Unit_PCU
Total_Salary_Cost_TSC = Men's_Salary_Cost_MSC+Women's_Salary_Cost_WSC
Total_Waste_TW = Production_Pr*Waste_per_Unit_Produced_WUP
Trabajadores_Hombres_TH = Workers_W*Percentage_of_Male_Workers_PMW
Units_per_Worker_UW = 20
Waste_per_Unit_Produced_WUP = 0.017
Waste_Treatment_Cost_WTC = 0.031
Women's_Salary_Cost_WSC = Women_Workers_WW*Women_Salary_WS
Women_Salary_WS = 243
Women_Workers_WW = Workers_W*(1-Percentage_of_Male_Workers_PMW)
Workers_in_Collective_Agreements_WCA = Workers_W*Percentage_of_Workers_in_Collective_Agreements_PWCA
Workers_Rotation_Time_WRT = RANDOM(48, 60)

Appendix B. List of parameters.

ID	Name	Value, function or graph	Description
PIRM	Percentage of Indirect Recycled Materials	0.0975	Percentage of recycled indirect materials used in manufacturing
IMCT	Indirect Material Coverage Time	1	Coverage time of the indirect materials safety stock
TCIM	Time to Correct Indirect Materials	0.15	Delivery time of the indirect materials supplier
IM	Indirect Materials	200	Initial stock of these materials
DMC	Direct Materials Coverage Time	1	Coverage time of the direct materials safety stock
DM	Direct Materials	100	Initial stock of these materials
PM	Production Materials	100	Initial stock of these materials
PCU	Production Cost per Unit	518.97	Cost per unit manufactured
St	Stock	1,000	Initial inventory of the finished goods
TCS	Time to Correct Stock	0.05	Manufacturing time
DI	Demand Increase	1	Percentage increase in demand for the final good
DSC	Desired Stock Coverage Time	1	Coverage time of the desired stock
SVU	Sales Value per Unit	$ 653.90	Sales price per manufactured unit
NOr	New Orders	0.003448813	Demand growth (applies to scenario analysis)
AOT	Average Order Time	12	Time considered for the calculation of the average of the orders
W	Workers	50	Number of initial workers
WRT	Workers Rotation Time	RANDOM(48, 60)	Permanence time of the workers in the company
HT	Hiring Time	1	Time required to hire a worker
PWCA	Percentage of Workers in Collective Agreements	0.0916	Percentage of workers in collective agreements
UW	Units per Worker	20	Number of units a worker can manufacture per month
PWD	Probability of Worker Disease	RANDOM(0, 0.015)	Probability of a worker suffering from an occupational disease
APDP	Affectation of Professional Diseases to Productivity		Impact on productivity due to worker diseases
PFCE	Probability of Faults to the Code of Ethics	RANDOM(0, 0.03)	Probability of a worker committing a fault to the code of ethics
AFCE	Affectation of the Faults to the Code of Ethics		Effect on productivity due to faults to the code of ethics
MS	Men Salary	$ 298	Salary of male workers per month
WS	Women Salary	$ 243	Salary of female workers per month
PMW	Percentage of Male Workers	0.59	Percentage of male workers
M	Machines	5	Number of initial machines
MW	Machines per Worker	Workers_W/10	Number of machines required per worker (corresponds to the number of initial workers)
TBM	Time to Buy Machines	1.5	Time required for machine purchase
MOT	Machine Obsolescence Time	120	Machines obsolescence time
MC	Machine Cost	20,000	Unit cost per machine
IID	Incentives for Innovation and Development	0.1244	Incentives percentage of innovation and development
IIT	Incentives Implementation Time	8	Time required for the implementation of incentives in innovation and development
ID	Innovation and Development ID	0.294	Initial innovation degree of the company

ID	Name	Value, function or graph	Description
PPISS	Percentage of Products that Impact S&S		Percentage of goods that impact customer health and safety
EID	Effect Innovation on Demand		Percentage increase in demand as an effect of increased innovation
MI	Marketing Investment	0.0544	Percentage of marketing incentives
MIT	Marketing Implementation Time	4	Time required for the implementation of incentives
Mk	Marketing	0.0153	Initial degree of marketing of the company
EMD	Effect of Marketing on Demand		Effect on demand of marketing investment
ECU	Energy Consumption per Unit	$ 17.21	Energy cost in dollars per unit manufactured
WUP	Waste per Unit Produced	0.017	Percentage of waste generated per unit produced
WTC	Waste Treatment Cost	$ 0.031	Treatment costs per unit of waste generated