Dynamic Model of Sustainable Development for a Coffee Supply Chain

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Abstract

Peru has become one of the world's leading producers and exporters of organic coffee, so it is necessary to understand sustainable supply chain initiatives, which involve the 3 axes that encompass it (economic, social, and environmental). In this sense, the importance of risk factors within a supply chain to establish sustainable objectives is recognized. This research seeks to analyze and understand these factors and how they could impact the integration of sustainable development. For this, the methodology for modeling was System Dynamics. The results of the research showed the importance of understanding these factors that impact a coffee supply chain, so that with this information the sustainable conditions of production can be improved, since this is the most important factor in a coffee company. In this sense, two scenarios of the possible variability of demand were also presented, at a linear and exponential level, based on the analysis of historical data. When evaluating the scenarios, the linear variation was the best, since it was coupled in a constant and not abrupt manner to the change of carrying out a sustainable management in a coffee logistic chain.

Keywords
System Dynamic, sustainable development, environmental impact, supply chain and coffee.

1. Introduction
Coffee is one of the most consumed beverages in the world, second only to water. It is estimated that more than 3000 million cups are consumed daily in the world. (El Mundo, 2022) On the other hand, currently the system dynamics model has become widely used because it is able to study and model complex systems (Zhu, et al. 2021). It is a quantitative analysis that allows dynamic simulation to support long-term strategic decision making, which is based on systems thinking (Bashiri, et al., 2021). On the other hand, supply chain management is about managing the production and information flow of a product or service, from materials before processing to delivery to the final consumer. In addition, consumers are currently more aware of environmental care, a fact that has led the management of the supply chain of a product or service to become sustainable and concerned about reducing the negative impact of production processes on the environment, to have a competitive advantage in the market (Madero-Gómez and Zárate, 2016). Thus, sustainable supply chain management can be defined as the integration of thoughts, strategies, and management, including financial, ecological, and social performance (Bratt and Roberto, 2021).

After oil, coffee is the second most traded commodity worldwide, so that approximately 400 billion cups of coffee are consumed annually (Sabora, 2022). However, according to the International Coffee Organization (2021), world production for the current period 2021-2022 will have a deficit of 3.1 million bags this season, while on the demand side, it will present an annual increase of 3.3%. Due to this problem, it is of utmost importance to have an efficient

supply chain, with fast delivery times, and above all, one that contributes to the environment by using green technologies.
In this context, the following question is asked How can a sustainable coffee supply chain be designed using system dynamics modeling? Being an important area for the operation of the company, it is possible to design a coffee supply chain through system dynamics modeling, which can be sustainable with the support of the review and analysis of scientific articles that have as results positive impacts for the company and the environment. System dynamics is used because it helps to create a new instrument for the coffee supply chain. In addition, this model will have great environmental relevance since it seeks to implement a responsible supply and promote sustainable development. Finally, there is a practical justification, since this article seeks to solve current problems that exist with respect to coffee supply management, demand management and environmental problems.

1.1 Objectives

Main:

- Model a sustainable coffee supply chain using system dynamics.

Specifics:

- Analyze and describe the introduction of sustainable development in a coffee supply chain model.
- To comprehensively understand the main risk factors that influence a coffee supply chain.
- Evaluate how risk factors influence the different scenarios proposed to promote the development of a sustainable supply chain.

2. Literature Review

Today it is necessary to have an agile supply chain, with an environmental perspective, to be able to supply the demand for coffee consumption. This can be seen as a competitive advantage since it is possible to respond quickly to environmental uncertainties. For this, it is necessary to have agile stakeholders, especially suppliers, since our supply chain begins with them and there must be a good exchange of updated information for better interaction (Aprilia, et al., 2021). In the same context, there is another scientific article that talks about the importance of supplier selection and how it can improve the dynamics in the supply chain. In today's companies, the quality of suppliers is of vital importance, as it directly affects the production operations and organization of the company. It also has a direct impact on productivity and competitiveness in the market (Chia-Nan, et al., 2022). To have an efficient agile supply chain, it is necessary to design a participatory model among the actors involved in the coffee industry to reduce the information gaps faced by those involved. In this way, a more sustainable supply chain for coffee is achieved by improving performance and coordination among stakeholders (Umaran, et al., 2022).

Coffee is one of the main agricultural products consumed worldwide, in Mexico, different types of coffee are grown; being the eighth largest coffee producer in the world (ICO, 2014). In this way, in the city of Chiapas-Mexico, a study was conducted because an accelerated process of deterioration was occurring in coffee production, due to different determining factors. It was found that among the main problems affecting the coffee sector, which affected its productivity and profitability, was the lack of improved and sustainable technologies, as well as a lack of transportation, where there were suppliers with high interest rate credits and inequitable prices (Medina et al., 2016). Likewise, another study focused on the decision support system for a green coffee supply chain, under the perspective of agent-based scheduling; this study found that the input and output inventory vary similarly over time for a unimodal demand pattern there was a service level of 88%, while, for the scenario of increasing demand, the service level decreased to 77%, falling below the expected. (Maria, et al., 2019). Thus, there are different difficulties associated with coffee production and supply management, so, a research case study about sustainability in the coffee supply chain and purchasing policies, mentions that coffee depends on factors not related to management, such as sustainable development, where it indicates that the supply chain management should be related to sustainable business practices, which include relevant values and sustainable purchasing policies (Joäo, et al., 2022).

Applying the system dynamics methodology is an effort to increase the added value and profitability of a company, as well as that of small coffee plantation farmers. This modeling allows to focus on systematic thinking using feedbacks with the objective of understanding at the physical, biological, and social level the behavior of a supply chain (SC). In sense, it is found that in the various scenarios presented that in Supply Chain management quality engineering intervenes a lot (Hakim, et al., 2019). Also, Indonesia is one of the world's largest coffee producing countries, so sustainability in its supply chains is of vital importance. Therefore, a study used system dynamics to assess and investigate sustainability risks in a coffee supply chain; both for Indonesia and UK. This research resulted in demonstrating the importance of improving agricultural productivity to support a sustainable coffee supply chain, as well as confirming that by combining a System Dynamics model and the multi-criteria decision-making technique, it is possible to achieve more practical and accurate solutions, ensuring a better understanding of all the issues affecting a coffee supply chain (Bashiri, et al., 2021).

3. Methods

This study is non-experimental and has a cross-sectional design because the purpose is to describe variables by analyzing their incidence and interrelation at a given time and moment (Hernández Sampieri, et al., 2014). Thus, the variables of supply chain and sustainable management in the coffee industry will be analyzed quantitatively in order to acquire new knowledge of sustainability.

The System Dynamics technique will be developed using the Powersim Studio 10 Express tool, where the relationship of the variables to be investigated mentioned above will be analyzed, together with the dimensions that are the risks for the development of a supply chain and environmental impact. On these dimensions we will explore the various environmental factors that influence the supply chain, which will be measured by the indicators of apparent domestic demand, coffee quality and land use.

Apparent Domestic Demand=Domestic Production+Imports-Exports

Coffee quality=1 + Compliance with regulations * Agricultural productivity * Change in coffee prices

Land use=1+0.1*((Total coffee exported) /(0.0000001+Total coffee exported+Domestic use))

4. Data Collection

Thus, the entire Peruvian coffee industry was taken as the research population. In 2021, annual production in 2021 was 365,000 MT. Likewise, 8,634 MT were imported, and 193,000 MT were exported. The FOB value exported was US$761.9 MM (Ministry of Agrarian Development and Irrigation, 2022).

A sample proportional to the size was made based on the percentage of participation of the importing and exporting companies. In this way, information on roasted coffee beans without decaffeination was obtained from the Veritrade database. From the information collected, with respect to exports, 5 companies accounted for 42.39% of the total kg of exports. Regarding imports, the top 5 importing companies accounted for 86.54%. (Veritrade, 2021).

In addition, the composition in percentage of coffee transport routes, both imports and exports, was obtained from the same database as showed in Table 1.

Table 1. Transport routes to import/export coffee beans 2021

Via Transport	Total records	Total US$ CIF Tot	%	Total KG	US$ / KG
Maritime	1,440	6,243,261	98.85%	666,922	9.361
Aerial	50	72,628	1.15%	6,274	11.577
Total	1,490	6,315,890	100.00%	673,196	9.382

Note: Veritrade 2021

Similarly, the research process is presented in Figure 1:

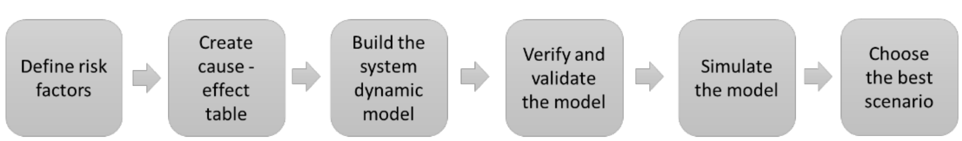

Figure 1. Process to follow in the investigation

Define risk factors
In this step we investigate the different factors that influence a conventional supply chain to be able to choose them with sustainable management criteria, since the focus is on the model of a sustainable supply chain. At the same time these factors are grouped into four main groups: coffee prices, potential growth of the industry, coffee quality and environmental impact. Finally, these groups will be broken down to elaborate the cause-effect table.

Create Cause-Effect table
The elaboration of this table will allow to determine the importance of the factors, from an environmental perspective. Thus, the influence between these factors will be defined.

For the elaboration of this table 2 the levels of effect High (A), Medium (M), Low (B) were taken into consideration. And they were classified into four types of risk: coffee price, potential growth of the industry, coffee quality and environmental impact.

Table 2. Cause and effect of risk factors broken down

	Exchange rate	Regulatory Compliance	Service level	Variation in demand for coffee	Coffee quality	Problems with red yellow	Green Tech Tools	Agricultural productivity
Exchange rate		M	M	M	M	B	A	B
Regulatory Compliance	B		A	A	M	A	A	
Service level	B	B		M	B	B	A	A
Variation in demand for coffee	A	B	B		M	B	M	M
Coffee quality	B	B	B	M		M	M	B
Problems with red yellow	B	B	B	B	B		B	A
Green Tech Tools	B	M	B	B	M	B		A
Agricultural productivity	B	B	A	A	M	B	B	

Build the system dynamics model
Once the information collected is available, a model is constructed that represents the vision of exporters, importers, and farmers, which converge in three different hypothetical scenarios to determine the impact of each one of them on the variables and measure them with the proposed indicators.

Verify the model
Once the model has been built, before simulating, it is verified that all the steps have been completed and that the necessary information is available. For this purpose, a checklist is elaborated to ensure the simulation:

- Consistency between Supply Chain risk factors and research parameters, indicators, and variables.
- Verify the cause-effect table ensuring the reasonableness of the factors studied are focused on environmental sustainability.
- Evaluate performance with current values to visualize the system for the period 2021.

Once the checklist has been passed, if everything is OK, the simulation continues. If there is a missing item, the previous steps are verified from the elaboration of the cause-effect table.

Simulate the model with what-if scenarios

At this point, what needs to be established are the scenarios to be simulated. The purpose of this is to put a sustainable supply chain in different situations. Two scenarios were defined based on the variation of demand, using two statistical distributions with a correlation coefficient greater than 95%, which were linear and exponential equations.

Choosing the best scenario

At the end, the best scenario for achieving sustainable supply chain effectiveness is selected. The choice is based on the best indicator results presented by each scenario.

Integrated model

The model starts with the integrated view of importers, exporters, and producers, which are reflected in the apparent domestic demand (initial demand). This demand is influenced by an input, which is based on the risk factors described above, which have a positive or negative influence on final demand.

The dynamic model of the vision explained above is shown below in Figure 2, using Powersim Studio Express 10 and causal loops are in Figure 3.

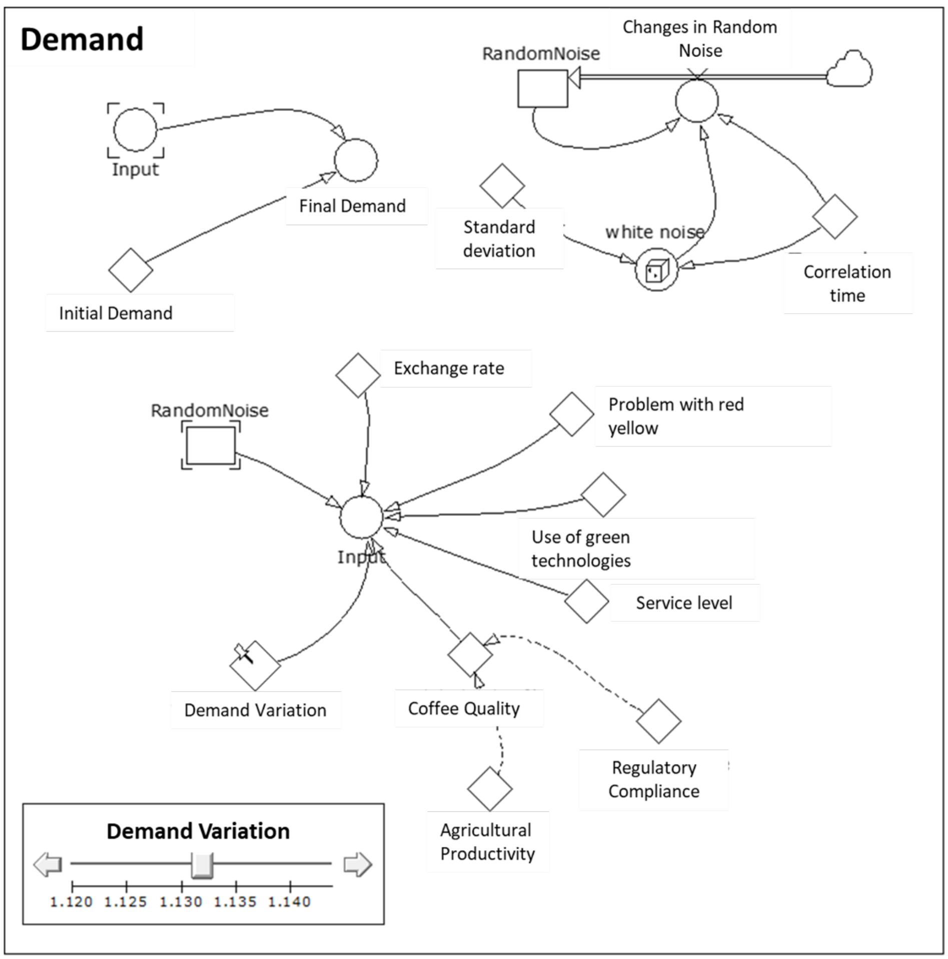

Figure 2. Dynamic Model - Demand Vision

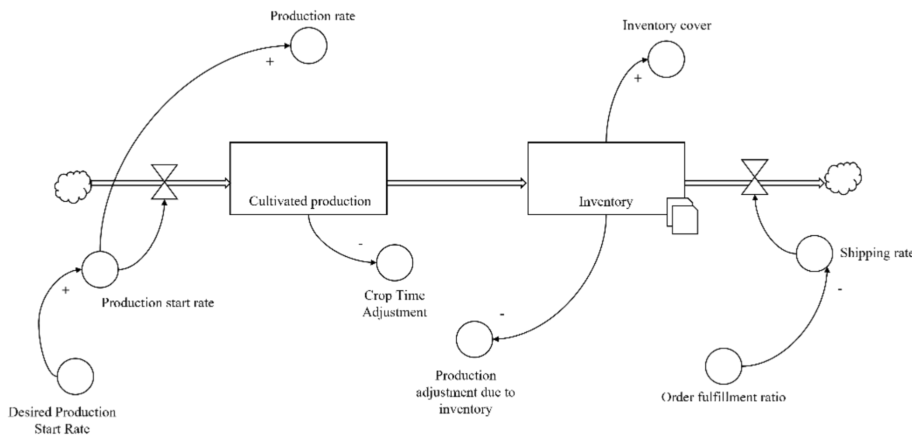

Figure 3. Core Flow Chart

This final demand is the input for the second view of production and inventory, which enters through 3 different places, affecting independent factors such as the order rate, the expected order ratio, and the change in desired production. Also, these factors mentioned above have a path and multiple influences on other related variables, where they finally culminate in the result of production and inventory, which are plotted with a different color.

In this way, 10 replications will be performed for each scenario, and then the data will be exported to Excel to verify the results of the model.

5. Results and Discussion

5.1 Numerical Results

With the historical data that was obtained from Veritrade, we obtained the correlation coefficients that were closest to 1, which were the linear and exponential model. Together with this coefficient, the equation of the projection was also obtained, which will be explained in item 5.4 of validation. In this way, 5 years of linear and exponential demand were projected, which will be explained below.

Scenario 1: Increase in demand (exponential equation)

Evaluating the historical data. A correlation coefficient of 0.9823 was obtained, very close to 1, so the equation will allow forecasting the next five years. This gives the following data (Table 3):

Table 3. Exponential Demand Forecast

2022	2023	2024	2025	2026
113,899.44	132,882.68	151,865.92	170,849.16	189,832.40

Note: Projection from Veritrade 2021

Thus, the variation of the demand forecast was found to be 13.6%, which was used to make the changes in the simulation and see how it affected the established parameters.

Scenario 2: Increase in demand (linear equation)

Similarly, a correlation coefficient of 0.9761 was obtained, a value close to 1, and the following data for the forecast were obtained. This gives the following data (Table 4):

Table 4. Linear Demand Forecast

2022	2023	2024	2025	2026
63,149.20	71,444.90	79,740.60	88,036.30	96,332.00

Note: Projection from Veritrade 2021

Thus, the variation of the demand forecast was found to be 11.1%, which was used to make the changes in the simulation and see how it affected the established parameters.

5.2 Graphical Results

Scenario 1: Increase in demand (exponential equation) Figure 4.

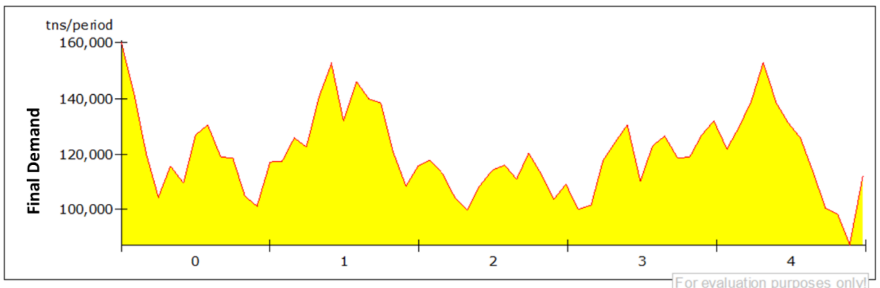

Figure 4. Exponential Demand Variation

In a scenario in which demand grows exponentially (Figure 5), the effect it has on the market is evident, since, unlike standard growth, it has several high peaks in which consumers' needs must be met.

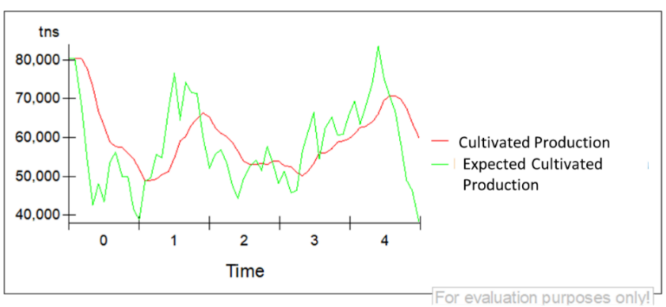

Figure 5. Expected Production with an Exponential Demand

This graph (Figure 6) shows how exponentially increasing demand affects expected production, since the market is wider. On the other hand, actual production oscillates most of the time below the expected production, so it is required that, in years 0 and 2, the largest possible amount can be grown to have a considerable safety stock and supply coffee.

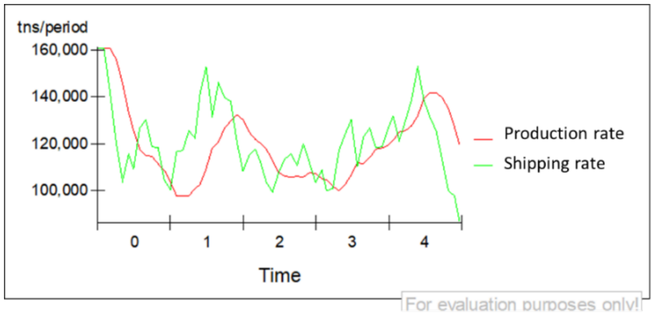

Figure 6. Production rate in an Exponential Demand

As for the production rate in an exponentially growing demand, it is observed (Figure 7) that almost always the attention to orders is below the shipment rate. This is an indicator that must be improved to satisfy demand. Considering the distribution variables, the delivery time variable should be reduced from 1 month to approximately 15 days, in addition to increasing the transportation fleet so that all orders can be distributed on time. At this point it is necessary to evaluate the possibility of outsourcing this last one, counting on sustainable and responsible suppliers with their carbon footprint that they emit for being a distribution company.

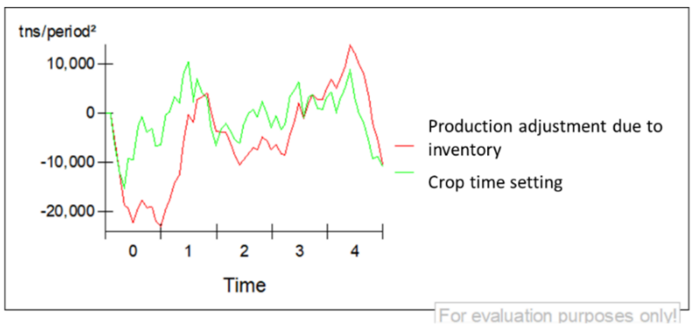

Figure 7. Adjustment of Production with an Exponential Demand

As for the adjustment of production, compared to the standard model, this decreases by 10,000 tons/year. The graph shows that in year 0 and the first months of year 1 there will be a difference between cultivation time and inventory management; however, this does not have a great impact on the chain since in the first years there is a high production rate, and it is not necessary to have high quantities of tons in the warehouse.

Scenario 2: Increase in demand (linear equation) (Figure 8)

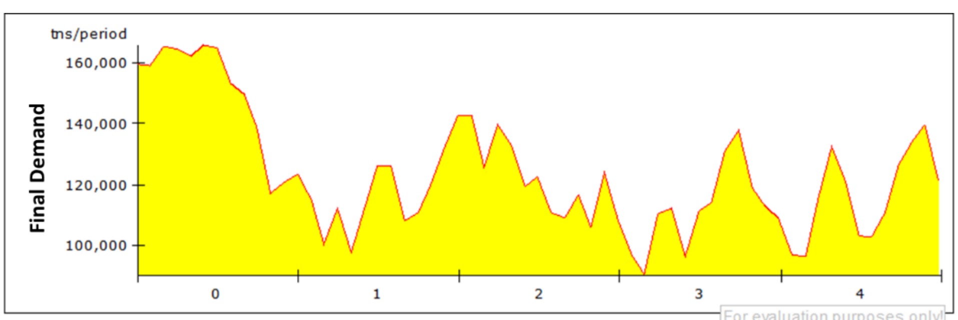

Figure 8. Linear Demand Variation

In a scenario in which demand grows linearly (Figure 9), as with the exponential model, high peaks are evident in the market as opposed to standard demand growth. However, these peaks compared to the exponential are smaller in size, showing a slightly more standard behavior.

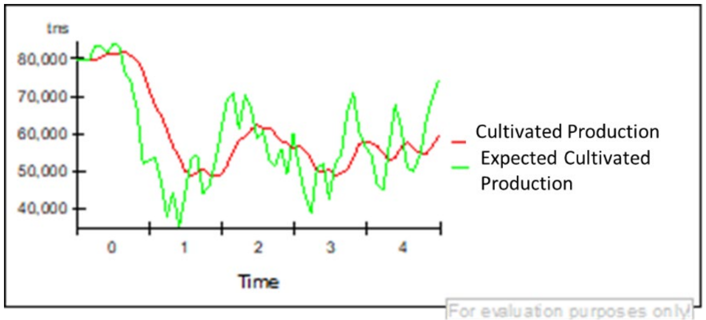

Figure 9. Expected Production with a Linear Demand

As in an exponential model, when there are multiple peaks of expected crop production, the actual production at the beginning of year 2, and during year 3 and 4, is not enough. Therefore, it is of utmost importance to have a safety stock and an efficient supply chain to be able to supply unexpected changes in the market (Figure 10).

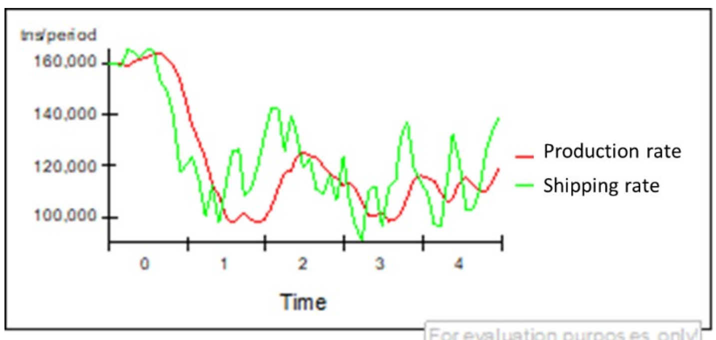

Figure 10. Production rate in a Linear Demand

As for the production rate in a linearly increasing demand, it is observed that, compared to the previous model, although the indicator must improve to always meet the demand (Figure 11), it is higher than the shipment rate on more occasions. Therefore, although an increase in the transportation fleet and outsourcing of distribution should be evaluated in the same way, this is required less urgently.

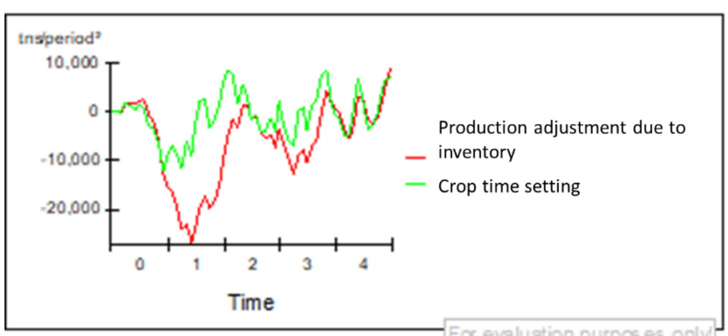

Figure 11. Adjustment of Production with an Exponential Demand

As with the exponential model, the production adjustment, compared to the standard model, decreases by 10,000 tons/year. It is shown that in year 1 there will be a difference between the time of cultivation and inventory management of 20,000 tons. This difference becomes regularized over the years, where it is observed that during the last year, this difference with respect to the crop time adjustment becomes minimal. Therefore, there is no warning from these indicators.

Finally, the best scenario for the dynamic model of sustainable development in a coffee supply chain is the scenario of linear demand variation, because it shows a more realistic increase in demand over the years and with fewer peaks, where a higher percentage of the expected cultivated production, the shipping rate and the shipping time adjustment are achieved.

5.3 Proposed Improvements

Modeling a supply chain made it possible to identify the processes that generate environmental impacts, such as production, inventories, and shipments. The present research focused on these three. Therefore, the knowledge provided by this article is that it is possible to introduce sustainable management in a coffee logistics chain. It is possible to identify and analyze the environmental impacts of each of the processes carried out in a company and take action to reduce or eliminate them. With the model presented, the impacts of a coffee company can be reduced by up to 15%, supported by the application of green technologies and organic fertilizers for a better product that in the end is valued by the final consumer.

5.4 Validation

For scenario 1: Increase in demand (exponential equation). It obtained a correlation coefficient of 0.9823. (Figure 12)

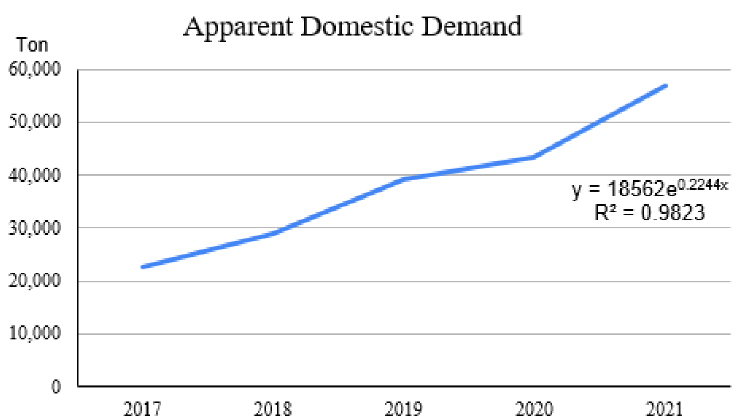

Figure 12. Apparent Domestic Demand - Exponential Demand

For scenario 2: Increase in demand (linear equation). It obtained a correlation coefficient of 0.9761 (Figure 13).

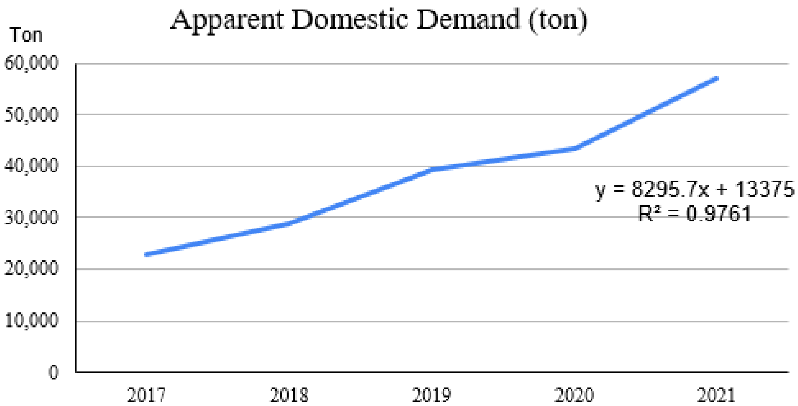

Figure 13. Apparent Domestic Demand - Linear Demand

6. Conclusion

It is concluded that it is possible to model a supply chain in a system dynamics software that helps to understand and analyze the behavior of the different parameters involved in a coffee logistics chain to integrate the sustainable management of the processes. In this sense, new knowledge was generated to introduce sustainability in a supply chain encompassing coffee production processes. For a better integration it was necessary to investigate and understand the main risk factors that influence a supply chain, finding that the main ones are the following: exchange rate, red-yellow plague, use of green technologies, service level of suppliers, compliance with regulations given by the Peruvian government and the quality of coffee that encompasses agricultural productivity. By identifying each risk, it was possible to understand the influence of each one. This was done to evaluate their impact in the two scenarios presented. First, linear variation of demand and second, exponential variation; the best scenario being the linear growth, since there are better production and customer service indicators.

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Biographies

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