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RESEARCH

Perspectives on the environmental Kuznets curve in America: a static panel approach for the period 2010-2020

Perspectivas sobre la curva de Kuznets ambiental en America: un enfoque de panel estático para el período 2010-2020

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Abstract

This study aims to determine the relationship between economic growth and CO, emissions through the hypothesis of the Environmental Kuznets Curve for 25 countries of the American continent covering the period 2010-2020. The methodology used is a panel data model that employs a static panel regression with cluster, measuring CO emissions and their relationship with the variables GDP per capita, electricity consumption, income from environmental taxes, exports, and imports in America. The result of the model allows for visualization of an inverted U-shaped association between environmental degradation and the variables considered, the estimates have the expected signs and are statistically significant, resulting in empirical support for the presence of a hypothesis of the Environmental Kuznets Curve, evidencing the need to implement public policies that promote environmental care.

Keywords: economic growth, CO₂ emissions, Environmental Kuznets Curve, American continent, panel data.

Code JEL: Q38, Q50, Q51, Q56

Resumen

El objetivo del presente estudio es determinar la relación entre crecimiento económico y emisiones de CO₂, a través de la hipótesis de la Curva de Kuznets Ambiental, para 25 países del continente americano que abarca el período 2010–2020. La metodología utilizada es un modelo con datos de panel que emplea una regresión de panel estático con clúster, midiendo las emisiones de CO₂ y su relación con las variables PIB per cápita, consumo de energía eléctrica, ingresos por impuestos ambientales, exportaciones e importaciones en América. El resultado del modelo permite visualizar una asociación en forma de U invertida entre la degradación ambiental y las variables



consideradas, las estimaciones tienen los signos esperados y son estadísticamente significativas, dando como resultado apoyo empírico a la presencia de una hipótesis de la Curva Ambiental de Kuznets, evidenciando la necesidad de implementación de políticas públicas que fomenten el cuidado del medio ambiente.

Palabras clave: crecimiento económico, emisiones CO₂, Curva Ambiental de Kuznets, continente americano, datos panel.

Código JEL: Q38, Q50, Q51, Q56

1. Introduction

Climate change and environmental degradation are global challenges that require a deep understanding of how economic development impacts the environment (Chen et al., 2024; Naseem et al., 2024; Magazzino et al., 2023). The Environmental Kuznets Curve offers one of the best-known theoretical perspectives to address this issue and demonstrates the relationship between economic growth and greenhouse gas emissions (Azimi & Bian, 2023; Chu, 2021; Fang et al., 2019).

Governments and international organizations are now taking stronger measures to combat climate change and promote sustainability as rising temperatures, melting glaciers, rising sea levels, extreme weather events, and changing precipitation patterns are increasingly evident around the world (Adebayo et al., 2022; Adedoyin et al., 2021; Ahmad et al., 2017).

Therefore, it is crucial to identify the key variables that influence per capita emissions so that the results of this study can significantly inform the formulation of effective environmental policies. The objective is to verify whether the Environmental Kuznets Curve (EKC) is fulfilled in America from 2010 to 2020 through an econometric model with panel data that allows the identification of some variables that are related to CO₂ emissions and thus determine whether the EKC is fulfilled for America in the last decade.

Using a static panel data econometric model is an advanced and robust methodology for analyzing a large amount of data over an extended period. This methodology can provide accurate and reliable results.

It was determined that it was important to analyze America because, despite the extensive literature on the Kuznets curve worldwide, there is a need for more specific studies investigating its applicability in America during the last decade. This study seeks to fill this gap and provide a more detailed view of the relationship between growth and the environment in the region. At the same time, it is possible to determine the level of correlation between per capita emissions and per capita GDP in the countries of America during the period 2010-2020, the variables that have had the greatest impact on the generation of emissions.

The article is organized as follows: The next section reviews the literature of the most representative research that relates the variables of economic growth and CO₂ emissions, emphasizing the methodologies used. Subsequently, the methodology and data used in this study are described. Finally, a discussion and conclusion of the findings obtained are presented.

2. Literature Review

Several investigations analyze the relationship between economic growth, energy consumption, and environmental pollutants, from two perspectives (Apergis & Ozturk, 2015; Bekun et al., 2023). The first focuses on environmental pollutants and their link with growth, which are closely related to testing the validity of the Environmental Kuznets Curve (EKC) hypothesis, which postulates that environmental degradation increases during the early stages of economic growth and then decreases with per capita income after reaching a threshold (Bao & Lu, 2023; Alsaedi et al., 2022; Gill et al., 2018; Grossman & Krueger, 1995). Results of these studies reveal that there is an inconsistent association between CO emissions and growth because there are other factors that largely depend on specific dynamics at the regional and national levels (Fakher et al., 2023; Massagony & Budiono, 2022; Cetin et al., 2022).

The second perspective supports evidence of causality between energy consumption and economic growth; the association of the two variables is related depending on the data set, the specification model, and the econometric technique involved (Bulut, 2019; Balsalobre-Lorente et al., 2022). In this sense, higher energy consumption to achieve a rapid pace of economic growth causes significant degradation of environmental



quality (Çobanoğulları, 2024; Ramzan et al., 2022; Wang & Jiang, 2020). That is, economic growth is characterized by urbanization, industrialization, and improvement of transportation infrastructure, causing a higher level of energy consumption and ultimately carbon emissions compounds (Pradhan et al., 2024; Ullah et al., 2022; Yang et al., 2015).

2.1. Economic growth and CO₂ emissions

Society tends to demand a healthy and sustainable environment as its income levels increase; these aspirations can be achieved if there are technological improvements or if governments impose stricter environmental controls (Zuhal & Göcen, 2024; Nawapanan et al., 2022; Kan et al., 2019). Currently, global economic growth has led to the generation of air pollutants caused by human activities such as deforestation, the change in land use to convert it into land for livestock or agriculture, electricity production, and the use of motor vehicles. Consequently, the expansion of economic activity and pollutant emissions tend to grow (Barut et al., 2023; Sun et al., 2021; Vadén et al., 2020).

Global CO2 emissions come mainly from several key industrial sectors (Mehmood et al., 2024; Zuhal & Göcen, 2024). The transport industry, which includes maritime cargo transport, is responsible for a significant share of emissions, due to the use of fossil fuels in ships and cargo vehicles (Awan et al., 2022). Commercial aviation also contributes significantly, with aircraft being one of the main sources of greenhouse gas emissions in the transport sector. In addition, the automotive industry, driven by the mass consumption of motor vehicles, represents another important source of CO2 emissions (Leal Filho et al., 2023; Li et al., 2023). Industrial production and energy generation from fossil fuels are also large emitters, consolidating themselves as key sectors in the fight against climate change. Other sectors, such as agriculture and construction, also play an important role, but to a lesser extent compared to those mentioned (Fakher et al., 2023; Qin et al., 2024). A sectoral understanding of emissions is crucial to developing effective mitigation strategies.

In particular, CO₂ emissions are considered to have the greatest participation in the greenhouse effect in the Earth's atmosphere and are considered the main cause of global warming. Therefore, these types of emissions in a country are an indicator of how it influences climate change (Li et al., 2016; Wang & Jiang, 2019; Huh, 2020).

Thus, Abid (2015) supports the relationship between economic growth and carbon emissions in the presence of the informal economy in Tunisia from 1980 to 2009; as a result, he obtained unidirectional causality from formal economic growth to CO₂ emissions, while bidirectional causality was demonstrated between CO₂ emissions and GDP.

For their part, Lv et al. (2019) investigate the impact on the short- and long-term equilibrium of the dynamic causality relationships between economic growth, CO₂ emissions, and fossil fuel consumption in China between 1965 and 2016; using econometric techniques (cointegration and linear and non-linear Granger causality in multivariate settings) they found that emissions not only lead to immediate economic growth, but also to future economic growth, both linear and non-linear. That is, greenhouse gas emissions and/or fossil fuel consumption do not lead to a slowdown in economic growth in China.

The study by Khan et al. (2022) supports a progressive correlation between carbon emissions, economic growth, and the use of energy and oil in 18 countries among the 20 main contributors to the tourism sector in the period from 1995 to 2019. The regression technique used shows that economic growth has a negative impact on environmental degradation. Therefore, in their quest to achieve stable and lasting tourism in the countries studied, the authors consider, as a first step, educating society to use public transport and other alternative fuels such as advanced hybrid technologies.

2.2. Environmental Kuznets Curve

The literature review allows us to identify that the most well-known assumption for investigating the possible detrimental impacts of economic growth on environmental quality is the Environmental Kuznets Curve (EKC) hypothesis. The main theoretical framework of the EKC hypothesis is inspired by the original idea of Simon Kuznets (1955), who stated an inverted U-shaped relationship between income inequality and economic growth; he stated that income inequality increases and reaches its maximum point in the initial phase of development. However, he stated that after that point, economic development and income inequality improved with economic growth.



Thus, the Environmental Kuznets Curve (EKC) proposes an inverted "U" relationship between economic growth and environmental degradation, which has been tested in different contexts and with different methodologies. For example, Adebayo et al. (2022) evaluate the effect of economic complexity on CO₂ emissions in Mexico, Indonesia, Nigeria, and Turkey (a group of countries called MINT economies), considering the role of financial development, economic growth, and energy consumption for the period between 1990 and 2018. The authors use the quantile moments regression method with fixed effects, which allows them to find that there is an inverted U-shaped interrelationship between economic growth and CO₂ emissions, thus validating the EKC hypothesis.

Wang, Yang, and Li (2023) set income inequality as the threshold variable, economic growth as the explanatory variable, and carbon emission as the explained variable, and the threshold panel model is developed using data from 56 countries. The empirical results show that income inequality has changed the relationship between economic growth and carbon emissions from an inverted U-shape to an N-shape, which means that income inequality redefines the environmental Kuznets curve and increases the complexity of the decoupling of economic growth and carbon emissions.

At the frontier of knowledge, there are a variety of empirical studies related to EKC in the American continent, both for developed countries as well as developing countries. Table 1 shows some research on the EKC, which studies the relationship between economic growth and CO₂ emissions, most of them refer to groups of countries (Pinilla-Rivera et al., 2018; Ortiz-Paniagua & Gómez, 2021; Zeraibi et al., 2023) and, to a lesser extent, those studies that show a single country or city (Bulut, 2019; Haider et al., 2022; Acevedo-Ramos et al., 2023).

Mainly, from the perspective of the methodology used, some studies from a multivariate framework use the Generalized Method of Moments(GMM) methodology (Taghvaee et al., 2022; Wang et al., 2023a), while others use both parametric and semiparametric additive models like Ordinary Least Square (OLS) regressions (Arango-Mirando et al., 2020; Bekun et al., 2021; Magazzino et al., 2023) and Autoregressive Distributed Lag (ARDL) stationarity models to analyze dynamic relationships with time series data in a single-equation (Haider et al., 2022; Çobanoğulları, 2024).

3. Methodology

3.1 Model specification

For this study, an econometric approach was used. This approach involved analyzing panel data from a sample of 25 American nations from 2010 to 2020. This approach consisted of creating a panel linear regression model, where clusters in the residuals were considered in geographic and temporal terms.

3.2. Model variables

A model was proposed considering endogenous variables such as the per capita emissions of 25 countries from 2010 to 2020 and exogenous variables such as GDP per capita, electricity consumption, tax revenues, and imports/exports as a percentage of GDP. This choice is based on the fact that these variables are widely used to calculate environmental degradation. This selection aligns with established methodologies, as variables like GDP per capita and per capita emissions are standard metrics in environmental-economic analyses, ensuring comparability and reliability in assessing environmental degradation.

The final formulation of the model is presented below:

PC emissions = f (GDPCC,, GWh,, IPI it, I/E GDP,,) + α_i + $\epsilon_i \square$ [Eq.1]

Where:

PC emissions = emissions per capita

GDPPC = Gross Domestic Product per capita

GWh = electricity consumption

IPI= tax revenues

I/E GDP = imports/exports about GDP

i = country

t= year

3.3. Signs and magnitudes of the parameters

Below is Table 2, which compiles the model's variables, including their nomenclature, meaning, and expected sign.

3.4. Model estimation

3.4.1. Data collection for model estimation

Panel data were used to carry out the model prediction, which amalgamated temporal and



Table 1. Previous studies validating/invalidating the EKC Hypothesis for America

Article	Period	Countries	Method	Dependent Variable	Explanatory Variables	EKC Hypothesis
Pinilla-Rivera et al. (2018)	1990-2015	10 countries, LatAm	Cointegration Test	CO ₂ Emissions	GDP (logarithmic equation)	Not confirmed
Bulut (2019)	2000-2018	USA	Cointegration Test	CO ₂ Emissions	Renewable energy consumption	Confirmation
Arango-Miranda et al. (2020)	1994-2020	USA, Canada, and Mexico	OLS, VAR	Environmental Degradation	CO ₂ emissions, energy consumption, GDPpc &	Confirmated (USA & Mexico)
(2020)		euco		2 eg. uuuron	Trade Openness	Not Confirmated (Canada)
Ortiz-Paniagua y Gómez (2021)	1970-2016	19 countries, LatAm	Cointegration Test	CO ₂ Emissions	GDPpc, GDPpc ²	Confirmated
Bekun et al. (2021)	1995-2016	E7 economies (2 from LatAm)	OLS	CO ₂ Emissions	GDPpc	Confirmated
Haider et al. (2022)	1970-2020	Canada	ARDL	N2O Emissions	GDPpc, GDPpc², ALU, exports	Confirmated
Taghvaee et al. (2022)	1971-2016	OCDE countries	GMM	CO ₂ Emissions	GDP	Confirmated
Zeraibi et al. (2023)	1990-2019	22 countries (6 from LatAm)	OLS	CO ₂ Emissions	GDPpc, Public Debt, Renewables Electricity Production	Confirmated
Magazzino et al. (2023)	1870-2008	9 countries (Canada)	OLS, FE	CO ₂ Emissions	GDPpc, GDPpc², Energy Consumption, Openness	Confirmated
Wang, Zhang & Li (2023)	1990-2018	208 countries (31 from America)	GMM	CO ₂ Emissions	GDPpc, Human capital index, Renewable energy consumption, Total resources rents, and Trade	Confirmated
Acevedo-Ramos et al. (2023)	1970-2018	Colombia	ARDL	CO ₂ Emissions Ecological Footprint CH ₄ Emissions	GDPpc, FDI, Non-REU, REU, Urban Population, Industry, Agriculture, Forestry and Fishing	Confirmated

Note: LatAm: Latin America; OLS: Odinary Least Squares; VAR: Vector Analytic Regression; FE: Fixed Effect; ARDL: Autoregressive Distributed Lag; GMM: Generalized Method of Moments; N2O: Nitrous Oxide; CH4: Methane; GDP: Gross Domestic Product; GDPpc: Gross Domestic Product per capita; ALU: Agriculture Land Use; FDI: Foreign Direct Investment; REU: Renewable Energy Use

Table 2. Variables and expected signs of the coefficients.

Nomenclature	Name/unit	Definition	Sign
PC emissions	CO2 emissions per capita (tonnes)	Human activities, especially in the transport, industry, and electricity generation sectors, are the primary sources of carbon dioxide (CO2), although there is also a natural contribution through the terrestrial carbon cycle. Per capita CO2 emissions reflect the amount of this greenhouse gas emitted by each individual and constitute a key indicator. (EPA, 2023).	
GDPPC	Gross Domestic Product per capita (US s at current prices)	It is an indicator that illustrates the sum of money each country's citizen would receive in the event of an equal distribution of the Gross Domestic Product generated by that nation in a given year. (INEGI, 2023).	Positive
GWh	Electrical energy consumption (GWh)	It refers to the energy available in the country and used for different purposes. (SEMARNAT, 2023).	Positive
IPI	Total tax revenue (millions of dollars)	They are the revenue collected by the government expressed as a percentage of the Gross Domestic Product (GDP), which shows how much economic production a country collects through taxes (OECD, 2020).	Negative
I/E GDP	Imports/Exports as a percentage of GDP (% of GDP)	It refers to the calculation in money terms of all transactions of goods bought and sold by a country with other countries during a specific period of GDP (SEMARNAT, 2016).	Positive

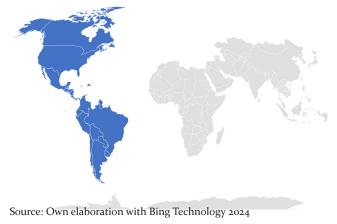
Source: Elaboration own, 2024.



structural elements, specifically the years and nations involved in this case. This data type provides certain advantages since it considers individual differences and how they change over time. Additionally, it enables the analysis of more complex models (Gujarati & Porter, 2010).

The period analyzed was from 2010 to 2020, and the selected countries were chosen based on their importance in America (Figure 1), their size and their available information; these are Canada, the United States, Mexico, Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama, Bahamas, Barbados, Jamaica, the Dominican Republic, Trinidad and Tobago, Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru and Uruguay. Likewise, these data were obtained from official sources such as the Organization for Economic Cooperation and Development (OECD), the World Bank, and other statistical sources.

Figure 1. Countries of America analyzed.



4. Results

4.1. Mathematical form of the model

 $\begin{array}{l} \text{PC Emissions} = \text{0.0003 GDP PC}_{[it]} \ + \text{2.521e-06 GWh}_{[it]} \ - \text{3.739e-06 IPI}_{[it]} \\ + \text{2.9035 I/E GDP}_{[it]} \ + \alpha_i + \epsilon_i \Box \end{array} \\ \end{array}$

The equation was obtained by running the final model in Python programming language Jupyter Notebook with the linear model library using a PanelOLS with Numpy. First, a traditional fixed-effects model was run. However, a static panel regression model was run without fixed effects or time effects with clustering in the residuals to correct the standardized error variance for autocorrelated errors. This allowed correcting the standardized error variance for autocorrelated errors within each entity and the standardized error variance for the time series, obtaining the results shown in Table 3.

Table 3. Results general model

PanelOLS Estimation Summary				
Dep. Variable:	Emissions pc		0.7420	
Estimator:	PanelOLS	R-squared (Between)	0.7478	
No. Observations:	275	R-squared (Within):	0.0236	
Date:	Fri, Aug 25 2023	R-squared (Overall)	0.7420	
Time:	11:19:08	Log-likelihood	-764.82	
Cov. Estimator:	Clustered			
		F-statistic:	194.82	
Entities:	25	P-value	0.0000	
Avg Obs:	11.000	Distribution:	F(4,271)	
Min Obs:	11.000			
Max Obs:	11.000	F-statistic (robust	3909.9	
		P-value	0.0000	
Time periods:	11	Distribution:	F(4,271)	
Avg Obs:	25.000			
Min Obs:	25.000			
Max Obs:	25.000			
	Parameter	Estimates		
Paramete	r Std. Err. T	-stat P-value L	ower CI Upper CI	

4.3373

1.7367

0.0000

0.0050

0.0836

1.377e-06

-0.3880

-6.341e-06

3.665e-06

-1.138e-06

Source: Elaboration own, 2024.

2.9035

2.521e-06

5.812e-07

1.6719

GWh

I/E GDP

It was decided to include the variable Imports/ Exports as a percentage of GDP (I/E GDP) although it is acceptable only at a level of 90% because its parameter turned out to be considerable and gives us a good contribution to the prediction of the model, fortunately this through the increase of the R square.

4.2. Choosing the appropriate econometric technique

The compare function was used to compare the optimal model between the static panel regression model without fixed or time effects and one with random effects. The results obtained from this test showed that the static model is superior, as shown in Table 4.

Since the highest T-stats values are found in the static model, with a better R square and a P-value of o.oooo, it was decided to stick with the static panel regression model. The P-value allows to compare the variables Gross Domestic Product per capita (GDP PC), Electrical energy consumption (GWH), Tax revenue (TAX), and Imports/Exports as a percentage of GDP (I/E GDP) in the Static panel with the Random effects.

4.3. Evaluation of the estimates

Based on the model's results, it was concluded that the parameters are statistically satisfactory because the coefficient of determination (R₂) was high, and all the P-values were below 0.10.

Also, in creating the model, the square of the coefficient of determination was used as a tool to



Table 4. Comparison of Static Panel Model and Random Effects

Model Comparison				
		RANDOM effects:		
Dep. Variable Estimator No. Observations	PanelOLS 275	Emissions pc RandomEffects 275		
Cov. Est. R-squared R-Squared (Within) R-Squared (Between)	Clustered 0.7420 0.0236 0.7478	Unadjusted 0.3332 0.2513 0.6618		
R-Squared (Overall) F-statistic P-value (F-stat)	0.7420 194.82 0.0000	0.6585 33.860 0.0000		
GDP PC	0.0003 (8.0875)	0.0001 (5.7680)		
GWh	2.521e-06 (4.3373)	3.458e-06 (3.7127)		
Tax	-3.739e-06 (-2.8303)	-2.46e-06 (-6.5124)		
I/E GDP	2.9035 (1.7367)	3.4241 (7.7896)		

T-stats reported in parentheses

Source: Elaboration own, 2024.

observe the statistical reliability of the estimates of the model parameters, which was 0.7420. This resulted in an acceptable parameter within the study of social sciences.

4.4. Evaluation of the predictive power of the estimated model

Below, the model's function is evaluated, taking the mean of the data as values for the variables and Eq. 2 as a basis.

PC Emissions = 0.0003(13004) + 2.521e-06 (2.3e+05) - 3.739e-06 (2.054582e+05) + 2.9035 (0.576220) +
$$\alpha_i$$
 + ϵ_i [Ec. 3]

PC Emissions = 5.38tCO₂

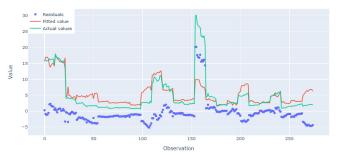
According to the model, if we consider a GDP per capita of 13,004 dollars, energy consumption of 230,000 Gwh, tax revenues of 205,458 million dollars, and 57.6% of imports/exports as a percentage of GDP, the result is an average of 5.38 tons of carbon dioxide per year per country.

4.5. Analysis of model results

We conducted a graphic analysis to evaluate the final model's results. This analysis contrasts the estimated results with the real values and their residuals, providing a comprehensive evaluation of the model's performance.

Figure 2 shows the results of the static panel regression without fixed effects or time effects for the 25 American countries, which were the object of study in this research, from 2010 to 2020. First, the results are shown. Residuals capture their random distribution and constant variance without an identifiable pattern, which indicates the correct fit of the data. In addition, it provides a graphical representation that allows the observed data to be contrasted with the model estimates, which is essential to evaluate the forecasting capacity of the model. As evident, there is a notable agreement between the real data and those fitted by the model, which indicates an adequate calibration of the model.

Figure 2. Static panel model with current, adjusted, and residual values



Source: Elaboration own, 2024.

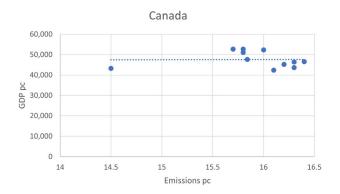
4.6. Analysis of the Kuznets curve in some countries

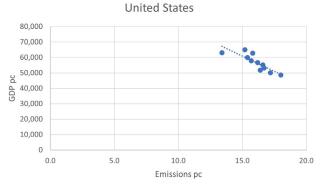
A graphical analysis of some countries was conducted to determine whether the Kuznets curve is fulfilled in the countries analyzed. In the case of developed countries, Canada and the United States were analyzed, finding that in the case of the United States, the hypothesis that as the economy progresses, there is a decrease in its emissions is fulfilled, as shown in Figure 3, however, in Canada no clear trend was found for the period analyzed (2010-2020).

On the contrary, in emerging countries, taking Mexico and Brazil as a reference (Figure 4), it was found that both have a positive slope, fulfilling the hypothesis of the Kuznets Curve, which tells us that in the initial stages of economic development, a country tends to increase its environmental degradation because it is in a stage of increasing urbanization and increasing its industrial production. Although the empirical evidence found confirms the ECK hypothesis, there could be other exogenous variables related to such behavior,



Figure 3. Kuznets curve in developed countries of America.





Elaboration own, 2024.

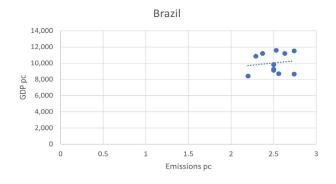
including stricter environmental regulations in developed countries and specific taxes on CO₂ emissions. It is important to note that international pressure within the framework of the Sustainable Development Goals (SDG) could also define the recent behavior of the ECK.

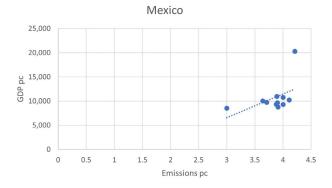
In the period analyzed, the Kuznets curve is generally fulfilled as, in most cases, reaching their inflection peak is necessary for countries to reduce emissions or for the government to implement more rigorous environmental policies.

5. Discussion

Various studies explain the relationship between environmental degradation and other variables, known as the expanded EKC; other explanatory variables are added to the original proposal. Thus, the results obtained in the present research work confirm the existence of an EKC for the countries of America in the period 2010-2020 through a panel data model, where CO₂ emissions are measured and their relationship with the variables GDP per capita, electricity consumption, income from environmental taxes, exports, and imports in America.

Figure 4. Kuznets Curve in some emerging countries in America.





Source: Elaboration own, 2024.

Previous studies used panel data models to test the EKC hypothesis and have obtained results similar to and different from this research. Among them, Zeraibi et al. (2023) argue that for emerging economies from 1990 to 2020, through an ordinary least squares model, there is a relationship between CO2 emissions and GDP per capita in the form of N; that is, the EKC hypothesis is confirmed. However, in the form of an N, not an inverted U for the region's countries, this form is sensitive if the sample of countries is modified.

In addition, the results of Pradhan et al. (2024) argue that, among developing countries in the South Asian region, with data spanning from 1996 to 2021, there is an inverted U-shaped relationship between CO₂ emissions, energy consumption, and economic growth; the authors show that higher per capita income encourages higher energy consumption. In addition to emissions, financial development, and population growth positively affect energy consumption in the countries considered to be in Asia.

Regarding environmental taxes, Vallés-Gimenez and Zarate-Marco (2021) analyze, in the context of the EKC, the determinants of the export intensity



of hazardous industrial waste among Spanish regions, with particular attention to the influence of waste taxes and environmental policies in their findings, they suggest that there is a dynamic spatial component in export intensity and that both regional taxes on waste disposal and the stringency of environmental policies seem to incentivize, albeit modestly, the rate of waste exported to other regions.

The variable imports and exports of GDP, like the findings of Boamah et al. (2017) that when investigating the role of international trade in China (considering total exports and imports) in mitigating CO₂ emissions as the nation advances economically, there is a long-term N-shaped relationship between economic growth and emissions, within the framework of the estimated EKC. Therefore, the recommendation is that China, as a leading exporter, should transform its trade growth mode by reducing CO₂ emissions and strengthening its international cooperation while adopting more environmental protections.

As a political implication, some measures must be taken to reduce environmental pollution without sacrificing countries' economic growth. Some of these measures involve reducing greenhouse gases from industry, transport, and heat, increasing the use of biodiesel, and applying environmental technologies. It is not expected that the policies will be applied homogeneously in the countries since they would have different impacts depending on each country's stage of development and even the estimation of its position in the EKC.

A higher per capita income represents a technological evolution that implies the reduction of environmental pressures. In turn, technological progress, which can be reflected in the production of goods and services under stricter environmental protection standards, encourages producers to innovate and, therefore, reduces CO₂ emissions and, in general, various pollutants that degrade environmental quality at a local and global level, in the short and long term. This impact can be seen in the coefficient of exports for the model, as it turns out to be significant because these exports made by countries in the American continent are generally under more lax environmental protection standards.

6. Conclusions

The hypothesis for the EKC was tested for 25 countries on the American continent between 2010 and 2020 through an econometric approach that involved the analysis of a model with panel data. The empirical evidence presented in this paper allows us to visualize an inverted U-shaped association between environmental degradation and the variables considered to test the EKC. The estimates have the expected signs and are statistically significant, resulting in empirical support for the acceptance of the EKC hypothesis in America.

Thus, there is a significant effect of GDP per capita, electricity consumption, GDP imports and exports, and taxes related to the environment on CO₂ emissions. Although it is recognized that the relationship may differ between countries (OECD, 2013), those that make up the American continent are responsible for more than 20% of global CO₂ emissions. The estimates of the EKC hypothesis in different countries should be considered an essential tool for effectively constructing environmental policies since environmental regulation has a moderating effect on CO₂ emissions.

One of the limitations of this research is that, as with most econometric models, they can not explain the entire relationship between the dependent variable and the independent variables, as they can often be complex and multidimensional, making it difficult to fully represent them. For example, this article did not consider CO2 emissions from natural sources (volcanoes, swamps, natural forest fires, among others), which can generate biases in the results.

Therefore, as future lines of research, considering the ECK hypothesis, it would be pertinent to explore the inclusion of additional factors that may influence the relationship between GDP and CO2 emissions, such as emissions of natural origin, which were not considered in this study. In addition, more complex econometric models could be incorporated to better capture the interaction of variables that are not directly observable; addressing the influence of climatic and geological phenomena on emissions and developing a more holistic approach that considers these external elements.

The findings of this study strongly recommend that policymakers propose comprehensive energy and economic policies aimed at encouraging balanced growth in the countries' regions, considering in their



agendas actions that involve the different sectors in incorporating renewable energies that allow improving environmental quality and reducing the ecological footprint.

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RESEARCH

Analysis of the relationship between the entrepreneurial profile and the impact of the university for students in the economic-administrative area

Análisis de la relación del perfil emprendedor y el impacto de la universidad para estudiantes del área económico-administrativa

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Abstract

The objective of this research is to analyze university students' perceptions of their entrepreneurial profiles, as well as the influence of the university's entrepreneurship programs and the impact of teaching activities. The study is conducted within a quantitative explanatory framework. Aquestion naire was administered electronically via Microsoft Forms to university students enrolled in economicadministrative degree programs at the Universidad de Sonora Nogales Campus. The sample consists of a statistically significant group representing 53% of active bachelor's program students. The results reveal that most students perceive themselves as average entrepreneurs (52.30%). Additionally, a significant majority believe that the information on institutional entrepreneurship programs is sufficient (71.55%). However, these programs are not significantly related to their self-perception as entrepreneurs. It was also found that the influence of teachers in shaping the entrepreneurial profile is substantial (46.86%) and positively correlates with the students' perception of their entrepreneurial profiles. In conclusion, an area of opportunity was identified at the institutional level to further promote entrepreneurship among students.

Keywords: entrepreneurship, students, university

JEL Codes: L26, M13, N86

Resumen

El objetivo de la investigación es analizar la percepción de los estudiantes universitarios sobre su perfil emprendedor, así como la influencia de los programas de emprendimiento de la universidad y el impacto de la actividad docente. La investigación se desarrolla bajo un paradigma cuantitativo de tipo explicativo. Se aplicó un cuestionario en formato electrónico a través de Microsoft Forms a estudiantes universitarios de programas de licenciatura de corte económico-administrativo de la Universidad de Sonora, en el campus Nogales. La muestra se compone de un conjunto estadísticamente significativo del 53% de alumnos activos en los programas de licenciatura. Los resultados revelan que la mayor proporción de estudiantes se perciben como emprendedores promedio (52.30%). Además, la gran mayoría considera que la información sobre programas institucionales relacionados con el emprendimiento es suficiente (71.55%), sin embargo,



estos programas no se relacionan significativamente con su percepción como emprendedor. También se determinó que la influencia del docente en la formación del perfil emprendedor es alta (46.86%) y se relaciona positivamente con la percepción del perfil emprendedor del estudiantado. En conclusión, se identificó un área de oportunidad a nivel institucional para fomentar el emprendimiento de los estudiantes universitarios.

Palabras clave: emprendimiento, estudiantes,

universidad

Códigos JEL: L26, M13, N86

1. Introduction

Over the years, the concept of entrepreneurship has been studied by various authors who have sought to explain its triggers. As a result, a wide range of research supports the formation of the entrepreneurial profile. In the university context, various factors may stimulate or discourage student entrepreneurship, such as the entrepreneurial climate, the program's learning structure, or the curricular framework offered by the institution. As a means of promoting entrepreneurship, these elements can play a crucial role in the development of entrepreneurs (Amorós Espinosa, Silveyra León, Ruiz Castro & Carlos Mancilla, 2022; Arango-Botero, Valencia-Arias, Palacios-Moya & Garcés, 2022; Valenzuela-Keller, Gálvez-Gamboa, Sierra Salgado & Podestá-Velarde, 2022; Antezana, 2020; Mayer Granados, Charles Coll & De la Garza Ramos, 2019).

In Mexico, one of the key factors influencing students' entrepreneurial intentions is their university environment, as highlighted by the Global University Entrepreneurial Spirit Student's Survey [GUESSS] (Amorós Espinosa et al., 2022). The same report, based on 2021 data, states that while students tend to seek organizational jobs immediately after graduation, many plan to start their own business within five years of completing their degrees (Sieger, Raemy, Zellweger, Fueglistaller & Hatak, 2021). Furthermore, Amorós Espinosa et al. (2022) concludes that entrepreneurial intention is significantly higher in emerging economies compared to more developed ones.

Currently, the study of entrepreneurship is distinguished by the growing interest and diversity of scientific publications. Research on the role of universities and university students in entrepreneurship has also emerged as a highly relevant topic. These studies focus on the attributes of entrepreneurs, the characteristics of ventures, and the factors influencing entrepreneurial intention (Mendieta-Andrade, 2023).

The training of university students as entrepreneurs can be fostered through the development of attributes such as passion, self-confidence, risk management, among others (López et al., 2013; Bóveda et al., 2015; Bacigulapo et al., 2016). However, within the university context, certain environments can either positively or negatively impact the development of these attributes (Amorós Espinosa et al., 2022; Miranda et al., 2017; Durán, Rosado & Quintero, 2019).

1.1 Entrepreneurship and the Entrepreneurial Profile

Defining the term "entrepreneur" is complex due to the various theoretical perspectives that shape its meaning based on different interests. The Global Entrepreneurship Monitor (2023) defines entrepreneurship as "any attempt at creating new businesses or new companies, such as self-employment, a new business organization, or the expansion of an existing business, by an individual, a team of individuals, or an established business" (para. 2). A key quality of an entrepreneur is the ability to turn ideas into realities that generate financial, cultural, or social value (Bacigulapo, Yves Punie & Van den Brande, 2016).

The entrepreneur is defined by a set of attributes and qualities that develop over time. Various authors have identified key characteristics that define entrepreneurs, such as passion, the ability to manage risks, self-confidence, and the ability to build connections (López et al., 2013; Bóveda et al., 2015; Bacigulapo et al., 2016). Table 1 below summarizes and compares these characteristics from diverse perspectives.



Table 1. Characteristics of the Entrepreneur

López et al. (2013)	Bóveda et al. (2015)	Bacigulapo et al. (2016)
Passion	Visualize	Discover, Explore
Strategic Perspective	Analyze, Identify	Critical Thinking, Ideas in Action
Ability to Manage Risk	-	Facing Challenges, Confronting Obstacles
Perseverance	To act	-
Ability to Build Connections	Decide, Design	Improve Skills Collaborative work
Self-Confidence	-	-

Note: Own elaboration based on López et al. (2013); Bóveda et al. (2015), and Bacigalupo et al. (2016).

These traits help define the degree of an individual's entrepreneurial profile, as they are present to varying extents in most people. According to López et al. (2013), a fundamental characteristic is passion, reflected in the enthusiasm to transform oneself to achieve personal goals. Entrepreneurs dedicate a significant portion of their day to activities that help them reach their objectives. Bóveda et al. (2015) further define this trait as the ability to visualize, meaning the capacity to recognize and establish various individual goals and their interconnections.

A strategic perspective involves observing the environment and focusing on development goals. It is not just about identifying key elements but also recognizing small details that stimulate demand for a product or service (López et al., 2013). Additionally, it is crucial for entrepreneurs to engage in analysis, which is, conducting a study that allows them to establish a relationship between the individual, the project, and its context. This is complemented by skills such as self-confidence, which helps shape a more integrative analytical profile (Bóveda et al., 2015).

The ability to identify new opportunities and a commitment to quality are also crucial. Seeking relevant information allows entrepreneurs to detect opportunities more effectively, leading to a broader perspective (Bóveda et al., 2015). Furthermore, critical thinking and experimentation play key roles in creating value through business experiences and taking responsibility for the outcomes (Bacigulapo et al., 2016).

Another essential attribute is the ability to manage risk, which determines how entrepreneurs respond to unexpected situations and make decisions that may not always lead to positive results. Developing an instinct to recognize and seize opportunities, even without full preparation, is crucial (López et al., 2013). This competency is necessary for navigating complex, rapidly environments with high uncertainty (Bacigulapo et al., 2016).

Entrepreneurs must also be prepared to face emerging challenges through new knowledge, research, and innovation to achieve excellence and transform existing practices (Bacigulapo et al., 2016). Finally, perseverance is a defining trait, as entrepreneurs often persist despite obstacles, choosing to move forward against the odds, no matter how long it takes (López et al., 2013).

For these aspects to materialize, action is essential, enabling entrepreneurs to transform strategies into effective outcomes. Achieving this requires developing skills such as perseverance, building support networks, and honoring commitments (Bóveda et al., 2015).

Another fundamental characteristic is the ability to establish connections. Knowing whom to approach and for what purpose is highly valuable, as a strong network of contacts accelerates goal achievement and provides support in challenging times (López, Gómez, González, Malpica, Lucatero, Smith, & Huezo, 2013). Entrepreneurs seek to enhance their skills to turn ideas into reality, embrace collaborative work, leverage their knowledge to generate value, and tackle increasingly complex challenges (Bacigulapo et al., 2016).

The ability to establish connections also requires sound decision-making, involving cost-benefit analysis to assess available options (Bóveda et al., 2015). Lastly, self-confidence is crucial for entrepreneurs, as it reflects their conviction that they possess the necessary tools and their decisions and actions are well-founded (López et al., 2013).

1.2 Universities and Entrepreneurs

University career choices among young people are a critical factor for governments, especially given the scarcity of jobs in many economies. Graduates represent the future and hope of proper economic growth, yet poor management of this resource can lead to brain drain. Since students are still in the early stages of their professional development, their knowledge is crucial for fostering innovation and market expansion (Olugbola, 2017).



Despite the presence of university students with the skills, knowledge, and experience to start businesses, entrepreneurial intention may remain low due to insufficient entrepreneurship education. This underscores the need to foster creativity, independence, and initiative through university programs (Nadrljanski, Grzinic, & Kinga Kowalczyk, 2019).

University graduates enter a competitive job market where academic knowledge alone may not be enough. Developing entrepreneurial skills provides opportunities to enter the workforce market creatively and innovatively. As a result, student preparation should move beyond textbooks to engage with real-word challenges. University entrepreneurship programs should be tailored to practical experiences and aligned with the dynamics of their environments (Olugbola, 2017).

Several authors emphasize the importance of promoting an entrepreneurial mindset within academic programs (Miranda et al., 2017), the development of business plans and entrepreneurial projects (Mayer et al., 2019), and activities focused on contemporary phenomena (Olugbola, 2017). The goal is to ensure that what students learn within the university endures in their professional lives, rather than remaining merely an academic requirement (Moran-Montalvo & Sánchez-Riofrío, 2018).

Considering this, we observe that the influence of academic programs offered by educational institutions presents a divided perception regarding their impact on students' entrepreneurial intentions. This provides an opportunity to assess various areas within the institution to determine the extent to which entrepreneurship and innovation activities are incorporated into its environment. Eight key areas are evaluated, which every higher education institution should consider equipping students with the necessary tools to face the new challenges of the market (European Commission & OECD, 2011).

Beyond offering attractive educational programs for entrepreneurs, it is crucial to establish effective administration that enhances faculty members' entrepreneurial competencies. The influence of institutional management on improving these competencies has gained recognition as one of the key drivers of economic growth, particularly following the COVID-19 health crisis (Zhu, Liu, Zhao, Huang, & Yu, 2023). The organizational capacity of a higher education institution also drives its ability to fulfill its strategic objectives. If committed to

developing entrepreneurial activities in line with its goals, institutions can leverage key sources—such as financing and investments, personnel, expertise, knowledge, and incentive systems— to sustain and enhance entrepreneurial capacity (European Commission & OECD, 2011).

An alternative to promoting new teaching techniques is blended learning programs, which offer diverse teaching models utilizing technology. A study indicates that academic reflexivity, social interaction, and agency, when dynamically combined, are crucial for understanding how academics navigate blended learning as a pedagogical characteristic (Truss & Anderson, 2023). This encourages the exploration of innovative teaching methods to stimulate entrepreneurial mindsets. It is not just about acquiring theory and literature on entrepreneurship; students must also be exposed to entrepreneurial experiences, acquiring the necessary skills and competencies to develop and entrepreneurial mindset (European Commission & OECD, 2011).

Promoting an entrepreneurial culture among students enhances innovation, creativity, problem-solving ability, and the ability to use available resources. For this reason, it is important to have faculty who are well-trained and equipped to develop students' entrepreneurial competencies, enabling them to think, act, and make decisions effectively both inside and outside the classroom (Durán, Rosado & Quintero, 2019). Establishing strong leadership and governance are essential is essential to fostering an entrepreneurial and innovative culture. Many higher education institutions include terms such as "enterprise" or "entrepreneurship" in their missions, however, achieving this goes beyond simple references (European Commission & OECD, 2011).

While universities can play an important role in developing young entrepreneurs, they do not necessarily represent a definitive factor in developing an entrepreneurial profile. Within the university setting, students engage in a range of disciplines taught by faculty members who can influence the development of future entrepreneurs. In this regard, a study conducted by Arango-Botero et al. (2022) identified three student profiles: "1) those who do not wish to become entrepreneurs; 2) those who plan to pursue entrepreneurship either immediately after graduation or within five years; and 3) potential entrepreneurs" (p. 55). The results showed no significant differences regarding variables such as



the university's entrepreneurial climate, program learning, and subjective norms, suggesting that these variables have little statistical impact on strategies to promote entrepreneurship. Similarly, Antezana (2020) found that universities have a neutral influence on students' entrepreneurial intentions and play an important role in fostering an entrepreneurial culture among students, with many of students considering themselves entrepreneurial individuals.

On the other hand, entrepreneurial students are also exposed to external environments, such as family backgrounds, prior work experience, and their entrepreneurial activity (Moran-Montalvo & Sánchez-Riofrío, 2018). Additionally, the individual's own entrepreneurial mindset and intentions (Valenzuela-Keller, Gálvez-Gamboa, Sierra Salgado & Podestá-Velarde, 2022), affect their development, though these aspects are excluded from this study due to the established delimitations.

The entrepreneurial intentions of university students create an opportunity for universities to develop programs that encourage entrepreneurship (Nadrljanski, Grzinic & Kinga Kowalczyk, 2019; Olugbola, 2017). This article aims to contribute to an essential area of study for developing countries, impacting the understanding of entrepreneurship at the local level. The research will analyze the perceptions of university students enrolled in economic-administrative programs regarding entrepreneurship, with a focus on the influence of university entrepreneurship programs and the role of faculty members.

Based on the context and objectives, three research hypotheses are proposed. The literature review shows that entrepreneurs possess specific attributes, such as passion, risk management skills, and the ability to face challenges (López et al., 2013; Bóveda et al., 2015). In the context of university entrepreneurs, Hypothesis 1 is proposed: the student perceives themselves as an outstanding entrepreneur. The more developed the entrepreneurial characteristics in a student, the more likely they are to perceive themselves as an outstanding entrepreneur.

Entrepreneurship promotion programs play a fundamental role in the development of entrepreneurial skills. The influence of university entrepreneurship programs on the formation of the entrepreneurial profile has been documented by authors such as Olugbola (2017) and Amorós Espinosa et al. (2022). From this, Hypothesis 2 is

presented: the way the student perceives themselves as an entrepreneur varies based on their knowledge of university programs related to entrepreneurship. It is suggested that the greater the knowledge of these programs, the higher the student's perception of themselves as an entrepreneur.

Faculty members play a crucial role in fostering the characteristics that make up the entrepreneurial profile (Miranda et al., 2017; Durán, Rosado & Quintero, 2019). From this, Hypothesis 3 is derived: the way the student perceives themselves as an entrepreneur is impacted by the role of university faculty. Entrepreneurial-oriented teaching by faculty could significantly impact students' perception of their entrepreneurial profile.

2. Methodology

2.1 Participants

The research is conducted within a quantitative explanatory framework due to its capacity to analyze casual relationships objectively. Data collection was employed to test the hypotheses through numerical measurement and statistical analysis. The explanatory design was adopted to assess the influence of university programs and faculty roles on students' entrepreneurial perceptions.

The study population comprises university students enrolled in economic-administrative degree programs at the University of Sonora (UNISON), Nogales campus, with a total of 454 students during the study period. The sample was selected to be statistically significant, representing 53% of the active student body. The sample size was calculated using a 95% confidence level from a finite population (Hernández-Sampieri & Mendoza, 2018).

Table 2. Sample calculation

	Data	Conversion
N	454	Population
p	50%	0.5
q	50%	0.5
δ	95%	1.96
e	3.50%	0.04
n	209	Sample

Source: Own elaboration.



The participants in the research consisted of 239 active students during the second semester of 2022. With their full consent, they completed an electronic questionnaire. To prevent duplicate responses, students were required to log in using their institutional email. However, no personal data is included in the results presented in this article. The sample comprised both male and female students from the undergraduate programs in Administration, Business, and International Commerce (see Table 3).

Table 3. Sample by Educational Program

Program	Frequency	Valid Percentage	Cumulative Percentage
Bachelor's degree in Business and International Commerce (BBIC)	196	82%	82%
Bachelor's degree in Administration (BA)	43	18%	100%
Total	239	100%	

Source: Own elaboration.

64.36% of the enrollment in the Department of Economic-Administrative Sciences corresponds to the Bachelor's degree in Business and International Commerce, with the remaining enrolled in the Bachelor's degree in Administration (UNISON, 2023). The participants in the study are aged between 16 and 29 years (see Table 4).

Table 4. Sample by Age and Educational Program

Ages	Total	BBIC	BA
(16 to 19 years)	116	100	16
	49%	51%	37%
(20 to 22 years)	116	89	27
	49%	45%	63%
(23 to 29 years)	7	7	О
	3%	4%	ο%
Total	239	196	43
	100%	100%	100%

Source: Own elaboration.

2.2 Technique and Instrument

The instrument used in this study was adapted from Torres-Figueroa, Mendoza-Olea, Lara-Soto & Zazueta (2016), developed for a previous study at the same university on the entrepreneurship of final-

year students. It is validated through Cronbach's Alpha for the constructs (0.789, 0.82, and 0.879) (Torres-Figueroa et al., 2016, p. 1693).

The first section of the instrument includes 16 items that assess motivational factors, personal characteristics, intellectual traits, and general competencies to determine the entrepreneurial profile of university students. This section uses a four-category Likert scale: (o) never; (1) occasionally; (2) frequently; and (3) always. The 4-point scale is designed to eliminate the neutral option, encouraging obtaining more definitive positive or negative perceptions.

The second section consists of 5 items regarding the institution's impact on students' entrepreneurship and 13 items on the role of faculty in students' entrepreneurship, both measured using dichotomous variables.

2.3 Procedure

For the scoring, values were estimated, and a classification was made according to the established evaluation parameters. Once the maximum values were obtained, grading parameters were assigned to group the data according to predefined ranges.

To perform the scoring, values from o to 3 were applied to the Likert scale items, and from o to 1 for the dichotomous items. This approach enabled the estimation of values, and the corresponding classification based on the established evaluation parameters.

The data collection process was carried out in October and November of 2022. For data analysis, the Statistical Package for Social Sciences (SPSS), version 27 (IBM, 2020), was used.

3. Results

The results are presented through visual groupings into three categories. First, the entrepreneurial profile of the students is defined. Then, in a cross-analysis, the relationship between this profile and the university programs is examined. Finally, the correlation between the entrepreneurial profile and the impact of faculty activity is explored.

To determine the entrepreneurial profile of the students, the following parameters were used: non-entrepreneurial, average entrepreneur, and



outstanding entrepreneur. This classification was derived using Chebyshev's theorem, which asserts that 75% of the population falls within two standard deviations (Mendenhall, Beaver & Beaver, 2010). The following formula was applied: (Mean \pm (standard deviation * 75%)), to obtain the grouping limits for the entrepreneurial profiles, as shown in Table 5.

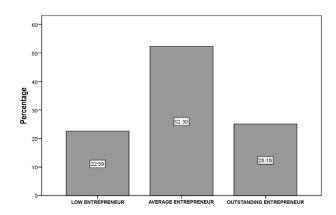
Table 5. Entrepreneurial Profile Grouping

Classification	Score
Low Entrepreneurial	0 - 27
Average Entrepreneur	28 - 37
Outstanding Entrepreneur	38 - 48

Source: Own elaboration.

In Figure 1, it can be observed that, among the total number of undergraduate students surveyed in the economic-administrative field, the majority (52.30%) identify themselves as "Average Entrepreneur," while 22.59% and 25.10% classify themselves as "Low Entrepreneur" and "Outstanding Entrepreneur," respectively.

Figure 1. Students' Self-Perception as an Entrepreneur



Source: Own elaboration.

The results indicate that university students in the economic-administrative field perceive themselves as average entrepreneurs. This suggests that, although there is some inclination toward entrepreneurship, it is not considered a sufficiently viable option for professional development. Based on this, Hypothesis 1 is rejected.

To determine students' perceptions regarding the programs and support offered by the educational institution, the concepts of "sufficient" and "insufficient"

were established, as shown in Table 6. To define the grouping limits for this classification, the following formula was used:

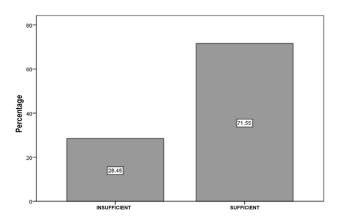
(Mean - Standard Deviation)

Table 6. Institutional Program Influence Grouping

Classification	Score
Insufficient	0 – 2
Sufficient	3 - 5

Source: Own elaboration.

Figure 2. Knowledge of institutional information related to Entrepreneurship



Source: Own elaboration.

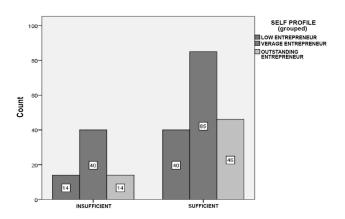
Students' perception of the institutional program, incentives, and support offered by the economic-administrative field related to entrepreneurship indicates that 71.55% of participants consider it "Sufficient", while the remaining 28.45% perceive it as "Insufficient".

It was found that, for each of the considered profiles (low entrepreneur, average entrepreneur, and outstanding entrepreneur), the majority believe that the information and programs provided by the institution are sufficient.

Nevertheless, through the analysis of cross-tabulations, it was determined that the perceived level of the entrepreneurial profile is not significantly related to institutional information, as indicated by the Chi-square analysis with a significance level of 1.714. Based on these findings, Hypothesis 2, which indicates that students' perception of themselves as entrepreneurs is influenced by their knowledge of and exposure to institutional entrepreneurship programs, is rejected.



Figure 3. Correlation Between the Student's Entrepreneurial Profile and Program Knowledge



Source: Own elaboration.

Additionally, the results highlight the necessity for the educational institution to take a more proactive role in promoting entrepreneurship. This involves fostering an environment conducive to the development of valuable ideas and ensuring access to the necessary resources for their realization.

Finally, limits were established to categorize the influence of faculty efforts in encouraging students' entrepreneurial spirit. The results demonstrate the impactof faculty work on fostering entrepreneurship. To analyze and manage this variable, a classification system—low, moderate, and high— was created, based on statistical ranges determined using the standard deviation.

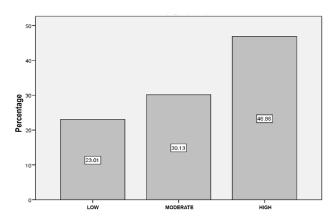
Table 7. Grouping of Teaching Effort Influence

Classification	Score
High	12 - 13
Moderate	11
Low	0 – 10

Source: Own elaboration.

The limits were established to categorize the influence of faculty efforts in encouraging students' entrepreneurial spirit using the classifications of high, moderate, and low, as shown in Table 7. These classifications were determined using the formula: (Mean ± (Standard Deviation * 50%)). A 50% coefficient was applied because the graph curve was skewed to the left.

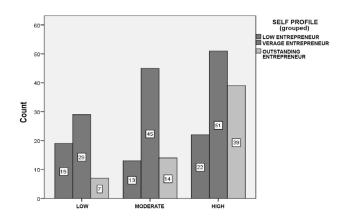
Figure 4. Influence of Faculty Work on Promoting Entrepreneurship



Source: Own elaboration.

The influence of faculty on shaping the entrepreneurial profile of students in undergraduate programs offered within the economicadministrative field can be determined through the results. A total of 46.86% consider this influence to be "High", while 30.13% classify it as "Moderate", and the remaining 23.01% perceive it as "Low".

Figure 5. Correlation Between the Student's Entrepreneurial Profile and Program Knowledge



Source: Own elaboration.

It was found that within the profiles of "Low Entrepreneur" (22 counts), "Average Entrepreneur" (51 counts), and "Outstanding Entrepreneur" (39 counts), the majority consider faculty efforts to motivate and promote entrepreneurship are "High".

In this regard, the perceived level of the



entrepreneurial profile is related to faculty work, as the Chi-square analysis through cross-tabulations yielded a significance level of 15.467. After analyzing the data, Hypothesis 3, which states that students' perception of themselves as entrepreneurs is influenced by faculty efforts, is not rejected.

Based on this reasoning, it is important to acknowledge the significant role that faculty members play in fostering an entrepreneurial spirit among students, helping them develop curiosity and a desire to generate new ideas that lead to business proposals. At the same time, there is a need to emphasize continuous professional development among faculty to effectively address the demands of the modern world.

5. Discussion

In reference to the results obtained in this study, we can generally observe that: a) students in the Department of Economic and Administrative Sciences exhibit an "Average Entrepreneur" profile, b) the perceived level of the entrepreneurial profile is not statistically significant in relation to institutional information and offered programs, and c) the perceived level of the entrepreneurial profile is statistically significant in relation to faculty efforts.

University students in the economic-administrative field perceive themselves as average entrepreneurs, indicating that while there is an intention to engage in entrepreneurial activities, it is not sufficient motivation to consider it a top professional priority. Therefore, Hypothesis 1 is not accepted. To expand the analysis, it is important to consider additional factors such as family environment, work experience, and previously developed business activities to form a more comprehensive framework for assessing students' entrepreneurial profiles (Moran-Montalvo & Sánchez-Riofrío, 2018). Additionally, based on Valenzuela-Keller et al. (2022), it would be advisable to emphasize the importance of developing an entrepreneurial mindset and intention.

Moreover, the entrepreneurial spirit is sometimes hindered by students' belief that access to sufficient resources and opportunities is essential for implementing their business ideas, which could indicate a lack of motivation (Amorós Espinosa et al., 2022). Consequently, we can conclude that a key

factor in developing entrepreneurs is promoting self-analysis, allowing students to identify their skills and qualities, and thereby strengthen their entrepreneurial profile. It was also revealed that while the information and programs offered by the institution are deemed sufficient, they are not statistically significant in shaping students' entrepreneurial profiles, indicating a disconnect between these two variables. As a result, Hypothesis 2 is not accepted. This finding contradicts previous research, which asserts that education has a positive impact on understanding the necessary actions for entrepreneurship (Amorós et al., 2022). When combined with the right entrepreneurial mindset, education fosters effective determination (Valenzuela et al., 2022). However, other researchers support the findings of this study, arguing that the entrepreneurial environment, programs, and institutional regulations have little influence (Arango et al., 2022) largely due to the lack of meaningful entrepreneurship education (Nadrljanski et al., 2019). This results in a neutral entrepreneurial intention among university students (Antezana, 2020).

Additionally, several authors highlight importance of fostering an entrepreneurial attitude within academic programs (Miranda et al., 2017), promoting the development of business plans and entrepreneurial projects (Mayer Granados et al., 2019), and incorporating activities that address realworld challenges (Olugbola, 2017). The goal is to ensure that what is learned in the university setting endures beyond the classroom and contributes to students' professional development, rather than serving merely as an academic requirement (Moran-Montalvo & Sánchez-Riofrío, 2018). Based on these perspectives, we can conclude that perceptions of the effectiveness of educational programs in fostering entrepreneurship remain divided.

Finally, the role of faculty members in shaping students' entrepreneurial profiles demonstrates a positive impact, indicating that professors play an effective role in fostering and promoting entrepreneurship. This led to the acceptance of Hypothesis 3. The literature highlights the importance of having well-trained faculty with access to the necessary tools for effective classroom instruction (Durán, Rosado & Quintero, 2019), as well as an institutional administration that encourages continuous improvement of the business competencies required for teaching



entrepreneurship (Zhu et al., 2023). Therefore, we emphasize the need for ongoing faculty training to ensure that educators are equipped to meet current demands and provide students with the knowledge and skills necessary to consider entrepreneurship as a viable career path upon graduation.

6. Conclusions

The research and its results highlight a strong need to create an environment that fosters motivation and self-confidence, enabling university students to envision themselves as entrepreneurs. They must be equipped with the necessary skills, abilities, and curricular knowledge to develop viable business plan that can be successfully implemented within their communities. Additionally, the study underscores the importance of exploring external factors beyond the university environment to better understand their influence on students' determination to pursue entrepreneurship.

Given the evidence, we can also identify a significant opportunity for educational institutions to take a more active role in promoting entrepreneurship. By cultivating an environment conducive to idea development and ensuring access to the resources necessary for implementation, universities can better support students in their entrepreneurial journey. Furthermore, this research recognizes the dedicated efforts of faculty members in fostering an entrepreneurial mindset among students, encouraging curiosity and innovation that lead to meaningful business proposals. At the same time, it highlights the crucial need for continuous faculty training to effectively meet the demands of an everevolving world.

Finally, it is essential to view entrepreneurship beyond the traditional notion of simply starting a business. Instead, it should be recognized as a pathway for personal, familial, social, and professional growth, empowering individuals to set ambitious goals that drive self-fulfillment and long-term success.

Based on the findings of this research, a series of recommendations are presented. First, it is suggested that the curriculum be restructured to incorporate relevant knowledge that supports the development of locally impactful and sustainable entrepreneurial ventures. Also, practices should

be implemented that allow students to engage with and learn from successful entrepreneurial cases in their environment through incubators, entrepreneurship fairs, and mentorship programs. In addition, continuous training programs should be established to equip faculty with the necessary tools to effectively teach entrepreneurship. Lastly, extracurricular activities should be encouraged to help students conceptualize, develop, and finance their business ideas.

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RESEARCH

Links of the Ecotourism Value Chain in San Carlos, Sonora, Mexico

Eslabones de la Cadena de Valor del Ecoturismo en San Carlos, Sonora, México

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Abstract

This study explores ecotourism and its potential to promote sustainable regional development (SRD) in a tourism-dependent area, specifically San Carlos, Sonora, Mexico (SCSM). The main objective is to characterize ecotourism activities in SCSM through the lens of value chains, analyzing the links that make up the Ecotourism Value Chain (EVC). The research employs a mixed methodology, including participant observation, semi-structured interviews, and the collection of 359 questionnaires. The results indicate that the locality has strong links in ecotourism activities, restaurant services, and hospitality. However, significant deficiencies were identified in marketing and both public and private transportation. Additionally, a notable disconnection between ecotourism businesses and other components of the EVC, hindering effective integration.

Key Words: Ecotourism, tourism value chain, mixed approach, San-Carlos-Sonora-México

IEL Codes: Z₃, Z₃₂

Resumen

Este estudio aborda la problemática de dependencia del turismo en San Carlos, Sonora, México (SCSM), identificando como desafío principal la fragmentación de la cadena de valor (CV) del ecoturismo. Esta desconexión entre los actores clave limita el desarrollo regional sostenible (DRS) y el aprovechamiento integral de los recursos turísticos. El objetivo principal es caracterizar la actividad ecoturística en SCSM desde el enfoque de las cadenas de valor, identificando fortalezas y debilidades en sus eslabones. La investigación emplea un enfoque metodológico mixto, que incluye observación participante, entrevistas semiestructuradas y la recolección de 359 cuestionarios. Los resultados revelan que la localidad presenta eslabones sólidos en cuanto a las actividades ecoturísticas, servicios de restauranteros y hotelería. Sin embargo, se observan deficiencias significativas en términos de comercialización y transporte tanto público como privado. Además, se constató una notable desconexión entre las empresas ecoturísticas y los otros componentes de la CV, lo que impide una integración efectiva.

Palabras clave: Ecoturismo, cadena de valor turística, enfoque mixto, San-Carlos-Sonora-México

Códigos JEL:Z₃, Z₃₂





Introduction

This work presents an analysis of the CV of ecotourism in SCSM, recognizing it as a powerful tool for strategic planning, value creation, and cost minimization (Vergara, Acevedo, & González, 2019). As previously noted by ECLAC (2012) and ECLAC (2016), socio-economic progress depends on sectors and activities that drive dynamic productive production, growth, positively impacting employment, and international integration while environmental conservation, promoting application of technological advancements, and the implementation of public policies aimed at equality. Following Padilla and Oddone (2017), in response to the global financial crisis (2008-2009), Caribbean and Latin American governments have increasingly focused on industrial policy. Countries such as Guatemala and El Salvador have implemented national plans for industrial policy development, crucial for defining objectives and priorities, influencing productive sectors, coordinating with other policies, and determining criteria for identifying the value chains that will benefit throughout the plan's duration. In contrast, Mexico and Costa Rica have implemented programs aimed at enhancing competitiveness and strengthening value chains.

The analysis of value chains helps identify constraints and develop strategies at different levels of participation within the chain, with the objective of increasing productivity and adding more value. According to the previously mentioned authors, reinforcing value chains fosters production diversification and structural transformation. This process involves increasing participation in more complex activities, shifting from simple tasks to those requiring greater sophistication.

In this study, integrating the concept of value chains into the analysis of ecotourism is considered essential, as it allows for identifying the strongest or most vulnerable links within this activity. This will facilitate a thorough examination of the actual involvement of all actors, creating the opportunities to propose new tourism management models. These schemes would be based on norms and strategies that span multiple sectors and departments, fostering coordinated public action.

Therefore, this study aims to characterize ecotourism activity in SCSM through the lens of value chains. To achieve this, the text is structured as follows, the first

section provides an initial introduction, followed by a literature review in the second section. The third section describes the methodology, while the fourth presents and discusses the study's results. The fifth section outlines the conclusions, and finally, the sixth includes the bibliographic references. Theoretical and empirical findings are considered useful for ecotourism management.

2. Theoretical Framework of Tourism Value Chains

The concept of value chains in tourism helps identify the various actors that form links within the chain, providing a holistic and innovative perspective on how tourism functions (Yumisaca et al., 2020). Similar to other value chains, it is essential to recognize the complexity of each link, as each one may be connected to multiple products (Oddone & Alarcón, 2017a).

Since tourism is an industry that encompasses diverse activities, actors, locations, and roles, its development and planning consider value-added activities that naturally form tourism value chains. These chains emerge at different scales and across all tourism modalities, with slight practical differences, generating benefits for suppliers, consumers, and key stakeholders (Sutomo et al., 2023).

Oddone and Alarcón (2017) describe the process as beginning with the tourist's initial desire to travel. The tourist purchases a ticket through a travel agency, a tour operator, or an online platform. The next step involves additional services such as airport transfers, currency exchange offices, and documentation procedures. Upon arrival at the destination, the tourist engages with various local services that enhance their experience, including tour operators, transportation companies, accommodations, gastronomic services, and excursions. Additionally, purchases of souvenirs and other goods contribute to local value chains, generating employment and income for the community.

In summary, Avalos et al., (2022) state that the fundamental links in a tourism value chain include the product, service provision, accommodation, food, intermediation, and transportation.

Similarly, according to Alvarado et al. (2017), the tourism value chain consists of:



Table 1. Components of the value chain

TERRITORY	COMPONENTS OF THE CHAIN	FOOD PRODUCT SUPPLIERS
	1. Tourists	
1. Tourism Territorial Planning Sectoral Plan	2. Distributors	1. Agricultural Producers
	3. Means of	2. Fishermen
	Transportation	3. Tour Guides
	4. Accomodation	
	5. Food Services	

Own elaboration based on the postulates of Alvarado et al (2017).

Intermediaries play a key role in the evolution and consolidation of destinations and products, as well as in the management of value chains (VC). Each link in the chain contributes to the overall value of a destination; if any of the elements fails to maintain an adequate level of quality, it can negatively impact the tourist's overall perception, as they evaluate the experience as a whole (Oddone & Alarcón, 2017a).

Pulido-Fernández and López-Sánchez (2016), argue that the value chain concept is essential for analyzing and planning ecotourism activities. They emphasize that this approach enables an innovative, holistic analysis of tourism, helping to establish the necessary guidelines for integrating sustainability as a strategic pillar in tourism management and in the competitive positioning of destinations within the markets.

Furthermore, López et al. (2008) describes the value chain as a collaborative framework among different organization, aimed at generating shared benefits, aligning goals with market demands, and maintaining a continuous flow of information between the involved parties. This model prioritizes quality, through a well-connected organizational structure.

Mapping these activities is crucial, as it provides a clear visualization of each stage of the process and the stakeholders involved. This approach facilitates the identification of market opportunities and the interaction between supply and demand (ILO, 2015). Pulido-Fernández and López-Sánchez (2016) highlight that it is an invaluable tool for tourism policy, as well as analysis planning and management, offering a comprehensive view of each link in the chain.

Its application allows for: the recognition of participants in tourism and their ability to manage

and negotiate, an increase in community awareness of the benefits of tourism, resource management with contributions from direct stakeholders and institutional support, the promotion and consolidation of the destination by business actors and committees, and the integration of new stakeholders due to the recognition of consistent and responsible work (López et al., 2008).

However, it is important to highlight that, according to the previously mentioned authors, various challenges have been identified in the development of ecotourism experiences. Among these difficulties is the pressure on stakeholders to achieve short-term results, which can undermine credibility when actions progress slowly. Additionally, conflicts may arise among chain members, as some prioritize competition over collaboration, though establishing common objectives can strengthen collaboration. Another significant obstacle is the reluctance of official agencies to actively engage, despite their crucial role in policy guidance and resource allocation.

Finally, López et al. (2008) highlights key challenges in applying the value chain approach, including the consolidating and increasing the recognition of destinations, ensuring the fair and equitable distribution of benefits, developing unique and distinctive products, improving stakeholder coordination to strengthen destinations, and enhancing organizational and management capacity.

3. Methodology

The methodological design followed a mixed approach, combining qualitative and quantitative techniques to analyze the ecotourism value chain in San Carlos, Sonora. For quantitative data collection, convenience sampling was employed, as surveys were conducted at various ecotourism sites with visitors who were available and willing to participate. The selected locations included beaches, trails, and protected areas, representing a diverse range of tourist sites characteristic of the region.

The sample size, consisting of 359 surveys, was determined using the formula for infinite populations, considering a 5% margin of error and a 95% confidence level. This approach was necessary due to the lack of specific data on the average ecotourism population in the region. Although convenience sampling presents certain limitations



in statistical representativeness, efforts were made to distribute surveys across different times and days to capture a broad spectrum of perspectives and visitor profiles.

In the qualitative phase, 13 semi-structured interviews were conducted with guides and entrepreneurs in the sector. Participants were intentionally selected based on criteria such as their experience in the ecotourism sector and involvement in key activities, allowing for a deeper understanding of the internal dynamics of the value chain.

The methodology was developed based on the first stage of the methodological model for Ecotourism and Sustainable Tourism Value Chains by López et al. (2008), titled "Development of the Chain," as well as the structural framework proposed by Alvarado, Oddone, & Gil (2017). The resulting structure consists of four levels:

Development of the Chain. - The objective is to understand how the value chain operates within ecotourism by identifying the attractions, products, services, involved actors, and the relationships that exist among them. To facilitate analysis, the study has been divided into four stages:

The Object of Study: SCSM. - Secondary information available about the area under analysis was collected.

Identification and characterization of attractions. - This process was carried out through participant observation, which involved creating a detailed inventory that characterized the ecotourism attractions. Several indicators were considered, such as: accessibility, promotional activities, site appeal, guides, infrastructure, service providers, safety, and complementary services.

Structure of the Ecotourism Value Chain. – The different links that make up the ecotourism value chain are detailed

and explained: accommodation, marketing, guides and sector entrepreneurs, food services, transportation, and visitors. Information was collected through semistructured interviews and questionnaires. Thirteen interviews were conducted with ecotourism guides and/or entrepreneurs, of whom 10 were men and 3 were women, aged between 31 and 60 years. Nine of them hold certification as tour guides, and eight manage businesses related to ecotourism. Additionally, 359 of the questionnaires applied to tourists were validated, allowing for an analysis of their profiles.

Mapping the value chain. – Finally, based on the collected information, a diagram of the value chain is developed, visualizing the links and their lack of interactions.

4. Results. The Development of the Chain

4.1 The Object of Study: SCSM.

SCSM is part of the urban area of Guaymas, which economy is diversified across sectors such as agriculture, livestock, fishing, maquiladoras, and, most notably, tourism (H. Ayuntamiento de Guaymas, 2019). Tourism plays a crucial role in the region, attracting approximately 850,000 domestic tourists and around 200,000 international visitors annually, mostly from the United States and Canada. This sector generates about 9,000 jobs, with around 3,000 being direct jobs. In 2023, the hotel infrastructure offered over 2,000 rooms, with an occupancy rate of 56%. Tourism revenues in SCSM reached 260 million pesos, solidifying the area as one of the most important tourist destinations in the state of Sonora (INEGI, 2020a; Mexico News Daily, 2023).

SCSM is located 117 km south of Hermosillo, the capital of Sonora, and 416 km from the U.S. border. Its beaches, situated on the western coast of Mexico, form part of the Sea of Cortez.



Figure 1. Geographic location



It is characterized by desert vegetation, a natural marine environment, and a notable high-level tourism offering (Playas México, 2019). Its reddish hills and warm waters further enhance the area's appeal. During the warmer months of July and August, SCSM is mainly visited by domestic tourists, with temperatures ranging from 23°C to 40°C. In contrast, December and January, which see the highest influx of tourists from the United States and Canada, have average temperatures ranging between 8°C and 27°C (AccuWeather, 2023).

The development of SCSM as a tourist destination began in 1964, driven by the growth of the real estate sector, which focused on attracting second-home visitors, mainly from the United States and Canada (García, 2011). This development was spearheaded by Rafael T. Caballero, who was instrumental in securing the official recognition of the bay as "Bahía de SCSM Nuevo Guaymas" by the H. Congress of the State of Sonora.

Weekend tourism, primarily from Hermosillo and Obregon, has played a significant role in the growth of SCSM. However, its distance of approximately 420 km from Tucson, Arizona, has made it difficult for the area to become a popular destination for

weekend visitors from that city (García, 2011). To address this challenge, the state government launched programs such as OnlySonora, which allows the temporary importation of vehicles by foreigners and Mexicans residing abroad, authorizing their circulation exclusively within Sonora.

Today, SCSM has established itself as one of the primary tourist destinations in Sonora, with a population of 2,508 residents, including those of U.S. and Canadian origin (INEGI, 2020a). The town boasts 45 restaurants, 12 hotels, and a wide variety of vacational rental houses I (INEGI, 2020b).

According to a study by Chavez and Enriquez (2022), SCSM achieved a Competitiveness Index of 51%, establishing itself as the second most competitive tourist destination in Sonora. This success is attributed to its strategic location, natural attractions, adequate infrastructure, and services designed to satisfy visitors, as well as its well-regarded market image.



4.2 Identification and Characterization of the Attractions

Through participant observation, a qualitative data collection technique, the necessary information was gathered to create an inventory that characterizes the attractions (Table 2). These were considered as such because they have the infrastructure required for various activities. For example, Rancho Nuevo, Rancho del Desierto, the three beaches of Los Algodones, and the Pearl Farm are private properties where tourist activities are carried out within defined areas. In contrast, places such as the inclusive beach, the SCSM sign, Estero El Soldado, the Mirador, and the Delfinario are managed by public organizations. As for public spaces such as the cliff/sundial, Isla San Pedro Nolasco, the Sawari trail, and the Aquarium, it was noted that private companies provide services at these locations. The indicators evaluated in the inventory include: promotion, service providers, infrastructure, guides, appeal, and accessibility.

Ecotourism resources in SCSM add value and provide an additional attraction for those visiting the bay. These elements are crucial in encouraging tourists to extend their stay or return multiple times, as they enhance the variety of experiences available in the area. Additionally, they help disperse the

influx of visitors, preventing overcrowding in any one location and encouraging the exploration of different points throughout the area, which in turn improves local tourism management.

4.3 Structure of the Ecotourism Value Chain in SCSM.

Following the proposals of Alvarado et al. (2017) and Oddone and Alarcón (2017a), the fundamental components of the ecotourism value chain include accommodation, marketing strategies, ecotourism guides and operators, transportation, food and beverage services, and tourists.

In the context of SCSM, each of these elements has its own characteristics, which are described below:

Ecotourism Guides and Entrepreneurs

According to the interviews, most ecotourism businesses (Table 3) are identified as family-owned businesses, such as Gary Shop, Enrike's Adventures, and Rancho Nuevo, oras micro-businesses, including Rancho del Desierto, Playa Libre, Playa Cobro, El Mar Diving Center, Cañón de Nacapule, and Beach Club Marinaterra. Only two, the Delfinario and Estero El Soldado, are managed by the Commission

Table 2. Identification and Characterization of Ecotourism Attractions in SCSM

At	traction	Accessibility	Infrastructure	Service Providers	Guides	Promotion
Granja de Perlas		Yes	Yes	Perlas del Mar de Cortez In situ		Yes
Estero el Soldado		Yes	Yes	Cedes	In situ	No
Playa	a Inclusiva	Yes	Abandoned	Ayuntamiento de Guaymas	No	No
N	Mirador	Yes	Yes	Ayuntamiento y Gobierno del Estado	No	No
Playa los Algodones	Playa libre	Yes	Yes	Playa libre	No	No
	Playa cobro	Yes	Yes	Playa cobro	No	No
	Playa Paradiso	Yes	No	Caseta de cobro	No	No
Playa S	San Francisco	Yes	No	No	No	No
Cerro	o Tetakawi	Yes	No	No	Privados	No
Cañón de Nacapule		Yes	Bathrooms, lack of maintenance	Cañón de Nacapule	Privados	No
Delfinario		Yes	Yes	Cedes	In situ	No
Isla San Pedro Nolasco		Yacht or boat.	No	No No		No
El Acuario		Yacht, boat, or walk	No	No No		No
Rancho Nuevo		Yes	Well-defined roads and trails	Rancho Nuevo	On-site and private	No
Sendero Sawari		Yes	No	Hotel Sawari	In situ	No
Acantilado, Reloj Solar		Privatized access by houses	No	No	Private	No
Rancho del desierto		Yes	Yes	Rancho del desierto In s		No
Letrero "San Carlos"		Yes	No	Ayuntamiento de Guaymas	No	No

Source: Own elaboration based on field information.



for Ecology and Sustainable Development (CEDES). These businesses operate independently, without being part of cooperatives, associations, or clusters. Fundings for these businesses comes from private and local sources. Regarding employment, it is estimated that approximately 162 jobs are generated by this sector. Interviewees mentioned that they are not aware of any policies that promote ecotourism.

According to the directory of tour guides, there are currently nine certified guides in SCSM. During the fieldwork, three additional individuals were identified working as ecotourism guides. Although all of them claimed to be certified, some mentioned that their certification was not up to date. Regarding the owners of ecotourism businesses, it was observed that most of them, except for Cañón de Nacapule, also take on the role of guides for the activities they offer.

Visitors

According to data from the Convention and Visitors Office (OCV), the Guaymas-San Carlos region recorded a significant tourist flow in 2023, attracting over 600,000 visitors. This accounted for approximately 11% of the total number of tourists who visited the state of Sonora, positioning SCSM as one of the state's most prominent tourist destinations, surpassed by Puerto Peñasco and Hermosillo (Meganoticias, 2023; OCV, 2023).

Based on the results obtained from the surveys and fieldwork observations, it can be concluded that ecotourism in the area, although still in its early stages, has experienced consistent and notable growth. The majority of ecotourists are day-trippers or weekend travelers who prefer to travel in groups, either with friends or family, with no significant gender differences observed. This group is mostly composed of young adults, aged between 15 and 64, with 51% falling in the 28-42 age range, and an average age of 31. The demographic is highly educated, with income levels ranging from medium to high.

The average spending of ecotourists in SCSM amounts to \$7,614 pesos. An analysis conducted using cluster segmentation techniques revealed three main segments: 23% of ecotourists spend approximately \$10,106; 38% allocate around \$6,037 pesos; and 39% spend about \$1,492 pesos. Common interests among these tourists include a connection with nature, an appreciation of local culture, gastronomy, and interaction with local communities. These preferences highlight their desire for a comprehensive and authentic experience at the destination.

Commercialization

The selection of a tourist site or activity depends on various factors, both internal and external. Internal factors include personal tastes and preferences, while external factors encompass the available information (Pérez and Echarri, 2021). In terms of the latter it was found that:

Table 3. SCSM: Ecotourism Service Providers

	Tipo de empresa				
Atractivo	Por tamaño	Cooperativa, asociación o clúster	Origen de capital	Empleos	Conocen políticas de fomento
Rancho Nuevo	Family-owned	No	Private	5	No
Rancho del Desierto	Micro	No	Private	3	No
Playa los Algodones	Free beach	No	None	Private	2
Playa los Algodones	Pay beach	No	None	Private	10
Marina San Carlos	Pyme	No	Private	120	No
Granja de Perlas	Pyme	No	Private	Sd	No
Gary Shop	Family	No	Private	3	No
Estero el Soldado	Micro	No	Governmental	4	No
Enríke's Adventures	Family	No	Private	2	No
El Mar Diving Center	Micro	No	Private	2	No
Delfinario	Governmental	No	Governmental	Sd	No
Cañón de Nacapule	Micro	No	Private	10	No
Beach Club Marinaterra	Micro	No	Private	1	No

Note: 'Sd' indicates that no specific information is available for this category.

Source: Own elaboration. Data collected through semi-structured interviews and direct field observation during the study conducted in SCSM.



- Ecotourists in SCSM usually organize their itinerary primarily based on recommendations from acquaintances. Most visitors arrive at the activities independently, using their private vehicles, and in less frequent cases, they hire the services of a guide.
- Despite the high interest and preparation of the guides, their operational reach is limited, as, like many of the tourist attractions in the area, their existence is not well known. Nearly 50% of the interviewees, both tourists and locals, stated that they are unaware or do not know how to contact a guide.
- No travel circuits/packages were found that integrate activities, hotels, restaurants, souvenirs, etc., or even a promotional alliance between these elements. According to Parillo (2022), the tourist package is more commercial, secure, and complete. It also helps in the revaluation of the territory, facilitates promotion, and is more practical for tourists in terms of planning time.
- Although the significant role of travel agencies and their influence on decision-making is well known (Cortés, Cañas, & Sarmiento, 2019), the role of intermediaries in SCSM, Sonora, is nonexistent.

In the words of an interviewee:

In this place, we don't have a single point where visitors can come to ask for information, so that anyone, regardless of their situation, can receive at least the basics... like what's going on with the area, how it's doing, and how far someone who struggles to move or has trouble seeing or hearing can go. (Ignacio, 59 years)

There is a Convention and Visitors Office; however, its location is not very visible, which hinders its ability to interact with the diverse range of tourism stakeholders. According to statements made in interviews, its reach is limited to distributing brochures to those who arrive directly at the office, as its main focus seems to be on promoting overnight stays in hotels.

Transportation

One of the main difficulties identified is the area's poor connectivity. There is no adequate transportation system to access the area or to move

around within it. Public transportation is not useful for tourists, and taxi service is limited. In reality, the only viable option for visitors is the use of private vehicles. As one interviewee mentioned:

- You arrive wanting to go to Nacapule... and there's no way to get there! It's that simple! There should at least be a bus that runs from Guaymas to San Carlos regularly, let's say every hour; and then, from San Carlos, there should be direct transportation to the canyon. That's where we lack a key connection.

 (Ignacio, 59 años)
- There are no buses, no taxis, no Uber, I mean, we don't have the basics for people to get to the destination. That's how the value chain is cut off, for both sun-and-beach tourism and those coming for ecotourism. (Estaban, 41 años)

Accommodation

According to the National Institute of Statistics and Geography (INEGI, 2020b), 12 accommodation establishments are identified in San Carlos (see Figure 2). Notably, some hotels are not listed in the registry, such as Hotel Sawari, which opened in 2019, and Hotel Gringo Pete, whose opening date is undocumented, though it is known to have been in operation for at least 20 years. It is also notable that the INEGI map does not include the Algodones area, where other important hotels and condominiums, such as Plaza San Carlos and Condominios Playa Blanca, among others, are located.

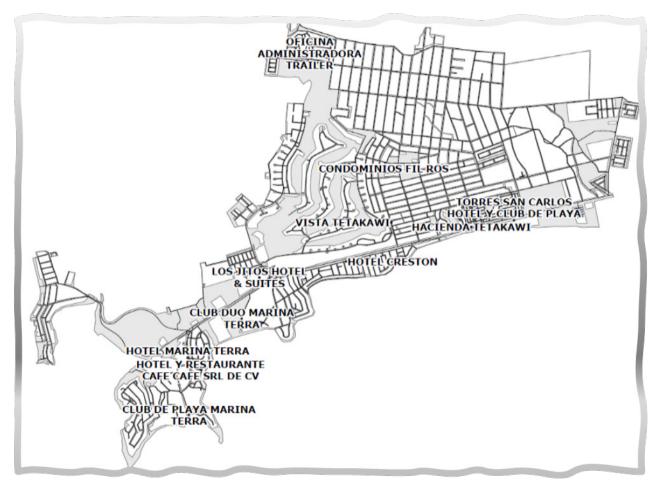
Two RV parks, five condominiums/apartments, six hotels, and residential homes for rent were observed, with the latter sector being the fastest growing. Of all the accommodations, only one, Hotel Sawari, offers a package combining the stay with an ecotourism tour. It is important to note that this hotel is also the only one belonging to an international chain, while the others are local or regional initiatives.

Gastronomic Services

According to data provided by the National Institute



Figure 2. SCSM (Urban Area). Accommodation



Source: Digital Map of Mexico, Cartographic Package 2020, INEGI.

of Statistics and Geography (INEGI, 2020b), there are 45 restaurants operating in the area (see Figure 3). Most of these are small local businesses that specialize in offering regional dishes. Only one of these restaurants has been incorporated into a larger chain, although it has maintained the authenticity of its menu, as well as in the hiring of employees and selection of suppliers.

In the surveys conducted, local restaurants were positively rated, receiving "good" ratings for both product quality and hygiene standards (see Figure 4).

Similar to other sectors, as part of the research, we explored whether there were connections between the restaurant industry and ecotourism activities. However, no links were identified between local restaurants and businesses or guides dedicated to ecotourism, which was found to be unsatisfactory.

4.4 Mapping of the Chain

I n summary, the ecotourism value chain (VC) in SCSM is considerably fragmented. Although the different links coexist in the area, no significant connections between them were identified. Ecotourism entrepreneurs show no interaction with other key sectors, such as restaurants, marketing, transportation, or accommodation. Only one case was identified where a guide was linked to a hotel to offer a package that included both the tour and accommodation. As one interviewee expressed:

The truth is that the ecotourism value chain doesn't even show up! It simply doesn't exist! CEDES, which leads the protected areas in San Carlos, has been working with the ejidatarios and the local people, but they do it without much structure, nothing that resembles a cluster. They provide support with training and everything, but they haven't managed to get them to come together in an organized way.

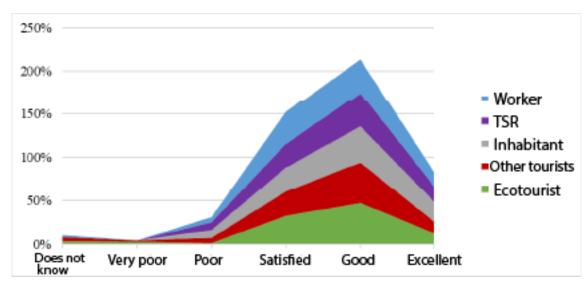


Figure 3. SCSM (Urban Area). Food Services



Source: Digital Map of Mexico, Cartographic Package 2020, INEGI.

Figure 4. Frequency Chart "Quality and Hygiene in Restaurants and Bars"



Source: Own elaboration based on field information.

And to top it off, the tourism office hasn't even gotten involved to help organize something properly. (Ignacio, 59 años)

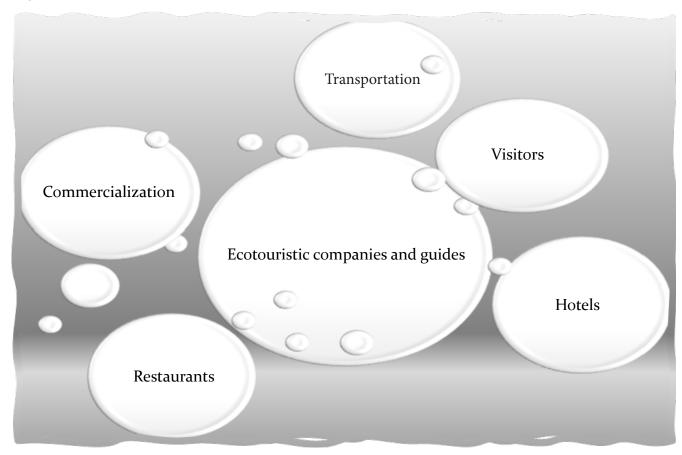
The analysis of the ecotourism value chain (VC) in SCSM reveals a fragmented and poorly cohesive structure. Although various components coexist in the region, such as guides, accommodations,

and gastronomic services, their lack of connection limits the sustainable development of ecotourism. The absence of interaction between ecotourism entrepreneurs and key sectors, such as restaurants and transportation, prevents the creation of synergies that could strengthen the tourism offering. Additionally, the lack of integrated tourist packages and the limited visibility of the



Convention and Visitors Bureau contribute to the market fragmentation. Overall, this lack of integration and collaboration highlights the urgent need to better structure the value chain to maximize the ecotourism potential in the region.

Figure 5. Value Chain for Ecotourism in SCSM. Without connections.



Source: Own elaboration based on field information

5. Conclusions

The tourism value chain is a crucial tool for analyzing and implementing the complex relationships among the multiple actors and activities that shape the tourism industry. Strengthening these connections enhances destinations by maximizing economic and cultural potential through collaboration and integrative, sustainable strategies. From planning to post-experience follow-up strategies, each link plays a key role in generating value and fostering visitor loyalty.

SCSM is one of Sonora's most significant tourist destinations, distinguished by its unique desert biodiversity and proximity to the "aquarium of the world," the Sea of Cortez. This study identifies

key aspects that could support the sustainable development of ecotourism in the region.

The diversity of attractions offers a rich and varied experience for visitors. Guides and tourism companies hold appropriate certifications, provide high-quality tours, and receive positive ratings from tourists. Visitors align with the classic ecotourist profile: they are day-trippers or group travelers, young adults with an average age of 31, highly educated, and earning medium to high incomes. They show strong interest in exploring and connecting with nature, culture, people, and cuisine. Despite these strengths, marketing efforts remain uncoordinated, limiting visitor reach. Local



and regional initiatives lack strategic partnerships that could enhance the promotion of the destination and improve its competitive positioning nationally and internationally. Additionally, transportation is a critical challenge. Public transportation and taxi services are scarce, restricting access to attractions, particularly for air travelers drawn by wedding tourism.

However, the lack of integration among the parties is evident, and it prevents the exploitation of synergies and economies of scale that could benefit all the stakeholders involved. The development of clusters or associations that promote collaboration is necessary.

In practical terms, this study provides a foundation for designing strategies to strengthen the ecotourism value chain. Key recommendations include developing strategic alliances between sectors and improving transportation infrastructure. In addition, training and organizational programs for local skateholders would support collaborative and sustainable management.

This research contributes to the conceptual framework of value chains in sustainable tourism by examining the dynamics of integration and disconnection in an emerging destination. Additionally, it provides a replicable analytical model that can be applied to other regions with similar characteristics, offering a broader framework for ecotourism development.

In summary, SCSM has considerable potential as an ecotourism destination. However, its future development depends on stakeholders' ability to collaborate, address existing challenges, and integrate the value chain.

As future lines of research, further studies should examine successful ecotourism destinations that have effectively integrated their value chains, identifying strategies applicable to SCSM.

Research should also explore cluster and association models that promote collaboration among the different links in the value chain, assessing their impact on ecotourism development. It is also recommended to conduct studies that analyze the economic impact of ecotourism on local communities, focusing on job creation and generated income, to support the development of public policies.

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RESEARCH

Low and declining wages in the automotive industry in Mexico. An analysis by state and branch of activity, 2003-2018

Salarios bajos y a la baja en la industria automotriz en México. Un análisis por entidad federativa y ramas de actividad, 2003-2018

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Abstract

The performance of real wages in the manufacturing of transportation equipment and at the branch levels of activities 3361, 3362, and 3363, which make up the automotive industry, is analyzed, focusing primarily on 17 federal entities where it is located. Real wages were determined using the wages of production, sales, and service personnel, as well as the hours worked by these groups. The results for the 2003-2018 period indicate that, in most federal entities, wages in the automotive industry have stagnated or decreased. The manufacturing of bodies, trailers, and auto parts shows the greatest lag. This trend of low and declining wages depends on the location of the plants and the years they have been established in the country and is influenced by factors such as labor productivity and the labor market structure of the sector.

Key words: Real wages, automotive Industry, Mexico, branch of activity, fixed effects.

JEL Codes: C33, J3, L2, L62

Resumen

Se analiza el desempeño de los salarios reales de la fabricación de equipo de transporte y a nivel ramas de actividad 3361, 3362 y 3363 que conforman la industria automotriz, principalmente en 17 entidades federativas donde se localiza. Con los salarios al personal de producción, ventas y servicios, y las horas trabajadas por personal de producción, ventas y servicios se determinaron los salarios reales. Los resultados para el periodo 2003-2018 señalan que, en la mayoría de las entidades federativas, los salarios de la industria automotriz están estancados o han disminuido; la fabricación de carrocerías y remolques, y de autopartes, son las que presentan el mayor rezago. Esta tendencia de los salarios, bajos y a la baja, dependen de la localización de las plantas, de los años en que se han instalado en el país, y de factores como la productividad laboral y la estructura del mercado de trabajo del sector.

Palabras clave: salarios reales, industria automotriz, México, ramas de actividad, efectos fijos.

Códigos JEL: C33, J3, L2, L62





Introduction

The automotive industry has been a key pillar of the Mexican economy in recent decades. Mexico accounts for 3.9% of global vehicle production, ranking seventh worldwide and first in Latin America. In terms of exports, the country ranks fourth in the export of light vehicles and auto parts and is the leading supplier of auto parts to the United States (Organisation Internationale des Constructeurs d'Automobiles [OICA], 2024; AMIA, 2024).

This industry contributes 3.6% to the national gross domestic product (GDP) and 18.0% to the manufacturing GDP. It employs more than 979,000 workers, representing 22.0% of total manufacturing employment, 102,538 of whom work in the terminal industry, while 876,697 are employed in the auto parts, bodywork, and trailer sectors. Additionally, the automotive industry is the country's primary source of foreign currency generation through foreign direct investment (FDI), attracting about 20.0% annually (AMIA, 2024). These figures highlight the significant role of the automotive industry in Mexico's economic activity. However, despite being considered a mature industry, it continues to face several challenges, one of the most notable being the persistent stagnation in wage growth for its workers.

The wage stagnation in Mexico's automotive industry has been analyzed from various perspectives and fields. On a global scale, and within the context of the NAFTA/USMCA region, studies by Linares (2018: 377) and Rodríguez and Sánchez (2017: 1) highlight a significant wage disparity between the countries that were part of NAFTA, as well as among 13 other countries. Their findings indicate that Mexico ranks last in this comparison, with an average of \$8.1 per hour (Linares, 2018: 377). Similarly, Tapia and Chiatchoua (2020: 85) compare wages across different positions in the automotive industry and consistently find that Mexico offers the lowest wages among the examined countries.

Through interviews with automotive workers, the studies by Covarrubias (2019: 92) and García-Jiménez, Carrillo, and Bensusán (2021) provide significant insights. The latter includes an estimation of a living wage within the automotive industry across various manufacturing plants in Mexico. In addition, a review of collective labor agreements in final assembly and first-tier companies highlights the contributions of Covarrubias (2014: 26), Covarrubias and Bouzas (2016: 7), García

(2023: 199), García-Jiménez, Carrillo, and Bensusán (2022), and Sánchez-González (2023: 220). Notably, García-Jiménez et al. (2022), apply the methodology of Anker and Anker (2017) to calculate the living wage for automotive companies located in different regions of Mexico and the wage gaps. Their findings indicate an increase in labor precarization between 2017 and 2019, due to a widening gap between the living wage and the wages paid in the analyzed companies. To mitigate this issue, they recommend that wage increases should be adjusted based on region, company, and seniority. They argue that wages should correspond to the cost of living in each metropolitan area where assembly companies are located. Furthermore, depending on the companies and their seniority, wage increases should be more significant in greenfield regions (San Luis Potosí, Hermosillo, and Aguascalientes) than in brownfield areas (Toluca and Puebla).

Sánchez-González (2023), using the Kruskal-Wallis and Dunn-Bonferroni tests, examines wage disparities among unionized workers in 20 automotive assembly companies in Mexico. His findings suggest that the establishment phase of a company, along with its geographical location, influences whether annual integrated wages are relatively high or low. He observes that wages tend to decline after the third stage of establishment. Additionally, he finds that wages are generally higher in the central and northern regions, while lower wages are observed in the western and central-northern regions. European companies had high wages, while those of Asian origin had low wages. Moreover, he identifies that companies with unions affiliated with the Federation of Trade Unions of Goods and Services Companies (Fesebs) pay better wages, while those affiliated with the National Federation of Independent Unions (FNSI) pay lower wages.

One of the key contributions to this study is the level of disaggregation by industry and federal entity, as well as the analysis based on a panel data model which aims to analyze the wage growth in the subsector of transportation equipment manufacturing, the branches of vehicle and truck manufacturing, bodywork and trailers, and auto parts manufacturing, at the national level and across the 17 federal entities where the automotive industry is primarily located. Additionally, it compares wages in the Mexican automotive sector with those in the United States and estimates a wage function with fixed effects. The variables used for the wage calculation are the total wages for production, sales, and service personnel along with the total hours



worked by production, sales, and service personnel, using census data from 2003, 2008, 2013, and 2018.

The paper is structured into four sections, in addition to the introduction and conclusions. The first section provides a literature review on the topic. The second outlines the methodology and variables used in the analysis. The third presents the main findings of the exploratory analysis, followed by an estimation of a real wage function using a fixed-effects panel data model.

1. Literature Review

Empirical evidence confirms the relationship between productivity and wages (Bino, 2014: 98; González et al., 2022: 29; Galtés, 20215: 108; Katovich and Maia, 2018: 7; Klein, 2012: 20; Korkmaz, 2021: 42; López-Villavicencio and Silva, 2011: 216; Medina, 2018: 78-80). However, research also highlights the weak or nonexistent wage increases despite productivity gains, as well as other factors influencing wage determination. These include public policies aimed at wage containment to control inflation (González et al., 2022: 29; Katovich and Maia, 2018: 7; Klein, 2012: 20; López-Villavicencio and Silva, 2011: 216), inefficient incentive systems (Galtés, 20215: 108), outdated labor legislation, and the absence of human capital training plans within companies (Bino, 2014: 98). Additionally, the inability of industrial sector companies to repay bank loans (Korkmaz, 2021: 42), weak worker bargaining power (Biesebroeck, 2011: 1342-1343; Biesebroeck, 2015: 30-31), and protection contracts that favor employers over workers (Covarrubias, 2019; García-Jiménez, Carrillo and Bensusán, 2021: 12-13; Linares, 2018: 378; Rubio, 2017: 56) further contribute to wage stagnation.

Moreover, low wages have been documented as a key determinant of company location, including within the automotive sector. For instance, Audi and Mercedes Benz established operations in Hungary in 1993 and 2012, respectively, with different wage levels corresponding to their locations in brownfield and greenfield areas (Arendas, 2016: 5). Similarly, some U.S. companies located in China have begun relocating back to the United States due to rising wages (Dolega, 2012: 10). Other companies actively seek regions with inexpensive, labor-intensive workforces for relocation (Bailey and De Propris, 2014: 392; Sánchez-González, 2023); while some

aim to weaken trade unions to secure cheaper labor without involvement (Arendas, 2016: 20). In Central and Eastern Europe, deregulated labor market environments have been conducive to achieving quality standards and skilled labor with low wages and precarious employment (Jürgens and Krzywdzinski, 2009: 486).

Mexico has been no exception in this regard; the country remains highly attractive for the establishment of automobile manufacturing plants, largely due to its low production cost associated with comparatively lower wages than those in the United States and Canada, both members of the USMCA. By the end of 2023, hourly wages were approximately \$21 in Canada, \$28 in the United States, and \$4.80 in Mexico⁴ (U.S. Bureau of Labor Statistics, 2024; Statistique Canada, 2024; INEGI, 2024).

Empirical evidence not only confirms that wages are significantly lower than in other USMCA countries but also indicates a persistent wage growth lag. Swiecki and Menk (2016: 46) demonstrate that one of the primary advantages of investing in Mexico over the United States is lower labor costs, which declined by 5.0% between 2008 and 2013, compared to a 10.0% increase in the United States during the same period. Additionally, total wages and benefits in Mexico were 25.0% lower than those estimated in the United States, generating cost savings of \$600-\$700 per vehicle (Covarrubias and Bouzas, 2016; Swiecki and Menk, 2016: 47).

Despite the industry's productivity and employment expansion, wages for automotive workers in Mexico have continued to decline. In 1994, a U.S. worker in the terminal industry earned \$35.91 per hour, a Canadian worker earned \$34.09, while a Mexican worker earned just \$6.65. By 2016, this wage gap persisted, with Mexican automotive workers earning only \$3.14 per hour, compared to \$28.60 in the United States and \$26.34 in Canada (Rodríguez and Sánchez, 2017: 3). In 2015, Mexican automotive wages were the lowest among the following countries: Norway, paid 8.5 times Mexico's wage, Germany 7.8 times, France 6.5 times, the United Kingdom 5.1 times, Spain 4.7 times, Japan 3.9 times, Argentina 2.3 times, Brazil 2.1 times, China 1.3 times, and Taiwan 1.2 times (Linares, 2018: 337).

⁴ This salary from the Mexican Automotive Industry was recovered from the Economic Information Bank of INEGI (2024).

Although Mexico's automotive industry has significantly contributed to GDP and manufacturing employment, wage growth has not kept pace. Tapia and Chiatchoua (2020: 94-95) show that from 2007 to 2017, wages in vehicle and truck manufacturing increased from 19,175 to 23,842 pesos per month. However, these figures represent total personnel compensation, including managerial salaries, which does not align with the broader literature on wage stagnation. The authors further argue that wage increases during this period merely compensated for inflation, resulting in no real improvements. They also compare salaries for specific positions in the automotive industry across Germany, Brazil, Canada, China, the United States, Japan, the United Kingdom, and Mexico in 2020. In this comparison, Mexico ranked last: a Mexican automotive electrician earned a monthly salary of 710.28 dollars, while their Chinese and Brazilian counterparts earned 2,100.90 and 1,533.42, respectively. Similarly, a Mexican automotive mechanic earned 753.32 dollars per month, significantly less than their Brazilian counterpart, who earned \$1,530.51, the second-lowest wage among the countries studied.

A review of the collective bargaining agreements for BMW in San Luis Potosí from 2014, 2016, 2018, and 2020 revealed a gradual increase in wages over time. In 2014, a worker in the lowest category earned 135 pesos per day (equivalent to 7.50 per day, based on an exchange rate of 18.10 pesos per dollar as of July 5, 2024). Given that the company had just begun operations in preparations for mass production, it is likely that all workers received this base wage. By 2016, this amount had increased to 142 pesos (7.8 dollars), and in 2018, when mass production began, it rose to 205 pesos (11.3 dollars). By 2020, the daily wage had reached 292 pesos (16.1 dollars/day) (Secretariat of Labor and Social Welfare [STPS], 2020). Although wages at BMW more than doubled over six years, they remained below the average for the Mexican automotive industry in 2020.

Studies by Covarrubias (2019: 99) and Covarrubias and Bouzas (2016: 8), which analyzed the collective bargaining agreements of 18 companies, indicate that in 2016, a Mexican automotive worker earned an average of 2.30 per hour, while their U.S. counterpart earned 26.5 dollars. When comparing these wages to those paid by BMW in San Luis Potosí in 2018, it becomes evident that a Mexican worker earned in an entire day less than a U.S. worker earned in a single

hour. These findings provide strong evidence of the wage advantages that make Mexico attractive for the automotive industry, which has driven the sector's expansion at the expense of workers' well-being.

Wages and rules of origin have been central topics in both NAFTA and its renegotiation under the USMCA. The latter includes a chapter aimed at improving labor security by reducing the wage gap within the industry across the three countries. In this context, Gómez Tovar and Ruiz Nápoles (2021) argue that the USMCA's wage provisions benefit Mexico, as they shift the focus from merely exploiting cheap labor to achieving wage parity within the industry.

However, Covarrubias (2021) contends that the new trade agreement sought to curb job losses and prevent capital flight due to Mexico's low wages by introducing monitoring mechanisms unprecedented in U.S trade agreements. The expectation was that these measures would lead to higher net profits in the U.S. automotive industry. Nonetheless, he points out that the labor provisions alone are insufficient to alter industrial location trends, given the significant wage gap that still exists between Mexico and the United States-Canada.

On another note, González Andrade (2024) highlights nearshoring as a strategic opportunity for Mexico's automotive sector. However, he emphasizes that for Mexico to fully capitalize on this trend, the government must implement a comprehensive strategy that includes investments in productive infrastructure — such as roads, ports, airports, and railways — along with trade facilitation measures, including customs modernization and logistics centers. Additionally, ensuring the availability of critical resources like water and electricity will be essential.

García Moreno et al. (2023) cautions that wage prospects in the sector remain uncertain, as the highest wages are concentrated in activities that generate the most added value. Therefore, an industrial policy is needed to prioritize research, development, and design activities, while also promoting a gradual recovery of wages.

2. Methodology

To analyze wage performance in the automotive industry, real average hourly wage indices for workers and production technicians from the 21



subsectors of national manufacturing, as published by INEGI, were first examined. A simple average was calculated for the 12 months of the years 2008, 2013, and 2018, both for the indices and growth rates. For the analysis of the wage trends in transportation equipment⁵ manufacturing subsector, specifically in motor vehicle and truck manufacturing (3361), body and trailer manufacturing (3362), and parts manufacturing for motor vehicles (3363) — which together constitute the automotive industry wages for production, sales, and service personnel were considered. These wages were deflated using the corresponding GDP6 deflator for the census years 2003, 2008, 2013, and 2018 to obtain real wages based on 2018 values. The wages were then divided by the total hours worked by production, sales, and service personnel to calculate wages in pesos per hour worked.

Seventeen federal entities with the highest concentration of automotive industry activity were included in the study: Aguascalientes, Baja California, Chihuahua, Coahuila, Estado de México, Guanajuato, Hidalgo, Jalisco, Morelos, Nuevo León, Puebla, Querétaro, San Luis Potosí, Sonora, Tamaulipas, Tlaxcala, and Veracruz.

The average growth rates presented in the body of the document correspond to 2018 in relation to 2003, with wages provided for the four census years. In the analysis of body and trailer manufacturing, Morelos and Sonora were excluded due to a lack of data on the variables necessary to calculate wages in pesos per hour. For parts manufacturing, data for Hidalgo was unavailable for 2013, and Morelos lacked data for 2008; however, they were included in the study, as their growth rate remained unaffected. Since INEGI does not publish wage data at the federal entity level for vehicle and truck manufacturing, the analysis for this branch was conducted through a review of collective labor contracts. The most recent contracts, signed in 2020 and published by STPS (2020), were examined. To compare the branches with those in the U.S. automotive industry, an exchange rate of 18.09 pesos per dollar, based on the rate from July 5, 2024, was used (Official Gazette [DOF], 2024).

Finally, a wage function (expressed in pesos per hour) for the Transportation Equipment Manufacturing subsector was estimated using panel data with fixed effects to serve as an indicator of wage behavior in the automotive sector. The detailed specification of this model is presented in Section 4.

3. Wages in Manufacturing and Transportation equipment manufacturing

Within Mexico's manufacturing sector, the automotive industry is one of the most significant due to its substantial contribution to manufacturing output, its generation of gross census value-added, the significant amounts of foreign direct investment it attracts annually, and the direct and indirect jobs it generates. However, despite its economic importance, wages in the sector remain significantly lower compared to other manufacturing subsectors that have a smaller impact on these key indicators.

Nationally, the highest-paying manufacturing subsector is petroleum and coal products, with a total of 189 pesos or 10.4 dollars per hour. In contrast, the transportation equipment manufacturing subsector ranks sixth, with an average of 54 pesos (3.0 dollars) per hour. Despite this, in four states—Hidalgo, Guanajuato, Tamaulipas, and Nuevo León—the automotive industry offers the highest wages within the manufacturing sector, ranging from 46 to 59 pesos per hour (2.5 to 3.3 dollars per hour) (see Table 1).

The states with the highest hourly wages in the automotive industry are Morelos, at 126 pesos (7.0 dollars); Puebla, at 95 pesos (5.2 dollars); Aguascalientes, at 82 pesos (4.5 dollars); and Estado de Mexico, where wages average 69 pesos (3.8 dollars) per hour (see Table 1).

Entities such as Coahuila, Sonora, San Luis Potosí, and Chihuahua stand out for the significant role the automotive industry plays within their economic activity. However, the wages it offers are lower than those in other subsectors. For instance, in Coahuila, transportation equipment manufacturing ranks eighth in terms of wages, paying workers 48 pesos or 2.7 dollars per hour, while basic metal industries, which rank first, pay 88 pesos or 4.9 dollars per hour. In Sonora, the

⁵ In addition to the mentioned sectors, the manufacturing of transportation equipment also includes the production of maritime, aerospace, and railway equipment, according to the SCIAN classification.

⁶ Recovered from the World Bank's World Development Indicators (2024).



automotive industry pays 46 pesos or 2.6 dollars per hour, whereas the plastics and rubber industry pay 65 pesos or 3.6 dollars per hour.

The case of Guanajuato and Jalisco is noteworthy as both have recently experienced significant growth in the automotive industry. However, these states also have some of the lowest wages in the automotive sector nationwide (see Table 1).

Additionally, the indices of real average wages per hour worked by production workers and technicians in the national manufacturing subsectors for 2008, 2013, and 2018 show that, despite the global financial crisis of 2008-2009, real wages grew in two-thirds of the subsectors, including transportation equipment manufacturing, which saw a 2.6% increase in 2008. By 2013, wages increased in 10 subsectors and decreased in 11, with transportation equipment manufacturing experiencing a significant decline,

showing a negative growth rate of -21.3%. By 2018, however, this subsector rebounded with a 3.7% growth (see Figure 1).

3.1. Wages in Transportation Equipment Manufacturing, 2003-2018

The real wages per hour worked in this subsector across the 17 federal entities where the automotive industry is mainly located are generally lower than the national averages (see Figure 2). For instance, in Morelos, wages were 151 pesos per hour in 2003 and rose to 168 pesos by 2018, marking the highest wage during the entire study period with an increase of 11.7%. In Puebla, wages declined by almost -9.0%; however, it still had the second-highest wage in 2018. Other states where wages increased from 2003 to 2018 include Coahuila (18.8%), Guanajuato (11.9%), Hidalgo (5.7%), Nuevo León (20.4%), San Luis Potosí (22.3%), Sonora (31.5%), Tamaulipas

Table 1. Real Average Wages of the National Manufacturing Subsectors and by Federal Entity, 2003, 2008, 2013, and 2018.

STATE	First Place	Sala	ary	Location and Transportation	Salary	
SIAIL	1 list 1 lacc	Pesos/ hr	Dollars/hr	Equipment	Pesos/hr	Dollars/hr
Hidalgo	Petroleum and coal products	189	10.4	4	59	3.3
Guanajuato	Petroleum and coal products	179	9.9	4	47	2.6
Tamaulipas	Petroleum and coal products	178	9.8	8	46	2.5
National	Petroleum and coal products	160	8.8	6	54	3.0
Nuevo León	Petroleum and coal products	152	8.4	7	52	2.9
Veracruz	Chemical industry	151	8.3	4	53	2.9
CDMX	Petroleum and coal products	148	8.2	5	52	2.9
Morelos	Transportation equipment	126	7.0	1	-	-
Baja California	Petroleum and coal products	104	5.7	2	61	3.4
Puebla	Transportation equipment	95	5.2	1	-	-
Querétaro	Petroleum and coal products	91	5.0	3	60	3.3
Coahuila	Basic metals	88	4.9	8	48	2.7
Chihuahua	Chemical industry	84	4.6	5	52	2.9
Aguascalientes	Transportation equipment	82	4.5	1	-	-
Jalisco	Petroleum and coal products	76	4.2	7	47	2.6
Edomex	Transportation equipment	69	3.8	1	-	-
Sonora	Plastics and rubber	65	3.6	8	46	2.5
San Luis Potosí	Machinery and equipment	61	3.4	6	44	2.4

Note: The exchange rate as of July 5, 2024, was 18.09 pesos per dollar.

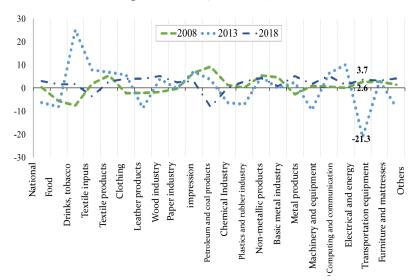
Source: Information from the Economic Censuses of INEGI (2024).

(4.0%), Tlaxcala (9.2%), and Veracruz (97.5%). On the other hand, states where wages decreased from 2003 to 2018 include Aguascalientes (-11.5%), Baja California (-4.4%), Chihuahua (-12.7%), Estado de Mexico (-16.6%), Jalisco (-18.5%), and Querétaro (-2.1%). Nationally, the transportation equipment subsector saw a decrease in wages from 54 to 52 pesos per hour worked, representing a -2.7% decline from 2003 to 2018.

In the study by García-Jiménez, Carrillo, and Bensusán (2021: 230), Aguascalientes is classified as having high wage precariousness. However, this does not align with the findings of this article, as Aguascalientes paid the highest real wages during the study period. The study agrees with the assertion that Puebla exhibits no wage precariousness, as it ranks second in terms of wages during the study period, surpassing even Estado de Mexico, which



Figure 1. Mexico: Index of Real Average Wages per hour worked by Production Workers and Technicians by National Manufacturing Subsector, 2008, 2013, and 2018 (2018 base).

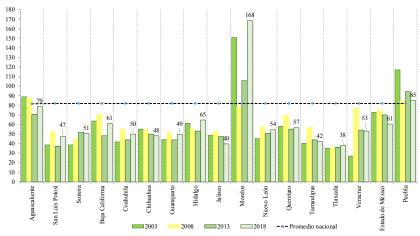


Source: Elaborated with information from the Economic Census of INEGI (2024).

also classified as having no wage precariousness. For San Luis Potosí, the result mirrors that presented by the authors, as it is one of the entities with the highest wage precariousness among the 17 studied. According to the study by Sánchez-González (2023: 228-229), companies that were established between 1962 and 1978 and located in the central part of the country (Estado de Mexico, Puebla, Morelos, and Hidalgo) have, on average, the highest wages. This observation aligns with the current study, which shows that Morelos (with an average of 126

pesos per hour) pays the highest wages, followed by Puebla (95 pesos), Aguascalientes (82 pesos), Estado de Mexico (69 pesos per hour), and Hidalgo (59 pesos). The central-northern region, which includes San Luis Potosí and Guanajuato, is found to have the lowest wages, with averages of 44 and 47 pesos per hour from 2003 to 2018, respectively. These wage differences are tied to the first companies established in states with institutional rigidities, known as brownfields (central region), compared to Greenfields in northern states (Chihuahua, Sonora, Coahuila, Baja California, and Nuevo León)

Figure 2. México: Real wages per hour in Transportation Equipment Manufacturing in the Federal Entities where the Automotive Industry is located, 2003, 2008, 2013, and 2018 (Pesos per hour, 2018 base).



Source: Elaborated with information from the Economic Census of INEGI (2024)



and western-central regions (Covarrubias, 2014: 28). Due to this flexibility, wages were lower in the Greenfields, resulting in automotive plants moving to these areas in the northern zone (Arteaga, 2003; Covarrubias, 2000: 53). However, Covarrubias (2014: 27) points out that while companies with better wages tend to be located in brownfields, this is not always the case. For example, General Motors Mexico has significant wage differences across its locations: in San Luis Potosí, the lowest salary category is 164.61 pesos per day; in Ramos Arizpe, Coahuila, it is 226.82, and in Toluca, it reaches 294.51 pesos per day. Stellantis also shows consistent low wages in Coahuila and Estado de Mexico, where the lowest category wages are 309 and 308.30 pesos per day, respectively (according to the collective labor agreements published in 2020) (STPS, 2020).

3.2. Real wages in the automotive industry sectors, 2003-2018

The most significant sector within the automotive industry is the manufacturing of parts for motor vehicles. This sector generates 51.2% of the gross census value added (GCVA) in the industry, employs 88.5% of the total workforce, and accounts for 79.6% of the wages and 74.8% of the salaries to administrative personnel. The manufacturing of automobiles and trucks follows, contributing 47.0% to GCVA but employing only 8.9% of the workforce and paying 18.2% of wages and 22.2% of salaries. Finally, the manufacturing of bodies and trailers accounts for 1.8% of the GCVA generation, 2.7% of the workforce, and 2.2% of wages and 3.1% of salaries (INEGI, 2018).

When examining wage trends in the automotive industry sectors, it is observed that only six states experienced wage increased in the manufacturing of parts for motor vehicles from 2003 to 2018. For example, Coahuila and Guanajuato increased wages from 36 to 46 pesos per hour, equivalent to 30.4%; Nuevo León 9.9%, San Luis Potosí 16.4%, Sonora 30.6%, and Tamaulipas 4.8%. In contrast, the following 10 states experienced wage decreases, Aguascalientes -36.7%, Baja California -18.1%, Chihuahua -11.6%, Jalisco -15.1%, Estado de Mexico -19.6%, Puebla -20.0%, and Veracruz -19.6%. Nationally, wages for auto parts manufacturing decreased by -4.0%, from 48 to 46 pesos per hour worked. It is noteworthy that there is no available

data for Hidalgo and Morelos for the years 2018 and 2013, respectively (see Figure 3).

The manufacturing of auto parts has recently become a more significant activity, only in traditionally strong states such as Coahuila, Nuevo León, Chihuahua, and Tamaulipas but also in states that have recently entered the automotive production sector. For instance, Yucatán saw a 117% increase in auto parts production in January 2024 compared to January 2023. Zacatecas and Durango also witnessed growth rates of 31.5% and 18.8%, respectively, during the same period (González, 2024).

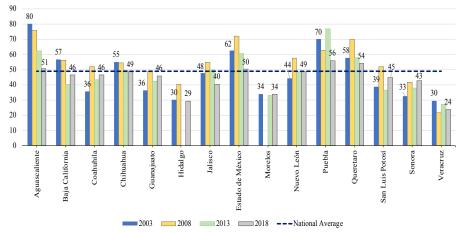
Among auto parts, the production of wiring harnesses and seat parts stands out, accounting for 32.0% of total automotive exports to the United States. According to Crossa (2024:74), these activities exhibit low levels of automation and contribute the lowest added value—1.0% of the car's value in the case of wiring harnesses. This could partially explain why the observed low wages in this sector are linked to low productivity. The limited production technology and the capital- and labor-intensive nature of these activities might be contributing factors to this wage discrepancy.

Unlike the auto parts sector, the wage performance in the vehicle and truck manufacturing sector is harder to analyze due to the lack of data from INEGI for the federal entities of interest. However, by reviewing collective labor contracts from some assembly companies, the daily base salary for the lowest and highest categories (new hires or workers with less than one year of seniority, and long-term employees) was identified (see Table 2). General Motors, located in San Luis Potosí, pays the lowest salary to new hires or employees with less than one year of seniority. The company's wages are influenced by the age of its plants—older plants tend to pay higher wages, while newer plants pay less. Similar trends are observed with Ford, Nissan, and Toyota. Unlike other companies, Stellantis (formerly Chrysler) pays a consistent wage, regardless of the location or establishment year. In contrast, Nissan in Morelos offers the highest salary in this category, surpassing other companies.

Ford, located in Hermosillo, Sonora, pays the lowest wage in the highest category, with two groups. The first one has six categories, and the highest wage within this group is 383.31 pesos per day. A worker progresses to the next group after six years, with annual promotions. In contrast, workers



Figure 3. Real Wages per hour in Auto Parts Manufacturing in the Federal Entities where the Automotive Industry is located, 2003, 2008, 2013, and 2018 (Pesos per hour, 2018 base).



Source: Elaborated with information from the Economic Census of INEGI (2024).

in the second group, at the highest category, earn 754.20 pesos per day. In contrast, Stellantis offers the highest wages, with 1,467.90 pesos per day in Coahuila and 1,411.40 pesos per day in Toluca. The difference between the highest and lowest salary in this category is 1,084 pesos, or nearly 60 dollars per day (see Table 2)

These salaries were also converted into dollars, and it can be observed that no company reaches the 144 dollars per day required by the USMCA for products to be considered regional or from the country. This means that a Mexican automotive worker earns

in one day what a U.S. worker makes in less than an hour. There are even companies that set salary increases up to three years in advance, such as Audi Puebla, which in 2019 set the salaries for 2020, 2021, and 2022 with an annual increase of 5.4%.

In the case of body and trailer manufacturing, it is observed that real wages increased in 10 states from 2003 to 2018 (see Graph 4). In Aguascalientes, wages rose from 28 to 31 pesos per hour, equivalent to 12.0%; in Baja California, 21.3%; in Hidalgo, 38.4%; in Jalisco, 13.5%; in Nuevo León, 11.3%; in Puebla, 22.1%; in Tlaxcala, 12.0%; and in Veracruz,

Table 2. México. Base Salary of Assembly Companies Located in the Federal Entities of Interest, 2020-2021

Plant State State Lowest cat egory salary (daily) H ighest cat egory salary (daily) Pesos dollars Pesos Dollars			Year of	T , ,	1 (1.11) TT		1 (1.1.)
Audi Puebla 2017 279.01 5.48 70.0 48.1 VolkswgenP uebla1 9643 15.1 17.4 1,024.85 6.6 BMWS an Luis Potosi 2019 292.01 6.15 70.0 31.5 Sonora 1986 197.91 0.93 83.3 21.2 Ford Sonora 1986 282.81 5.67 54.2 41.7 Edomex 1964 319.41 7.77 13.9 39.5 General Motors Coahuila 1981 226.81 2.55 73.6 31.7 General Motors San Luis Potosi2 0081 64.6 9.16 62.7 36.6 HondaG uanajuato2 0142 09.9 11.6 517.82 8.6 Mazda Guanajuato 2014 207.61 1.54 28.6 23.7 Nissan Aguascalientes A11 9922 16.9 12.0 639.83 5.4 Nissan Aguascalientes A22	Plant	State	starting	Lowest cat egory salary (dally) H		ighest category salary (daily)	
VolkswgenP uebla1 9643 15.1 17.4 1,024.85 6.6 BMWS an Luis Potosi 2019 292.01 6.15 70.0 31.5 Sonora 1986 197.91 0.93 83.3 21.2 Ford Sonora 1986 282.81 5.67 54.2 41.7 Edomex 1964 319.41 7.77 13.9 39.5 Coahuila 1981 226.81 2.55 73.6 31.7 General Motors Coahuila 1981 226.81 2.55 73.6 31.7 General Motors Coahuila 1981 226.81 2.55 73.6 31.7 General Motors Coahuila 1981 226.81 2.55 73.6 31.7 Mazda Guanajuato 20142 09.9 11.6 517.82 8.6 Mazda Guanajuato 2014 207.61 1.54 28.6 23.7 Aguascalientes A1	1 14111		operations	Pesos	dollars	PesosD	ollars
BMWS an Luis Potosí 2019 292.01 6.15 70.0 31.5 Ford Sonora 1986 197.91 0.93 83.3 21.2 Ford Sonora 1986 282.81 5.67 54.2 41.7 Edomex 1964 319.41 7.77 13.9 39.5 General Motors Coahuila 1981 226.81 2.55 73.6 31.7 San Luis Potosí2 0081 64.6 9.16 62.7 36.6 HondaG uanajuato2 0142 09.9 11.6 517.82 8.6 Mazda Guanajuato 2014 207.61 1.54 28.6 23.7 Aguascalientes A11 9922 16.9 12.0 639.83 5.4 Nissan Aguascalientes A22 0131 89.2 10.5 566.43 1.3 Morelos 1966 400.42 2.18 01.4 44.3 Stellantis Coahuila 1995 3	Audi	Puebla	2017	279.01	5.48	70.0	48.1
Ford Sonora 1986 197.91 0.93 83.3 21.2 Ford Sonora 1986 282.81 5.67 54.2 41.7 Edomex 1964 319.41 7.77 13.9 39.5 Coahuila 1981 226.81 2.55 73.6 31.7 San Luis Potosí2 0081 64.6 9.16 62.7 36.6 HondaG uanajuato2 0142 09.9 11.6 517.82 8.6 Mazda Guanajuato 2014 207.61 1.54 28.6 23.7 Aguascalientes A11 9922 16.9 12.0 639.83 5.4 Nissan Aguascalientes A22 0131 89.2 10.5 566.43 1.3 Morelos 1966 400.42 2.18 01.4 44.3 Stellantis Coahuila 1995 309.01 7.11 ,467.9 81.1 Tovota Baja California2 0043 20.0 17.7 844.04<	VolkswgenP	uebla1	9643	15.1	17.4	1,024.85	6.6
Ford Sonora 1986 282.81 5.67 54.2 41.7 Edomex 1964 319.41 7.77 13.9 39.5 General Motors Coahuila 1981 226.81 2.55 73.6 31.7 San Luis Potosí2 0081 64.6 9.16 62.7 36.6 HondaG uanajuato2 0142 09.9 11.6 517.82 8.6 Mazda Guanajuato 2014 207.61 1.54 28.6 23.7 Aguascalientes A11 9922 16.9 12.0 639.83 5.4 Nissan Aguascalientes A22 0131 89.2 10.5 566.43 1.3 Morelos 1966 400.42 2.18 01.4 44.3 Stellantis Coahuila 1995 309.01 7.11 ,467.9 81.1 Tovota Baja California2 0043 20.0 17.7 844.04 6.7	BMWS	an Luis Potosí	2019	292.01	6.15	70.0	31.5
Edomex 1964 319.41 7.77 13.9 39.5 General Motors Coahuila 1981 226.81 2.55 73.6 31.7 San Luis Potosí2 0081 64.6 9.16 62.7 36.6 HondaG uanajuato2 0142 09.9 11.6 517.82 8.6 Mazda Guanajuato 2014 207.61 1.54 28.6 23.7 Aguascalientes A11 9922 16.9 12.0 639.83 5.4 Nissan Aguascalientes A22 0131 89.2 10.5 566.43 1.3 Morelos 1966 400.42 2.18 01.4 44.3 Stellantis Coahuila 1995 309.01 7.11 ,467.9 81.1 Edomex 1964 308.31 7.01 ,411.4 78.0 Toyota Baja California2 0043 20.0 17.7 844.04 6.7		Sonora	1986	197.91	0.93	83.3	21.2
General Motors Coahuila 1981 226.81 2.55 73.6 31.7 San Luis Potosí2 0081 64.6 9.16 62.7 36.6 HondaG uanajuato2 0142 09.9 11.6 517.82 8.6 Mazda Guanajuato 2014 207.61 1.54 28.6 23.7 Aguascalientes A11 9922 16.9 12.0 639.83 5.4 Nissan Aguascalientes A22 0131 89.2 10.5 566.43 1.3 Morelos 1966 400.42 2.18 01.4 44.3 Stellantis Coahuila 1995 309.01 7.11 ,467.9 81.1 Toyota Baja California2 0043 20.0 17.7 844.04 6.7	Ford	Sonora	1986	282.81	5.67	54.2	41.7
General Motors San Luis Potosí2 0081 64.6 9.16 62.7 36.6 HondaG uanajuato2 0142 09.9 11.6 517.82 8.6 Mazda Guanajuato 2014 207.61 1.54 28.6 23.7 Aguascalientes A11 9922 16.9 12.0 639.83 5.4 Nissan Aguascalientes A22 0131 89.2 10.5 566.43 1.3 Morelos 1966 400.42 2.18 01.4 44.3 Stellantis Coahuila 1995 309.01 7.11 ,467.9 81.1 Edomex 1964 308.31 7.01 ,411.4 78.0 Toyota Baja California2 0043 20.0 17.7 844.04 6.7		Edomex	1964	319.41	7.77	13.9	39.5
San Luis Potosí2 0081 64.6 9.16 62.7 36.6 HondaG uanajuato2 0142 09.9 11.6 517.82 8.6 Mazda Guanajuato 2014 207.61 1.54 28.6 23.7 Aguascalientes A11 9922 16.9 12.0 639.83 5.4 Nissan Aguascalientes A22 0131 89.2 10.5 566.43 1.3 Morelos 1966 400.42 2.18 01.4 44.3 Stellantis Coahuila 1995 309.01 7.11 ,467.9 81.1 Edomex 1964 308.31 7.01 ,411.4 78.0 Toyota Baja California2 0043 20.0 17.7 844.04 6.7	Canaral Matara	Coahuila	1981	226.81	2.55	73.6	31.7
Mazda Guanajuato 2014 207.61 1.54 28.6 23.7 Aguascalientes A11 9922 16.9 12.0 639.83 5.4 Nissan Aguascalientes A22 0131 89.2 10.5 566.43 1.3 Morelos 1966 400.42 2.18 01.4 44.3 Stellantis Coahuila 1995 309.01 7.11 ,467.9 81.1 Edomex 1964 308.31 7.01 ,411.4 78.0 Toyota Baja California2 0043 20.0 17.7 844.04 6.7	General Motors	San Luis Potosí2	0081	64.6	9.16	62.7	36.6
Aguascalientes A11 9922 16.9 12.0 639.83 5.4 Nissan Aguascalientes A22 0131 89.2 10.5 566.43 1.3 Morelos 1966 400.42 2.18 01.4 44.3 Stellantis Coahulla 1995 309.01 7.11 ,467.9 81.1 Edomex 1964 308.31 7.01 ,411.4 78.0 Toyota Baja California2 0043 20.0 17.7 844.04 6.7	HondaG	uanajuato2	0142	09.9	11.6	517.82	8.6
Nissan Aguascalientes A22 0131 89.2 10.5 566.43 1.3 Morelos 1966 400.42 2.18 01.4 44.3 Stellantis Coahuila 1995 309.01 7.11 ,467.9 81.1 Edomex 1964 308.31 7.01 ,411.4 78.0 Toyota Baja California2 0043 20.0 17.7 844.04 6.7	Mazda	Guanajuato	2014	207.61	1.54	28.6	23.7
Morelos 1966 400.42 2.18 01.4 44.3 Stellantis Coahuila 1995 309.01 7.11 ,467.9 81.1 Edomex 1964 308.31 7.01 ,411.4 78.0 Toyota Baja California2 0043 20.0 17.7 844.04 6.7		Aguascalientes A11	9922	16.9	12.0	639.83	5.4
Stellantis Coahuila Edomex 1995 1964 1964 1964 1964 1964 1964 1964 1964	Nissan	Aguascalientes A22	0131	89.2	10.5	566.43	1.3
Edomex 1964 308.31 7.01 411.4 78.0 Toyota Baja California2 0043 20.0 17.7 844.04 6.7		Morelos	1966	400.42	2.18	01.4	44.3
Edomex 1964 308.31 7.01 411.4 78.0 Toyota Baja California2 0043 20.0 17.7 844.04 6.7	Stellantis	Coahuila	1995	309.01	7.11	,467.9	81.1
Toyota		Edomex	1964	308.31	7.01	,411.4	78.0
Guanajuato 2019 261.51 4.55 22.8 28.9	Toyota	Baja California2	0043	20.0	17.7	844.04	6.7
20101 100 22.0		Guanajuato	2019	261.51	4.55	22.8	28.9

Note: The exchange rate as of July 5, 2024, was 18.09 pesos per dollar.

Source: Elaborated with information from the Economic Censuses of INEGI (2024).



4.6%. On the other hand, the entities that showed negative growth rates were Coahuila (-51.4%), Chihuahua (-10.7%), Guanajuato (-8.4%), San Luis Potosí (-44.8%), and Tamaulipas (-18.5%). For this branch, the entities of Morelos and Sonora were not considered in the analysis due to the lack of information from INEGI. Nationally this branch increased from 44 to 48 pesos per hour, equivalent to a 9.7% increase from 2003 to 2018.

In general, from 2003 to 2018, wages in the automotive industry through its vehicle and truck manufacturing sector increased by 1.9 pesos, body and trailer manufacturing increased by 4.2 pesos, and parts manufacturing experienced a real decrease of 1.9 pesos. Therefore, it can be argued that wages in Mexico's automotive industry have stagnated for at least 15 years.

Furthermore, the wages paid in Mexico's automotive industry are considerably lower compared to those in the United States (when converted to U.S. dollars). For instance, in 2018, the wage in vehicle and truck manufacturing in the United States was 4.7 times higher than in Mexico; while the U.S. paid 29.8 dollars per hour, Mexico paid only 6.4 dollars. In body and trailer manufacturing, the wage difference between the two countries was even greater, with wages in the U.S. being 7.5 times higher than in Mexico. In parts manufacturing, the difference was 8.2 times greater, as the U.S. paid 20.9 dollars per hour, while Mexico paid just 2.6 dollars (see Figure 5).

It is also important to note that real wages have

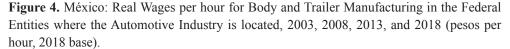
stagnated the analyzed period in both Mexico and the United States, as wage increases have been practically negligible in both countries. In fact, wages in parts manufacturing even saw a decline. In 2003, 2.7 dollars were paid per hour, and in 2018, this figure dropped to 2.6 dollars (see Figure 5).

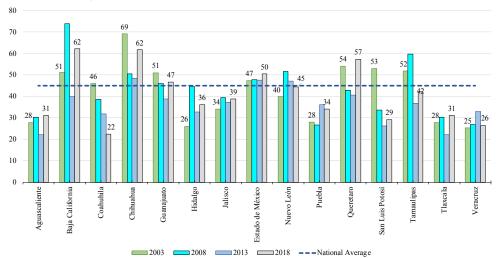
This behavior of low wages with a downward trend can be observed at this level of disaggregation of the national automotive industry and within the federal entities. The results presented in this study align with the statement made by Covarrubias (2019), who notes that "wages are low and declining" (2019: 91). Alternatively, "wages have been stagnant and, in some cases, have decreased... wages are not only not increasing, but are actually decreasing." (Carrillo y García-Jiménez, 2018: 1).

4. Wages in the Automotive Sector: Mexican Empirical Evidence

The discussion regarding the conditions prevailing in wages within the automotive sector, which, as discussed in the previous section, shows a downward trend, necessitates the search for empirical evidence that can contribute to the explanation of this process. In this regard, a wage function is estimated—measured by the wages (pesos per hour) in the transportation equipment manufacturing subsector as an indicator of wage behavior in the automotive sector—as follows:

LSALFETR: = $\beta_0 + \beta_1 PRODFET_i + \beta_2 ISUB_i + \beta_2 CH1P_i + \varepsilon_i$





Source: Elaborated with information from the Economic Census of INEGI (2024).



Where LSALFETR is the logarithm of wages in the transportation equipment manufacturing subsector, PRODFET is the labor productivity of the transportation equipment manufacturing subsector, ISUB is a subcontracting index that relates the number of hours worked by workers supplied by another legal entity to the total number of worker hours in the same subsector (see Murillo, Carbajal, and De Jesús, 2021), and CH1P is the percentage of the population with technical and high school education that seeks to approximate a human capital variable in terms of the available workforce for the automotive sector. For i = 1, ..., 16 federal entities in Mexico where the automotive sector is located; t = 2003, 2008, 2013, 2018, data from the economic censuses (INEGI, 2003, 2008, 2013, and 2018).

This approach to identifying the factors central to explaining wages in the automotive sector is based on important theoretical arguments and empirical evidence. Among the theoretical literature related to wage determinants, those considering productivity as a central factor are identified, particularly the neo-Keynesian efficiency wage hypothesis (see Akerlof and Yellen, 1990; Mankiw and Romer, 1991). As explained by López and Mendoza (2017: 188), the efficiency wage "can be understood as a wage higher than the average market wage, through which costs derived from the hiring process are minimized and greater productivity for workers is promoted." This argument helps explain the positive relationship between productivity and wages.

In the case of the automotive sector, under the efficiency

wage hypothesis, it is assumed that labor productivity will have a positive effect on wages because it is a highly dynamic, innovative sector with relatively high productivity compared to other sectors, being considered a central variable. Furthermore, recent empirical evidence has documented a positive relationship between productivity and wages (see González et al., 2022; Katovich and Maia, 2018; Korkmaz, 2021; Medina, 2018), particularly for the automotive sector (Covarrubias, 2019; García-Jiménez, Carrillo, and Bensusán, 2021; Rodríguez and Sánchez, 2017).

ISUB (subcontracting index) is a variable that attempts to consider the importance of the prevailing labor conditions in the sector, in terms of labor flexibility and outsourcing, elements that have gained importance in recent years. A negative relationship is assumed because it has been considered that the formalization of outsourcing, rather than encouraging productivity and wages, has led to their precarization (see Andrés-Rosales et al., 2023, and Murillo et al., 2021). Furthermore, some experts claim that with the 2012 labor reform, Mexico aimed to reduce labor informality (Loría and Salas, 2019); however, with labor flexibility and outsourcing, many benefits that were the result of union achievements have gradually been eliminated (Andrés-Rosales et al., 2023).

Murillo et al. (2021) state that the fragmentation of the production processes of large companies and the increasing relevance of global value chains have primarily aimed at seeking low labor costs. This is why

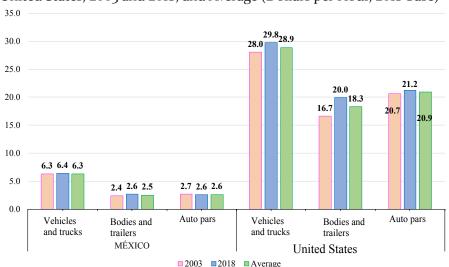


Figure 5. Real Hourly Wages in the Automotive Industry in Mexico and the United States, 2003 and 2018, and Average (Dollars per Hour, 2018 base)

Note: At the exchange rate of July 5, 2024, 18.09 pesos.

Source: Elaborated with information from the INEGI Economic Censuses (2024) and the U.S. Bureau of Labor Statistics (2024).



the way in which work is organized—associated with processes that favor labor flexibility and reduce union participation—must be considered a factor in explaining the evolution of wages. In this regard, the inclusion of ISUB as a variable for labor flexibility is justified. Finally, CH1P, as a human capital variable, seeks to test the hypothesis that the availability of relatively skilled labor may be a factor contributing to higher wages.

Panel data were used due to the availability of statistical information on the automotive sector at the federal entity level and, as suggested by Mayorga and Muñoz (2000), the technique allows for combining the temporal dimension, in the sense of incorporating information over a period of time, and the crosssectional cut, which represents the analysis of available information for the federal entities. The estimation was performed using R version 3.0.1 from a fixed-effects panel data model with the purpose of identifying the presence of specific factors that prevail in the federal entities in the determination of wages in the automotive sector. The panel data was assembled as a short panel with information from the Economic Censuses of 2003, 2008, 2013, and 2018 for 16 federal entities in Mexico where the automotive industry is significantly present. These entities are: Aguascalientes, Baja California, Coahuila, Chihuahua, Guanajuato, Hidalgo, Jalisco, México, Morelos, Nuevo León, Puebla, Querétaro, San Luis Potosí, Sonora, Tamaulipas, and Tlaxcala.

The results of the estimation are presented in Table 3. A positive impact of labor productivity (PRODFET) on wages in the transportation equipment manufacturing subsector is confirmed (coefficient of 0.145). This indicates that labor efficiency in the sector, in terms of its productivity, is a determining factor for wage levels. The relatively small magnitude of the coefficient suggests that as sector productivity increases, the impact on wage growth will be positive.

Regarding ISUB and CH1P, the results presented in Table 3 indicate negative and statistically significant coefficients (-0.812 and -0.069). These results show that flexibility in hiring, measured by the subcontracting index, has been a factor negatively affecting wage growth in the sector. This can be explained by the arguments of Loría and Salas (2019), who state that Mexico's 2012 labor reform aimed to reduce labor informality by promoting more flexible hiring modalities; especially since the federal government during the 2012-2018 period considered that reducing informality was both a necessary and sufficient means to increase productivity and economic growth. This result is associated with the fact that a significant percentage of the labor force available for the automotive sector, with technical and high school education (CH1P), becomes an element that exerts downward pressure on sector wages.

Finally, the fixed effects resulting from the estimation (see Table 3) can be interpreted as the effect of contextual or entity-specific variables that may either mitigate or exacerbate the wage levels prevailing in the automotive sector.

Conclusions

The results indicate that the estimation shows a positive impact of labor productivity on wages in the transportation equipment manufacturing subsector (coefficient of 0.145), suggesting that the recovery of wages in the sector is linked to increases in labor productivity. Additionally, a negative impact of ISUB and CH1P on wages is reported, providing evidence to analyze the effects that the labor reform has had on sector wages, which, combined with a relatively high labor supply, have created the conditions for the trend of wage reduction.

Undoubtedly, the proximity to the United States, the numerous free trade agreements with many countries worldwide, low taxes, skilled labor, and low wages have been the main competitive advantages that have attracted automotive companies to establish operations in Mexico. In this regard, the automotive industry pays the highest wages in brownfield regions, where unions have greater bargaining power and where U.S., Japanese, and German companies are located. The lowest wages are found in greenfield regions, where almost the same companies are present; this difference is related to wage flexibility, unions with less willingness to negotiate, and the imposition of collective contracts. This has motivated companies established in brownfields to move to Greenfields. Low wages also depend on the timing of companies' establishments (first in Estado de Mexico, Puebla, Morelos, and Aguascalientes, then in Chihuahua, Coahuila, Nuevo León, Sonora, Coahuila, followed by Jalisco, and finally in San Luis Potosí, Guanajuato, and Querétaro, where mainly Korean and Chinese companies are located). This pattern aligns with the high, medium, and low wages.

The information presented also highlights the wage gap between the countries in the USMCA; in the best-case scenario, with sustained increases in Mexican wages, it would take years for them to match those of the United States and Canada.



hoping that automation and artificial intelligence do not eliminate cheap labor. However, the labor content value rules established in the USMCA do not guarantee that wages in the Mexican automotive industry will increase, as this agreement only requires that 40-45 percent of the value added to vehicles must be incorporated in North American regions that pay wages of at least 16 dollars per hour. Therefore, these wage increases will have to be pursued through legitimized collective labor contracts and under the Federal Center for Conciliation and Labor Registration, once workers have elected union representatives through voting who advocate for better working conditions, including fair wages.

Future studies should examine whether this trend continues as automotive companies establish

Table 3. Real Wages in the Automotive Sector (Transportation Equipment Manufacturing Subsector). Fixed-Effects Estimation

Subsector). Fixed-Effects Estimation				
PRODFET	0.145 (0.014)*			
ISUB	-0.812 (0.000)***			
CH ₁ P	-0.069 (0.000)***			
Fixed Effec	ts by Federal Entity			
Aguascalientes	5.655 (0.000)***			
Baja California	5.627 (0.000)***			
Coahuila	5.407 (0.000)***			
Chihuahua	5.326 (0.000)***			
Guanajuato	5.057 (0.000)***			
Hidalgo	5.612 (0.000)***			
Jalisco	5.284 (0.000)***			
México	5.896 (0.000)***			
Morelos	6.250 (0.000)***			
Nuevo León	5.554 (0.000)***			
Puebla	5.720 (0.000)***			
Querétaro	5.558 (0.000)***			
San Luis Potosí	5.211 (0.000)***			
Sonora	5.349 (0.000)***			
Tamaulipas	5.279 (0.000)***			
Tlaxcala	5.448 (0.000)***			
R ²	0.77			
Adjusted R ²	0.68			
F-statistic	52.50 (0.000)			
Pooled data test	10.92 (0.000)			
Hausman test	536.3 (0.000)			

Note: Balanced panel, n=16, T=4, N=64. Probability of the t-statistic in parentheses. Statistical significance at 10% *; ** at 5%; and *** at 1%. Source: Estimates performed using R version 3.0.1.

operations in Mexico, as wages are likely to become increasingly lower. It is also necessary to determine the impact on the workforce and wages due to the implementation of automation, robotics, and artificial intelligence. In this regard, policies on training are essential to ensure a skilled workforce that meets the demands of cutting-edge technologies. The update of the minimum wage should consider, in addition to inflation, improvements in labor productivity. It will also be necessary to review whether the legitimization of existing collective contracts is being carried out by workers, as established in the USMCA and the Federal Labor Law, to which the Mexican government has committed.

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RESEARCH

A Structural Analysis with SmartPLS of Second-Hand **Clothing Consumption Practices in the Centennial** Generation

Un Análisis estructural con SmartPLS de las Prácticas de Consumo de Ropa de Segunda Mano en la Generación Centennial

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Abstract

The research aims to explore the relationship between ethical norms and second-hand clothing consumption behavior among Generation Z, focusing on thrift store shopping, responsible consumption, and the use of vintage clothing. The growing popularity of purchasing used garments is addressed, considering ethical aspects such as garment origin, labor conditions, and hygiene. The study was conducted with a sample of 366 randomly selected Generation Z participants, using a digital survey through Survey Monkey. The results reveal that Generation Z individuals with high ethical standards show a strong preference for thrift store shopping, valuing the diversity and uniqueness of the garments. Additionally, a positive connection is observed between ethics and responsible consumption, as well as the use of vintage clothing, indicating that ethical beliefs influence sustainable practices and the choice of distinctive fashion. In conclusion, ethical norms emerge as an integral factor in Generation Z's consumption decisions, positively impacting thrift store shopping, responsible consumption, and the use of vintage clothing. These findings provide opportunities for marketing strategies that emphasize authenticity and sustainability, aligned with the ethical values of this generation, thus contributing to a positive impact on the fashion industry.

Keywords: Centennials, Consumption, Clothes.

JEL Classification: D12, D18, E21.

Resumen

La investigación tiene como objetivo explorar la relación entre la normatividad ética y el comportamiento de consumo de ropa de segunda mano en la generación Centennials, centrándose en la compra en tianguis, el consumo responsable y el uso de ropa vintage. Se aborda la creciente popularidad de la compra de prendas usadas, considerando aspectos éticos como la procedencia de las prendas, las condiciones laborales y la higiene. El estudio se realizó con una muestra de 366 participantes Centennials seleccionados aleatoriamente, utilizando encuesta digital a través de Survey Monkey. Los resultados revelan que los Centennials con alta normatividad ética muestran una marcada preferencia por la compra en tianguis, valorando la diversidad y singularidad de las prendas. Además, se observa una conexión positiva entre la ética y el consumo responsable,



así como el uso de ropa vintage, indicando que las convicciones éticas influyen en prácticas sostenibles y elección de moda distintiva. En conclusión, la normatividad ética emerge como un factor integral en las decisiones de consumo de los Centennials, afectando positivamente la compra en tianguis, el consumo responsable y el uso de ropa vintage. Estos resultados ofrecen oportunidades para estrategias de marketing que resalten la autenticidad y sostenibilidad, alineadas con los valores éticos de esta generación, contribuyendo así a un impacto positivo en la industria de la moda.

Palabras Clave: Centennials, Consumo, ropa.

Código JEL: D12, D18, E21.

Introduction

In recent years, the purchase of second-hand clothing has experienced a significant increase in popularity, driven by various factors ranging from growing environmental awareness to the search for more economical and sustainable alternatives. (Humana Fundación Pueblo para Pueblo, 2023). This shift in consumer preferences not only reflects a transformation in shopping patterns but also raises crucial ethical considerations related to the original of garments and labor conditions in the industry. From Zinn's (2019) perspective, responsible consumption involves making conscious and thoughtful decisions when choosing products, considering their environmental and social impact. The acquisition of second-hand clothing aligns with this approach, reducing the demand for new garments and promoting reuse to consume more sustainably.

However, ethics in the purchase of second-hand clothing is not limited to sustainability; it also addresses aspects such as fair trade, the origin of garments, and hygienic safety (Fair ,2023). Additionally, the World Health Organization (2016) emphasizes the importance of ensuring the hygiene and safety of used garments to prevent health risks. The ethical dilemma lies in how the purchase of second-hand clothing, while promoting sustainability, highlights the aspect of acquiring products of unknown origin. Furthermore, consumer ethics, especially among Centennials, influence the choice of garments, considering the generational belonging factor (IPMARK, 2023).

This study examines the ethical standards in the purchase of second-hand clothing, particularly within the Centennial generation. Ethical standards have been recognized in previous research as a key factor in purchasing decisions, as they influence consumption choices based on moral principles and social responsibility (Forteza, 2020). Regarding purchases in flea markets, this acquisition channel has stood out for its connection to responsible and sustainable consumption practices, as it allows consumers to choose products that favor the circular economy (Urbinati, Chiaroni, y Chiesa, 2017). On the other hand, responsible consumption has gained relevance in recent studies, where it is associated with the preference for products that contribute to waste reduction and the promotion of sustainability (García, 2019). Finally, the use of vintage clothing has become popular as an ecological and stylistic alternat, hive within the Centennial generation, who value the authenticity, history, and sustainability of garments (Martín, García, y López, 2022). Based on these findings, this study aims to identify how ethical principles influence purchasing decisions, the choice of acquisition channels, the practice of responsible consumption, and the preference for vintage clothing. The main objective of this study is to analyze the ethical standards in the purchase of second-hand clothing, focusing on the Centennial generation, to generate valuable information to adapt marketing strategies and promote ethical and sustainable consumption practices in the fashion industry.

1. Theoretical framework

While the fashion industry is one of the largest in the global economy, due to its mass production practices, it is also the second most polluting industry on the planet (Papasolomou, 2019). As a result, more and more people are expressing their commitment to the planet and the responsible use of available resources by choosing alternatives such as purchasing second-hand or used items (Euromonitor, 2023). For this reason, buying second-hand or used clothing has gained popularity in recent years as a way to reduce the environmental impact of the textile industry and promote sustainability (Humana Fundación Pueblo para Pueblo, 2023). In this regard, there are ethical standards that regulate the purchase of second-hand or used clothing.



1.1 Ethical Standards

First, it is important to highlight that ethical standards in the purchase of second-hand or used clothing are based on responsible consumption ethics. According to Zinn (2019), responsible consumption involves the conscious and thoughtful selection of the products we buy, considering their environmental and social impact. Purchasing second-hand or used clothing is a way to consume more responsibly, as it reduces the demand for new garments and promotes reuse. It is also crucial to consider the origin of the clothes being purchased. According to Azapagic and Perdan (2014), buying second-hand or used clothing can promote fair trade and support local communities if garments are sourced locally or ethically produced. Another important ethical concern is the hygiene and safety of the garments. According to the World Health Organization (WHO,2016), second-hand or used clothing can be a vector for diseases if not properly disinfected. Therefore, it is essential to ensure that garments are clean and disinfected before purchasing them at a flea market.

1.2 Second-hand clothing purchases

In recent years, there has been an increase in secondhand clothing consumption, driven by the rise in environmental awareness and the search for more affordable and sustainable alternatives. According to a study on circular fashion conducted in 2021, the second-hand clothing market is projected to reach 77 billion by 20225 (ThredUp, 2021). Buying second-hand or vintage clothing not only affects employment types among consumers but also can also be seen as an ethical and sustainable practice in terms of fashion and the environment. A study conducted by Lee y DeLong (2021) in South Korea found that university students and lower-income individuals were more likely to buy second-hand clothing. On the other hand, professionals and office employees were less inclined to purchase secondhand clothing. These findings suggest that secondhand clothing consumption is more related to economic situations and personal needs rather than profession. According to a report by McKinsey and BOF, 52% of Centennials claim to seek information about the origin and manufacturing conditions of a garment before purchasing it, representing a 10% increase compared to Baby Boomers (McKinsey, 2019). This trend indicates that Centennials are more aware of the social environmental impact of

their purchases, motivating them to make informed decisions. Additionally, the growing interest in sustainability is driving a significant shift in the fashion industry, forcing brands to adapt to the demands of younger consumers. Furthermore, belonging to certain social groups can also influence ethical purchasing standards. For example, a study by Aftab et al. (2017) found that second-hand consumers in the United Kingdom tend to be young, low-income individuals with left-wing political ideologies. These factors may influence their perceptions of value and willingness to buy secondhand clothing. The use of second-hand clothing can also be mediated by psychological factors such as identity and self-esteem. For example, a study conducted by Lu et al. (2017) found that the social identity of second-hand consumers was strongly related to their self-esteem. Those with occupations considered socially valuable may have a greater need to demonstrate their status and, therefore, be less willing to wear second-hand clothing.

1.3 Consumption Among Centennials

The analysis of different generations plays a crucial role in understanding consumer behavior, as it facilitates segmentation and evaluation of purchasing decisions. A detailed understanding of each generation from a current perspective becomes essential for organizations, as lifestyles have undergone significant influences and continue to evolve into new dynamics of general interest (Contreras & Vargas, 2021).

Pledger y Schaffert (2021) provide an enlightening definition of generational cohorts, referring to these groups as sets of individuals who not only share similar birth years but also experienced common historical events during their formative and developmental processes. This concept highlights the significant influence that historical contexts and shared experiences have in shaping the perspectives and behaviors of these groups over time. Generation Z, also known as Centennials, stands out as the successor to Generation Y or Millenials, sharing certain social traits with them, the most notable being their digital behavior. However, Centennials possess unique characteristics, as they are considered digital natives, having experienced early exposure to technology since childhood. This demographic group, born between 1995 and 2010, is recognized for its consumption habits, social behavior, and distinct philosophies (Popescu et al., 2019).



Under labels such as Generation Z, Post-Millenials, Centennials, or the Snowflake Generation, these young individuals exhibit a constant connection to the Internet. Their immediacy in communication is evident in their preferences for platforms such as WhatsApp or Snapchat instead of email, which this generation considers obsolete. (Diario Financiero, 2012). Regarding their consumption and behaviors, Centennials tend to favor brands that promote diversity, inclusivity and social responsibility. Additionally, they value authenticity and seek personalized experiences when making purchases (Influencity, 2023).

A person's age can influence their purchasing behavior, including their willingness to buy second-hand clothing. Different generations may have distinct values, interests, and priorities that are reflected in their consumption patterns. For instance, Centennials are more concerned with sustainability and may be more inclined to purchase second-hand clothing, whereas older generations may be more attached to buying new garments (Eckhardt et al., 2019). The preference for second-hand clothing among Centennials may stem from their desire to participate in a more circular economy, where products are reused, and waste is minimized.

According to a Kantar report, in 2021, 7% of Mexican households were headed by a Centennial, representing the same percentage of expenditure on mass consumer products, amounting to 40 billion pesos in a year.

Socioeconomic factors also influence the purchase of second-hand clothing. For example, it has been found that people with lower incomes are more likely to acquire these types of garments for financial reasons. On the other hand, people with higher incomes may buy them for sustainability or fashion-related reasons. Purchasing second-hand clothing can also be motivated by economic considerations, as it can be a more accessible and affordable option for Centennials, especially those looking for quality brands at lower prices (Chavez, 2020).

There are differences in fashion perception and the values associated with it among different generations. Values that promote sustainability and the collaborative economy are more common among younger generations, which may increase their willingness to buy second-hand clothing (Myllylä y Kronqvis, 2020). The Centennial generation often values authenticity and vintage aesthetics.

Second-hand clothing contributes to shaping the consumer's image in society and reinforces their stance on environmental issues (Chaturvedi et al., 2020). Finally, people's motivations and needs can influence their willingness to buy second-hand clothing. The reasons for purchasing it may include economic, stylistic, or sustainability-related factors, among others. These motivations and needs may vary depending on age, economic situation, and other individual characteristics (Myllyläy Kronqvist, 2020). Centennials are known for their rejection of fast fashion due to its environmental impact and labor practices. Opting for second-hand clothing can be a way to move away from fast fashion culture.

2.Methodology

The research is exploratory in nature and was conducted with a sample of 504 participants, selected through random sampling. Among the participants, 59.1% are female, 39.7% are male, and 1.2% identify as non-binary. In terms of age, 58.7% of respondents are between 18 and 21 years old, 14.1% are between 22 and 25 years old, and 16.2% are between 26 and 29 years old. Regarding their occupation, 39.5% are entrepreneurs, 25% study and work, and 22.2% work as operators. The survey was conducted online via the SurveyMonkey platform in the southeastern region of the state of Coahuila, Mexico. The instrument used was a questionnaire specifically designed for this research, consisting of 35 items distributed across four dimensions. These dimensions were evaluated using a 5-point Likert scale, where 1 indicates "strongly disagree" and 5 "strongly agree." The items were adapted from the following previously validated scales: the Green Consumption Values Scale by Haws et al. (2014), the Prosocial Consumption Scale by Cavanaugh et al. (2015), and the Purchase Activism Scale by Paharia, Avery y Keinan et al., (2014). These scales helped identify participants' attitudes toward fast fashion, circular fashion, and purchasing clothing at flea markets, as well as measure their level of knowledge about activities carried out by companies in the textile sector. The Green Consumption Values Scale by Haws et al. (2014) was used for the Clothing Purchase (CP) dimension, measuring consumers' environmental concerns when buying new clothes. The Prosocial Consumption Scale by Cavanaugh et al. (2015) was applied to the Responsible Consumption (RC) dimension and the



Vintage Clothing Use (VCU) dimension, assessing responsible and pro-environmental attitudes when purchasing second-hand clothing, such as at flea markets and in vintage fashion. Finally, the Purchase Activism Scale by Paharia, Avery y Keinan et al., (2014) was used to measure Ethical Normativity (EN), related to the ethical perception of purchasing second-hand or vintage clothing, evaluating acceptance and proactive behavior toward sustainability. The data analysis was divided into two parts: descriptive and inferential. In the descriptive part, SPSS v.27 software was used to obtain basic statistics on demographic variables and response distribution. In the inferential part, the structural equation modeling (PLS-SEM) algorithm was applied using the SmartPLS v.4 statistical package. This inferential analysis allowed for the exploration of relationships between the research dimensions and the validation of proposed models. Based on rhe collected information, the following hypotheses were formulated:

H1: The ethical normativity of Centennial consumers positively influences their inclination toward purchasing second-hand clothing at flea markets. Ethical normativity has been linked to responsible behavior, purchasing especially concerning sustainability and social responsibility. Several studies suggest that ethically conscious consumers tend to prefer purchasing sustainable products and supporting local markets (Paharia et al., 2014; Cavanaugh et al., 2015). In view of this, the inclination toward purchasing at flea markets, as a form of responsible and local consumption, may be influenced by high ethical normativity among consumers.

H2: The ethical normativity of Centennial consumers positively influences their practice of responsible consumption. The concept of responsible consumption has been widely studied as a manifestation of consumers' ethical awareness. Individuals with high ethical awareness tend to avoid excessive consumption and seek products with a lower environmental impact (Haws et al., 2014). Therefore, the ethical normativity of Centennials may be a key determinant of their responsible purchasing behavior.

H3: The ethical normativity of Centennial consumers positively influences their propensity to use vintage clothing. Ethical normativity is associated with a preference for products that promote sustainability, such as vintage clothing. Several studies indicate

that consumers who value ethics and sustainability tend to choose second-hand or vintage clothing over new products, as they consider this behavior to reduce environmental impact and promote the circular economy (Cavanaugh et al., 2015).

H4: Responsible consumption by Centennial consumers positively influences their inclination towards purchasing second-hand clothing at flea markets. Responsible consumption is closely linked to the preference for sustainable and lowimpact products. Responsible consumers prefer local markets and alternatives such as flea markets, which help reduce waste and support their circular economy (Paharia et al., 2014). Thus, responsible consumption among Centennials is likely to translate into a greater inclination to purchase second-hand clothing at flea markets. H5: The adoption of responsible consumption practices by Centennial consumers positively influences their preference for vintage clothing. Responsible behavior and the adoption of sustainable practices are correlated with the preference for vintage clothing. Responsible consumers seek to reduce their environmental footprint and tend to choose alternatives like vintage clothing, which represents a more ethical and sustainable consumption. (Haws et al., 2014; Cavanaugh et al., 2015).

H6: The purchase of second-hand clothing at flea markets by Centennial consumers positively influences their use of vintage clothing. Buying second-hand clothing at flea markets can have a positive effect on the adoption of vintage clothing, as both. b La compare based on values of sustainability, circular economy, and ethical consumption (Cavanaugh et al., 2015). Purchasing clothing at flea markets can serve as a gateway to vintage fashion, encouraging its use among consumers.

H7: The ethical normativity of Centennials varies significantly depending on age. Ethical normativity and awareness of sustainable practices vary with age, with younger generations (such as Centennials) being more likely to engage in ethical and sustainable behaviors. Age influences values and attitudes towards responsible consumption and sustainability (Haws et al., 2014; Cavanaugh et al., 2015).

H8: The occupation of Centennials significantly influences their frequency of purchasing at flea markets. Consumers' occupations influence their purchasing behaviors, with certain occupational groups (such as entrepreneurs or students) being



more likely to participate in local markets, such as flea markets, due to flexible schedules or the search for affordable options (Paharia et al., 2014).

H9: The gender of Centennials significantly influences their propensity to wear second-hand clothing.

Gender influences consumption decisions with research suggesting that women are more inclined to wear second-hand clothing due to factors such as fashion, savings, and sustainability (Cavanaugh et al., 2015).

3. Analysis of the Results

Regarding the experience of purchasing secondhand or vintage clothing, 56.3% stated that they had acquired it at flea markets or bazaars, 37.7% received it as an inheritance from siblings or relatives, and 6% exchanged it with friends or family members. This information reflects sustainable consumption practices within the Centennial generation, highlighting the demographic and gender diversity in their participation in second-hand fashion.

3.1. Validity of the Measurement Model

For the estimation of the Structural Equation Model (SEM), a minimum of 100 to 200 observations is required for the model to be reliable. This study meets this requirement with a sample size of 366 observations. Figure 1 shows the four latent variables of the models. Since these are multifaceted variables, they are measured through multiple items obtained using a five-point Likert scale, where five

represents "strongly agree" with the statement, and one represents "strongly disagree."

Figure 2 presents the final model, which includes a total of 13 items distributed among the four key constructs. Ethical normativity consists of 4 items, while responsible consumption is reflected through 3 items. The flea market purchases construct includes 4 items, and vintage clothing use also consists of 4 items. These items were selected after applying the established criteria to ensure the reliability and validity of the model.

In the analysis of the external loadings of the indicators, a value above 0.708 is considered acceptable, which means explaining more than 50% of the variance of the corresponding latent variable (Hair et al., 2019). Values close to 0.70 are considered sufficiently close to this threshold, especially in the case of underdeveloped or new scales, where it is common to find loadings below this value. For our research, we have adopted a refinement criterion in which indicators with loadings between 0.40 and 0.70 are removed, as long as this action significantly improves the model's reliability.

The results presented in Table 1 indicate that only three indicators have loadings below the established threshold. However, their removal did not result in a significant improvement in the model's performance, so it was decided to keep them. It is important to note that the remaining external loadings exceed the recommended value of 0.708, supporting the robustness of the proposed model.

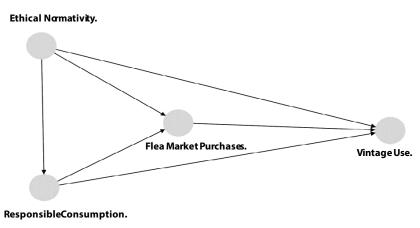
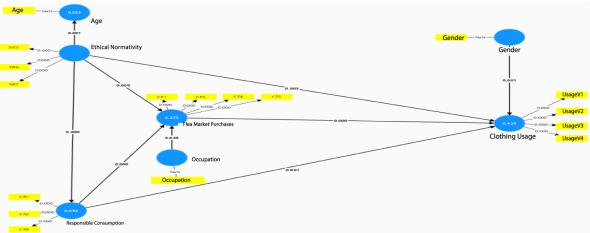


Figure 1. Conceptual Model

Source: Own elaboration



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Source: Own elaboration

Table 1. External Loadings of the Items

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ítems	Load				
CR1: I read the labels before buying new clothes	0.743				
CR2: When buying clothes, I consider myself a socially responsible consumer.	0.621				
CR4: Buying new clothes makes me feel guilty towards the environment.	0.825				
CT1: Buying clothes at flea markets makes me a smart consumer.	0.723				
CT3: I save money by buying clothes at a flea market.	0.768				
CT4: When buying clothes at a flea market, I support local	commerce 0.691				
CT ₅ : It is cool to buy clothes at flea markets.	0.801				
NE ₂ : Buying second-hand or vintage clothes is acceptable					

NE2: Buying second-hand or vintage clothes is acceptable

0.847

NE6: It is ethical to buy vintage clothes.

0.722

NE7: I ask my friends where to buy the best second-hand or vintage clothes.

USOV1: It allows me to have more variety of clothes

0.767

USOV2: It helps me save money.

0.762

USOV3: It allows me to take care of the environment.

0.820

USOV4: It is trendy to buy it

0.772

Source: Own elaboration

In this analysis, we are evaluating convergent validity, which checks whether the items of a construct are aligned and capable of effectively representing the latent construct they belong to. Table 2 presents the composite reliability of the constructs, measured by rho_c, all of which exceed the recommended threshold of 0.70, indicating high internal reliability. Additionally, convergent validation is carried out through the Average Variance Extracted (AVE). According to the criterion of Fornell and Larcker (1981), the AVE should be greater than 0.50, suggesting that more than 50% of the variance of the construct is explained by its items. In the model, the AVE values for the four constructs exceed the minimum required, ranging from 0.532 to 0.610, validating

Table 2. Reliability and Validity of the Constructs

Construct	Composite reliability (rho_c)	Average variance extracted(AVE)
Flea market purchase	es 0.834	0.558
Responsible consumption	0.776	0.539
Ethical normativityo	.769	0.532
Clothing use	0.862	0.610

Source: Own elaboration based on data obtained from SmartPLS

the convergence of the indicators within their respective constructs.

In the evaluation of discriminant validity, the HTMT statistic was used, representing the average of Heterotrait-Heteromethod correlations in relation to the average of Monotrait-Heteromethod correlations. It is established that, for the acceptance of discriminant validation, the HTMT value must be below 0.85 (Henseler et al., 2015). The results, presented in detail in Table 3, indicate that this criterion is met, thus validating the discrimination between constructs.

3.2. Validity of the Structural Model

At this stage of the analysis, various indices are used to assess the validity of the structural model. The coefficient of determination (R^2), which ranges from 0 to 1, reflects the model's predictive accuracy. Higher values indicate a greater level of precision, where 0.67 represents a substantial effect, 0.33 a moderate effect, and 0.19 a weak effect (Hair et al., 2011). To evaluate the significance of the standardized path coefficients (β), the bootstrapping method is employed. A minimum value of 0.2 is considered appropriate, with a preference for values above 0.3.



Table 2. Reliability and Validity of the Constructs

Construct	Flea Market Purchasess	Responsible Consumption	Age	Gender	Ethical Normativity	Occupation	Clothing
Flea Market							
Purchases							
Responsible	0.500						
Consumption	0.500 1						
AGE	0.160	0.091					
GENDER	0.076	0.255	0.093				
Ethical Normativity	0.722	0.534	0.192	0.205			
Occupation	0.157	0.067	0.528	0.082	0.144		
Clothing Use	0.789	0.531	0.145	0.236	0.626	0.104	

Source: Own elaboration based on data obtained from SmartPLS

Table 2. Reliability and Validity of the Constructs

	β	T-statistic	P-value
Flea market Purchase -> Clothing Use	0.486	11.275	0.000
Responsible Consumption -> Flea market purchase	0.203 e	4.743	0.000
Responsible Consumption -> Clothing Use	0.140	3.361	0.001
GENDER -> Clothing Use	-0.129	3.397	0.001
Ethical Normativity ->Flea market Purchase	0.412	10.032	0.000
Ethical Normativity ->Responsible Consumption	0.307	7.409	0.000
Ethical Normativity -> AGE	-0.150	3.356	0.001
Ethical Normativity -> Clothing Use	0.135	3.011	0.003
OCCUPATION -> Flea market Purchas	e ^{0.080}	1.975	0.048

Source: Own elaboration based on data obtained from SmartPLS 4

In the context of analyzing the relationship between "Ethical Normativity" and "Flea market Purchase" (H1), the results show a positive relationship between the two variables. This suggests that as the Ethical Normativity of Centennials increases, so does the likelihood of them making purchases in flea markets. The t-statistic used to test the statistical significance of the relationship indicates that the observed effect is significant, supporting the robustness of the relationship between the two variables. Additionally, the p-value, which is much lower than the common threshold of p<0.05,

implies that the relationship is highly significant, providing strong evidence that Ethical Normativity significantly influences Flea Market Purchase. These results indicate that Centennials with a stronger ethical orientation are more likely to buy clothing in flea markets.

The results (H2) show a significant positive connection between Ethical Normativity and Responsible Consumption in the context of Centennials. This indicates that, for this group, those who have a strong consumption ethic tend to adopt more responsible practices, which directly influence their purchasing decisions. It is suggested that ethical awareness is not only reflected in the preference for certain shopping locations but also plays a key role in considering sustainable and ethical factors when choosing clothing. Thus, ethical normativity appears to be a determining factor that promotes more conscious consumption behavior aligned with responsible principles.

The significant positive relationship (H₃) between Ethical Normativity and the Use of Vintage Clothing in the context of Centennials highlights how ethical values influence the choice of second-hand garments. Those with strong ethical normativity tend to be more inclined to incorporate vintage pieces into their wardrobe, as they seek not only a unique style but also to actively contribute to sustainability. This behavior reflects a growing trend among Centennials to value the life cycle of products and be aware of the environmental impact of their purchasing decisions. The results obtained for this group show that consumption ethics go beyond the choice of new products, creating space for practices that support the circular economy.

There is also a significant positive connection (H₄) between Responsible Consumption and Shopping



at Flea Markets, suggesting that Centennials, by adopting more responsible consumption practices, tend to prefer purchasing clothing in informal markets, such as flea markets.

This indicates that young people in this group not only focus on reducing environmental impact and promoting sustainability, but the observed relationship also reflects a growing trend among Centennials to prioritize options that are not only more economically accessible but also aligned with their ethical values. In this context, flea markets provide an opportunity to access high-quality clothing at lower prices while contributing to the collective effort to reduce textile waste and promote a circular economy model.

Responsible Consumption and Use of Vintage Clothing in the Context of Centennials reinforces the idea that environmental and ethical awareness plays a fundamental role in the preference for vintage garments. This suggests that, by adopting a more responsible approach to consumption, they are not only attracted to more sustainable alternatives but also show a natural inclination towards second-hand clothing, seeking incorporate these garments into their wardrobe choices. Vintage clothing, being a reused option, aligns perfectly with the principles of responsible consumption, allowing them to satisfy their fashion needs without contributing to the environmental damage caused by the fast-fashion industry.

The results presented in the standardized path coefficients table (β) highlight significant associations between the constructs of the model, providing valuable insights, especially in the context of Centennials. The substantial relationship between "Shopping at Flea Markets" and "Use of Vintage Clothing" (H6) suggests that Centennials show a marked preference for acquiring garments in informal markets, such as flea markets, and tend to incorporate these unique pieces into their daily wear. This reflects a preference for reusing garments, with a focus on sustainability and responsible consumption, reinforcing the idea that vintage clothing is seen as an attractive alternative for this group.

The relationship between gender and behavior patterns (H6) regarding clothing use has been a relevant topic in the analysis of consumption habits. It examines whether there is a significant association between gender and preferences or habits related

to clothing use. Understanding how gender differences impact behavior patterns concerning clothing provides a deeper perspective on variations in consumption habits between men and women. The results show a value, where the low p-value indicates that the difference between genders in terms of clothing use is statistically significant. This confirms that gender has a significant impact on clothing use behavior.

The negative mean suggests that, on average, gender is associated with less clothing use, which could be interpreted as a lower frequency of use or fewer garments being worn by one gender compared to the other. The results obtained corroborate the robustness of the relationships proposed in the model, validating the hypotheses and offering solid statistical evidence that supports the consistency and relevance of the relationships, reinforcing the general validity of the theoretical and conceptual framework used in the research.

4.Discussion

The research results reveal a significant relationship between the ethical normativity of Centennial consumers and their purchasing behavior in the second-hand fashion market.

The strong preference for shopping at flea markets, valuing the diversity and uniqueness of garments among Centennials with high ethical normativity, reflects the influence of their ethical convictions on their choice of acquisition channels. This finding aligns with existing literature emphasizing the importance of ethical values in contemporary consumers' purchasing decisions

(Ong et al.,2021). The results obtained in this study show that clothing use not only fulfills the basic function of dressing but has also become a powerful tool for personal expression and identity, particularly among Centennials. This group, in selecting garments, reflects their core values, such as sustainability and ethics, which establish a significant connection between consumption decisions and underlying beliefs about the environment and social responsibility.

However, while this finding confirms previous studies on the growing importance of responsible fashion, it also invites further exploration of the



true depth of this connection across different sociocultural and geographical contexts.

The way sustainability education is integrated into marketing strategies will be crucial in determining the effectiveness of these practices in driving behavioral change. In this regard, further studies are needed to explore the relationship between sustainability information and actual purchasing behaviors, especially considering factors such as the economic accessibility of sustainable products (Saavedra, 2022).

Educational campaigns could also serve as an effective means to increase environmental awareness. However, it is important to consider that Centennials are a generation saturated with information, so the effectiveness of such campaigns will depend on how well they emotionally connect with the audience and create a sense of urgency about changing habits.

While collaborating with influencers and content creators who share sustainability values seems like a promising strategy, further investigation is needed to determine to what extent these messages have a tangible impact on purchasing habits beyond stated intentions (Schneider, 2020).

Finally, education strategies on minimalism and slow fashion also raise questions about the practical reality of these movements. Although Centennials appear inclined toward these ideas, their long-term effectiveness depends on the availability of accessible alternatives, both economically and practically. The versatility and durability of second-hand clothing are essential aspects to highlight, but are consumers truly willing to invest in quality if fast fashion alternatives remain more affordable and convenient in terms of price and availability? (MarketingDive, 2023).

In summary, the results of this study open an important debate on Centennial consumption behavior, suggesting that while sustainability and ethics are key factors in their purchasing decisions, the social, economic, and technological context also plays a fundamental role in shaping their perception and practice of these values. The brands that wish to target this.

5. Conclusions

Brands looking to attract Centennials must consider not only the quality of their products but also how they communicate their ethical sourcing and sustainability efforts. While the study suggests that brands promoting authenticity and diversity in their second-hand products might strongly resonate with this generation, it's important to reflect on the perception of authenticity: Are consumers really seeking authenticity in the sense of a story behind the product, or is this desire more related to the social context in which the purchase is made? The difference in the meaning of authenticity among different consumers can impact the marketing strategies of brands, which must take these nuances into account (Centro de Comercio Detallista, 2024). This buying approach, characterized by financial awareness and support for local entrepreneurs, is especially relevant to the Centennial generation, known for its pragmatic focus, valuing sustainability, authenticity, and social responsibility. Shopping at flea markets resonates with these values, as it not only allows them to save money but also aligns with their interest in supporting local and sustainable initiatives. An important limitation of this study is the sampling bias, as the sample of 366 Centennial participants was randomly selected, but only those with internet access and familiarity with online survey platforms like Survey Monkey were included. This could exclude certain groups within the Centennial generation who lack access to these technologies or who do not actively participate in digital surveys, limiting the representativeness of the sample in a broader context. Additionally, self-reported data may be subject to social desirability bias, where participants may respond in ways they perceive as more socially acceptable, which might not reflect their actual behaviors or attitudes. In terms of future research directions, it would be interesting to explore how sociocultural and economic differences affect the adoption of responsible and ethical consumption practices among Centennials, particularly in contexts outside large cities. Furthermore, investigating the impact of digital platforms and emerging technologies, such as the metaverse, on promoting sustainable fashion and ethical behavior in clothing consumption could be a promising area.



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RESEARCH

Blockchain use in Auditing: Advantages and Challenges in Transaction Verification

Uso de Blockchain en la Auditoría: Ventajas y Desafíos en la Verificación de Transacciones

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Abstract

Financial auditing faces constant challenges in the verification and assurance of accounting information. Blockchain has emerged technology with the potential to transform these processes, offering greater transparency, security and traceability in records. However, its implementation faces technological, economic and regulatory barriers that hinder its widespread adoption. The objective of this study is to analyze the feasibility of blockchain in auditing, identifying its benefits and limitations, as well as the key factors that influence its adoption. Through a qualitative methodological approach, based on a systematic literature review and the analysis of real use cases, aspects such as scalability, interoperability and implementation costs are examined. The findings suggest that, although blockchain can improve efficiency and reliability in auditing, its adoption requires regulatory adjustments and professional training. It is concluded that regulatory evolution and the development of specific standards will be key to its integration in the accounting and financial sphere.

Keywords: Blockchain, financial auditing, technology, regulation, transparency.

JEL Codes: M41, M42

Resumen

La auditoría financiera enfrenta desafíos constantes en la verificación y aseguramiento de la información contable. Blockchain ha emergido como una tecnología con el potencial de transformar estos procesos, ofreciendo mayor transparencia, seguridad y trazabilidad en los registros. Sin embargo, su implementación enfrenta barreras tecnológicas, económicas y regulatorias que dificultan su adopción generalizada. El objetivo de este estudio es analizar la viabilidad de blockchain en auditoría, identificando sus beneficios y limitaciones, así como los factores clave que influyen en su adopción. A través de un enfoque metodológico cualitativo, basado en una revisión sistemática de literatura y el análisis de casos de uso reales, se examinan aspectos como la escalabilidad, interoperabilidad y costos de implementación. Los hallazgos sugieren que, aunque blockchain puede mejorar la eficiencia y confiabilidad en auditoría, su adopción requiere ajustes regulatorios y capacitación profesional. Se concluye que la evolución normativa y el desarrollo de estándares específicos serán clave para su integración en el ámbito contable y financiero.

Palabras clave: Blockchain, auditoría financiera, tecnología, regulación, transparencia.

Códigos JEL: M41, M42





Introduction

In an environment where the digitalization of accounting and financial processes is increasingly relevant, auditing faces the challenge of adapting to emerging technologies that improve efficiency, transparency, and security of information. In this context, blockchain has emerged as an emerging technology with the potential to transform how financial transactions are verified and recorded. Blockchain is a distributed ledger technology that allows for the secure, transparent, and immutable storage of information. Its application in financial auditing could revolutionize the way data is verified, reducing the need for intermediaries and enhancing the reliability of records.

This study analyzes the feasibility of adopting blockchain in financial auditing, identifying the main benefits that this technology can offer, as well as the limitations and challenges that must be overcome for its effective integration. Based on a literature review and analysis of implementation experiences, key aspects such as information security, interoperability with traditional accounting systems, and the costs associated with its application are explored.

The objective of this research is to provide a comprehensive view of the impact of blockchain in auditing, contributing to the academic and professional debate on its usefulness in verifying financial statements. It also aims to generate knowledge that can be used by auditing firms, regulators, and academics interested in the evolution of auditing practices in the digital age. Throughout the analysis, the main technological, economic, and regulatory barriers that could limit its adoption are highlighted, as well as the opportunities that this technology offers to strengthen the reliability and traceability of accounting information.

To address this topic, the study is structured as follows: first, a theoretical review of the fundamentals of blockchain and its applications in auditing is presented. Then, the regulations and standards that govern its use in the accounting and financial sectors are analyzed. Next, the main challenges in its implementation are identified, considering technological, regulatory, and economic aspects. In the methodological section, the research approach and the sources used are

described. Then, the findings are presented and discussed, evaluating their impact on financial auditing. Finally, conclusions and recommendations are provided, highlighting the implications of blockchain technology for the future of auditing.

1. Theoretical Development and Literature Review

1.1 Basic Concepts of Blockchain

Blockchain is an emerging technology that enables the creation of distributed and secure digital records without the need for a central authority. Its structure is based on a chain of blocks, where each block contains a set of transactions that are validated and then cryptographically linked to the previous block, forming a chronological and immutable sequence. Each block includes a unique identifier (hash), generated from the information contained in the block itself and the hash of the previous block, ensuring the continuity and integrity of the chain. "The generation of the hash uses cryptographic algorithms such as SHA-256 in networks like Bitcoin, which ensures that any modification in a block would alter its hash and make any attempt at manipulation evident" (Narayanan et al., 2016, p.88). This characteristic of immutability is one of the main advantages of blockchain, as it ensures that once a transaction is recorded, it cannot be modified or deleted, guaranteeing the integrity of the information. Although blockchain introduces significant improvement in data security and transparency, its classification as a "disruptive innovation" remains a subject of debate, as it does not necessarily meet all the criteria established for that term in the academic literature.

One of the main advantages of blockchain is its decentralization and transparency. Unlike traditional data storage systems, where information is managed from a central server, in blockchain, the information is distributed across multiple nodes in the network. This reduces the dependance on a central entity and decreases the risks associated with single points of failure. "Moreover, since all recorded transactions can be verified by network participants, trust in the system's integrity is strengthened" (Tapscott & Tapscott, 2016, p. 46). However, it is important to differentiate between decentralization and distribution. A distributed system divides the workload across several nodes, but it does not necessarily eliminate centralized control. "In contrast, a decentralized system, like



blockchain, does not depend on a single authority for the validation and storage of transactions, which allows greater autonomy in the network" (Crosby et al., 2016, p. 15).

Blockchain should not be confused with other technological models, such as open-source systems, which allows software modification by any user, or open data systems, which allow software modification by any user, or open data systems, which provide public access to information without restrictions. Although they may share principles of transparency and collaboration, blockchain is distinguished by its cryptographic architecture and its consensus mechanism to validate transactions without requiring trust between parties. "Moreover, distributed computer systems process information across multiple connected nodes, but this does not necessarily mean they are decentralized, as they may still depend on a central authority for management" (Tapscott & Tapscott, 2016, p. 47). "Moreover, as a distributed technology, blockchain provides greater transparency, as all recorded transactions can be verified by network participants, increasing trust in the system" (Peters & Panayi, 2016, p. 255). However, not all blockchain implementations are entirely open; in private and consortium blockchains, access to information may be restricted to certain participants, reducing transparency compared to public blockchains. Security is another fundamental characteristic of blockchain. It employs advanced cryptographic techniques to ensure transactions are secure, and data is accessible only to those with the appropriate permissions. Each block contains a unique code (hash) generated through cryptographic algorithms such as SHA-256 in networks like Bitcoin, linking it immutably to the previous block. "This means that any attempt to manipulate a block's data would change its hash and break the chain, making any alteration immediately detectable. Any attempt to manipulate the data of a block would change the block's code, making any alteration evident, thus making the system highly resistant to fraud" (Crosby et al., 2016, p. 10).

There are several types of blockchain, which can be classified based on access and control:

 Public Blockchain: In this type of blockchain, anyone can join the network, validate transactions, and participate in the consensus process. This model is used by cryptocurrencies such as Bitcoin. "Its structure is entirely decentralized, meaning that no entity has exclusive control over the network, and decisions are made through consensus protocols such as Proof of Work (PoW) or Proof of Stake (PoS). Full decentralization is one of its main characteristics, as there is no central authority governing the network" (Dai & Vasarhelyi, 2017, p. 5).

- Private Blockchain: Unlike public blockchain, this type is restricted to a specific group of participants. Organizations may use private blockchain to securely manage internal transactions without relying on a public network. "Transactions and data access are controlled by a central organization, ensuring greater privacy but limiting decentralization. This model is commonly used in corporate environments where security and access control are essential" (Peters & Panayi, 2016, p. 245).
- Consortium Blockchain: This type of blockchain is controlled by a group of organizations rather than a single entity, combining characteristics of both public and private blockchains. "Access is restricted to approved participants, but consensus and decision-making are shared among consortium members. This model is ideal for industries where multiple entities require shared control, such as the financial sector and supply chain management, enabling greater collaboration without compromising data privacy" (Tapscott & Tapscott, 2016, p. 45).

1.2 Applications of Blockchain in Auditing

The adoption of blockchain in auditing has created new opportunities to enhance the accuracy and transparency of financial auditing processes. The main applications of this technology in the field of auditing include:

1.2.1 Improved Transaction Traceability

Blockchain enables the sequential and chronological recording of each transaction within a block. This facilitates the tracking and verification of financial data across the entire blockchain, enhancing transaction to traceability. "Each time a transaction is recorded, it is a cryptographically linked to the previous block, ensuring the integrity and accuracy of the information" (Dai & Vasarhelyi, 2017, p. 5). However, it is essential to distinguish between two main approaches to blockchain auditing. The



first refers to the integration of crypto assets into financial statements and their accounting audit. In this case, auditors must assess the valuation, classification, and control of these assets within the framework of Financial Reporting Standards (NIF) and International Standards on Auditing (ISA). The second approach involves using blockchain as a tool for auditing any type of asset, whether digital or traditional, ensuring the integrity of accounting records through an immutable and verifiable infrastructure.

1.2.2 Reduction of Fraud and Manipulation of Accounting Data

The immutability feature of blockchain, where once data is recorded, it cannot be altered, is crucial for fraud prevention. "As a contributed network, any attempt to modify a block in the chain will be immediately visible through a discrepancy in the block's code, altering auditors to potential manipulation of accounting data. This security measure increases confidence in the audited data and minimizes the risk of fraud, which is especially valuable in audits involving large volumes of financial transactions" (Crosby et al., 2016, p. 12)

1.2.3 Transparency and Reliability in Financial Auditing

"One of the greatest benefits of blockchain technology is the transparency it provides. Since blockchain operates as a distributed system, recorded transactions are accessible to all network participants in controlled and secure manner. This allows auditors to access up-to-date records in real time, ensuring that the information they review is accurate, complete, and tamper-proof" (Peters & Panayi, 2016, p. 255).

1.2.4 Process Automation Through Smart Contracts

Another significant application of blockchain in auditing is the use of smart contracts. These self-executing programs automate certain processes in financial transactions, such as verifying contractual conditions, processing invoice payments, and ensuring compliance with tax audits. "Smart contracts enhance auditing efficiency by reducing manual work and human intervention while ensuring that established conditions are met accurately and transparently" (Tapscott & Tapscott, 2016, p. 63).

1.2.5 Increased Efficiency in Internal Auditing

In internal auditing, blockchain has the potential to improve efficiency by automating and digitizing records. This reduces the need for manual audits and increases accuracy by providing a centralized, accessible, and up-to-date database. Additionally, blockchain enables automated audits through smart contracts, which can be programmed to perform real-time reviews and verifications. These tools help detect anomalies immediately, facilitating the auditing of large volumes of data without manual intervention, thereby reducing fraud risks and accounting manipulation. It is essential to recognize that blockchain is not limited to auditing crypto assets. It can also serve as a tool to improve the traceability and verification of traditional financial records. Its implementation allows auditors to ensure that financial statement data is accurate and that transactions are verifiable in real time, strengthening the reliability of financial information. "Companies can use blockchain to maintain a continuous record of all transactions and activities, enabling real-time internal auditing and early detection of potential issues before they become significant organizational risks" (Narayanan et al., 2016, p. 112).

1.3 Regulations and Standards Related to Blockchain in Auditing

The regulatory framework in Mexico concerning the use of blockchain in the financial sector is constantly evolving. "The Law to Regulate Financial Technology Institutions (Fintech Law), published in 2018, represents the primary regulatory framework governing the use of digital technologies in the financial sector, including the supervision of virtual assets and blockchain-based platforms" (H. Congreso de la Unión, 2024, p. 1-74). This law establishes guidelines for financial institutions operating with distributed ledger technology (DLT), allowing the incorporation of innovative models within a regulated framework. Although the Fintech Law does not explicitly mention the use of blockchain in auditing, it regulates key aspects related to its application. "First, it defines virtual assets and establishes that only authorized financial institutions can offer services related to them under the supervision of the Bank of Mexico (Banxico)" (Banco de México, 2019). "Second, it imposes strict anti-money laundering (AML) and counter-terrorism financing (CTF) requirements,



where blockchain plays a fundamental role in ensuring transaction traceability and transparency" (H. Congreso de la Unión, 2024, p. 16-17).

Since the enactment of the Fintech Law, several secondary provisions have been issued to regulate the operation of technology platforms in the financial sector:

- Regulations of the National Banking and Securities Commission (CNBV): "Establishes guidelines for the supervision and operation of financial entities using blockchain in digital asset management" (Comisión Nacional Bancaria y de Valores, 2021, p. 34).
- Criteria of the Bank of Mexico (Banxico): "Determines the conditions for authorizing platforms that operate with virtual assets, prioritizing financial stability" (Banco de México, 2020, p. 4-7).
- Regulations of the Ministry of Finance and Public Credit (SHCP): "Regulates the application of blockchain technology in financial processes to ensure compliance with international transparency standards" (H. Congreso de la Unión, 2024, p. 1).

Furthermore, the Fintech Law has driven amendments to other key financial sector regulations, directly impacting the auditing of companies using blockchain:

- Law on Credit Institutions: "Establishes new supervision mechanisms for entities operating with digital technologies, including blockchain platforms" (H. Congreso de la Unión, 2024, p. 1-232).
- Securities Market Law: "Incorporates provisions for regulating blockchain-based crowdfunding platforms under CNBV supervision" (H. Congreso de la Unión, 2024, p. 1-319).
- Bank of Mexico Law: "Grants Banxico authority to regulate the use of virtual assets in the financial system and ensure its stability" (Banco de México, 2020, p. 4-7).

The integration of blockchain in auditing presents regulatory and legal challenges, requiring adaptations to existing standards, such as the International Standards on Auditing (ISA) and Financial Reporting Standards (NIF), to ensure compatibility with fundamental auditing principles. The goal is to guarantee the integrity,

confidentiality, and availability of information within a decentralized and distributed environment. ISAs must include specific guidelines for verifying blockchain-recorded transactions, considering their immutability and the potential for real-time audits. Similarly, NIFs must address the accounting recognition of digital assets and the proper auditing methods to ensure compliance with international financial standards.

1.3.1 Adaptation of International Standards on Auditing (ISA)

ISAs, which serve as global guidelines for auditors, must be adapted to incorporate blockchain-related considerations, such as blockchain verification and smart contract validation. "For example, auditors must be able to verify that transactions recorded on the blockchain are accurate, complete, and unaltered" (Sikka, 2009, p. 1). "Moreover, auditing blockchain-based systems requires new verification techniques and control testing procedures that go beyond traditional accounting record reviews. As blockchain becomes a key tool in auditing, ISAs must also provide specific guidance on using technology for evaluating internal controls and collecting audit evidence, ensuring that information quality and reliability are not compromised" (Coyne & McMickle, 2017, p. 104).

1.3.2 Normas de Información Financiera (NIF)

Regarding Financial Reporting Standard (NIF), the adoption of blockchain necessitates a review of the regulations governing the presentation and evaluation of financial statements. The NIF must recognize that blockchain not only enables the traceability of crypto assets but also facilitates their auditing without requiring conversion to traditional assets. "The auditing of cryptocurrencies and tokens must be addressed within the framework of the NIF, establishing clear criteria for their valuation, recognition, and control" (Gavilán et al., 2021, p. 1). It is essential to develop clear guidelines on how to account for transactions and assets recorded on a blockchain, particularly when they involve smart contracts or cryptocurrencies. Additionally, the NIF should provide a framework for recognizing assets and recording revenue in blockchain environment, given that this technology can reshape the perception of assets and the valuation of financial transactions. "In particular, the classification and valuation of cryptocurrencies and digital assets require a precise interpretation within the context of the NIF, which is currently not entirely clear" (Deloitte, 2021, p. 7).



1.3.3 International Regulatory Standards and their Impact

International regulatory authorities are also beginning to address the use of blockchain in auditing and accounting. "The International Auditing and Assurance Standards Board (IAASB), for example, is developing specific guidelines for adopting emerging technologies such as blockchain in auditing. These guidelines include the requirement for auditors to assess the controls and tests associated with blockchain usage, particularly concerning financial reporting and evidence collection" (Bonsón et al., 2019, p. 32). At the national level, countries like Mexico have begun exploring how to adapt their own accounting and auditing standards to integrate blockchain. "The National Banking and Securities Commission (CNBV) in Mexico has issued recommendations for implementing new technologies, urging companies and auditors to remain aware of the legal and tax implications of using blockchain, with particular attention to decentralized accounting systems and smart contracts" (Martínez et al., 2020, p. 12).

1.3.4 Regulatory Challenges

However, the adoption of blockchain in auditing also faces several regulatory challenges. The lack of standardized global legal framework for implementing blockchain and auditing in decentralized environments is one of the main obstacles. "The European Commission, for example, is assessing the implications of using blockchain in auditing, particularly regarding data protection and privacy, which poses challenges for financial audit regulations" (European Commission, 2020, p. 7). "Audit firms must adapt to this evolving regulatory landscape, ensuring that the use of blockchain complies with personal data protection and privacy requirements established by regulations such as the General Data Protection Regulation (GDPR) in the European Union" (Zafar, 2025, p. 2).

1.4 Challenges in the Implementation of Blockchain in Auditing

Despite the advancements that blockchain offers in terms of efficiency, transparency, and security, its implementation in auditing faces multiple challenges. Next, the main obstacles that audit firms and regulators must overcome to adopt this emerging technology are explored. To facilitate its integration, a roadmap is proposed in three phases. (1) Training awareness, where auditors

acquire knowledge about blockchain and its impact on accounting audits. (2) Pilot projects, in which audit firms assess the feasibility and benefits of blockchain through specific test cases. (3) Gradual integration, combining hybrid records that leverage blockchain's advantages with traditional methods to ensure an efficient and secure transition.

1.4.1 Costs and Technological Barriers

One of the main challenges in implementing blockchain in auditing is the cost associated with adopting this technology. Establishing an adequate blockchain infrastructure may require significant investments in hardware, software, and, most importantly, staff training. According to Narayanan et al. (2016), "companies must invest in secure decentralized networks and platforms that enable the integration of blockchain with existing accounting systems, which implies a high initial cost" (p. 105). "Additionally, audit firms must train their staff in the use of the technology, a process that can be complex due to the necessary specialization in areas such as cryptography and smart contract programming. Despite the potential benefits, resistance to change and a lack adequate resources to manage this technological transition represent a significant barrier for many organizations, especially smaller ones" (Tapscott & Tapscott, 2016, p. 82).

1.4.2 Resistance to Change in Audit Firms

The adoption of new technologies always comes with resistance to change, and blockchain is no exception. Peters and Panayi (2016) "argue that many audit firms prefer to continue using traditional methods due to their familiarity and the perceived security of these processes. This resistance is partly due to uncertainty about how blockchain technology may alter existing workflows, as well as a lack of confidence in auditors' ability to manage decentralized systems" (p. 256). "Furthermore, the use of blockchain requires auditors to adopt new data verification and validation methodologies, which can be perceived as a significant challenge, especially for those accustomed to conventional auditing approaches" (Zafar, 2025, p. 7). In this context, audit firms must be willing to shift their approach and adopt technologies that enhance their performance, which may require a cultural transformation within the organization.

1.4.3 Regulatory and Legal Challenges

Another major challenge is the absence of a clear regulatory framework guiding the implementation



of blockchain in auditing. Crosby et al. (2016) "highlight that the lack of precise guidelines on the legal validation of transactions in blockchain and auditors' responsibilities regarding decentralized records generates uncertainty and legal risks" (p. 16-17). "In many countries, existing laws are not yet prepared to address decentralized accounting systems and smart contracts, which can hinder the practical adoption of blockchain technology in auditing. Globally, there are significant differences in cryptocurrency and digital asset regulations, further complicating the establishment of uniform standards for auditing blockchain-based systems. Legal standards that ensure the validity of records and transactions may not be easily applicable in decentralized environments, creating uncertainty for both audit firms and regulators" (Deloitte, 2021, p. 10). "In Mexico, the National Banking and Securities Commission (CNBV) has begun establishing guidelines for adopting new technologies, but there is still no clear legislation regulating the use of blockchain in auditing" (Martínez et al., 2020, p. 26).

1.4.4 Interoperability and Scalability Challenges

Another technical aspect to consider is the interoperability between different blockchain systems. "Blockchains systems from different providers are not always compatible with one another, which can complicate their integration into the existing technological platforms of companies and audit firms. Moreover, scalability concerns are crucial, as blockchain networks, particularly public ones, may experience bottlenecks when handling large transaction volumes" (Zafar, 2025, p. 3). "While more advanced blockchain networks are working on solutions to these issues, the widespread implementation of blockchain in auditing could face technical limitations due to network capacity constraints in efficiently processing large-scale transactions" (Tapscott & Tapscott, 2016, p. 87).

2. Methodology

The research on the implementation of blockchain in auditing is based on a methodological approach that combines theoretical and empirical perspectives to analyze the effects of this technology on the accounting profession. "A non-experimental design with an exploratory and descriptive scope was adopted", aiming to identify the impact of blockchain on auditing processes without manipulating any variables (Hernández et al., 2014, p. 104). The

study relies on a document review of academic and professional literature, including scientific articles, reports from regulatory bodies, and case studies of companies that have implemented blockchain in auditing, such as Deloitte, PwC, and Ernst & Young.

The qualitative approach of the research allows for a thorough understanding of the implications of blockchain in auditing, analyzing opportunities, challenges, and regulatory aspects. "This approach is appropriate since the adoption of blockchain is still in its early stages in auditing, limiting the availability of generalizable quantitative data" (Guba & Lincoln, 1994, p. 113). Through the document review, information was gathered from reliable secondary sources, such as scientific articles published in indexed journals, reports from international bodies (International Federation of Accountants - IFAC, International Auditing and Assurance Standards Board - IAASB, National Banking and Securities Commission - CNBV), and "case studies of companies that have implemented blockchain in auditing" (Deloitte, 2021, p. 1-24). "Despite its qualitative nature, the research also includes an exploratory analysis of previous data, which helps contextualize trends and challenges associated with the implementation of blockchain auditing" (Yin, 2018, p. 75).

2.1 Documents Review and Sources Used

The research is based on a comprehensive document review that allows for an examination of the current state of blockchain usage in auditing through academically recognized sources. A systematic search strategy was employed in scientific databases such as Scopus, Web of Science, and Google Scholar, ensuring the inclusion of peer-reviewed articles and high-impact publications. The reviewed sources include three main types:

Scientific Articles: Study of the application of blockchain in financial auditing, its impact on transaction traceability, and data reliability.

Reports from Regulatory Bodies: Documents from entities like IFAC, IAASB, and CNBV analyzing the viability and regulation of blockchain in auditing.

Case Studies: Analysis of blockchain implementation in auditing firms and international companies such as Deloitte, PwC, and Ernst & Young.

The document review process was divided into two main phrases. First, inclusion and expulsion



criteria were defined to select relevant sources. Publications exploring the impact of blockchain on auditing, analyzing the viability and challenges of its implementation, and providing empirical evidence on its use were included. Studies with outdated information, unfounded opinions, or articles not providing relevant evidence were excluded. Second, each selected source was analyzed to identify trends and key findings, such as the specific applications of blockchain in auditing, regulatory challenges, and barriers to its implementation.

2.2 Selection Criteria for the Reviewed Literature

Strict criteria were established to ensure the quality and relevance of the information used. The selected publications had to address the use of blockchain in auditing, with a solid empirical or theoretical foundation, and be published in reputable academic journals. Priority was given to recent studies (2016-2024) due to the rapid advancement of blockchain technology. To avoid biased information, articles without empirical support, non-peer reviewed publications, or studies with conflicts of interest were excluded. This approach ensured that the document review was based on solid and relevant scientific evidence.

2.3 Study Limitations

Despite efforts to conduct aa comprehensive investigation, several limitations must be considered when interpreting the findings. These included restricted availability and access to key information, which limits the inclusion of certain critical studies: the focus on academic literature, which excludes practical perspectives from auditing firms; and the absence of a consolidated regulatory framework for blockchain, making it difficult to analyze the adaptation of accounting and auditing regulations across different jurisdictions. Additionally, since blockchain is a continuously evolving technology, the findings of this study may become outdated in the short term. Regulatory and economic differences between countries must also be considered, as they influence the feasibility of implementing blockchain in different regions.

Despite these limitations, the findings. Provide a solid foundation for future research on the impact of blockchain in auditing and its adaptation to existing regulatory frameworks.

3. Discussion and Analysis of Results

The application of blockchain in auditing faces various technological, economic, regulatory, and cultural barriers that limit its large-scale implementation. Based on the adopted methodology, key findings have been identified to better understand the implications of this technology in financial auditing.

However, the adoption of blockchain can begin gradually with actions such as integrating automated tools based on smart contracts to verify accounting transactions in real time. Likewise, companies can apply blockchain in internal audits as a first step toward its adoption in external and regulatory audits.

Despite these challenges, several auditing firms have begun exploring blockchain as an effective tool for financial data verification. Companies such as Deloitte, PwC, and Ernst & Young have developed blockchain-based auditing models, demonstrating its applicability in validating accounting records and detecting fraud. These advancements indicate that blockchain has the potential to be effectively integrated into auditing practices, requiring only regulatory adjustments and specialized training for large-scale adoption.

3.1 Technological Barriers and Factors

One of the most significant technological obstacles to implementing blockchain in auditing is scalability. Networks using the Proof of Work (PoW) consensus model—one of the most widely used protocols in blockchains like Bitcoin-have high energy consumption and limit transaction speeds, which could make their use in auditing inefficient. Audits require high speed and large volumes of data processed in real time, which may be hindered by PoW's scalability limitations. According to Cosby et al. (2016), "PoW-based systems present limitations in transaction processing speed, making large-scale auditing applications difficult. Latency and energy consumption are technological barriers that do not align with the speed and performance required in modern audits" (p. 17).

To mitigate these issues, transitioning to more sustainable and efficient models such as Proof of Stake (PoS) could be a viable solution. PoS significantly reduces energy consumption and enhances scalability by eliminating the intensive mining process characteristic of PoW. This would make the technology more efficient and suitable for



adoption in auditing, as it could process a higher number of transactions with fewer resources. However, PoS also requires a higher level of trust in validators and may be more susceptible to certain vulnerabilities, demanding greater confidence in validation systems.

Additionally, interoperability between blockchain and traditional accounting systems remains a technical challenge. Integrating these platforms may require significant adjustments to existing infrastructures, posing a barrier for many organizations still reliant on conventional systems. Dai & Vasarhelyi (2017) "argue that the lack of integration between blockchain and traditional accounting systems limits its adoption in auditing, as many companies still depend on centralized software and conventional databases. Companies using legacy accounting software, such as traditional database management systems, face difficulties linking these systems to blockchain networks without incurring high costs and additional complexities" (p. 6).

Regarding security, while blockchain is generally considered secure due to its decentralized structure and robust cryptography, smart contracts may contain coding errors that create vulnerabilities. Although blockchain ensure the immutability of recorded data, errors in smart contract programming can lead to incorrect or even malicious transactions. Coyne & McMickle (2017) "warn that the lack of specific regulations on smart contract auditing could pose a risk, as programming errors may compromise the validity of transactions and the integrity of financial records. This highlights the importance of continuous audits and the development of more rigorous coding practices for these contracts" (p. 107).

According to Table 1, the technological factors limiting blockchain adoption in auditing include scalability, interoperability, and vulnerabilities associated with smart contracts.

Table 1. Technological Barriers in Blockchain for Auditing

Factor	Description	
Scalability	PoW-based networks require high energy consumption and limit transaction speeds.	
Interoperability	Difficulty integrating blockchain with traditional accounting systems.	
Security	While blockchain is secure, errors in smart contracts may create vulnerabilities.	

Source: Own elaboration.

3.2 Economic Impact and Financial Barriers

Implementing blockchain requires a significant initial investment, particularly in terms of technological infrastructure and training. The adoption of new technologies—especially in organizations that rely on traditional processes—entails a considerable upfront cost. For many small and medium-sized audit firms, this cost can be a substantial barrier. The need to acquire high-capacity equipment and specialized software, along with expenses related to platform implementation, can be prohibitive for many companies.

However, adopting this technology may yield long-term financial benefits, as it could reduce fraud risks, enhance audit accuracy, and optimize operational processes. Automating certain tasks—such as transaction verification— and reducing human errors could improve operational efficiency and lower costs associated with error correction. Gavilán et al. (2021) "argue that while blockchain investment is high, its benefits in terms of fraud reduction and operational efficiency improvements can justify the costs in the long run. Potential savings from enhanced security and operational efficiency can offset the initial investment and generate a positive return over time" (p. 7).

Recurring costs related to maintaining technological infrastructure must also be considered, as blockchain platforms require periodic updates to keep up with technological advancements. Maintaining and upgrading blockchain system is essential to ensuring that the platform remains secure and efficient, which involves additional expenses over time. Training specialized personnel is another significant cost but is crucial to ensuring effective use of the technology. Blockchain audits require professionals with expertise in cryptography and Smart contract development, representing a continuous investment in human capital.

According to Table 2, the main costs associated with blockchain implementation in auditing include technological infrastructure, training, and maintenance expenses.

In the long run, the reduction of fraud and errors could justify this investment, enabling a favorable economic return.



Table 2. Implementation Costs of Blockchain in Auditing

Concept	Estimated Cost
Technological Infrastructure	High initial investment in hardware and software.
Training	High initial investment in hardware and software.
Maintenance	Recurring costs for updating and maintaining the platform.

3.3 Regulatory and Legal Challenges

The regulatory framework for blockchain in auditing remains ambiguous, creating uncertainty regarding its applicability. Currently, there are no specific provisions within the International Standards on Auditing (ISA) or the Financial Reporting Standards (IFRS) that directly address blockchainbased transactions. This regulatory gap leads to inconsistencies in interpreting best practices for blockchain use in auditing. Coyne & McMickle (2017) state that "the ISA has yet to incorporate clear guidelines for auditing blockchain transactions, creating uncertainty about its applicability in financial auditing. The absence of clear directives may pose legal risks for companies and auditors, as there are no standardized rules on how to verify transactions recorded on blockchain" (p. 106).

Compliance with data protection regulations, such as the European Union's General Data Protection Regulation (GDPR), is another major concern, as blockchain enables decentralized data storage, which may conflict with privacy laws governing personal data storage and management. This immutable nature of blockchain also raises questions about how errors in recorded data can be corrected once they have been stored on the network.

Varying jurisdictional regulations further complicate blockchain adoption in international audits. Given blockchain's decentralized operation, a regulatory framework must account for differences in legal systems across countries. Audits involving cross-border transactions could be affected by national regulatory discrepancies, introducing additional complexities into the auditing process.

According to Table 3, the key regulatory barriers identified include the lack of specific regulations, data protection restrictions, and jurisdictional differences that impact the global implementation of blockchain.

Table 3. Regulatory Barriers of Blockchain in Auditing

Barrier	Implications		
Lack of Regulation	No specific ISA or IFRS standards exist for auditing blockchain transactions.		
Data Protection	GDPR and other regulations limit the storage of personal data on blockchain.		
Variable Jurisdictions	Regulatory differences between countries hinder its adoption in international audits.		

Source: Own elaboration.

3.4 Cultural and Trust Factors

The acceptance of blockchain in auditing also faces cultural and trust-related barriers. Although blockchain technology has proven to be secure and efficient, many auditors and accounting professionals remain skeptical about its adoption due to a lack of understanding of how it works. Peters & Panayi (2016) explain that "the lack of knowledge about blockchain and the absence of training in its use have led to resistance to change within the accounting profession. Blockchain transactions are perceived as complex and difficult to audit due to the decentralized nature of the technology and the need to understand advanced concepts such as cryptography and smart contracts" (p. 256).

The limited knowledge of auditors on how to use blockchain is another key factor in the technology's low adoption rate. Many auditors have not received sufficient training to understand how to integrate blockchain into their auditing processes, raising doubts about their ability to use the technology effectively. Dai & Vasarhelyi (2017) suggest that "blockchain training should be a priority for audit firms, as technical ignorance is one of the main barriers to its adoption. As blockchain becomes more common, training in this area will be crucial to increasing auditors' confidence in its use" (p. 6).

Furthermore, the perception of complexity associated with blockchain may discourage audit firms from adopting the technology. The belief that blockchain is difficult to implement and manage could hinder its adoption despite its potential benefits. Gavilán et al. (2021) highlight that "although blockchain has the potential to improve the traceability of financial information, the lack of trained personnel and resistance to change in audit firms limit its implementation. Simplifying its deployment and developing more accessible



solutions could be key to overcoming these barriers" (p. 5).

According to Table 4, the main cultural factors affecting the adoption of blockchain include distrust in technology, lack of knowledge, and the perception of its complexity.

Table 4. Cultural Factors Affecting Blockchain Adoption in Auditing

Factor	Impact
Distrust in technology	Skepticism about the security and reliability of blockchain in auditing.
Lack of knowledge	Few auditors deeply understand how blockchain works.
Perception of complexity	Blockchain is seen as a difficult technology to implement.

Source: Own elaboration.

Training and education in blockchain will be key to increasing its acceptance in the accounting and auditing community.

3.5 Future Perspectives

Despite existing barriers, the results suggest that blockchain has the potential to transform financial auditing. As the technology matures, more efficient models are developed, and specific regulations are established, blockchain adoption in auditing will become more accessible and effective. Government incentives, increased specialized training, and improved technological infrastructures will facilitate its integration into auditing processes.

However, it is not necessary to wait for legislative changes to begin its implementation. Auditing firms can drive adoption through proof of concept (PoC), developing hybrid auditing models that combine blockchain records with traditional accounting systems. Additionally, collaboration with international organizations will help generate standards that facilitate its acceptance without exclusively relying on regulatory changes.

The creation of international standards and the harmonization of regulations between countries will allow companies to conduct international audits more efficiently and securely, leveraging blockchain's advantages in terms of transparency and traceability.

Although blockchain faces significant technological, economic, regulatory, and cultural barriers, future prospects are promising. If these limitations are

resolved, blockchain could redefine how audits are conducted, providing greater transparency, security, and efficiency in the process.

4. Conclusions and Implications

The analysis of blockchain implementation in financial auditing allows us to conclude that, while this technology presents significant advantages in terms of transparency, security, and immutability, its adoption is limited by various technological, economic, regulatory, and cultural factors. The scalability of blockchain networks and the lack of interoperability with traditional accounting systems hinder its integration into current audits, requiring the evolution towards more efficient and flexible models. Additionally, security, although considered a strength of blockchain, can be compromised by errors in the programming of smart contracts, highlighting the need for more robust verification and validation protocols.

Fromaneconomic perspective, high implementation costs represent a considerable barrier, especially for small and medium-sized auditing firms that lack the necessary resources to invest in technological infrastructure and training. However, in the long term, process automation and fraud reduction could generate a positive return on investment, making the technology financially viable.

In the regulatory field, the lack of specific standards for blockchain-based auditing creates legal uncertainty and hinders its acceptance in financial and accounting environments. The absence of harmonized regulatory frameworks at an international level prevents its adoption in cross-border audits, making it urgent to develop global standards that allow its integration into International Standards on Auditing (ISA) and Financial Reporting Standards (FRS).

On the other hand, cultural barriers and resistance to change among auditing professionals have been identified as key obstacles to blockchain adoption. The lack of knowledge about this technology and the perception that its implementation is complex limit its acceptance in the sector. In this regard, training and educating auditors in blockchain-based tools are essential to bridging the adoption gap and promoting its widespread use.

The implications of these findings suggest that the future of auditing will be influenced by the



development of more accessible and efficient blockchain solutions, as well as by the evolution of regulations that allow its integration without affecting legal security. Collaboration between regulatory bodies, auditing firms, and technology developers will be key to creating an ecosystem where blockchain can add real value to financial auditing, optimizing processes and enhancing trust in accounting information.

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RESEARCH

Service quality as determinant of Brand Equity and its dimensions in higher education institutions

Calidad del servicio como determinante del valor de marca y sus dimensiones en instituciones de educación superior

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Abstract

The objective of this research is to analyze the effect of service quality on the brand value and its dimensions of an educational institution located in Rioverde, San Luis Potosí. The methodology was quantitative, descriptive in scope and crosssectional in design. The population consisted of 1329 consumers of educational services, with a sample of 302. Data were collected through a survey and the instrument was composed of twenty-nine items to calculate brand value and the SERVQUAL scale composed of twenty-two items to measure service quality. A canonical correlation was conducted where it was determined that service quality has a significant impact on brand equity ($\rho = 0.817$, sig.=0.000). Likewise, the PLS Smart program was used to evaluate the hypotheses, which were accepted. It was concluded that if service quality is good, it will have a good impact on brand equity and its dimensions, since service quality has an indirect impact on these dimensions.

Keywords: Brand Equity, Service Quality, Educational Services

JEL Codes: I20, M31

Resumen

Esta investigación tiene como objetivo analizar el efecto de la calidad del servicio en el valor de marca y sus dimensiones de una institución educativa ubicada en Rioverde, San Luis Potosí. El enfoque fue cuantitativo de alcance descriptivo y de diseño transversal. La población se integró por 1,329 consumidores de servicios educativos, con una muestra de 302. Los datos se recopilaron mediante una encuesta y el instrumento se integró por 29 ítems para calcular el valor de marca y la escala SERVQUAL compuesta por 22 ítems para calcular la calidad del servicio. Se llevó a cabo una correlación



canónica donde se determinó que la calidad del servicio impacta significativamente en el valor de marca (ρ =0.817, sig.=0.000). Por otro lado, se utilizó el programa PLS Smart para comprobar las hipótesis planteadas, las cuales fueron aceptadas. Se estableció que si la calidad del servicio es buena tiene repercusiones buenas en el valor de marca y en sus dimensiones, debido a que la calidad de servicio determina de forma indirecta en estas.

Palabras Clave: Valor de Marca, Calidad del Servicio, Servicios educativos

Código JEL: I20, M31

Introduction

Service quality today plays an important role, as it allows companies to improve the services they offer to their clients and thereby achieve customer satisfaction. Considering that the market is highly competitive across different sectors, service quality becomes crucial to continuously improve and meet consumers' demands—since they are the ones who decide where to make their purchases (Tinco, 2022). For this reason, companies strive to ensure high service quality, focusing on maintaining and enhancing each aspect of their service to satisfy their customers and build a relationship with them.

n the education sector, there has been intense competition among institutions. Currently, they do not only compete with those offering in-person programs, but also with those providing virtual modalities. Moreover, educational institutions face the challenge of student dropout. In Mexico, only 38% of university students graduate (Otero, 2022). A high dropout rate suggests a low quality of higher education, indicating that institutions are not able to provide students with the necessary resources to complete their studies (Garrido & Pajuelo, 2024). Due to these factors, especially higher education institutions have focused their efforts on improving service quality, aiming to address students' primary needs by planning, supporting, and enhancing the performance of their procedures effectively and efficiently, to gain competitive advantages (Hernández & Trinidad, 2021). Evaluating service quality offers a broader perspective for identifying areas perceived as deficient by students—areas that need improvement to align with their needs and expectations. That is why service quality is a key factor for organizations, as it enables them to meet consumer needs, which in turn impacts their loyalty and, consequently, the image and market positioning of the organization (Mori & Palomino, 2021).

On the other hand, brand equity is also a key point for educational institutions. Those that have built strong brand recognition and a solid reputation hold a significant competitive advantage in a highly competitive market (Sánchez et al., 2024). Brand equity is defined by consumers based on how they perceive the service, and this perception gives value and recognition to the brand. Therefore, universities have sought to identify the factors that influence brand equity, aiming to foster student connection and loyalty toward the institution. Understanding brand equity in the educational sector is crucial due to growing competition and increased demand for higher education (Grimaldo et al., 2023).

Based on the above, the objective of this study is to determine whether the service quality of Unidad Académica Multidisciplinaria Zona Media de Rioverde, San Luis Potosí, influences brand equity. To that end, the following hypotheses were proposed:

H1: Service quality (SQ) determines brand equity H2: SQ is related to the quality dimension of brand equity

H3: SQ impacts the image dimension of brand equity

H4: SQ correlates with the loyalty dimension of brand equity

H₅: SQ determines the awareness dimension of brand equity

Theorical framework

Table 1 below presents the concept of service quality as defined by various authors.

Table 1. Concepts of service quality

Author(s)	Concept		
Izquierdo (2021)	Service quality develops in the minds of clients and users; it is formed based on the understanding of consumer needs and the exceeding of their expectations regarding a service		
Huizache et al. (2024)	It is the result of implementing competitive strategies and actions, allowing brands to differentiate themselves or provide better customer service		

Source: Own elaboration.



Service quality is analyzed through the SERVQUAL model, proposed by Parasuraman et al. (1985). This model evaluates service quality through five dimensions, which are essential for optimizing service quality aspects. These dimensions are defined in the following table.

Table 2. Dimensions of service quality

Dimension	Definition		
Tangibles	Refers to physical facilities, equipment, personnel, and communication tools (Yovera & Rodríguez, 2018).		
Empathy	The individualized attention that the brand provides to consumers (Coronel et al., 2019).		
Responsiveness	The willingness to help customers and provide prompt service (Cevallos et al., 2019).		
Assurance	The knowledge, skills, and attentiveness of employees to inspire trust and credibility (Osejos & Merino, 2020).		
Reliability	The ability to deliver the promised service accurately and dependably (Siavichay et al., 2023		

Source: Own elaboration.

In Table 3, various authors' conceptualizations of brand equity are presented.

Table 3. Concepts of brand equity

Author(s)	Concept		
Kotler & Armstrong (2013)	It is the effect that enables differentiation through brand recognition, as a result of consumer response to its marketing or product.		
Palomino et al. (2022)	It encompasses the set of characteristics associated with a brand—such as personality, values, relationships, and quality—which influence the purchasing process and reside in the consumer's mind.		

Source: Own elaboration.

Brand equity was analyzed using Aaker's model (1991), which comprises four dimensions to understand how consumers perceive a brand. The definitions of these dimensions are presented in Table 4.

Table 4. Dimensions of brand equity

Dimension	Definition
Brand loyalty	A consumer's consistent behavior in choosing a specific brand, showing reluctance to switch to others (Gutiérrez et al., 2020).
Brand awareness	The effect a brand has on a consumer when it is known or recognized by its outstanding elements (Salazar & Oña, 2021).
Perceived quality	The associations a client develops after hearing about or experiencing a brand, which can enhance a company's profit margins (Alvarado & Ordoñez, 2019).
Brand image	The way a brand is perceived in the consumer's mind when they pay attention to, associate with, or refer to a brand, service, product, company, organization, or institution (Torres et al., 2020).

Source: Own elaboration.

Several authors have conducted studies on service quality and brand equity, which have contributed to understanding how the relationship between these two variables works. Some of these studies are described below.

Sarfraz et al. (2018) investigated the role of satisfaction between service quality and brand loyalty, corporate image, and perceived value in the educational sectors of Pakistan. The sample consisted of 500 students using non-probabilistic and snowball sampling. The findings concluded that service quality, brand image, and perceived value have strong effects on brand loyalty only when satisfaction serves as a mediating variable.

Esquen (2018) aimed to determine the correlation between service quality and brand equity in movie theaters such as Cinerama and Cine Star, Tarapoto – 2017. This quantitative study had a descriptive-correlational scope. The data collection instrument consisted of 14 items to assess service quality and 20 items for brand equity. The instrument was applied to a sample of 57 consumers for each movie theater. Results obtained using Pearson correlation showed a relationship between brand equity and service quality in the theaters under study.

Pérez (2019) analyzed how brand equity is determined by product quality in a chocolate



company based in Tacna. The methodology was quantitative, with a non-experimental and cross-sectional design at an explanatory level. A survey was applied to a sample of 385 consumers. The instrument was based on Garvin's theory to assess quality and Aaker's model to measure brand equity. Results established that service quality has a direct influence on brand equity.

Pinar et al. (2020) aimed to understand students' perspectives and the interactions of brand equity dimensions in developing a strong university brand in Turkey. Using a quantitative method, data were collected via a survey from 1,300 students across all academic years and faculties of the university. The PLS-SEM model revealed that brand equity dimensions significantly impact the university learning experience, thus helping develop solid university brand equity.

Pi et al. (2020) examined the factors influencing Chinese students' decision to study in Malaysia. The study was based on the theory of planned behavior, primarily used in marketing to analyze consumer behavior. The sample included third-year high school students from urban areas of four third-tier cities in Jiangxi Province, China. Simple random sampling was employed. The analysis revealed that academic expectations were not relevant to Chinese students' intentions; however, brand equity significantly influenced their decision to study in Malaysia.

Shahila and ArulPrasad (2021) conducted a study to examine the correlation between service quality dimensions and consumer brand equity in the telecommunications network market. The sample included 517 individuals selected via systematic random sampling. A survey was used as the data collection technique. Descriptive statistics, ANOVA, multiple regression, and correlation tools were employed. Findings indicated that the tangible elements and assurance dimensions of service quality significantly affect brand equity.

Agurto (2021) aimed to determine how brand equity is shaped by the service quality received by customers of a restaurant in Cercado de Lima. The study had a quantitative, non-experimental, and cross-sectional design. A survey was administered to a sample of 173 individuals. The instrument was adapted and validated using Cronbach's alpha coefficient (0.973), indicating high reliability. Results showed that service quality positively

influences brand equity dimensions.

Neyra et al. (2021) examined the relationship between expectation and perception of service quality in the National University of Education. The study used a quantitative methodology with a sample of 189 students. The SERVQUAL model was used to assess expectations and perceptions. Spearman's rho was used for correlation analysis, revealing a weak relationship between expectations and perceptions.

Dam and Dam (2021) aimed to analyze the correlation between service quality, the brand image dimension of brand equity, customer satisfaction, and loyalty. The study used a quantitative approach with a sample of 299 supermarket customers in Ho Chi Minh City, Vietnam, selected via convenience sampling. Data were analyzed using PLS-SEM. Scale reliability was examined using internal consistency and composite reliability, and discriminant validity was assessed using the Fornell-Larcker criterion. Findings showed that service quality correlates with brand image, customer satisfaction, and loyalty. Additionally, brand image affects consumer satisfaction and loyalty.

Shagui et al. (2022) studied the effects of service quality on consumer loyalty and the brand image dimension of brand equity, acting as mediating variables in major Ecuadorian fashion retail chains. Using a quantitative method, an instrument with five service quality items, and four items each for brand image and loyalty, was applied to a sample of 384 consumers. Results demonstrated that service quality significantly impacts brand image and loyalty.

Alvarez (2022) examined the correlation between service quality and brand equity among wholesale supermarket consumers in North Lima. This descriptive-correlational study used a non-experimental and cross-sectional design. A 28-item Likert scale questionnaire was applied, and data were analyzed using SPSS version 29. A moderate correlation was found between the variables, leading to the conclusion that service quality impacts brand equity.

Yusuf and Fajari (2022) studied the impact of key service quality elements on the success of various educational institutions. References included international journals indexed in Scopus, Web of Science, Index Copernicus, Google Scholar, and



others. A total of 72 publications from 2004 to 2021 were included. Results concluded that key factors directly affect service quality in educational institutions.

Mamani (2022) aimed to determine the association between gastronomic service quality and brand equity based on tourists' opinions in Tacna, Chile, during 2019. The quantitative, non-experimental, cross-sectional study surveyed 384 tourists from a population of 714,534. Spearman's rho revealed that gastronomic service quality correlates with brand equity. Elements such as reliability, responsiveness, assurance, empathy, and tangibles positively impact brand equity through brand associations, loyalty, perceived quality, and brand recognition, influencing consumer behavior.

Espinoza and Vergara (2022) analyzed service quality and brand equity in sports betting on the Te Apuesto platform by La Tinka. This non-experimental, transactional, and quantitative correlational study surveyed 205 users. The SERVQUAL scale assessed service quality, while Aaker's model evaluated brand equity. Spearman's rho was used to assess the association, which confirmed that service quality influences brand equity.

The study of Larico (2023) aimed to determine the correlation between service quality and brand equity among Vea Tacna plaza consumers in 2021. The quantitative, non-experimental, and cross-sectional study surveyed 384 consumers. Spearman's rho showed a significant direct correlation between constructs, suggesting that improving service quality enhances brand equity.

Kabanova and Vetrova (2023) evaluated students' assessment of online educational service quality at higher education institutions in Moscow. The sample included 423 students from the Moscow State University of Food Production and 350 from the Russian State Social University. Results showed that the transition to online education due to the pandemic was rapid and effective. Maintaining quality depended on student motivation, readiness, communication channels, and digital infrastructure.

Sosa et al. (2023) investigated the correlation between pedagogical management and service quality in early childhood education at the private school "Aprendo Jugando" in San Martin de Porres, Lima, Peru. This quantitative, non-experimental, correlational study used Spearman's rho to analyze data. A strong and significant relationship was found (r = 0.789, p = 0.00), prompting changes in pedagogical management through methodological tools and increased teacher leadership and commitment.

Paredes (2024) analyzed the correlation between service quality and brand equity in face-to-face channels of telecommunications companies in Lima. This quantitative, correlational, cross-sectional study surveyed 384 consumers. The questionnaire included SERVQUAL to measure service quality across five dimensions and Aaker's model to assess brand equity, analyzing brand association through organization association and brand personification. The responsiveness dimension was excluded based on expert validation. Results showed a high positive correlation (r = 0.896) between service quality and brand equity. The study concluded that prioritizing service quality is essential to enhance brand equity in a competitive business market.

Özdemir and Aydın (2024) analyzed the effects of service quality (IDSQ) on brand equity (BE) and brand love (BL). Instruments were based on literature-derived scales. Consumers from Van province were surveyed using simple random sampling. Structural equation modeling (SEM) was used for analysis. Findings showed that service quality positively influences both brand equity and brand love. Brand love also affects brand equity, mediating the relationship between service quality and brand equity.

Becerra (2025) examined the effect of service quality on brand equity in the company Industrial y Comercializadora Vikingo SAC – INCOVIK SAC, a subsidiary of AW Faber Castell Peruana SA, headquartered in Germany. The quantitative methodology involved a survey administered to 89 consumers. The questionnaire was based on Utrera et al. (2022), using the SERVQUAL scale for service quality and Aaker's model for brand equity. Pearson's r showed that service quality has a continuous and positive effect on brand equity.

Mishra et al. (2025) explored the dimensions of educational service quality in online learning that foster brand equity, student commitment, and satisfaction. The quantitative study surveyed 250 students and used structural equation modeling (PLS-SEM) to analyze data. Results showed that service quality dimensions significantly affect student commitment, which positively impacts



satisfaction and strongly influences brand equity. Student commitment was found to mediate the relationship between service quality and brand equity.

On the other hand, Sah et al. (2025) analyzed the correlation between circular economy service quality and brand equity, considering the mediating roles of brand image, consumer satisfaction, and customer loyalty. This quantitative study collected data from loyal consumers of brands using circular economy practices. A questionnaire measured perceptions of service quality, satisfaction, brand image, loyalty, and brand equity. SEM analysis showed that circular economy service quality correlates with satisfaction, brand image, and loyalty. The mediating variables in the correlation between service quality and brand equity were satisfaction, loyalty, and brand image.

Method

This is a quantitative study with a descriptive, correlational, and explanatory scope and a cross-sectional design. The population consists of 1,329 students enrolled in a higher education institution in Rioverde, San Luis Potosí. The university offers eight academic programs, seven undergraduate degrees, and one higher technical degree. A stratified sampling method was used. The sample size was 302, calculated with a 95% confidence level and a 5% margin of error.

The instrument included 24 items to measure brand equity based on Aaker's model (1996), and the SERVQUAL scale by Parasuraman et al. (1980) with 22 items across five dimensions to assess service quality. Reliability of the instrument was tested using Cronbach's alpha based on the George and Mallery criteria cited in Hernandez and Pascual (2017). The reliability levels were: tangibles (0.814), reliability (0.881), responsiveness (0.845), assurance (0.892), and empathy (0.868).

Similarly, the brand equity dimensions were tested for reliability: loyalty (0.827), brand image (0.809), quality (0.905), and awareness (0.816), all showing good reliability, except for quality, which showed excellent reliability.

Table 5 presents the operationalization of sociodemographic variables used to describe the sample, including gender, age, marital status, number of children, academic program, semester,

scholarship status, and GPA.

Table 5. Operationalization of Sociodemographic Variables

Item code	Variable	Dimension	Туре	Scale	
VS1	Gender	Not applicable	Qualitative	Nominal dichotomus	
VS2	Age	Not applicable	Qualitative	Scale	
VS ₃	Marital status	Not applicable Qualitative		Nominal polytomus	
VS ₄	Children	Not applicable	Qualitative	Nominal dichotomus	
VS ₅	Academic program	Not applicable	Qualitative	Nominal polytomus	
VS6	Semester	Not applicable	Qualitative	Nominal polytomus	
VS ₇	Scholarship	Not applicable	Qualitative	Nomina dichotomus	
VS8	GPA	Not applicable	Qualitative	Scale	

Source: Own elaboration

Table 6 operationalizes the variable service quality and its dimensions, showing that each item is quantitative and measured on a Likert scale.

Table 6. Operationalization of Service Quality

Item code	Variable	Dimension	Туре	Scale
TAN1 TAN2 TAN3 TAN4	Service quality	Tangibles	Quantitative	Likert Scale
CON5 CON6 CON7 CON8 CON9	Service quality	Reliability	Quantitative	Likert Scale
RES10 RESP11 RESP12 RESP13	Service quality	Responsiveness	Quantitative	Likert Scale
SEG14 SEG15 SEG16 SEG17	Service quality	Assurance	Quantitative	Likert Scale
EMP18 EMP19 EMP20 EMP21 EMP22	Service quality	Empathy	Quantitative	Likert Scale

Source: Own elaboration.

Table 7 shows the operationalization of the brand equity variable with its four dimensions measured using a Likert scale.

Table 7. Operationalization of Brand Equity

Item code	Variable	Dimension	Туре	Scale	
L1 L2 L3 L4	Brand equity	Loyalty	Quantitative	Likert Scale	
I1 I2 I3 I4 I5 I6	Brand equity	Image	Quantitative	Likert Scale	
C1 C2 C3 C4 C5 C6 C7 C8 C9 C10 C11	Brand equity	Quality	Quantitative	Likert Scale	
N1 N2 N3 N4 N5	Brand equity	Awareness	Quantitative	Likert Scale	

Findings

It was found that 61.7% of the respondents were female and 38.3% male. The average age was 20.55 years with a standard deviation of 2.416. Moreover, 89% were single and 96.6% had no children.

Most students were enrolled in the Bachelor of Nursing program (27.8%), followed by Civil Engineering (16.9%), Business Administration (14.6%), and Accounting and Finance (13.6%). Mechatronics Engineering accounted for 12.3%, Marketing 7.9%, Agroindustrial Engineering 6%, and the Higher Technical Degree program 1%.

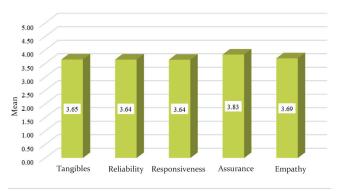
Regarding semester distribution, most students were in the fifth semester (37%), followed by the seventh (27%), ninth (14.3%), first (12.7%), and third semester (9%).

A total of 94.7% of students did not have a scholarship. The average GPA was 7.77 with a

standard deviation of 0.77; the maximum grade was ten and the minimum six.

Figure 1 displays the components of service quality. The highest-rated dimension was assurance with 3.82 points, indicating the university performs well in this aspect. It was followed by empathy with 3.69 points, suggesting adequate individualized attention to students. Below the average were the dimensions of tangibles and reliability, both scoring 3.64 points, and responsiveness with 3.63 points—indicating these are the least efficient areas and require improvement to provide better service.

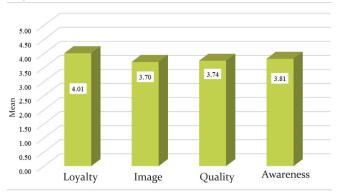
Figure 1. Components of service quality



Source: Own elaboration.

Figure 2 shows the dimensions of brand equity, with the highest-rated criterion being loyalty with 4.01 points, followed by awareness with 3.81 points. Lastly, quality and image scored 3.74 and 3.70 points, respectively. These last two were the lowest scores, thus indicating a need to specify strategies to improve these dimensions.

Figure 2. Dimensions of Brand Equity



Source: Own elaboration.

Correlational analysis

Table 8 shows a canonical correlation, which aimed to verify the effect that service quality has on brand



equity. The coefficient was 0.817, indicating a strong correlation.

Table 8. Canonical correlation

	Correlation	Eigenvalue	Wilks' Lambda	F	Number D.F.	Denominator D.F.	Sig.
1	0.817	2.004	0.322	19.837	20,000	972.721	0.000
2	0.163	0.027	0.966	0.856	12.000	778.142	0.592
3	0.087	0.008	0.992	0.391	6.000	590.000	0.885
4	0.019	0.000	1.000				

Source: Own elaboration.

Table 9 displays the canonical loadings of service quality, showing that they load onto their own construct, with reliability being the primary dimension. Additionally, the canonical loadings for brand equity indicate a direct correlation between the construct and its dimensions, where quality stands out among the others. Regarding the crossloadings, all dimensions share the same sign, which indicates that the correlations are significant and positive. Furthermore, the effect of service quality on brand equity is mainly explained by the reliability dimension, whose correlation level is 0.762, indicating a high value, followed by the safety dimension with 0.742, then empathy with 0.734. The tangibles dimension has a cross-loading of 0.700, and lastly, responsiveness with a value of 0.695.

As a consequence of the data in Table 9, the following canonical equations were obtained through the unstandardized coefficients that allow refining the value of the studied constructs.

V=f (Service quality) = -0.310X1 - 0.403X2 - 0.038X3 - 0.384X4 - 0.297X5U=f (Brand equity) = -0.146 Y1 + 0.248Y2 - 1.570Y3 - 0.126Y4

There is evidence to accept that service quality significantly impacts brand equity (ρ =0.817, sig.=0.000).

Table 9. Canonical set

	Service quality (V) canonical set 1								
	Standardized coefficients	Unstandardized coefficients	Canonical loadings	Cross- loadings					
Tangibles	-0.232	-0.310	-o.8 ₅₇	-0.700					
Reliability	-0.309	-0.403	-0.933	-0.762					
Responsiveness	-0.030	-0.038	-0.851	-0.695					
Assurance	-0.310	-0.384	-0.908	-0.742					
Empathy	-0.230	-0.297	-0.899	-0.734					
	Brand equ	uity (U) canonical s	set 2						
Loyalty	-0.108	-0.146	-o.668	-0.546					
Image	0.155	0.248	-0.717	-0.586					
Quality	-0.982	-1.570	-0.992	-0.810					
Awareness	-0.094	-0.126	-0.690	-0.563					

Source: Own elaboration.

Explanatory analysis

Subsequently, this correlation was analyzed using the PLS Smart software. Figure 3 shows each variable with its corresponding dimensions. Additionally, the Path coefficients, which are the values located on the arrows corresponding to the original sample, can be observed.

The five hypotheses proposed were accepted through bootstrapping, as their significance values were less than 0.05. Thus, it is established that service quality positively impacts brand equity (0.000) with a Path coefficient of 0.732. Furthermore, service quality is indirectly correlated with quality (0.000) with a Path coefficient value of 0.634. Similarly, service quality affects image (0.000) with a Path coefficient of 0.651. It was confirmed that service quality is indirectly correlated with loyalty (0.000) and awareness (0.000), having Path coefficients of 0.617 and 0.593 respectively, as shown in Table 10.

The coefficient of determination R² is shown in Table 11. This represents the predictive power of the model, showing the amount of variance of the endogenous construct explained by the exogenous constructs; that is, how brand equity and its dimensions are explained by service quality. Considering the above, it shows 0.752 for the quality construct, while image presents a determination coefficient of 0.792. Likewise, loyalty has a value of 0.710, awareness 0.656, and brand equity 0.535.

Additionally, Table 11 also shows the predictive relevance (Q²) evaluated through PLSpredict/CVPAT. Values greater than zero indicate predictive relevance of exogenous constructs for endogenous ones. Based on this, it was concluded that service quality explains and has moderate predictive relevance for quality (0.592), image (0.322), loyalty (0.292), awareness (0.322), and brand equity (0.533).

Table 12 shows the f² value indicating the effect size that the independent variable has on the dependent variable. Considering this, it was found that service quality has a large effect on brand equity (1.153). Furthermore, brand equity has a large effect on quality (3.030), image (3.799), loyalty (2.454), and awareness (1.910).



Figure 3. Tested model

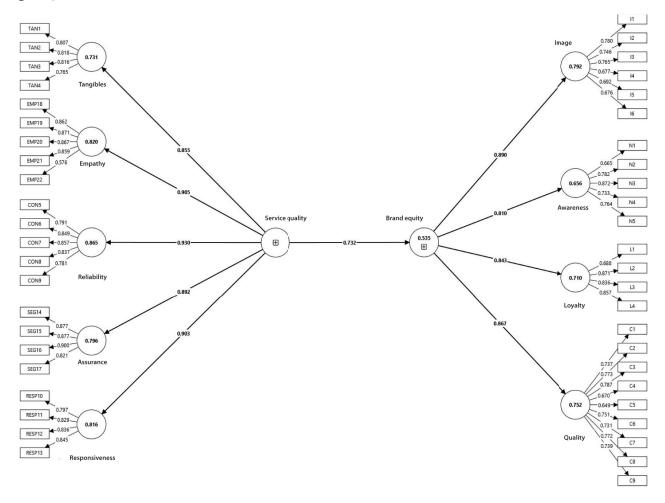


Table 10. Hypotheses

	Hypothesis	Original sample	Sample mean	Standard deviation	t Statistics	p Value	Decision
H1	Service quality > Brand equity	0.732	0.731	0.030	24.638	0.000	Accepted
H2	Service quality > Quality	0.634	0.635	0.031	20.275	0.000	Accepted
Н3	Service quality > Image	0.651	0.652	0.029	22.132	0.000	Accepted
H4	Service quality > Loyalty	0.617	0.030	0.030	20.287	0.000	Accepted
Н5	Service quality > Awareness	0.593	0.594	0.033	18.154	0.000	Accepted

Source: Own elaboration.



Table 11. Coefficient of determination and predictive relevance

	R ²	Q^2
Quality	0.752	0.592
Image	0.792	0.322
Loyalty	0.710	0.292
Awareness	0.656	0.322
Brand equity	0.535	0.533

Table 12. Effect size

		f²
Service quality	→ Brand equity	1.153
Service quality	→ Quality	3.030
Service quality	→ Image	3.799
Service quality	→ Loyalty	2.454
Service quality	→ Awareness	1.910

Source: Own elaboration.

Discussion and conclusions

Discussion

Previous research such as Agurto (2021) and Álvarez (2022) has demonstrated that the service quality variable has significant effects on brand equity, achieving improvements in their service. Although there are studies addressing the relationship between these two variables, very few focus on the educational sector. Therefore, the present research analyzes educational service quality and brand equity, obtaining significant and consistent results with Mishra et al. (2025), establishing that for an educational institution to face a competitive market, it is necessary that students associate the brand with high value. Hence, the institution must deliver quality service, as it has been demonstrated that educational service quality influences brand equity.

Thus, service quality plays an important role, as Larico (2023) mentions: by providing quality service considering each of its dimensions, brand equity will also be enhanced due to the impact of the first variable on the latter. Similarly, Paredes (2024) concludes that service quality should always be prioritized because it is a key and fundamental element for increasing brand equity. Therefore, it is important for educational institutions to address

service deficiencies through strategies that meet all student expectations. Yusuf and Fajari (2022) mention the need to identify key institutional factors that allow service quality to increase, as these enable the development of strategies to address weaknesses. These studies are crucial due to their contributions in better understanding the problem, aligning with the conclusions presented in this study.

Conclusion

This study determined that the university's service quality significantly impacts brand equity; thus, the institution's quality must be a priority so students develop this value towards the brand. Therefore, corrective actions should be taken regarding tangibles, focusing on areas students consider needing improvement. Likewise, administrative and teaching staff should be properly trained to enhance the reliability and responsiveness dimensions, aiming to improve service quality. It is recommended that classrooms be equipped with necessary tools so students can perform activities without issues, and that laboratories be provided for each program to facilitate dynamic learning experiences. Regarding staff training, it is necessary to evaluate each instructor at the end of every semester to determine if they meet the requirements to teach effectively. Additionally, administrative personnel should be involved in courses to ensure efficient and pleasant student service.

In this way, good service quality will have immediate repercussions on brand equity and its dimensions, significantly impacting them.

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RESEARCH

A study of water Supply in the Municipality of Hidalgo del Parral, Chihuahua

Un estudio del agua en el Municipio de Hidalgo del Parral, Chihuahua

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Abstract

The 2030 Agenda and the introduction of the Sustainable Development Goals (SDGs) presented by the United Nations in 2015 include goals aimed at fighting poverty, caring for the planet, and reducing inequalities. Among them is Goal 6: Clean Water and Sanitation. Accordingly, this document aims to analyze statistical information regarding the current water situation in the city of Hidalgo del Parral, Chihuahua. A total of 500 statistically significant household surveys were conducted. Among the most relevant findings, the average monthly payment was approximately \$378.00 pesos, while the average consumption was 13.5 cubic meters. Additionally, households are willing to pay, on average, 16% more on their monthly bill in exchange for constant water supply 24 hours a day. Therefore, it is recommended to support scientific research on water-related issues to broaden and deepen the diagnosis of the local water situation from a multidisciplinary perspective, encompassing various aspects related to water management.

Keywords: Water, Sustainable Development Goals, public policy.

JEL Codes: Q25- Water; Q28-Public Policy; R23-Housing Characteristics.

Resumen

La Agenda 2030 y la presentación de los Objetivos de Desarrollo Sostenible presentadas por las Naciones Unidas en 2015 incluye objetivos para la lucha contra la pobreza, el cuidado del planeta y la reducción de las desigualdades. Entre ellos está el Objetivo 6: Agua limpia y saneamiento. Por lo anterior, es que este documento tiene como objetivo analizar información estadística de la actual situación hídrica en la ciudad de Hidalgo del Parral, Chihuahua. Se aplicaron 500 encuestas, estadísticamente significativas, en hogares. En los resultados más relevantes se encontró que el pago promedio mensual oscila alrededor de los \$378.00 pesos, mientras que el consumo promedio fue de 13.5 metros cúbicos y, además, los hogares están dispuestos a pagar, en promedio, un 16% más sobre el pago mensual que les permita tener agua constante las 24 horas del día. Por tanto, se recomienda apoyar la investigación científica en el





tema del agua para ampliar y profundizar sobre el diagnóstico de la situación hídrica a nivel local, de manera multidisciplinaria, para abarcar distintos aspectos relacionados con la gestión del agua.

Palabras clave: Agua, Objetivos de Desarrollo Sostenible, políticas públicas.

Código JEL: Q25 – Agua; Q28 – Política Pública; R23 – Características de las viviendas.

1. Introduction

The so-called "Day Zero" is a term coined to describe the moment when access to (fresh and potable) water is exhausted and becomes irreversible. This scenario has become increasingly concerning in recent years, as it appears to be approaching more rapidly, both internationally and nationally. For instance, in the case of Mexico, there is an alarming situation regarding water access in several regions throughout the country, from the north to some areas in the center and south (Coparmex, 2024).

Due to this situation, there is an urgent social need for actions that ensure access to this vital resource and promote the changes and improvements necessary to secure economic and social development and, above all, human survival. According to the National Water Plan 2024–2030, the main objective framed as a human right is to provide water in both quality and quantity in a safe manner, thereby enabling the sustainability of resources through more objective and responsible water management.

Access to clean and safe water leads to improved levels of health and well-being. However, uncontrolled population growth, persistent droughts, and the lack of efficient water collection systems have significantly reduced water availability over the past 60 years. "Clean Water and Sanitation" is one of the Sustainable Development Goals (SDGs) introduced by the United Nations General Assembly in 2015 (Agenda 2030). Numerous countries, including Mexico and specifically the state of Chihuahua have made commitments to achieve these goals, integrating the SDGs with the State Development Plan. According to a recent report, despite the 2030 SDG goals, progress in water management has been limited, with a global SDG index score of 54 out of 100 far from meeting Goal 6.5, which states: "the implementation of integrated water resources management at all levels..." (United Nations, 2023).

According to the Mexican Institute Competitiveness (IMCO, 2023), the distribution of water consumption is as follows: 76% is used in agriculture, livestock, and aquaculture; 15% is allocated to public supply, which includes businesses, commerce, households, and services connected to the public network; and the remaining percentage is used by thermoelectric plants and selfsupplied industries. Given the importance of this vital resource, many studies in recent decades have focused on analyzing the current situation related to network services, storage, distribution, as well as problems and their potential causes and short-term solutions. In fact, López (2017) identified that a large part of Mexico's water problems stem from the fact that settlements and main economic activities are located in the country's most water-scarce regions.

In 2017, the National Institute of Statistics and Geography (INEGI) published the Household and Environment Module (MOHOMA) of the National Household Survey (ENH), representative only at the national level. Notable among the findings are the results on water supply methods and perceptions of the potable water network system. Likewise, the National Survey of Household Income and Expenditure (ENIGH), also published by INEGI (2022), allows for national and statelevel analysis of household water availability, especially the supply of potable water. However, in both cases, there is no municipal-level data, making it necessary to assess water supply and household perceptions of water management in the municipality of Hidalgo del Parral.

Therefore, the objective of this study is to gather and analyze statistical information on the current water situation in Hidalgo del Parral, Chihuahua, to provide an overview of cost, consumption, and evaluation of public water service, among other characteristics. This contributes to maintaining an updated descriptive framework of the conditions and perceptions of potable water consumers. Accordingly, this document is divided into four sections. The first contains this introduction; the second presents the contextual and referential framework, which includes the argument of climate change and the water situation in Parral; the third section explains the data and methodology used in the research; the fourth presents the results analysis, and finally, the last section offers the conclusions.



2. Contextual and referential framework

In recent years, studies on the global water situation have focused on analyzing possible short- and medium-term scenarios related to water availability and access. However, according to Toledo (2002), after conducting a planetary water balance, he identified that less than 1% of freshwater is actually available for human consumption. This finding aligns with Simonovic (2000), who, through various international organizations, projected that by the year 2025, two-thirds of the global population would experience direct consequences and stress related to water scarcity. A 2023 study by IMCO also revealed that from 1960 to 2020, water availability has decreased significantly, dropping from an average of 10,000 cubic meters to just 3,200 cubic meters. This problem has been worsened by population growth, increased droughts, and more frequent extreme weather events.

According to Pacheco (2014), the governance of common goods such as water has been studied based on the work of Elinor Ostrom (1990), which has inspired research from various disciplines and perspectives, helping to build a multidisciplinary reference framework enriched by case studies and theoretical foundations. In Mexico, the issue of water has been examined from general perspectives (Ávila, 2003; Peña, 2006; Ávila, 2008), as well as through studies focused on community management and social participation in decision-making within a sustainability framework, such as the work of Guerrero-De León et al. (2010) and Sandoval and Günther (2013).

The study by García et al. (2013) analyzes the perception of scarcity risk and awareness among individuals regarding the potential shortage of water resources. Meanwhile, the analysis of institutional capacity or water governance through public policies has been addressed by authors such as Domínguez (2010), in the case of Veracruz, and Salcido et al. (2010), for the state of Jalisco, emphasizing the importance of citizen participation in decision-making.

Overview of the water situation in the context of climate change

The state of Chihuahua is the largest state in Mexico, accounting for 12.6% of the national territory, with a significant economic activity.

According to the 2023 annual report on Science and Technology for Mexican Agriculture by the National Institute of Forestry, Agricultural, and Livestock Research (INIFAP, 2023), the agro-industrial GDP contributed approximately 11% to the total, with a cultivated area of 1.12 million hectares, 51% of which was irrigated. Chihuahua ranks nationally in the production of apples, yellow corn, cotton, pecans, jalapeño peppers, alfalfa, forage oats, beans, onions, and peanuts. This information on cultivated area is relevant in relation to water availability, which depends on both surface and groundwater sources.

The water situation in the state is marked by sharp contrasts; it records the lowest average annual precipitation. According to data published by the National Meteorological Service, in 2024, Chihuahua was the third state with the lowest rainfall, following Baja California Sur and Baja California, with an average annual precipitation of just 20.4 mm. Figure 1 visually illustrates the average precipitation levels for the year 2024.

According to Cervantes (2019), the state of Chihuahua has committed to addressing the challenges of climate change through the 2030 Agenda for Sustainable Development by modifying its legislation to align with the Sustainable Development Goals (SDGs) established by the United Nations since 2015. The State Climate Change Program (PECC) presents a general descriptive analysis of the state's characteristics, a detailed quantification of greenhouse gas emissions, mitigation scenarios, and a vulnerability and adaptation analysis to climate change. It includes data on extreme weather events, droughts, and wildfires. The PECC (2019) provides a detailed summary of the state's hydrological regions and the watersheds that supply its water resources.

Water study in Hidalgo del Parral

Hidalgo del Parral is a municipality located in the southern part of the state of Chihuahua, which, according to the Population and Housing Census, had a total of 34,570 households and a population of 116,662 inhabitants as of 2020. This made it the fifth most populated municipality, following Ciudad Juárez, Chihuahua City, Cuauhtémoc, and Delicias, respectively. Additionally, it has been characterized as the economic leader among the municipalities of southern Chihuahua, including the region of Valle de Ignacio de Allende, Matamoros, Santa Bárbara, San Francisco del Oro, among others.

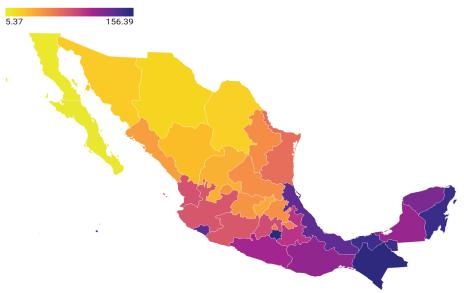


Figure 1. Annual precipitation by Federal Entity, 2024

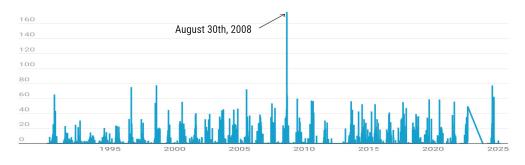
Source: Own elaboration based on data from the National Meteorological Service, National Water Commission

On the other hand, according to 2018 data published by the Government of the State of Chihuahua, the municipality of Hidalgo del Parral sources its potable water from 21 underground sources and 1 surface source. However, the overexploitation of aquifers and persistent droughts in the state have caused significant challenges in accessing potable water for the residents of Parral, leading to supply issues for the city.

According to the 2023 Annual Report from the National Institute of Forestry, Agricultural, and Livestock Research (INIFAP), the year 2023 was marked by a significant decrease in precipitation, severely affecting the state of Chihuahua and, in

particular, Hidalgo del Parral. Graph 1 presents the historical record of daily rainfall for station 8305. An increase in rainfall volume can be observed, but with more widely spaced occurrences, which negatively impacts aquifer recharge. However, the available data published by this administrative unit does not allow for a comparison with the Climatological Normal for Hidalgo del Parral, hindering thorough analysis and decision-making. In addition, Cervantes and Dévora (2019) argue that in Hidalgo del Parral, water use is distributed among agriculture, livestock, commerce, and services. Although water rates are among the lowest in the country, only 43% of the cost of extracting water from aquifers is recovered.

Graph 1. Daily precipitation, Station 8305, Parral, Chihuahua



Note: Precipitation in millimeters (mm).

Source: Own elaboration based on data from the National Water Commission, General Directorate of the National Meteorological Service. Historical daily records. Station 8305, Name: Parral, Municipality: Hidalgo del Parral, Chihuahua.



3. Methodology

Data collection

This section explains how the data were collected to analyze statistics related to the current water situation in households within the municipality of Hidalgo del Parral, Chihuahua. First, a survey was developed that included sociodemographic and economic aspects of the households. Additionally, questions were incorporated based on the National Household Survey (2017), specifically from the Household and Environment Module (MOHOMA) by INEGI. Second, for the sampling process, the total number of occupied private dwellings reported in the 2020 Population and Housing Census was used as a reference specifically in the urban area, totaling 34,570 households. Subsequently, Equation 1 was applied to ensure population inferences:

$$n = \frac{z^2 q DEFF}{r^2 p (1 - t n r)} \tag{1}$$

Where:

n = sample size

p = estimated proportion of interest

q = 1 - p

r = maximum expected relative error

z = z-value from statistical tables that ensures the desired confidence level

DEFF = design effect, defined as the ratio of the variance in the estimation using the employed sampling design to the variance obtained with simple random sampling for the same sample size

tnr = expected non-response rate

For the calculation of Equation 1, the following values were used:

p = 0.5, a maximum relative error of 0.11, a z-value corresponding to 95% confidence; when the DEFF value is unknown, a value of 1.44 is used, based on the methodology of the 2020 Population and Housing Census. A 5% non-response rate was applied. After inserting these values into the formula, a total of 481 surveys was obtained, which was rounded up to 500. This represented 1.44% of the total number of households. Finally, a weighted stratification was applied based on the Basic Geostatistical Area (AGEB), which was obtained from

the National Institute of Statistics and Geography (INEGI). It is important to note that each AGEB includes data on the number of occupied private dwellings, total population classified by age, among other relevant features for decision-making. Map 1 shows the distribution of the AGEBs considered for the sampling, while Map 2 displays how the surveys were implemented across the city of Hidalgo del Parral, weighted by AGEB.

Finally, each household was randomly selected by blocks and streets within each AGEB. The interviews were conducted face-to-face in each of the 500 selected households. In each household, individuals aged 18 or older who were knowledgeable about the questions were considered. To verify both water payments and consumption, respondents were asked to have their water bill on hand during the interview.

Map 1. Distribution of AGEBs in the city of Hidalgo del Parral, Chihuahua



Source: Own elaboration based on GOOGLE Earth and the AGEB classification by CONEVAL (2020).

Map 2. Distribution of surveys weighted by AGEB.



Source: Own elaboration based on Google My Maps and the survey results database.



4. Results

Among the most relevant results, it stands out that of the 500 households surveyed, 52.3% of respondents identified themselves as the head of the household, of which 59.8% were women. The average age was 51.5 years, and the average years of schooling reached 11.5 years, approximately equivalent to the second year of high school.

Fortheanalysis of the water situation, Table 1 presents variables of monthly payment, consumption, and willingness to pay based on income classification by deciles; that is, decile I includes households with the lowest income levels, while decile X comprises those with the highest incomes. It was found that monthly payment does not show a clear positive relationship with income deciles for example, households in decile I pay about 49.00 pesos more than households in decile V. However, there is a clear trend between monthly payment and water consumption: as water consumption increases by decile, the monthly water payment also increases. Regarding willingness to pay which measures the percentage change between what households currently pay and what they are willing to pay above the bill it shows that, regardless of household income level, they are willing to pay an average of 16% more for having constant water supply 24 hours a day. For example, households in decile VIII would pay up to 46% more, while decile IX only 6.3%.

A more detailed analysis of the dispersion between water payment and consumption is shown in Graph 2, which implies that there is a more exponential than linear trend between these

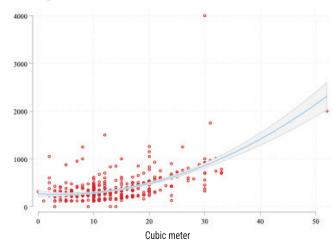
Table 1. Classification of water payment and consumption by decile

Decile	Monthly payment (in pesos)	Consumption m ³	Willingness to pay (%)
I	\$369.08	11.01	16.4
II	\$354.45	13.88	12.6
III	\$451.42	13.91	17.5
IV	\$336.65	11.63	13.2
V	\$320.41	11.07	13.4
VI	\$434.00	14.65	10.0
VII	\$384.45	14.17	15.0
VIII	\$325.63	13.81	46.0
IX	\$345.30	11.10	6.3
X	\$433.02	26.09	28.0
Total	\$378.15	13.50	16.0

Source: Own elaboration based on the survey results on water supply and consumption in households in the city of Hidalgo del Parral, 2024.

two variables. This means that water payment is not proportional to consumption, resulting in a form of consumption restriction.

Graph 2. Monthly household payment vs. monthly consumption

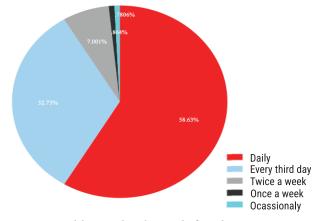


Note: The trend curve was estimated with a 95% confidence interval using STATA 17.1 software.

Source: Own elaboration based on results from the survey on water supply and consumption in households of the city of Hidalgo del Parral, 2024.

On the other hand, the main source of water supply within households comes from the public network (99.1%), a statistically similar result to that reported by the Population and Housing Census sampling by INEGI (2020). Regarding water billing, 87.3% is measured through a meter, 12% by a fixed fee, and about 1% do not pay for water. Graph 3 shows the frequency of water delivery to homes. These results are similar to those published by various local media outlets referring to "tandeo" (scheduled water rationing), which affects approximately 28 neighborhoods (Murillo, 2025).

Graph 3. Water delivery to households.



Source: Own elaboration based on results from the survey on water supply and consumption in households of the city of Hidalgo del Parral, 2024.



Table 2 represents the percentage ratings of aspects of the public water service, except for the last column, which shows the average rating of the service aspects (where 1 is the lowest rating poor and 5 is the highest excellent). The data show that the highest percentage concentration was for customer service at 48.6%, followed by supply pressure at 40.7%, both in the "good" category. Meanwhile, the "poor" rating was most frequent for leak repairs at 22.5%, followed by trust regarding health at 20.2%. However, when considering the lowest ratings (poor and deficient), trust regarding health accumulated a total of 38.2% of households, which is higher than that of leak repairs.

from the tap, and the remainder use other methods. Among those who consume bottled water, 68% responded that they do so because it is healthier. On the other hand, the average monthly expenditure on bottled water was 320.00 pesos; however, when classified by income levels (deciles), the amount ranges from 249.00 to 433.00 pesos in the lowest and highest deciles, respectively.

Regarding water-saving mechanisms, 34.7% save water by using toilets with water-saving tanks, and 9% use a device designed to conserve water; 28.1% used water-saving showerheads or faucets, and only 3.6% used other water-saving mechanisms.

Table 2. Rating of aspects of the public water service

	Poor	Deficent	Regular	Good	Excellent	Mean
Taste, odor, clarity of water	12.30%	12.70%	33.70%	30.40%	10.90%	3.15
Trust regarding health	20.20%	18%	26.50%	31.10%	4.20%	2.81
Supply pressure	7.50%	14.60%	26.10%	40.70%	11.10%	3.33
Continuity of supply	14.40%	20%	22.50%	30%	13.10%	3.07
Amount charged	12.80%	16.80%	30.40%	29.50%	10.50%	3.08
Measurement of water consumption	10.40%	20.80%	27.80%	30.50%	10.40%	3.09
Customer service at offices	11.80%	12%	21.80%	48.60%	5.80%	3.24
Leak repair	22.50%	13.30%	27.35	32.50%	4.40%	2.83

Source: Own calculations based on results of the Water Survey in Parral, 2024.

In fact, in the case of continuity of supply (see Table 2), 34.4% of households rated it as poor or deficient, and 22.5% rated it as regular; that is, about 58% disapproved of the service. These results confirm that water is not available every day or is supplied only through rationing ("tandeo"). For example, 24 neighborhoods suffer from interrupted supply, with some lacking water for up to 15 days. For a more specific analysis, results were analyzed by AGEB (see Table 3), calculating average ratings for each service (where 1 = poor and 5 = excellent), and AGEBs were ordered from lowest to highest rating. It was found that water service ratings were much lower in those AGEBs (the first 13 in total) that include neighborhoods where water is supplied by rationing (every third or fourth day, or even every 15 days). Similarly, the continuity of supply service had failing ratings in these same AGEBs.

Continuing with the survey results, regarding the sources of drinking water (potable water), 87.4% purchase bottled or jug water, 11% consume directly

Finally, the rest of the water-saving practices within households are shown in Graph 4.

5. Discussion and conclusions

In Mexico, the issue of water has become a priority considered even a matter of national security as it is seen as a key element within social and economic development policies. Access to water ensures development across various regions of the country and, fundamentally, its quality supports health conditions that improve the general well-being of the population (CONAGUA, 2006). According to the United Nations Sustainable Development Goals Progress Report (2023), there has been global improvement in water quality and sanitation. However, guaranteed access to water remains conditioned by external factors such as recurring droughts, aquifer overexploitation, and the state of local infrastructure.

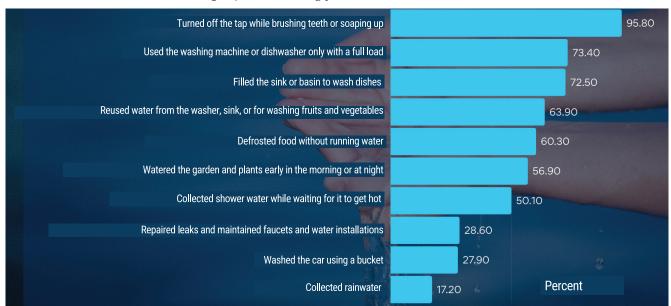


Table 3. Average rating of aspects of the public water service by AGEB.

AGEB	Taste	Trust	Pressure	Continuity	Amount paid	Water measurement	Custom service	Leak repairs	Mean
1441	1.0	1.0	1.5	1.5	2.0	1.5	1.0	1.0 1.0	1.3
725	2.1	1.5	2.5	1.8	2.2	2.2	2.3		2.0
655	2.3	1.4	2.5	2.0	2.1	2.3	2.5	1.0	2.0
1422	2.3	2.7	3.0	1.2	2.3	1.6	2.0	1.0	2.0
1371	2.0	2.3	1.6	1.8	2.5	2.3	2.8	2.3	2.2
674	1.4	1.6	3.0	2.0	2.2	2.6	2.8	2.3	2.2
975	2.6	2.7	2.0	1.5	1.5	2.3	3.6	•	2.3
098A	2.2	1.8	2.4	2.2	2.2	2.4	3.8	2.3	2.4
1297	3.0	3.0	2.5	1.5	2.0	2.5	2.5	2.3	2.4
689	2.0	1.8	3.2	1.5	1.5	3.0	3.4	3.0	2.4
1206	2.7	1.7	2.7	2.7	3.3	3.3	1.0		2.5
1070	2.6	2.0	2.7	2.7	2.0	2.1	3.0	3.0	2.5
693	2.2	1.8	3.4	2.1	3.0	2.8	3.0	1.8	2.5
1189 640	2.0	2.2	2.9	2.5	2.4	2.5	2.9	2.8	2.5
1282	2.5	2.4	2.8	2.3	2.9	2.7	2.9	1.7	2.5
066A	2.4	2.6 1.8	3.7	1.4	2.0	2.0	3.3	3.1	2.6
	2.1		3.2	2.0	2.4	2.6	3.7	3.0	2.6
636	2.2	1.4	2.7	2.5	3.4	3.5			2.6 2.8
041A	2.4	1.6	3.7	3.7	2.8	2.6	2.4	3.0	2.8
763 710	2.3	2.4	2.7	3.0	2.7	2.2	3.6	3.5	
710	2.7	2.5	3.1	2.2	2.9		3.9		2.9
073A 778	2.4	2.1	3.6 2.8	3.5		2.9	2.7 3.6	3.0	2.9
1085	2.5	2.7		3.4 1.8	2.9 2.6	2.1		3.1	2.9
	3.0	3.1 2.6	3.4			3.7	3.7	2.2	2.9
994 528	3.0	2.8	3.0	3.3	3.1	2.2	3.0	3.3 1.6	2.9
	3.2 2.6	2.6	3.8 3.8	3.5	3.2	2.8	3.1		3.0
513				3.0 3.6	3.2		3.0 2.6	3.3 2.8	3.0
392	3.6	3.5	3.0		3.0 2.8	2.4			3.1
405 1348	2.7	2.7	3.2	3.2 2.1		3.2	3.5	3.4	3.1
509	3.3 3.6	3.1 3.6	3.1	3.8	3.4	3.3	3.3 2.8	3.0 2.2	3.1
			3.3 4.0		3.1	2.7	1.0	1.5	3.1 3.2
547	4.3	4.0	3.0	3.3 3.2	3.3 2.8	4·5 2.6		_	_
1047	3.9 3.6	3.5 3.6	3.6	3.0			3.7 3.2	3.7	3.3
744 602	3.8	3.1	3.8		3.0	3.2 3.0	_	3.2	3.3
759	2.8	3.1	3.6	3.9 2.4	3.4 3.3	3.9	3.3 4.2	2.3 3.3	3.3 3.3
1193	3.0	3.0		,	3.0		4.0		3.3
	2.8	3.2	3.7 2.8	3.3 4.6	3.4	3.3			
373 1028	3.8	2.6	3.8	4.2	3·4 4.1	3.4 4.0	3.3 1.0	3·3	3.3
1066	3.7	3.2	3.5	3.4	3.4	3.6	3.6	2.6	3·4 3·4
458		_							
1174	4·3 3·9	1.4 1.8	3.4 3.1	3.9 3.0	3.2 3.9	3·5 4·1	4.0 2.5	5.0	3.4 3.4
1136	3.8	3.8	3.0	2.5	3.9 3.5	3.5	3.8	3.8	3·4 3·4
116A	4.1	3.2	3.9	3.5	3·3	3.6	3.0	3.0	3.4
059A	4.1	4.0	3.9	2.9	3·3	3.5	3.0	2.9	3·4 3·5
424	3.4	3.6	3.8	4.0	3·7 3·7	3.2	3.8	3.0	3.6
388	3.8	3.6	3.4	4.0	3.8	3.6	4.0	2.6	3.6
551	3.8	3.8	3.8	3.7	3.5	3.5	3.6	3.5	3.6
1051	4.3	4.2	4.3	3.8	3·3 3·4	3.1	3.1	3.0	3.6
1013	4.0	4.3	3.8	4.1	3.2	3.6	3.3	3.2	3.7
532	3.4	3.2	4.0	4.0	3.8	3.8	3.6	3.6	3·7
782	4.0	4.0	3.9	3.9	3.7	3.7	3.2	3.2	3.7
1032	4.0	4.0	3.9 4.3	4.0	3·7 3·5	3·5	3.3	3.3	3·7
1009	3.5	3.9	4·3 3·3	4.0	3.8	3·5	3·3 4.0	3·3 4.0	3.7 3.8
1352	3·5 4.0	3.9 4.0	3·3 4.0	2.0	4.0	3·3 4.0	5.0	4.0	3.9
462	4.1	2.9	4.0	3.9	3.5	3.8	5.0	4.0	3.9
	4.6			3.9 4.6			2.0	4.0	
443 570		3.5	4·5		4.1	4.3			3.9
	4.1 4.7	3.3 2.7	3.7 4.3	4·3 4·7	4.2 4.7	4·4 4·7			4.0 4.3
1437				4./	4./	4./			4.3

Source: Own elaboration based on the results of the Water Survey in Parral, 2024.





Graph 4. Water-saving practices within households

Source: Own elaboration based on the survey results on household water supply and consumption in the city of Hidalgo del Parral, 2024.

Against this backdrop, the need emerged to analyze the current water situation in one of the most vulnerable areas in northern Mexico the so-called "big state" specifically, the city of Hidalgo del Parral. The data collected provided insight into the water situation in terms of supply, quality, price, and other relevant variables.

Based on the survey results, it was found that monthly payments tend to have a more exponential than linear relationship with water consumption. This suggests that citizens are more careful with their water use due to its cost. Although the weak correlation between consumption and income levels may suggest that water is not excessively expensive, households expressed a willingness to pay an average of 16% more than their current water bill to ensure 24-hour daily water availability. This finding aligns with studies by Vásquez et al. (2009), who concluded that households have a payment capacity between 1.8% and 7.5% of their reported income.

Households' perceptions of public water service suggest an inequitable distribution of water. This is mainly due to the fact that supply sources or wells vary across city zones, meaning each sector depends on different water sources. Consequently, certain AGEBs (Basic Geostatistical Areas) are more affected than others, impacting their service ratings. However, a high percentage rated the flavor, smell, and clarity of the supplied water

positively, with about 42% scoring it as good or excellent. Nonetheless, a lack of trust in its safety persists, as reflected in the 87.4% of households that purchase bottled water, spending around \$320 pesos per month.

The availability and access to potable water through the public network are fundamental for household well-being. In the case of Hidalgo del Parral, the water issue is becoming more severe. Of the 70 neighborhoods included in the survey, 20% still rely on a rotation-based system to access water every third day or weekly. Corona and Miranda (2024) demonstrated that households with less water availability face limitations in carrying out basic activities, often leading to increased unpaid labor. This confirms that households are negatively impacted by a lack of access, which indirectly affects other aspects of well-being among household members.

Finally, there is still a lack of widespread education and culture around water conservation. However, households have gradually adopted basic practices to protect water, such as using faucets efficiently, reusing water, and following designated watering schedules for gardens. These efforts, though, must be supported by clear directives from the Municipal Water and Sanitation Board of the State of Chihuahua (JMAS).

The results of this research fulfill the objectives outlined at the beginning of the document, which



aimed to describe the current water situation in Hidalgo del Parral, Chihuahua. The findings serve as a reference to issue the following public policy recommendations to support efficient and effective decision-making toward solving the problems identified in the survey.

Policy recommendations

The State Development Plan 2022–2027 includes, under Axis 3: Modern and Sustainable Territorial Planning, a focus on integrated water management. To ensure the right to water, four strategies and their corresponding lines of action are proposed, aimed at increasing water collection, improving infrastructure, and promoting proper water use. However, the plan lacks a clearly defined diagnostic action line to assess the current situation.

Within the action line titled: "Encourage water sector governance and governability at the federal, state, and municipal levels with society's involvement", it is recommended to:

- 1. Support scientific research on water issues to broaden and deepen the diagnosis of the local water situation from a multidisciplinary perspective, covering various aspects related to water management.
- 2. Conduct ongoing studies in neighborhoods affected by water scarcity to improve decision-making for more efficient water supply support.
- 3. Challenge the belief in fixed rates; people are indeed willing to pay variable rates, allowing for more targeted billing proposals.
- 4. Charge higher rates in neighborhoods with daily water access to help subsidize support for communities facing water shortages.
- 5. Improve customer service to provide quicker and more objective responses.
- 6. Streamline the complaints process at the Municipal Water and Sanitation Board (JMAS).
- 7. Develop awareness programs about water issues to promote water conservation and strengthen JMAS's public image and service among residents of Parral.

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RESEARCH

Ergonomic design of a sequencing workstation in an automotive manufacturing process

Diseño ergonómico de una estación de trabajo de secuenciado en un proceso de manufactura automotriz

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Abstract

Ergonomics has gained importance in modern industry as a key tool to optimize workplace well-being and productivity. This study presents an ergonomic redesign of a workstation in an automotive plant, aligned with the guidelines of the Mexican standard NOM-036-STPS-2018, related to the manual handling of loads. Analytical tools such as RULA, REBA, Sue Rodgers, and the NIOSH equation were used to identify critical postures and physical loads associated with material handling (fuel tanks), taking into account factors such as applied force, frequency, and task duration.

The project positively impacted the reduction of ergonomic risks and the prevention of musculoskeletal disorders (MSDs) among workers. The results highlighted the need to incorporate specific ergonomic aids and solutions for the workstation, which reduce or eliminate direct manual load handling. Furthermore, caloric expenditure studies and the RAPP Tool confirmed that the tasks can be performed within safe physical

limits. The redesign of the work sequence not only ensures compliance with current regulations but also promotes a safer working environment, minimizing injury risk and enhancing operational efficiency.

Keywords: ergonomics, manufacturing, workstation design, manual material handling.

JEL Codes: J81, L62, M54, O14

Resumen

La ergonomía ha cobrado relevancia en la industria moderna como una herramienta clave para optimizar el bienestar laboral y la productividad. Se presenta un estudio enfocado en el rediseño ergonómico de una estación de trabajo en una planta automotriz, bajo los lineamientos de la norma mexicana NOM-036-STPS-2018, relativa al manejo manual de cargas. Se utilizaron herramientas de análisis como RULA, REBA, Sue Rodgers y la ecuación NIOSH para identificar posturas críticas y cargas físicas asociadas a la manipulación de material (tanques de combustible), considerando factores como fuerza



aplicada, frecuencia y duración de la actividad.

Se logró impactar positivamente en la reducción de riesgos ergonómicos, así como en la prevención de trastornos musculoesqueléticos (TME) entre los trabajadores. Los resultados evidenciaron la necesidad de incorporar soluciones y ayudas ergonómicas específicas para la estación de trabajo, las cuales reducen o eliminan la carga manual directa. Además, los estudios de gasto calórico y RAPP Tool confirmaron que las tareas pueden realizarse dentro de los márgenes de seguridad física permitidos. El rediseño de la secuencia de trabajo no impacta únicamente el cumplimiento de la normativa vigente, también promueve un ambiente de trabajo más seguro, minimizando el riesgo de lesiones e incrementando la eficiencia operativa.

Palabras Clave: ergonomía, manufactura, diseño de estaciones, manejo manual de cargas.

Códigos JEL: J81, L62, M54, O14

Introduction

Currently, organizations particularly those in industrial processes recognize the positive impact of ergonomics on productivity, occupational safety, increased job satisfaction, and cost reduction. As a result, the consideration of human factors provided by this branch of engineering has become essential in the design of production processes, contributing to the creation of healthier, more efficient, and more productive work environments for employees.

The study of ergonomics is not new; however, its recognition as a scientific discipline began in the 1940s (Torres & Rodríguez, 2021). During the same decade, Mexico established the Secretaría del Trabajo y Previsión Social (STPS), aimed at ensuring compliance with labor rights and improving workers' quality of life. Currently, there are 41 active Mexican Official Standards (NOMs) related to occupational health and safety, classified into five areas: safety, health, organization, specific, and product-related standards.

In 2018, the STPS issued NOM-036-1-STPS-2018, which outlines the requirements to identify, analyze, prevent, and control ergonomic risk factors in workplaces resulting from manual load handling, with the goal of preventing health impairments (Secretaría del Trabajo y Previsión Social, 2018).

The publication of this regulation necessitated significant changes in many processes involving such activities. Although it was published in November 2018, full compliance was granted a grace period until March 31, 2024.

An assembly line, also known as a production line, is a manufacturing process in which a product is assembled sequentially through various workstations, each responsible for a specific task. At each station, components are added or operations are carried out until the semi-finished product moves to the next stage.

This research was conducted at a stamping and assembly automotive plant, where the final assembly processes include work sequences that require manual load handling, a situation common across many operations in the automotive industry (Bahramian et al., 2021).

The objective of the research is the ergonomic design of a sequencing workstation. This involves the integration of a secondary element into a variant of the main assembly in a pre-established sequence within the production flow, using ergonomic aids that allow personnel to handle and move the product safely and in accordance with ergonomic principles. The design also ensures compliance with Mexican regulations and the specific standards required by the automotive manufacturer, aiming to minimize the risk of musculoskeletal disorders (MSDs) and related injuries.

Theoretical Framework

2.1 Occupational risks

S According to data from the International Labour Organization (ILO, 2011a), approximately 160 million people worldwide suffer from non-life-threatening illnesses and injuries each year due to work-related activities. Technological advancements, social transformations, and economic changes have created new challenges and exacerbated existing ones, with a significant proportion related to musculoskeletal disorders (MSDs).

Nationally, statistics from the Mexican Social Security Institute (IMSS) show that in 2020, there were 4,315 cases of osteoarticular diseases in Mexico, accounting for 42.35% of all work-related health conditions. The primary cause of these cases



was identified as inflammatory back conditions. Furthermore, a study conducted by the National Rehabilitation Institute (2014) on patients with musculoskeletal pain revealed that 11.5% of the 3,508 individuals surveyed performed manual labor as machine operators, mechanical artisans, or installation operators.

Hazardous working conditions such as lifting heavy objects, exposure to vibration, awkward postures, neck twisting, and high-repetition tasks cause musculoskeletal disorders. These injuries affect the musculoskeletal system and joints due to the high physical demands arising from inadequate workspace design or work methods (Jirapongsuwan et al., 2023). MSDs impact bones, muscles, joints, tendons, ligaments, nerves, and blood vessels.

2.2 Egronomics

Ergonomics is the discipline that analyzes work in relation to the environment and the people performing it. It is based on principles of human physical and psychological capabilities to adapt or design equipment, tools, and workspaces to reduce the risk of injuries and illnesses, improve efficiency, and enhance quality of life in the workplace (ILO, 2011b). Although its formal conception dates back to 1949 (Lehto & Landry, 2012), its relevance has steadily grown in industrial contexts.

2.3 Regulations for evaluating manual load risks

An occupational risk refers to the likelihood of a worker suffering harm to their health or physical integrity due to work activities. Such harm may include diseases, injuries, or conditions caused by work environment factors, chemical agents, physical hazards, or psychosocial elements. As progresses industrialization and technology becomes more embedded in production systems, positive contributions have emerged. However, this fast pace has also led to an increase in MSDrelated illnesses. Handling materials, tools, and machinery has contributed to workplace accidents (Simsek & Turhan, 2023), negatively impacting process efficiency and resulting in worker absences (Safaeian et al., 2021).

In response, international regulations have been established, including ISO-11228-1 (2021) and HSE (Health and Safety Executive, 2020), which set guidelines for safe manual lifting, recommending

maximum loads of 25 kg. Similarly, the U.S. National Institute for Occupational Safety and Health (NIOSH) sets the limit at 23 kg (2021).

In Mexico, NOM-036-STPS-2018 defines the necessary elements to identify, evaluate, anticipate, and manage ergonomic risks associated with manual load handling in workplaces. This standard applies to tasks involving loads of 3 kg or more that are handled more than once per day, setting the manual handling limit at 25 kg. Its implementation requires considering preventive measures such as applied force, vertical and horizontal transport distances, frequency of movements per minute, total task duration, and body postures during the activity (STPS, 2018).

Additionally, several methods are used to evaluate postural load: RULA (Rapid Upper Limb Assessment), it analyzes critical postures during assembly work. It evaluates Group A (arm, forearm, and wrists) and Group B (legs, trunk, and neck) on both the right and left sides (Diego-Mas, 2015a). REBA (Rapid Entire Body Assessment): Complementary to RULA, it analyzes the entire body, including the upper limbs, trunk, neck, and legs, and considers static muscle activity and force exerted (Diego-Mas, 2015b; Yazdanirad et al., 2018). NIOSH Lifting Equation: Assesses the risk of MSDs using seven task-specific parameters (Diego-Mas, 2015c; NIOSH, 2021). Sue Rodgers Method: Evaluates muscle effort levels, effort duration before rest, and activation frequency per minute, predicting muscular fatigue based on task duration and posture (Rodgers, 1988).

2.4 Caloric expenditure estimation

The American Medical Association (AMA) does not prescribe a single formula for estimating caloric expenditure but endorses scientifically validated methods for calculating Basal Energy Expenditure (BEE) and Total Energy Expenditure (TEE) (AMA, 2008). BEE represents the number of calories the body requires at complete rest to maintain vital functions such as breathing, heart rate, and body temperature. The Mifflin-St Jeor formula is one of the most accurate for BEE estimation (Mifflin et al., 1990). TEE is then calculated by multiplying BEE by a physical activity factor ranging from 1.2 (sedentary) to 1.9 (very active). Other influencing factors include body composition, physiological state, age, sex, and thermogenesis from food intake (AMA, 2008).



2.5 Related studies

In a study by López and Martínez (2019), workers on a home appliance assembly line in Spain performed manual lifting and transporting tasks. Pneumatic assist devices were implemented to lift components, work surface heights were adjusted, and a task rotation scheme was introduced. These interventions reduced the RULA risk score from 7 to 3, corresponding to a change from very high to low-moderate risk.

Martínez and González (2022) conducted a study on an automotive engine assembly line in Barcelona, Spain, where manual handling of components weighing up to 15 kg was performed. The NIOSH lifting index was reduced from 2.1 (high risk) to 0.85 (acceptable risk). This improvement was achieved through the introduction of mechanical lifting aids and the reorganization of tools and equipment within workstations to minimize workers' body twisting.

In the research by González and Herrera (2020), carried out in a motorcycle assembly plant in Colombia where engines and wheels were manually lifted, the assembly sequence and workstation layout were redesigned to reduce material handling and carrying distances. Additionally, height-adjustable work surfaces were introduced. These changes led to a reduction in lower back injury risk, minimized idle times, and significantly decreased the number of work-related disability cases due to lower back injuries.

Methodology

This study adopts a non-experimental approach. The research setting was observed in its natural environment without altering any variables (Fernández-Collado & Baptista-Lucio, 2014). The study was conducted over a six-month period, during which the production process operated under normal conditions. Observations were made across all three shifts in the final assembly area of an automotive stamping and assembly plant located in Hermosillo, Mexico. The sample included 80 observations/evaluations during this period. Operators included in the study were those assigned to the workstation under analysis, performing tasks that involve manual load handling and repetitive physical efforts. A design/redesign

method is proposed for workstations where manual handling activities occur (e.g., lifting, moving, pushing, holding), taking into account dimensional, environmental, and regulatory aspects. The methodology consists of five phases, described below:

3.1 Preliminary analysis

This phase involves a technical review of the characteristics and conditions under which tasks are performed at the workstation. The automotive manufacturer adheres to two types of regulations: Mexican Official Standards (NOMs)and its own internal standards and evaluation methods.

The first step was to analyze applicable Mexican standards. The STPS provides a web-based tool to identify relevant NOMs based on specific process characteristics (STPS, 2025), which are categorized into safety, health, and organizational standards. Organizationally, and for each type of manufacturing process, it is essential to identify the occupational safety and risk standards that must be met. The outcome of this analysis is a list of applicable standards and regulations to be considered in the design or redesign of the workstation.

3.2 Initial design

3.2.1 Problem Identification and Risk Conditions: Based on a review of internal (NOM) and external standards, the specific risks and issues associated with the task are identified.

3.2.2 Ergonomic Risk Assessment: Ergonomic risk factors to which workers are exposed are identified in order to guide appropriate workstation design.

3.2.3 Workstation Design: Considerations include the dimensions of the work area, anthropometric data, internal company standards, and applicable regulations.

3.2.4 Design of Tools and Support Devices: Ergonomic aids for lifting and manual handling specific to the assembly sequence are designed. These tools are developed in accordance with the standards identified in Phase 1, with a focus on mitigating identified risks through the ergonomic support elements of the workstation.

3.3 Design validation

With the risks already identified, proposed redesigns of workstation layout and prototypes of



ergonomic aids for manual handling and transport were developed and implemented.

A preliminary risk assessment was conducted using a checklist aligned with relevant NOMs and the automotive manufacturer's internal evaluation methods. Based on the assessment results, adjustments were made to both the work sequence and the physical layout of the station.

3.4 Implementation

This phase involved executing the redesign through detailed planning, including start and end times for each activity, workstation dimensions, environmental conditions, ergonomic aids, tools, and necessary process control softwareinstallations.

Upon completion, operators and supervisors were trained, trial production runs were conducted, and initial cycle times were calculated. Following this pilot phase, adjustments were made to station layout, work sequences, and ergonomic aids as needed.

3.5 Continous improvement

Based on issues identified in the initial design whether related to physical layout, environmental conditions, or ergonomic aids as well as problems discovered in the work sequence, it will be evaluated whether it is necessary to repeat the design process from Phase 1. This would aim to address overlooked risks or improve existing conditions.

Results

The assembly line processes two types of automotive units, which share the same platform; however, the main assembly component fuel tanks has minor variations between the two vehicle types. Figure 1 shows one of the types of fuel tanks.

4.1 Preliminary analysis

4.1.1. General standards and regulations

To comply with Mexican regulations, NOM-STPS-036 (2018) regarding the manual handling of materials was considered. In terms of safety conditions, the following Official Mexican Standards were met:

• NOM-004-STPS: Protection systems and safety devices on machinery and equipment used in

Figure 1. Type 1 fuel tank



Source: Own elaboration

the workplace (1999)

- NOM-006-STPS: Handling and storage of materials (2014)
- Similarly, for the health approach, the following standards were taken into account:
- NOM-011-STPS: Safety and hygiene conditions in workplaces where noise is generated (2001)
- NOM-024-STPS: Safety and hygiene conditions in workplaces where vibrations are generated (2001)
- NOM-025-STPS: Lighting conditions in the workplace (2008)

4.1.2. Internal standards

Internal directives and standards were also taken into consideration. These relate to the company's own workstation design principles, mainly concerning shelf design, aisle (traffic) dimensions, minimum space for handling and supplying materials, and general dimensions of work areas. The starting point was a verification of the characteristics of similar workstations within the assembly line, along with a meeting with final assembly management to receive design recommendations.

4.2 Initial design

The initial design of the station's physical layout was developed (Figure 2), considering appropriate dimensions for efficient handling of the supply area where sequenced material is located towards the assembly cell for the tank to the vehicle unit. The size of the material packaging was adjusted

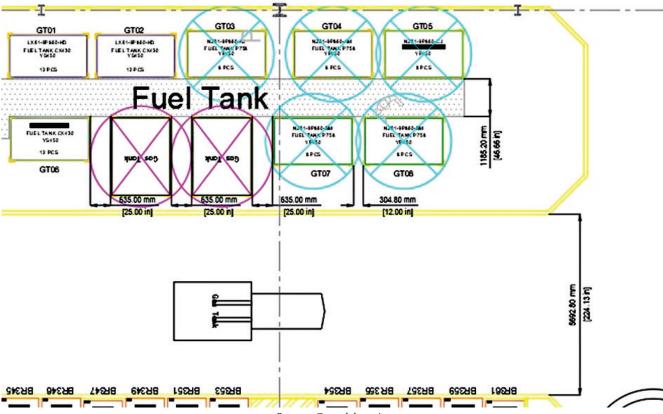


Figure 2. Physical layout of the workstation

to facilitate operations and minimize the physical effort required from the operators.

Prototypes of two sequenced transport and temporary storage devices were designed and manufactured for the types of fuel tanks to be installed in the two automobile models processed on the assembly line (figure 3).

Finally, an ergonomic aid prototype was designed and built (Figure 4), specifically to efficiently transfer material from the storage racks to the location where the vehicle will be for installation. This aid completely eliminates the need for operators to carry the material during transfer, thereby reducing physical effort and minimizing potential risks associated with lifting or manual

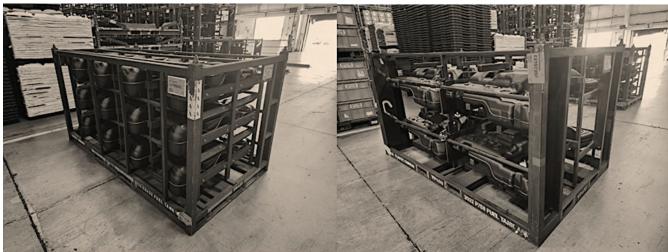


Figure 3. Temporary storage rack for fuel tanks. Designs 1 and 2

Source: Own elaboration



handling. To ensure smooth and easy movement of this device across the work area, the ergonomic aid was equipped with bearings that move along rails installed between the aisles designated for material traffic.

Figure 4. Ergronomic aid



Source: Own elaboration

4.3 Design validation

During this phase, ergonomic evaluations of the workstation were carried out over a trial period. In addition, feedback and improvement suggestions were gathered from operators and supervisory personnel, considering that at this initial stage the workstation had not yet been permanently incorporated into the production line.

4.3.1 Postural risk assesment – Sue Rodgers Method

A detailed analysis was conducted using the Sue

Rodgers ergonomic assessment method, which focused on evaluating the most demanding postures in the work sequence. Clearly, during the assembly sequence, the operator adopts various postures, among which the most hazardous were analyzed. The material handling process was precisely defined, taking into account both the posture required and the applied force. Based on this, it was determined that the sustained effort lasted less than 6 seconds, placing it within the recommended limits to prevent muscle fatigue.

However, it is important to note that the weight of the handled material (fuel tanks) ranges between 9 and 13 kilograms, which requires careful analysis of the physical load this represents for the workers involved in the task. The evaluation results are presented for the two products that will be processed at the workstation, along with images of the high-risk postures during the assembly sequence (Figures 5 and 6).

In the case of postural effort related to the handling of fuel tanks installed in model 1, it was found that the right shoulder is the most affected, with a score of 7, indicating significant strain. In addition, the arms and back showed sustained load with scores of 4, while wrists, hands, neck, and legs experienced lower levels of effort. The analysis highlights the importance of implementing breaks to reduce physical strain and prevent injuries.

The ergonomic study of the sequenced tank rack identified the shoulders as the most affected area, with a score of 7, reflecting high and sustained

Figure 5. Sue Rodgers anaysis for fuel tank model 1

E LYST	Sue Rodgers 3/9/2024 Paulina M Fuel tank	ergonomic a - -	nalysis	EFFORT TIME EFFORT EFFORTBY M		1=light 2=medium 3=high 1=<6 seconds 2=6 a 20 seco 3=20 a 40 sec 1=menos 1 per 2=1 a 5 per min 3=5 A 15 per min	nds conds minute aute
		effort					
MUSCLES	ванг	MEDIUM	HCH		POIN	ITS	-
NECK	Head partially turned to one side, slightly forward or back	Head to one side, fully back, approximately 20 degrees forward	Same as moderate plus a weight or force, head at reloted forward	1	1	2	1
SHOLDERS		多影	图	RH 3	1	2	7
	Arms slightly out to the sides; arms extended with some support	Arms away from the body, without any support, work above the head	Heavy efforts or weights held with arms away from the body or above the head	3	1	2	7
BACK	Learning slightly to one side or bending slightly; aroting the back	Bending forward without alload; lifting me derately heavy loads close to the birdy, working overhead.	Testaling while lifting or applying great forces, bending under heavy force or load	2	1	2	4
ARMS AND	315	8 A B	群岛	RH 2	1	2	4
ELBOW	Arms away from the body without load; lift objects with light effort close to the body	Rotate your arm white exerting moderate effort	Rotating the armivible exerting great effort: Iffling cojects with arms extended	ы 1	1	2	1
WRIST, HAND, AND	Sanding or walking without bending or	逐	m - 33	^{RH} 2	1	2	4
FINGERS	stooping, weight on bothlegs, pulling or pushing with little force and moderate posture	Finger grips with wide or narrow arm spacing; moderate wrist angles, flexion, use of glovies with moderate effort	Pincer grips, sharp angles at the wrists, slippery surfaces; pushing with excessive force.	н 1	1	2	1
LEGS Y ANKLES	Standing or walking without bending or	E ending, learning over at able, putting weight on one cide (weight en one leg).	1000	RH 1	1	2	1
	stocoing, weight on both legs pulling or pushing with little force and moderate posture	pivoting when applying force. Pushing or pulling with little strength or awww.ard posture.	Pulling or pushing with graat effort, bending down white making an effort	ы 1	1	2	1

Source: Own elaboration



Figure 6. Sue Rodgers analysis for fuel tank model 2

DATE: ANALYST: RK STATION:	Sue Rodgers ergonomic analysis 3/9/2024 Paulina Martinez 4 fuel tank P785					INUTE	1=light 2 = medium 3 = high 1 = <6 seconds 2 = 6 a 20 seconds 3 = 20 a 40 seconds 1 = menos 1 per minute 2 = 1a 5 per minute 3 = 5 A 15 per minute			
MUSCLES	na-u	ITENSIDAD DEL ESFUERZ	O HIGH			PUNT/	-		1	
NECK	Head partially turned to one side; slightly forward or back	Head to one side, fully back, approximately 20 degrees forward	BRR.		1	1	2	1	MADA	3 3 2 3 3 1 3 2 3 3 2 2
SHOLDERS	Arms slightly out to the sides; arms	Arms away from the body, without any	Heavy efforts or weights held with arms	RH	3	1	2	7	2	3 1 3
BACK	extended with some support Learing slightly to one side or bending slightly, arching the back	Support; work above the head Bending forward without a load; lifting mod erately heavy loads dose to the body.	away from the body or above the head Twist ing while lifting or applying great forces, bending under heavy force or load		1	1	2	1	DERADO	3 1 2 2 3 2 2 3 1 2 2 2 2 1 3
ARMS AND ELBOW	Arms away from the body without load; lift	Rotate your arm while exerting moderate	Rotating the armwhile exerting great	RH	2	1	2	4	1	1 2 3
WRIST, IAND, AND FINGERS	objects with light affort close to the body Standing or walking without bending or stooping, weight on both legs; pulling or pushing with little force and moderate	effort Finger grips with wide or narrow arm spacing, moderate wrist angles, flecion.	effort, lifting objects with arms extended Pincer grips, sharp angles at the wrist s, slopery surfaces, pushing with excessive	RH	1	1	2	1	2	2 1 1
LEGS Y ANKLES	posture Sanding or walking without bending or	use of gloves with moderate effort Bending, engage e. putting weight on one side (weight on one leg);	sippery surfaces, pushing with excessive force.	RH	1	1	2	1	W8 1	1 2 1
	stooping, weight on both legs; pulling or pushing with little force and moderate posture	pivoting when applying force. Pushing or pulling with little strength or awlovard posture.	Pulling or pushing with great effort, bending down while making an effort	Ш	1	1	2	1		1 1 1



effort due to a fixed posture with raised arms. The back, arms, and elbows showed moderate to high risk, with scores of 4 due to repetitive and continuous movements. In contrast, the wrists, hands, and fingers showed low effort with a score of 2, while legs and ankles experienced a moderate load with a score of 4 due to prolonged weight bearing. These results underscore the importance of adjusting posture and task duration to minimize ergonomic impact.

4.3.2 Caloric. expenditure

An Excel template was used to calculate caloric expenditure during the specific assembly sequence at the station, based on the method recommended by the American Medical Association (AMA). See Figure 7.

For the activity sequence in each cycle, arm movement was considered moderate, with displacements greater than 50 cm. Additionally, it was calculated that the operator walks approximately 8 meters per minute. The weight of the parts exceeds 5 kg. The task frequency (speed) was considered moderate. Finally, it was considered that material handling requires considerable effort when pushing or pulling with a force of 13 kg and a displacement of 1 meter per minute. Based on this data, the total metabolic expenditure for performing the task is 270.4 Kcal/hr, considering different activities such as arm movement (50 Kcal/hr), walking (16 Kcal/hr), task execution (52 Kcal/hr), and material handling (33.8 Kcal/hr).

It was determined that a male operator has the capacity to work up to 826 minutes, meaning a 420-minute work shift would not pose any problem. In the case of female operators, work capacity was calculated at 470 minutes, a value closer to the length of the work shift. Nonetheless, both fall within the permitted range, indicating that the activity can be carried out without issues during the workday (see Figure 8).

4.3.3 RAPP Tool

The RAPP (Risk Assessment of Pushing and Pulling) method (HSE, 2016) is used to analyze risks associated with manual pushing and pulling operations. It helps identify high-risk activities and evaluate the effectiveness of risk-reduction measures, particularly those involving full-body effort. With the inclusion of ergonomic aids (devices that improve operator comfort, safety, and efficiency during a task) for movement (Figure 4), RAPP results were obtained for the workstation (Figure 9).

The RAPP assessment results show that most of the factors analyzed such as load weight, posture, grip, transport distance, and equipment condition scored o, indicating no significant risk. However, work pace scored a 3, suggesting a moderate risk level and indicating that adjustments are needed. Overall, the total score of 3 suggests that the ergonomic condition is acceptable, but it is advisable to review the work pace to optimize the operation.



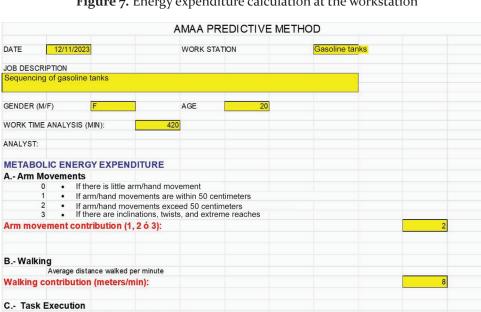


Figure 7. Energy expenditure calculation at the workstation

Figure 8. Energy expenditure results at the workstation

Weight contribution (1, 2 ó 3):

Frequency contribution (1, 2 ó 3):

D.- Manual Handling of Materials (Pull/Push)
Force contribution pulling/pushing (Kgs):
Walking while pulling/pushing (meters/min)

2

If most parts weigh less than 1.8 kg
If most parts weigh between 1.8 and 5 kg
If most parts weigh more than 5 kg

If there are fewer than 2 cycles per minute
 If there are 2 cycles per minute
 If there are more than 2 cycles per minute

	METABO	LIC ENERGY	EXPENDI	TURE	
Basal Met	abolic			117.000	Kcal/hr.
arm move	ment			50.000	Kcal/hr.
Walking				16.800	Kcal/hr.
task meas	ure			52.800	Kcal/hr.
Manual ma	aterial handlin	g		33.800	Kcal/hr.
	1	OTAL		270.400	
				4.507	Kcal/min
	PHYS	SICAL WORK	CAPACIT	Y	
ISF:		1.160			
CTF MEN		6.330			
CTF WOME	N	4.735			
Maximum	time before	fatigue occı	ırs (IF CTF	> GME)	
MEN	826.187484	Min			
WOMEN	470.288495	Min			
Recovery	time (IF CTF	> GME)			
	-305,451979	Min			
MEN					

Source: Own elaboration

Figure 9. RAPP Tool results

Ī	RAPP Equipment on wheel					
		Medium e	quipment			
	Risk Factor	Color	Value			
1	Work load		0			
2	Posture		0			
3	Grip		0			
4	Work Rythem		3			
5	Walking distance		0			
6	Equipment Condition		0			
7	Floor Condition		0			
8	Obstules in Route		0			
9	Other Factors		0			
	Total Score		3			

Source: Own elaboration

4.4 Implementation

The time study, conducted along with the work instructions, allowed each part of the process to be defined and optimized. Based on the results, a cycle time of 7 minutes was established. With this parameter, the workload was calculated at 85.62% (6 minutes), with a rest time between cycles of 14.38% (1 minute), which remains within the manufacturer's internal standards, ensuring an adequate level of productivity without physical overload.

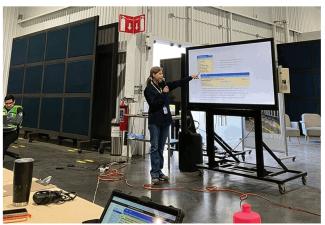


Quality Process System Operator Instruction Sheet (QPS-OIS/JSA) HERMOSILLO ASSEMBLY Created By: PMART318 DELTA KEYED SEQUENCE K KEY QUALITY *Place PPE according to the operation to be performed* 10 Go to the scanner charging cabinet * * Turn on scanner * *Enter the sequencer cell to sequence gasoline tank rack* 40 **Verify that the VIN number and the sequenced number of the components match the system 50 Scan the PLACCARD and sequence barcode every 12 gasoline tanks) 100% UNITS 10 Walk to PLACCARD 0 Align scanner with PLACCARD 30 Press scanner trigger 40 Scan PLACCARD *time 100% UNITS Scan the ETAG and sequence barcode (every 12 gasoline tanks) 10 WALK TO DOLLY TO SEQUENCE 20 Align scanner with ETAG 30 Press scanner trigger 40 Scan ETAG *time* Walk to the cart and change the tanks UNITS 10 Walk to the cart Walk to the Rack Place in sequence the part number, rotation, and location as indicated by the system when sequencing 100% UNITS Tox. Tex JCARRISO 2024/11/06 PSTMLD

Figure 10. Example of process sheet

The implementation process included two additional activities related to understanding the new task workflow. On one hand, process sheets were created (Figure 10), which are documents detailing the steps required for assembly, including operations, machines, tools, time, and materials. They include key icons highlighting critical points, as well as a more in-depth explanation of the subtasks.

Figure 11. Presentation and training meeting



Source: Own elaboration

Finally, meetings were held with both operational and supervisory staff. In these sessions, the redesign was described, along with its benefits for productivity and risk reduction. Operators were trained and shown the station's operational metrics (Figure 11).

4.5 Continuous improvement

As part of the improvement process, an opportunity for enhancement was identified. Therefore, the materials department was requested to implement a new material supply sequence to optimize material flow and improve operational efficiency. This adjustment aims to streamline the distribution of material usage options, ensuring each component is available at the right time and in the correct quantity. Additionally, implementing these options will help reduce waiting times and optimize overall system performance.

Discussion

In the context of existing literature, this study aligns



with the increasing importance given to ergonomics in the automotive industry to improve productivity, safety, and job satisfaction. The application of regulations such as NOM-036-STPS-2018 and consideration of international standards (ISO-11228-1, HSE, NIOSH) form the basis of a comprehensive approach to managing ergonomic risks. Likewise, the use of multiple evaluation methods (Sue Rodgers, RAPP, caloric expenditure analysis) provides a holistic view of the physical demands of the task, strengthening the validity of the conclusions.

One limitation of this study could be its focus on a single workstation within the assembly line. The ergonomic evaluation results of the redesigned workstation suggest a substantial improvement compared to previous scenarios where manual load handling posed a potential risk for musculoskeletal disorders (MSDs).

Thisstudy, similar toother research findings, supports the idea that designing work environments using a systematic approach and specialized assessment tools represents a significant advancement toward reducing ergonomic risks. The results support the effectiveness of the implemented interventions and highlight the importance of a continuous improvement approach to working conditions from an ergonomic perspective.

The study by García et al. (2021) provides a detailed view of ergonomic challenges in the food industry, specifically in the asparagus packing process. The research revealed that operator fatigue not only reduced productivity but also raised serious concerns regarding worker health and well-being. It was found that repeated stretching over long periods caused fatigue, clearly indicating suboptimal working conditions.

Upon deeper analysis of the packing activities, it was discovered that most of the postures adopted by operators were ergonomically incorrect. This not only increased the risk of long-term injuries but also affected the efficiency of the packing process. The conclusion that a workstation redesign was necessary revealed an opportunity for significantly improving workplace ergonomics.

The redesign proposed by García et al. (2021) suggests integrating adjustable workstations that accommodate the height and reach of each individual operator, thereby minimizing muscle

strain and fatigue. Regular breaks and stretching exercises for employees were also recommended, which could help mitigate the effects of standing or remaining in a static position for long periods.

Future research could expand the scope to analyze the impact of similar ergonomic interventions at other workstations where potential risk exists particularly for MSDs. In the medium to long term, it would also be valuable to assess the impact on worker health and process productivity.

Conclusions

The ergonomic design of a sequencing workstation in an automotive stamping and assembly plant was addressed, motivated by the need to mitigate the risk of musculoskeletal disorders (MSDs) associated with manual material handling, in accordance with NOM-036-1-STPS-2018 and the manufacturer's standards. Through a five-phase methodology (analysis, design, validation, implementation, and continuous improvement), the assembly sequence was redefined by developing a new physical layout of the workstation, incorporating facilities and ergonomic aids aimed at optimizing the handling and transport of components in the sequencing phase.

Workstation design validation was conducted through various ergonomic evaluation methods, including Sue Rodgers and RAPP. The moderate score obtained in the work pace assessment highlights an opportunity for optimization, aiming for a balance between productivity and prevention of physical overload. The caloric expenditure analysis indicated that the metabolic demands of the task fall within acceptable limits for both genders during a standard work shift. However, the calculated work capacity for female operators was closer to the shift duration, suggesting the need to monitor fatigue and consider implementing breaks or task rotations if signs of long-term exhaustion are detected.

The results showed a significant improvement in the ergonomic conditions of the redesigned station. During the implementation phase, staff training and the definition of an optimized cycle time began, achieving adequate levels of efficiency and idle time, even exceeding standard process expectations, thus demonstrating the proposal's feasibility in terms of productivity. Finally, the continuous improvement stage lays the



groundwork for future adjustments that will allow for sustained optimization of the workstation.

In summary, this research exemplifies the practical application of ergonomic principles in the automotive industry, demonstrating their potential for creating safer, healthier, and more efficient work environments while ensuring compliance with current regulations. The findings of this study may serve as a reference for similar interventions in other production processes involving manual material handling.

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