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Application of the Sustainability Barometer in the sugarcane-producing microregions in Paraná (Brazil)

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Authors' notes'

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Abstract

Objective: Collecting information related to sugarcane production in the microregions of Paraná, such as pesticide use, technical guidance received, GDP per capita, among others, to measure sustainability using the Sustainability Barometer.

Methodology: A literature review and a quantitative approach (collection and grouping of 17 variables) were used, focusing on the microregions of Paraná with a high LQ for sugarcane production. Subsequently, the Sustainability Barometer methodology (Prescott-Allen, 1997) was applied.

Originality/Relevance: Sustainability can be considered a relevant topic, capable of being analyzed from various perspectives (climate change, population growth, among others). However, measuring sustainability is often not a simple task due to the numerous elements that constitute it. Prescott-Allen (1997) developed a tool that can assist in this measurement, evaluating the potential and challenges of the analyzed areas.

Results: In the analyzed microregions of Paraná, it was observed that the variables classified as Human (such as IFDM Health, IFDM Education, and GDP per capita) are mostly positioned in the "Potentially Sustainable" range. In contrast, the Environmental indicators (such as establishments that do not use pesticides, that receive technical guidance, among others) are in the "Intermediate" or "Potentially Unsustainable" range. This reveals that there is still a need to improve sugarcane production in terms of sustainability.

Social/Management Contributions: The Sustainability Barometer methodology includes elements that aid in the development of the Human Well-being Index (HWI), the Environmental Well-being Index (EWI), and, complementarily, the Overall Well-being Index. It integrates disparate data to create a comprehensive overview of the sustainability of a region or country. Few studies utilize this tool for analysis, indicating that there is room for further research.

Keywords: Sustainability Barometer, sugarcane, sustainability, microregions of Paraná

Aplicação do Barômetro da Sustentabilidade nas microrregiões produtoras de cana-de-açúcar do Paraná (Brasil)

Resumo

Objetivo: Coletar informações relacionadas à produção de cana-de-açúcar das microrregiões paranaenses, tais como uso de agrotóxicos, orientação técnica recebida, PIB per capita, dentre outras, para mensurar a sustentabilidade com o uso do Barômetro da Sustentabilidade.

Metodologia: Foram utilizadas pesquisa bibliográfica e abordagem quantitativa (coleta e agrupamento de 17 variáveis), das microrregiões paranaenses com QL elevado para a produção de cana-de-açúcar. Posteriormente, utilizou-se a metodologia do Barômetro da Sustentabilidade (Prescott-Allen, 1997).

Originalidade/Relevância: A sustentabilidade pode ser considerada um tema relevante, podendo ser analisado sob diversos aspectos (mudança climática, aumento da população, entre outros). No entanto, mensurar a sustentabilidade por vezes não é tarefa simples, devido aos diversos elementos que a compõem. Prescott-Allen (1997), elaborou um ferramental que pode auxiliar nesta mensuração, avaliando potencialidades e dificuldades das áreas analisadas.

Resultados: Observou-se nas microrregiões paranaenses analisadas que, as variáveis denominadas Humanas (como IFDM Saúde, IFDM Educação e PIB per capita), em sua maioria, encontram-se posicionados na faixa denominada “Potencialmente Sustentável”, enquanto os indicadores Ambientais (estabelecimentos que não utilizam agrotóxicos, que recebem orientação técnica, entre outros), localizam-se na faixa “Intermediária” ou “Potencialmente Insustentável”, revelando que ainda é necessário aprimorar a produção de cana-de-açúcar no que tange à sustentabilidade.

Contribuições sociais / para a gestão: A metodologia do Barômetro da Sustentabilidade, possui elementos que auxiliam na elaboração do Índice do Bem-estar Humano (IBH), Índice do Bem-estar Ambiental (IBA) e de forma complementar no Índice do Bem-Estar e coaduna dados díspares para a elaboração de um panorama da sustentabilidade de uma região ou país. Poucas pesquisas usam esta ferramenta para análise, demonstrando que há espaço para novas investigações.

Palavras-chave: Sustainability Barometer, sugarcane, sustainability, microregions of Paraná

Aplicación del Barómetro de la Sostenibilidad en las microregiones productoras de caña de azúcar en Paraná (Brasil)

Resumen

Objetivo: Recopilar información relacionada con la producción de caña de azúcar en las microrregiones de Paraná, como el uso de pesticidas, orientaciones técnicas recibidas, PIB per cápita, entre otros, para medir la sostenibilidad mediante el Barómetro de Sostenibilidad.

Metodología: Se utilizó investigación bibliográfica y enfoque cuantitativo (recopilación y agrupación de 17 variables), de las microrregiones de Paraná con alta QL para la producción de caña de azúcar. Posteriormente se utilizó la metodología del Barómetro de Sostenibilidad (Prescott-Allen, 1997).

Originalidad/Relevancia: La sostenibilidad puede considerarse un tema relevante y puede analizarse desde diferentes aspectos (cambio climático, aumento de población, entre otros). Sin embargo, medir la sostenibilidad en ocasiones no es una tarea sencilla, debido a los diferentes elementos que la componen. Prescott-Allen (1997), desarrolló una herramienta que puede ayudar en esta medición, evaluando potencialidades y dificultades de las áreas analizadas.

Resultados: Se observó en las microrregiones analizadas de Paraná que las variables denominadas Humanas (como IFDM Salud, IFDM Educación y PIB per cápita), en su mayoría, se posicionan en el rango denominado “Potencialmente Sostenible”, mientras que las Los indicadores ambientales (establecimientos que no utilizan pesticidas, que reciben orientación técnica, entre otros), se ubican en el rango “Intermedio” o “Potencialmente Insostenible”, lo que revela que aún es necesario mejorar la producción de caña en términos de sostenibilidad.

Contribuciones sociales/para la gestión: La metodología del Barómetro de Sostenibilidad cuenta con elementos que ayudan en la elaboración del Índice de Bienestar Humano (IBH), Índice de Bienestar Ambiental (IBA) y de forma complementaria en el Índice de Bienestar y combina dispares datos para crear una visión general de la sostenibilidad de una región o país. Son pocos los estudios que utilizan esta herramienta de análisis, lo que demuestra que hay espacio para nuevas investigaciones.

Palabras clave: Barómetro de Sostenibilidad, caña de azúcar, sostenibilidad, microrregiones de Paraná

Introduction

With the rapid growth of large urban centers and the population, and the resulting need to increase production (food, machinery and equipment, vehicles, and numerous other items), the discussion around more sustainable development has intensified. In other words, the focus is on achieving economic growth and development while preserving the environment and ensuring the well-being of the population.

According to Souza (2008), rapid and uncontrolled economic growth can devastate forest reserves, deplete mineral resources and animal species, and extinguish or contaminate potential sources of drinking water. Therefore, it is essential to maintain a balance between development and sustainability.

Regarding sugarcane production, two key products stand out for household consumption: sugar (a food and energy source) and hydrous ethanol (a vehicle fuel). Additionally, other by-products are generated, which are fully utilized in some mills, such as bagasse from sugarcane milling (used for generating bioelectricity after burning), molasses, spirits, and other derivatives (Galafassi *et al*., 2020).

To meet the growing demands, it is necessary to increase sugarcane production, which implies expanding the planted area, requiring more fertilizers and pesticides, and, in some cases, the use of pre-harvest burning by some producers, which contributes to air pollution.

To assess how sustainable sugarcane production is, encompassing aspects of environmental and human well-being, the Sustainability Barometer tool, developed by Prescott-Allen (1997), can be used. This tool measures and reports the scale of population and ecosystem well-being in the pursuit of sustainability by analyzing specific indicators. Thus, the problem addressed in this paper is: What is the current state of sustainability in sugarcane production in the producing microregions of the State of Paraná?

The aim of this paper is to collect reliable information related to sugarcane production in the microregions of Paraná, such as pesticide use, receipt of technical guidance, FIRJAN indices (IFDM, Education, Health, Employment, and Income), GDP per capita, among other data, to measure sustainability (human and environmental well-being) using the Sustainability Barometer tool developed by Prescott-Allen.

To achieve this, this paper is divided into four sections, in addition to this introduction. Next, a brief theoretical framework will be provided, addressing the topics of sugarcane production in Paraná, sustainable development, and the Sustainability Barometer. Following that, the methodology, researched data, and calculations will be detailed. Then, the results and respective analyses of the microregions will be presented, concluding with the final considerations and the references used.

Theoretical framework

Sugarcane Production in Paraná

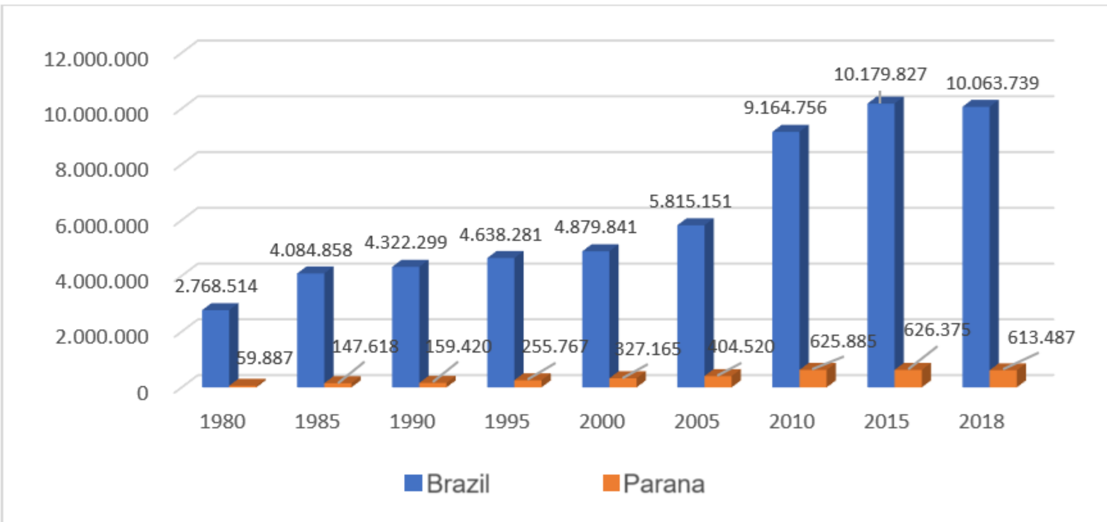
According to Galafassi *et al*. (2020), sugarcane originates from southeastern Africa, with the scientific name *Saccharum officinarum*. It arrived in Brazil in the 16th century and became a source of income and employment, as it was a highly valued product in Europe. Several factors were favorable for its production, such as edaphoclimatic conditions, land availability, and labor supply.

According to Rissardi Júnior (2015), sugarcane has great productive potential, and along with the natural resources, which are characteristic of its cultivation, it requires a range of variables, not only natural but also technical and institutional, to enable its large-scale agro-industrialization.

In the 1980s and 1990s, the planted area of sugarcane expanded in various microregions of Paraná, with some of these areas replacing coffee plantations lost during the Black Frost of 1975. Favorable soil and climate conditions, increased consumption and production of alcohol through the Pró-Álcool program, and the growing global demand for sugar also contributed to this expansion (Clein, 2021).

Figure 1

Planted Area of Sugarcane (hectares), Brazil and Paraná (1980-2018)



Source: Sugarcane Industry Union (UNICA, 2022).

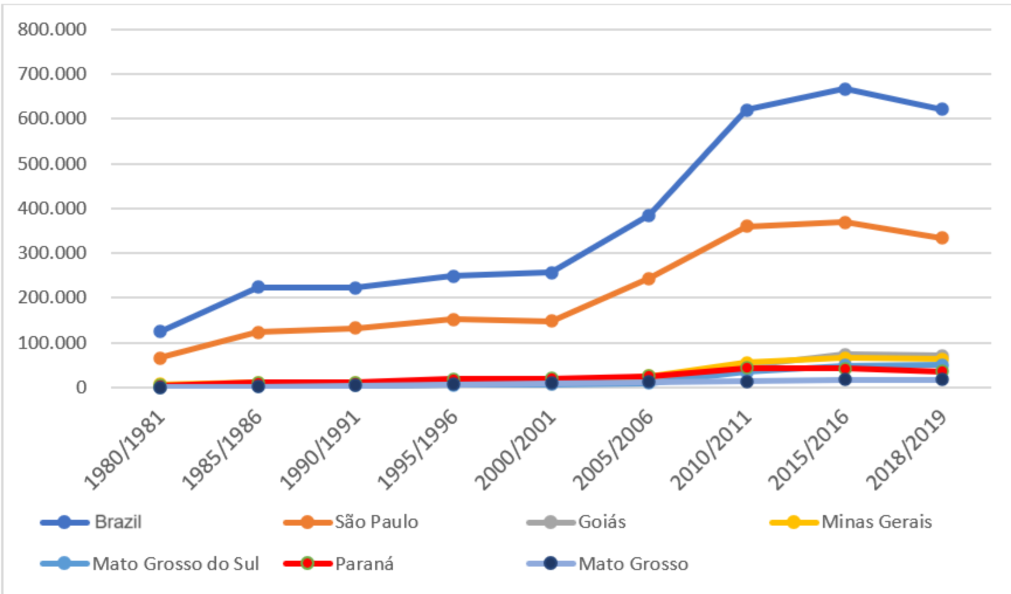
As shown in Figure 1, during the 1980s, Paraná accounted for just over 2% of the sugarcane planted area compared to Brazil. This percentage increased to around 7% in 2007 and 2008, before experiencing a slight decline and stabilizing at just over 6% until 2018. This places Paraná in fifth position in Brazil in terms of planted area, with a total of 613,487 hectares.

Regarding sugarcane production, Paraná currently also ranks fifth, behind São Paulo (first place), followed by Goiás, Minas Gerais, and Mato Grosso do Sul. Figure 2 presents a graph of sugarcane production for selected harvest seasons.

The graph shows that sugarcane production experienced a slight decline when comparing the 2015/2016 and 2018/2019 harvests. According to information collected from the Sugarcane Observatory website (UNICA, 2022), several factors contributed to this reduction, such as climatic conditions, fluctuations in consumer demand, and the closure of some mills during this period, among others.

Figure 2

Sugarcane Production Graph for Brazil and the Six Largest Producing States (in thousand tons, selected harvest seasons)

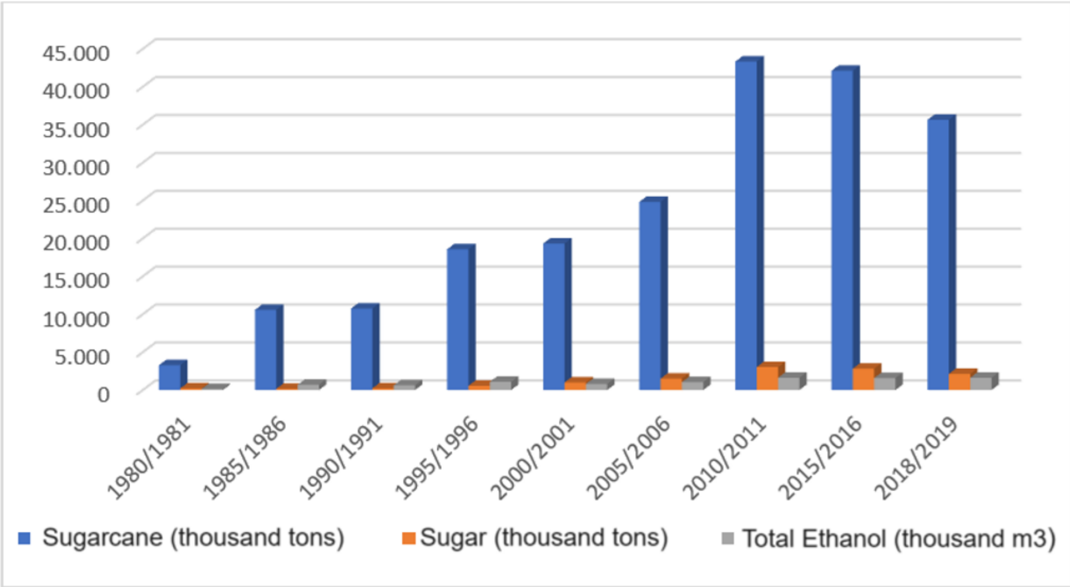


Source: Sugarcane Industry Union (UNICA, 2022)

Regarding sugar production, Paraná currently ranks third (behind São Paulo and Minas Gerais), while in total ethanol production, the state ranks sixth, with São Paulo in first place, followed by Goiás, Mato Grosso do Sul, Minas Gerais, and Mato Grosso. Figure 3 shows the quantities of sugarcane, sugar, and total ethanol produced in the state of Paraná.

Figure 3

Sugarcane Production (thousand tons), Sugar (thousand tons), and Total Ethanol (thousand m³) in Paraná, from 1980-1981 to 2018/2019



Source: Sugarcane Industry Union (UNICA, 2022)

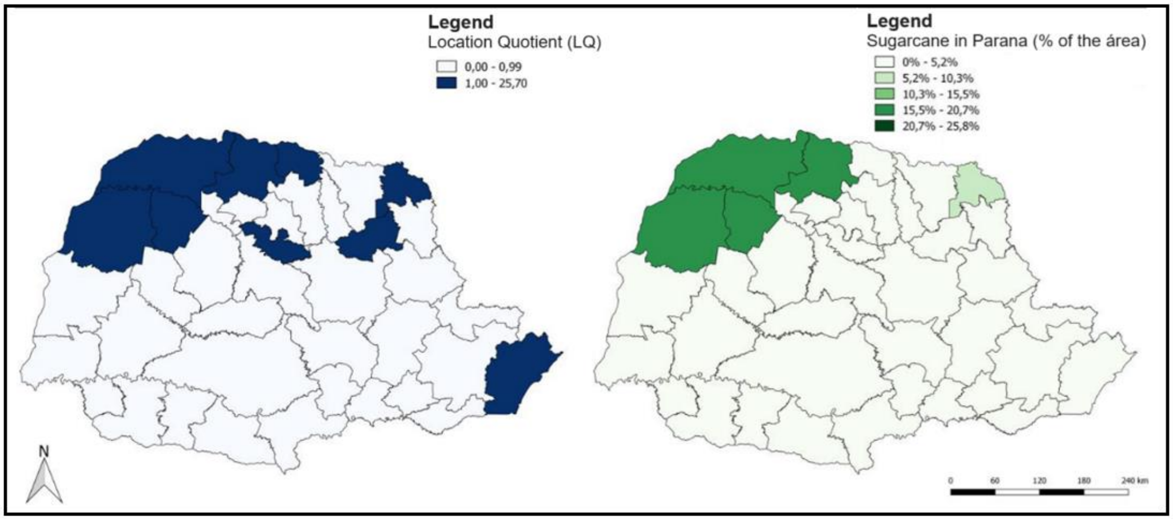
It can be observed that there was a slight downward trend in the production of all three products. According to Santos (2021), this decline was due to periods of crisis and setbacks, changes in demand, as well as bankruptcies and judicial recoveries after 2014/2015, which resulted in an average annual growth rate of -0.5% in sugarcane production (i.e., negative).

Despite all these adversities, Paraná is maintaining its position in sugarcane production and its related products. At this point, it is important to emphasize that the area allocated for sugarcane cultivation is relatively small (613,487 hectares) when compared to the total area of the State of Paraná, which is 19.93 million hectares.

Galafassi *et al*. (2020) conducted research to determine which microregions in Paraná had a concentration of sugarcane production, using a historical series and the Location Quotient (LQ). After data collection and analysis, the results were presented in Figure 4.

Figure 4

Location Quotient and Percentage Proportion of Harvested Sugarcane Area in the Microregions of the State of Paraná – 2018



Source: Galafassi et al. (2020)

It is observed that there is a concentration of sugarcane production in the microregions of Astorga, Cianorte, Paranavaí, Umuarama, Porecatu, Jacarezinho, Ibaiti, Faxinal, and Paranaguá. Paranaguá is more focused on the production of spirits, while the others primarily produce alcohol and sugar. In Galafassi *et al*.'s (2020) study, other concentration areas were identified; however, these were also limited to the production of molasses and spirits.

Considering the results of the cited research, this article will conduct Sustainability Barometer analyses in the Paraná microregions with the highest representativity (LQ) in sugarcane production. In the next section, concepts and foundations related to sustainable development will be discussed, as well as how they are connected to the Sustainability Barometer.

Sustainable Development

One of the first scholars to highlight the issue of population growth with scarce (productive) resources was Thomas Robert Malthus (1766-1834). He noted that when unchecked, the population grows at a geometric rate, while food (subsistence) only increases at an arithmetic rate (Malthus, 1996).

Evidently, Malthus could not have anticipated technological innovations, such as the use of fertilizers, the development of new seeds and varieties, and the increased productivity using labor and capital. Throughout the 20th century, as cities and countries experienced economic growth and development, debates began to focus on achieving this progress in a way that would preserve the environment, both in the present and for the future.

According to Souza (2008), economic development can be defined by the presence of continuous economic growth at a rate higher than population growth, encompassing structural changes with improvements in economic, social, and environmental indicators. It is also important to remember that development occurs unevenly, reflecting the disparities that exist within a region (city, microregion, mesoregion...) (Ferrera de Lima, 2016).

Sustainable Development is defined as "that which preserves the environment, especially non-renewable natural resources" (Souza, 2008, p. 8). When expanding productive areas, it is essential to assess the environmental impacts and how to minimize them in various ways: by preserving native areas and their respective fauna, water sources (springs and watercourses), mineral reserves, fish and animal species, among others.

In 2015, the United Nations (UN) established goals that cities, states, and countries need to achieve by 2030, with the aim of eliminating (or reducing) poverty, protecting the environment and the climate, and ensuring that people everywhere can enjoy peace and prosperity (UN, 2022).

To achieve these goals, the Sustainable Development Goals (SDGs) were designated, which are:

1. No Poverty
2. Zero Hunger and Sustainable Agriculture
3. Good Health and Well-being
4. Quality Education
5. Gender Equality

6. Clean Water and Sanitation
7. Affordable and Clean Energy
8. Decent Work and Economic Growth
9. Industry, Innovation, and Infrastructure
10. Reduced Inequalities
11. Sustainable Cities and Communities
12. Responsible Consumption and Production
13. Climate Action
14. Life Below Water
15. Life on Land
16. Peace, Justice, and Strong Institutions
17. Partnerships for the Goals

The 17 goals are further divided into 169 targets, which encompass the eradication of poverty, sustainable agriculture, quality education, affordable and clean energy, responsible consumption and production, reduction of inequalities, among many others. These targets can be found through various online search tools, particularly those related to the UN and governmental agencies (UNDP, 2022).

Regarding the analysis of the sustainability of sugarcane production, several of these goals can be specified, such as SDG 2 (Zero Hunger and Sustainable Agriculture), SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation, and Infrastructure), and SDG 12 (Responsible Consumption and Production). Each SDG has branches and details that can be explored through various online search tools, especially those linked to the UN and governmental agencies.

To assess the sustainability conditions of sugarcane production in the state of Paraná, the use of the Sustainability Barometer tool is proposed, which will be demonstrated in the following sections.

Sustainability Barometer

The Sustainability Barometer is a methodological tool developed by researcher Robert Prescott-Allen and published in 1997. It became the official method for assessing sustainability by the IUCN[1].

To properly employ the Sustainability Barometer, it is necessary to combine various indicators, such as information on health, population, employment, economy, education, crime, erosion, water quality, protected areas, and many others. However, simply collecting and presenting the data in a chart or table may not be sufficient for drawing clear conclusions from the data (Prescott-Allen, 1997).

Therefore, it is necessary to assign values to the indicators, with lower (minimum detected) and upper (maximum practicable) limits. However, they still cannot be evaluated together, necessitating the creation of a Performance Scale, ranging from 0 (zero) to 100, divided into 20-point sectors, classified as Good, Fair, Medium, Poor, and Bad (Prescott-Allen, 1997).

Using this performance scale, numerous variables can be applied, and the barometer can even be inverted: instead of the maximum value being the best and classified as Good (as in an analysis of Sustainability or Population Well-Being), the minimum value or zero would be considered the best. For example, when analyzing infant mortality or crime rates, the closer to zero, the better the human well-being.

In the study by Guimarães *et al*. (2010), a scale was outlined to weigh the results obtained from the Sustainability Barometer calculations, and this scale will also be used in this paper, as shown in Table 1.

[1] International Union for Conservation of Nature and Natural Resources

Table 1

Sustainability Barometer Scale, Divided into Segments and Colors

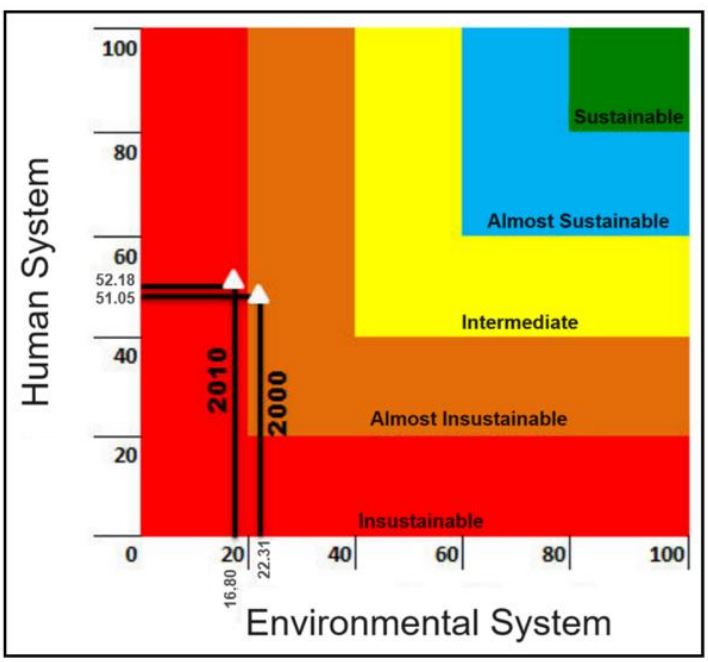
Colors	Sectors	Classification	Result
	0-20.00	Bad	Unsustainable
	20.01-40.00	Poor	Almost unsustainable
	40.01-60.00	Medium	Intermediate
	60.01-80.00	Fair	Almost sustainable
	80.01-100.00	Good	Sustainable

Source: Adapted from Guimarães *et al*. (2010)

According to Van Bellen, as cited in Hachmann and Rippel (2015, p.9), the selected indicators are collected and evaluated, with their values forming a two-dimensional graph, with scales ranging from 0 to 100. This indicates a situation from bad to good (in relation to sustainability), so that the position of the studied system within this graph provides a measure of the system's sustainability or unsustainability as a whole. Figure 5 provides an example of how the results of the Sustainability Barometer are presented.

Figure 5

Sustainability Barometer Results for the Western Mesoregion of Paraná (2000 and 2010)



Source: Hachmann and Rippel (2015)

As shown in Figure 5, the study conducted by Hachmann and Rippel (2015) examined the Western Mesoregion of Paraná in 2000 and 2010. Following the data collection and analysis, and applying the Sustainability Barometer, the authors found indices of 51.05 for the year 2000, and 52.18 for 2010 (Human Subsystem); and indices of 22.31 for 2000, and 16.80 for 2010 (Environmental Subsystem). This indicated that the Western Mesoregion of Paraná was in the Almost Unsustainable area of the graph in 2000 and had become Unsustainable by 2010.

The formulas used to calculate the Sustainability Barometer are relatively simple but require careful attention in data collection and analysis. The information and detailed methodology will be presented in the next section.

Methodology

According to Oliveira (2007), research can be segmented based on the objectives to be achieved, as well as the procedures and techniques used. The most common forms of research are: exploratory, which aims to provide a general explanation of a certain phenomenon; experimental, which uses data obtained in laboratory and field settings, employing research instruments; and descriptive, which seeks to identify, observe, and describe phenomena.

To assist in achieving the objective, a literature review will be conducted first, which includes publications such as books, theses, papers, and journals. The purpose is to familiarize the researcher with the information already published on the subject to be studied (Marconi & Lakatos, 1999).

For the application of the Sustainability Barometer, a quantitative approach is also necessary, as techniques for data collection, analysis, decomposition, and grouping were employed.

Reaffirming what was mentioned by Víctora *et al*. (2000), after analyzing quantitative data, it is possible to apply a qualitative technique to deeply analyze and understand specific findings from the quantitative analysis. Qualitative approaches will be employed, which, according to Godoy

(1995), align with the fact that qualitative researchers are concerned with the process (development) and not just the final results.

The research and data were collected from the sugarcane-producing microregions of Paraná (Astorga, Cianorte, Paranavaí, Umuarama, Porecatu, Jacarezinho, Ibaiti, Faxinal, and Paranaguá), which were delineated using the Location Quotient (LQ) study by Galafassi *et al*. (2021). This study utilized data from the 2017 Agricultural Census and FIRJAN Indices.

Methodological Procedures

To begin the search for indicator data, it is necessary to identify and quantify the municipalities that belong to the microregions that will be included in the Sustainability Barometer calculations, as well as the respective data on the number of establishments and the quantity of sugarcane produced, as shown in Table 1.

Table 1

Descriptive Data of Sugarcane-Producing Microregions in Paraná

Microregion	No. of Municipalities (Total)	No. of Agricultural Establishments	No. of Establishments with Temporary Crops	No. of Establishments Producing Sugarcane	Quantity Produced in Temporary Crops (Sugarcane) (tons)	Production Value of Temporary Crops (thousand Reais)	Production Value of Sugarcane Crops (thousand Reais)
Paranavaí	29	11,056	2,365	214	9,945,626	1,133,642	649,371
Umuarama	21	14,814	3,055	221	4,041,535	1,085,264	279,849
Cianorte	11	4,937	1,462	140	5,843,798	671,570	400,053
Astorga	22	7,024	2,301	141	8,483,461	1,160,875	545,715
Porecatu	8	2,162	1,489	27	1,439,747	609,423	97,550
Faxinal	7	3,023	1,465	23	853,265	404,779	52,101
Jacarezinho	6	4,252	1,266	237	2,549,548	358,200	197,564
Ibaiti	8	5,392	1,066	84	57,255	175,046	9,609
Paranaguá	7	1,889	347	171	1,701	10,081	1,077

Source: IBGE Agricultural Census (2017)

It is observed that the nine microregions that are the focus of this article encompass 119 municipalities, which represent 87.9% of the total sugarcane production in the state of Paraná, highlighting the significance of analyzing these microregions.

For the application of the Sustainability Barometer, data reflecting the Human Subsystem and the Environmental Subsystem are required. In the study conducted by Guimarães *et al*. (2010), which analyzed Mato Grosso do Sul, six indicators were collected: two related to the Environmental Subsystem (pesticide use and households served by the water supply network) and four related to the Human Subsystem (Gini index, agricultural employment, GDP per capita, and trade balance surplus). In this paper, 17 indicators will be used, as described in Table 2.

Table 2

Analyzed subsystems, indicators used, and their sources

System	Subsystems	No. of Indicators	Indicator	Source
Sugarcane-Producing Microregions of Paraná	Environmental	9	No. of agricultural establishments receiving technical guidance	Agricultural Census 2017
			No. of establishments with temporary crop production	Agricultural Census 2017
			No. of agricultural establishments that used fertilization	Agricultural Census 2017
			Production Value of Sugarcane Crops (thousand Reais)	Agricultural Census 2017
			No. of agricultural establishments that did NOT use pesticides	Agricultural Census 2017
			No. of agricultural establishments with water sources*	Agricultural Census 2017
			No. of agricultural establishments with tractors	Agricultural Census 2017
			No. of agricultural establishments with irrigation	Agricultural Census 2017
			No. of establishments with electricity	Agricultural Census 2017
	Human	8	General IFDM	FIRJAN (2018)
			Education IFDM	FIRJAN (2018)
			Health IFDM	FIRJAN (2018)
			Percentage of employed population	IBGE Cities (2022)
			Employment & Income IFDM	FIRJAN (2018)
			GDP per capita (R$)	IBGE Cities (2022)
			Average monthly salary	IBGE Cities (2022)
			Percentage of population earning up to 1/2 minimum wage	IBGE Cities (2022)

Source: Adapted by the authors from Cetrullo et al. (2013)

Note: Some data are available only for temporary crops, but not specifically for sugarcane.

According to Ferrera de Lima (2022, p.72), “rural territories have three functions: the production function, characterized by the transformation of production factors into products; the territorial function, characterized by the occupation, management, and preservation of space, landscapes, and natural resources; and the social function, characterized by the generation of employment and income, the provision of collective services, and the stimulation of the rural environment". Thus, rural areas influence not only their surroundings but also nearby urban spaces, indicating the need to maintain the sustainability (economic, social, environmental) of rural areas to ensure they exert a positive influence on urban areas.

Thus, nine indicators were collected for the Environmental Subsystem, as specified in Table 2, and briefly explained in the following paragraphs: total data (from both Family and Non-Family Agriculture) were collected for establishments that do not use pesticides. The assumption is that properties not using pesticides are ecologically sustainable, as they do not contaminate the soil, watercourses, and springs, and do not harm animals and beneficial insects. Conversely, the use of pesticides can contribute to environmental degradation.

The remaining indicators, such as Establishments Receiving Technical Guidance, also have some impact on the environment. With proper guidance, inputs, fertilizers, and even pesticides can be used correctly, without excess. The indicators for Water Source and Electricity, as well as the Number of Tractors, suggest a certain level of development in the rural region analyzed. Consequently, the inhabitants would have better living conditions (well-being) and the ability to use Irrigation (another indicator collected).

In the Human Subsystem, eight indicators were collected: the FIRJAN Municipal Development Index (IFDM), including the General Index and the specific indices for Education and Health. The IFDM monitors the development of more than 5,000 Brazilian municipalities. It was created in 2008, and according to Raiher (2018), it reflects aspects of quality of life, contributing to the formation of individuals' skills and qualifications.

An important quality of the IFDM is its breadth and regularity (annual) and its availability for all levels of regional aggregation. Its interpretation is quite simple: the closer the index is to 1 (one), the more developed the municipality; the closer to 0 (zero), the less developed it is. Therefore, these indicators will demonstrate that the ideal is to be close to 1, to be considered efficient (sustainable).

The percentage of the employed population was used, sourced from the Brazilian Institute of Geography and Statistics (IBGE) and condensed on the IBGE Cities page. This indicator also shows that the higher the employed population, the better the living conditions of the population as a whole (as it reflects income, education, housing capacity, and various goods). The data for the IFDM and the percentage of the employed population are provided at the municipal level, so the data for all municipalities within each microregion were collected, and a simple arithmetic average was calculated.

In the same vein, the FIRJAN Employment & Income IFDM was selected, which reflects how developed a municipality is in this aspect. Its analysis is similar to the previous indicators: the closer it is to 1 (one), the more developed the municipality is in terms of Employment and Income.

The other three indicators (GDP per capita, average monthly salary, and the percentage of the population earning up to half a minimum wage) are directly related to the population's income and, consequently, their ability to purchase food and other subsistence products. Additionally, if there are many people in more modest conditions (those earning below half a minimum wage). These data are available at the municipal level, and were collected for each microregion, with a simple arithmetic average calculated.

Calculation of the Sustainability Barometer

The calculation of the Barometer is considered simple: based on reference values and aiming to calculate the indices with Good as the maximum value and Bad as the minimum value, we have Equation 1:

({Rvalue – MinValue} ÷ {MaxValue – MinValue}) x 100(1)

Where:

RValue = real value

MinValue = minimum value

MaxValue = maximum value

If Bad refers to the maximum value and Good represents the minimum value, the equation to be used will be Equation 2.:

({Rvalue – MinValue} ÷ {MaxValue – MinValue} – 1) x 100(2)

Where:

RValue = real value

MinValue = minimum value

MaxValue = maximum value

The combination of indicators and their subsequent evaluation allows the researcher to draw conclusions related to the studied location. As illustrated in Figure 6, the scales of the Sustainability Barometer and their respective axes related to the well-being of the Human Subsystem and the well-being of the Environmental Subsystem are observed, where socioeconomic and environmental indicators are aligned in convergence.

Table 3 presents the indicators and their respective limits (upper and lower) that will be used for the analysis of the results.

Tabela 3

Collected Indicators and Their Respective Limits (Lower and Upper) Used in the Calculation of the Sustainability Barometer in the Sugarcane-Producing Microregions of Paraná

Indicador	Reference Values	
	Lower Limit	Upper Limit
Percentage of agricultural establishments receiving technical guidance	0	100
Percentage of establishments with temporary crop production	0	100
Percentage of agricultural establishments that used fertilization	0	100
Percentage of Production Value of Sugarcane Crops (thousand Reais)	0	100
Percentage of agricultural establishments that did NOT use pesticides	0	100
Percentage of agricultural establishments with a water source*	0	100
Percentage of agricultural establishments with tractors	0	100
Percentage of agricultural establishments with irrigation	0	100
Percentage of establishments with electricity	0	100
General IFDM	0	1
Education IFDM	0	1
Health IFDM	0	1
Percentage of employed population*	0	52.8
Employment & Income IFDM	0	1
GDP per capita (R$)**	0	40,788.77
Average monthly salary***	660.00	6,578.41
Percentage of the population earning up to 1/2 minimum wage****	0	48.8

Source: Adapted by the authors from Cetrullo et al. (2013)

*Highest percentage of employed population in the municipalities of the microregions (Jaguapitã).

**Average GDP of Paraná.

***Upper limit: Necessary minimum wage according to Dieese (June 2023); lower limit: half the national minimum wage.

****Upper limit: Value found in the city of Guaraqueçaba (microregion of Paranaguá).

To adequately analyze the indicators, which are disparate from each other, Prescott-Allen (1997) proposes that they be arranged in a way that allows for easy comparison. In some studies, it was possible to equalize the data in monetary terms (how much each indicator represents in dollars). In this paper, the environmental indicators were expressed as percentages to simplify calculations. The IFDM indicators have a predetermined scale (ranging from 0 to 1).

For the values of GDP per capita, average monthly salary, and the percentage of the population earning up to half a minimum wage, the studies by Cetrullo et al. (2013) and Amorim et al. (2014) were used as a basis and adapted for the current analysis and region.

In the next section, the results obtained after data collection and the application of the Sustainability Barometer for the sugarcane-producing microregions of Paraná will be presented.

Results and Discussions

After collecting all the listed data, conducting the relevant analyses, and calculating the necessary averages (when the data were available only by municipalities and needed to be aggregated by microregions), the results were obtained and will be presented in this section.

It is important to note that the data were collected from reliable sources (IBGE, FIRJAN). However, most of the available information is related to the Agricultural Census, which was last published in 2017. Therefore, to ensure consistency, the information collected from IBGE Cities and FIRJAN was also based on this period (2017/2018).

From the initial structured data, several considerations can be made. In the analysis by microregions, Cianorte stands out the most, with the highest average GDP per capita at R$ 37,767.72; an IFDM of 0.7800 (recalling that the closer to 1, the better); and an employed population percentage of 26.25%. These indicators suggest that the Cianorte Microregion can be considered as developing, with a high per capita income and an acceptable percentage of employed population (when compared to the other microregions).

When breaking down the data and analyzing it at the municipal level, Cianorte remains prominent with a General IFDM of 0.8377 (second only to Paranavaí at 0.8739). The IFDM Health indicator for Cianorte is also high at 0.9718, followed by Cafeara with 0.9640. For the IFDM Education indicator, Cruzeiro do Oeste ranks first with 0.9636, followed by Paranavaí with 0.9428. In terms of the IFDM Employment & Income indicator, Umuarama leads with 0.7335, closely followed by Paranavaí with 0.7309.

Regarding GDP per capita, an unexpected result emerged: the municipality of Indianópolis (in the Cianorte microregion), with approximately 4,450 inhabitants according to the 2022 Demographic Census (IBGE, 2023), has a GDP per capita of R$118,889.63, while the second place is held by Paranaguá with R$62,846.15.

Upon researching information related to the municipality of Indianópolis, it is evident that it is a city in full development, primarily based on agriculture (which represents 40% of the municipal GDP, followed by services at 39%). The city engages in the production of poultry, sericulture (including the production of cocoons and mulberry trees), sugarcane, cattle farming, swine farming, among others (Prefeitura de Indianópolis-PR, 2022).

Sericulture is quite significant in the state and in Brazil: Paraná has more than 2,300 producers associated with Abraseda, involving around 10,000 people and covering nearly 5,000 hectares, mostly small properties. The state produces 3.025 thousand tons of cocoons, representing 83% of the total volume produced in Brazil (Maliszewski, 2021). From the analysis of these data, it can be inferred that the region has a reduced and even more controlled use of pesticides. This is because mulberry leaves, which are used to feed the silkworms that form cocoons, must be free from any contamination by pesticides or other products. Contamination could result in the loss of the entire cocoon production, making this a good indicator of environmental Sustainability.

Regarding the percentage of the employed population, another unexpected result was found: the municipality of Jaguapitã (in the Astorga microregion) had the highest percentage among all those analyzed, at 52.8%. Researching information about the city, which has just over 13,700 inhabitants, revealed that agriculture is a significant sector. Just five products account for more than 70% of the Gross Production Value (GPV): broiler chickens (19.98%), cattle (14.70%), sugarcane (14.31%), hatching eggs (11.30%), and soybeans (10.37%), generating a GPV of R$ 40,716,737.15 (Prefeitura de Jaguapitã, 2022).

Regarding the percentage of the population earning up to half a minimum wage, the high numbers in several cities were surprising, such as Guaraqueçaba (48.8%), Jundiaí do Sul (39.9%), Antonina (39.4%), Curiúva, and Sapopema (38.9%). These percentages, combined with the low percentage of employed individuals, may indicate that a portion of this population relies on social assistance programs (such as Bolsa Família, Auxílio Brasil) and does not seek other forms of work and income. Another possibility is that employment in these cities is informal and not recorded in official databases. This presents a new opportunity for further research.

After these initial results, the next step in the objectives proposed in this paper was undertaken, which is to analyze the sustainability of the sugarcane-producing microregions of Paraná using the Sustainability Barometer tool. Table 4 presents the results of the Sustainability Barometer calculations (as per the formulas mentioned earlier).

Table 4

Results of the Sustainability Barometer Calculations for Sugarcane-Producing Microregions in Paraná

Indicator / Microregion	(01)	(02)	(03)	(04)	(05)	(06)	(07)	(08)	(09)
Percentage of agricultural establishments receiving technical guidance	35.2	32.8	38.9	54.3	58.6	52.7	22.6	23.4	30.2
Percentage of establishments with temporary crop production	21.3	20.6	29.6	32.7	68.8	48.4	29.7	19.7	18.3
Percentage of Production Value of Sugarcane Crops (thousand Reais)	57.3	25.8	59.6	47	16	12.9	55.2	5.5	10.7
Percentage of agricultural establishments that used fertilization	46.5	52.8	65	63.5	81.2	71.5	48.2	58.9	62.4
Percentage of agricultural establishments that did NOT use pesticides	71.7	66.5	53.1	53.9	32.4	30.5	65.7	52	70.4
Percentage of agricultural establishments with a water source*	70.1	75.2	77.4	78.3	66.7	77.3	80.1	86.6	74.9
Percentage of agricultural establishments with tractors	24.5	19.7	28.8	33.5	49	34.4	26.1	20.4	23.6
Percentage of agricultural establishments with irrigation	33.2	20.8	34.1	28.9	24.3	83	20.7	41.4	53.2
Percentage of establishments with electricity	83.7	77.3	78.1	81.8	74.1	77.2	85.8	92.2	92.6
Environmental Well-being Index (EWI)	**49.29**	**43.50**	**51.63**	**52.66**	**52.36**	**54.23**	**48.24**	**44.46**	**48.47**
General IFDM	73.1	72.4	78	74.8	73.5	73.3	72.1	69.1	70.3
Employment & Income IFDM	54.4	49.9	61.2	52.8	52.2	52.1	53.2	47.6	60.3

Indicator / Microregion	(01)	(02)	(03)	(04)	(05)	(06)	(07)	(08)	(09)
Education IFDM	82.1	84.1	82.8	84.5	82.1	84.9	80.3	76.9	75.9
Health IFDM	82.7	83.1	89.9	87.1	86	83	82.8	82.8	74.6
GDP per capita (R$)	69.5	73.8	92.6	73.4	75.6	62.2	74.6	50.1	72.6
Average monthly salary	31.7	29.7	31.9	31.8	31.3	28.3	32.9	29.3	32.1
Percentage of employed population	35.9	35.7	49.7	44.6	41	33	38.7	26.8	37.1
Percentage of the population earning up to half a minimum wage	64.7	61.3	54.2	59.1	63.7	65	67.6	73.7	75.6
Human Well-being Index (HWI)	**61.76**	**61.25**	**67.54**	**63.51**	**63.18**	**60.23**	**62.78**	**57.04**	**62.31**
Well-being Index (WI)	**55.16**	**51.86**	**59.12**	**57.77**	**57.45**	**57.05**	**55.08**	**50.38**	**54.99**

Source: Research results

Legend: (01) Paranavaí; (02) Umuarama; (03) Cianorte; (04) Astorga; (05) Porecatu; (06) Faxinal; (07) Jacarezinho; (08) Ibaiti; (09) Paranaguá

As presented by Prescott-Allen (1997), the Sustainability Barometer is a combination of indicators that can be established to assess the environmental and human sustainability of a particular city, region, or country. It can also be used on the BS scale to represent **Good** as the **maximum** value (100) and Bad as the minimum value (zero), along with intermediate classifications (Fair, Medium and Poor) according to the methodology used for these indicators as described earlier.

Analyzing Table 4, it is evident that the highest values (in the Good and Fair ranges) are found in the indicators IFDM Education, IFDM Health, and General IFDM across most of the microregions analyzed. Regarding GDP per capita, only Cianorte stands out with a score of 92.6 (in the Good range). However, the other indicators fall within the Medium or Poor ranges, indicating that the studied microregions still have a significant journey ahead to reach better positions on the BS scale.

It is also observed that a cluster of indicators falls within the Poor range, particularly the Percentage of Employed Population and Average Monthly Salary. These indicators may suggest that lower income is associated with lower economic development. According to Ribeiro and

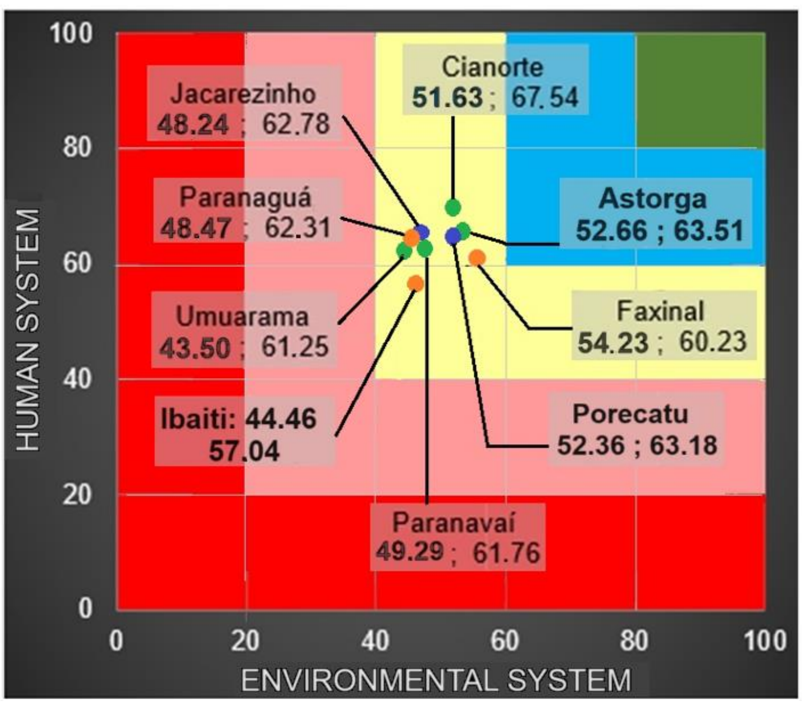
Ferrera de Lima (2021), developed regions tend to be more dynamic and reflect a better quality of life and higher income for the population.

Calculating the average indicators for the Human and Environmental Subsystems in the microregions revealed that, regarding the Human Subsystem, eight of the nine microregions (Paranavaí, Umuarama, Cianorte, Astorga, Porecatu, Faxinal, Jacarezinho, Paranaguá) fall within the "Almost Sustainable" range, while one (Ibaiti) is in the "Intermediate" range. As for the Environmental Subsystem, all microregions are in the "Intermediate" range. It is important to note that some specific data for sugarcane crops were not found and were instead derived from data for temporary crops.

To finalize and facilitate the analysis of the Sustainability Barometer, the results of the calculations will be presented in graphical form, as shown in Figure 6.

Figure 6

Sustainability Barometer (Environmental Subsystem and Human Subsystem) for Sugarcane-Producing Microregions in Paraná



Source: research data

As shown in Figure 6, all sugarcane-producing microregions in Paraná fall within the Intermediate Sustainability range. These results were obtained because some of the indicators used in the analysis boosted the calculations, particularly the General IFDM, Health IFDM, and Education IFDM in the HWI (Human Well-being Index). Similarly, the percentage of agricultural establishments with a water source and the percentage of establishments with electricity had a significant impact on the EWI (Environmental Well-being Index).

The microregions of Paranavaí, Umuarama, Jacarezinho, and Paranaguá had results considered "Fair" regarding the non-use of pesticides. This indicator, combined with the presence of electricity and water sources, contributed to the elevation of the Environmental System index for these microregions.

Regarding the Well-being Index, which is the result of the final average of the Sustainability Barometer (Environmental and Human Subsystems), as shown in the last row of Table 4, all sugarcane-producing microregions in Paraná fall within the Intermediate range. The Cianorte microregion stands out with an average of 59.12, indicating that although it enjoys relatively good indices in the Human Subsystem, some aspects related to the Environmental Subsystem need improvement to achieve sustainable development across all microregions.

Final Considerations

This article analyzed the application of the Sustainability Barometer in the sugarcane-producing microregions of Paraná (Astorga, Cianorte, Paranavaí, Umuarama, Porecatu, Jacarezinho, Ibaiti, Faxinal, and Paranaguá). The research problem addressed was "What is the current state of sustainability in sugarcane production in the producing microregions of the State of Paraná?"

The Sustainability Barometer, developed by Prescott-Allen (1997), is a tool used to measure the sustainability (human and environmental well-being) of a region, state, or country by utilizing various indicators that determine how sustainable the studied area is.

Seventeen indicators were collected and analyzed: eight related to the Human

Subsystem and nine to the Environmental Subsystem. The calculations were performed in accordance with the methodologies of the Sustainability Barometer, using the sustainability scale recommended for the BS.

Regarding the Human Subsystem, it was observed that, out of the eight indicators analyzed, five were rated as Good or Fair, namely (in order) IFDM Health, IFDM Education, GDP per capita, General IFDM, and the Percentage of the Population Earning up to Half a Minimum Wage. Thus, after calculating the Human Well-being Index, only the Ibaiti microregion (57.04) was positioned in the Intermediate range, while the other eight were in the Almost Sustainable range (above 60.01).

As for the Environmental Subsystem, only two indicators fell within the Good or Fair ranges: the Percentage of Establishments with Electricity and the Percentage of Establishments with a Water Source. Two other indicators deserve mention, though they were observed only in some microregions: the Percentage of Establishments that Used Fertilization and the Percentage of Establishments that Did Not Use Pesticides. Following the calculations of the Environmental Well-being Index, it was observed that all the analyzed microregions were positioned in the Intermediate range, with Faxinal (54.23) in the "best" position and Umuarama (43.5) in the last position.

After the analyses, it is evident that the Human Subsystem shows better results than the Environmental Subsystem. This highlights the urgent need to expand the technical guidance provided to agricultural producers. With better understanding, producers can adopt more efficient and sustainable methods for using equipment, fertilization, and pesticides, thereby reducing potential environmental impacts and increasing the productivity of their operations.

With the indices calculated for Human Well-being and Environmental Well-being, it was possible to generate the Sustainability Barometer graph. This resulted in all the analyzed microregions being positioned within the Intermediate Sustainability range. This indicates that, although some indicators contributed to an increase in the Human Well-being Index, the results of the Environmental Well-being Index led to a reduction in the overall index. Thus, the graph clearly demonstrates that the sugarcane-producing microregions of Paraná require attention and action from various stakeholders (government agencies, cooperatives, producer unions, equipment companies, technical assistance, and rural extension services). The goal should be to disseminate knowledge of new practices that are more efficient and environmentally sustainable.

Several factors limited our analyses, such as the lack of updated data, as we relied on information from the 2017 Agricultural Census due to the unavailability of more recent and reliable data. Another limiting factor was the lack of detailed information, such as specific data related to each crop — in this case, sugarcane.

It is hoped that this paper has successfully highlighted the sustainability condition of the sugarcane-producing microregions of Paraná, which, according to the data collected, analyzed, and calculated using the Sustainability Barometer tool, are in an Intermediate condition.

As suggestions for future work, other microregions or municipalities producing sugarcane could be evaluated, possibly with the assistance of cooperatives or production mills. Using updated data could provide different and even more specific insights into the activity.

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