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ARTICLE

Analysis of environmental sustainability perception in Paraná Basin III residents via Item Response Theory

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Abstract

Environmental sustainability perception encompasses an individual's ability to process and interpret sensory information related to the environment. This understanding guides them to consciously and actively protect and care for the environment through continuous learning. This article aims to analyze the environmental sustainability perception of residents of the Paraná Basin III using IRT models for polytomous items, relating it to socio-economic and location characteristics. The choice to conduct the research in this Brazilian territory is driven by the hydrographic basin's substantial influence on the Itaipu hydroelectric power plant and its significance as a crucial water resource for the region. Results showed that: (1) 13.1% of residents have a low perception of sustainability, (2) there were significant differences in perception between cities, with Toledo having the lowest values, and (3) there was a positive relationship between remuneration and perception of sustainability. By analyzing the results presented, it becomes possible to develop effective public policies to improve the region's perception of sustainability.
Keywords: IRT models; Latent variable; Sustainability.

1. Introduction

The concept of sustainability has been becoming increasingly important for humanity and has been the subject of various research efforts due to anthropogenic actions that harm the natural ecosystem (Dockry *et al.,* 2016). Sustainability presents a principle of equilibrium between mercantile productivity that utilizes natural raw materials and the preservation of these materials for the continued functioning of all ecological and vital processes.

The critical importance of sustainability necessitates the development of a scale for measuring its perception. By providing access to a characteristic of a population that would otherwise not be observable, this scale has immense potential to assist in the development of public policy proposals and innovative educational initiatives that promote sustainable practices. This encouragement of behavioral changes can help people better understand the world they live in. However, measuring perception in this study is not a straightforward task, as it involves both knowledge about sustainability and psychometrics.

Some studies propose to evaluate the sustainability perception through different approaches and in different contexts. Ma & Okudan Kremer, 2015 conducted a study regarding the determination of appropriate actions for the end-of-life of retired product components using quantitative indicators to assess sustainability dimensions (economic, environmental, and social) through fuzzy logic. Guida Johnson *et al.,* 2015 surveyed residents in Argentina living along a river in one of Buenos Aires' most polluted basins, evaluating their environmental perceptions. Siegrist *et al.,* 2015 used regression analysis in a study to investigate individuals' perceptions regarding the environmental impacts of changing eating habits over time. Buultjens *et al.,* 2016 applied a variety of qualitative methods, including document analysis, semi-structured interviews, and active observation to investigate the characteristics, management, and sustainability of the industry.

The approach proposed in Vincenzi *et al.* (2018) uses Item Response Theory (IRT), a class of statistical models that estimate unobservable characteristics, and provide information about the quality of items used in the measurement scale of interest. The proposal in Vincenzi *et al.* (2018) is to validate items for the construction of a scale to measure the perception of environmental sustainability. More details about IRT can be found in Andrade *et al.* (2000), Baker & Kim (2004) and Embretson & Reise (2000).

However, a detailed study on the sustainability perception of respondents is necessary, including the relationship with socio-economic and location characteristics. An illustration of the work process in Vincenzi *et al.* (2018) is presented in Figure 1. It is noted that the sustainability perception of respondents was not explored in detail.

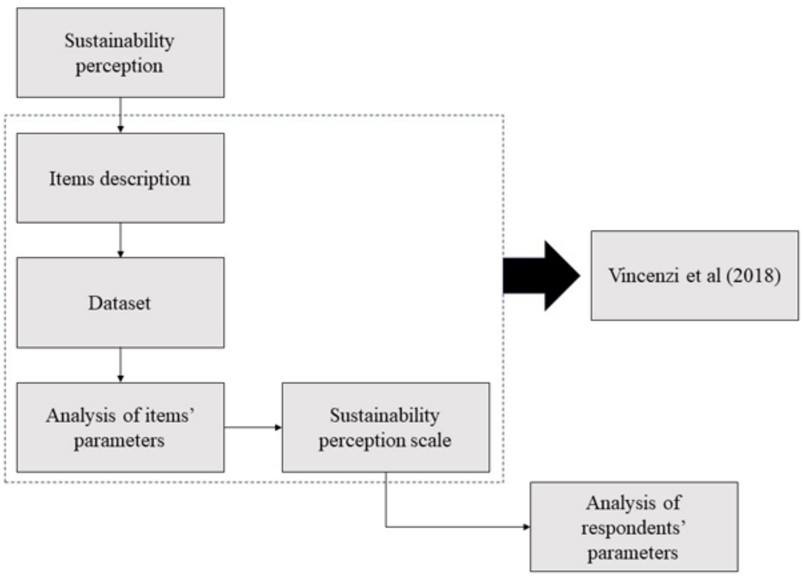

Figure 1. Illustration of the work process on the perception of environmental sustainability dataset.

The purpose of this article is to analyze the environmental sustainability perception of residents of the Paraná Basin III using IRT models for polytomous items. The specific objectives are interpret and contextualize the estimated latent trait, relating it to socio-economic and location characteristics.

This analysis ultimately seeks to facilitate the development of timely and effective public policies that can elevate these levels of perception.

This article is organized as follows. Section 2 details the data used, the IRT models for polytomous items, and the applied model comparison criteria. Section 3 presents the obtained results, including item parameter estimates, the distribution of respondents' sustainability perception estimates, and the relationship between perception and the covariates city, gender, age, education, profession, and remuneration. Some conclusions and remarks are seen in Section 4.

2. Methods

This section describes the dataset used in the study, presents the Graded Response Model (GRM), proposed by Samejima (1969), and the Generalized Partial Credit Model (GPCM), by Muraki (1992), describes the computational resources used, as well as the model comparison criteria.

2.1 Sustainability perception data

The data for this study was gathered from the southwestern region of Paraná, Brazil, specifically in Paraná Basin III, encompassing the only three cities with over one hundred thousand inhabitants: Cascavel, Foz do Iguaçu, and Toledo. The choice to conduct the research in this Brazilian territory is driven by the hydrographic basin's substantial influence on the Itaipu hydroelectric power plant, Brazil's largest, and its significance as a crucial water resource for the region. The basin's water sustains human life, agriculture, industry, and energy production. Moreover, the region has a rich diversity of flora and fauna.

The study utilized a dataset of 52 items, constructed by Vincenzi et al. (2018), to examine the sustainability perception of 2,519 residents of the three cities mentioned. The items were equally divided into four blocks, and by combining two blocks, six different questionnaires were generated, each of them being administered to approximately 420 respondents. Vincenzi *et al.* (2018) used a 6-point Likert scale with the following response categories: strongly disagree, disagree, slightly disagree, slightly agree, agree, and strongly agree. From the original 52 items, Vincenzi et al. (2018) selected the 32 most informative items based on discrimination and differentiation criteria. These items are presented in Table 1.

2.2 IRT models for polytomous items

To define both the GRM and GPCM models, consider a measurement instrument comprising J items administered to n respondents, where the jth item has m_j response categories. Let the random variable Y_{ij} represent the response of respondent i to item j, defined as follows:

$$Y_{ij}|\theta_i, \xi_j \sim \text{Categorical}(P_{ij1}, P_{ij2}, P_{ij3}, ..., P_{ij_{m_j}}), \tag{1}$$

where θ_i is the latent variable of the respondent i, ξ_j is the parameters vector related with the item j, with $i = 1, 2, \ldots, n$, $j = 1, 2, \ldots, J$, $Y_{ij} = 1, 2, \ldots, m_j$.

2.2.1 Graded Response Model

The GRM proposed by Samejima (1969) is considered an extension of the Two-Parameter Logistic Model (Lord, 1952; Birnbaum, 1968), as it is used to handle polytomous items. This model was also defined as the Difference Model by Thissen & Steinberg (1986), because response probabilities are modeled as the difference between adjacent cumulative probabilities.

Table 1. The detailed description of the validated items in Vincenzi *et al.,* 2018

Items	Description
1	I consider it important to have the most recently released phone model.
2	I believe that in the coming years, we will have problems due to a lack of water.
3	I do not care how long my baths take.
4	Air pollution bothers me.
5	I do not mind burning the garbage/waste produced in my home/yard.
6	I prefer to use scrap paper for drafts.
7	I leave the computer/notebook/radio/TV on when I am not using it.
8	The release of waste into rivers and streams bothers me.
9	I seek information about the environmental impacts caused in the production, use and disposal of a product before purchasing it.
10	I believe that it is important to hose down the sidewalks in front of my house every day.
11	I typically reuse product packaging (pots, glasses, plastic vessels) for other purposes.
12	I believe that industries follow environmental regulations.
13	I typically leave the air conditioning on even in unoccupied rooms.
14	I guide my family/friends on environmental issues.
15	I do believe it is not important for sustainability to buy locally manufactured products.
16	I do believe it is not important to purchase products that pollute less.
17	When buying an appliance, I check the power consumption indication.
18	Leaving trash on the ground ensures employment for street sweepers.
19	In buying a product, I prefer those that can be recycled.
20	The garbage thrown onto the street bothers me.
21	I prefer plain paper, which is recycled.
22	I believe it is not important to use energy-saving lamps (fluorescent).
23	I believe it is important to participate in lectures related to the environment.
24	I believe that industries cause environmental damage.
25	At lunch, I do not care about leaving leftovers on my plate.
26	I often put garbage on the street at any time of the day.
27	I find it easy to identify recyclable materials.
28	I do believe the reuse of organic waste (food remains) can be favorable for composting and fertilizing.
29	I typically separate recyclable waste from organic waste.
30	I do believe it is not important to buy used books.
31	When purchasing products, I do not consider their recycling important.
32	The quality of recycled products is lower than that of non-recycled ones.

According to the model, the probability P_{ijk} of the respondent i selects the category k in item j is modeled based on cumulative probabilities (P^+_{ijk}), defined as

$$P^+_{ijk} = P(Y_{ij} \leq k|\theta_i, \xi_j) = \begin{cases} L(\eta_{ijk}), & \text{if } k \in \{1, 2, ..., m_j - 1\} \\ 1, & \text{if } k = m_j \end{cases}, \quad (2)$$

where $L(\cdot)$ describes the item response function often used in the cumulative logistic distribution, given by

$$L(x) = \frac{\exp(x)}{(1 + \exp(x))}. \quad (3)$$

In the GRM, there are m_j response categories for a given item j, and therefore, there are $m_j - 1$ difficulty parameters (b) for each item. The latent predictor η_{ijk} is defined as

$$\eta_{ijk} = a_j(b_{jk} - \theta_i) = b^{\star}_{jk} - a_j\theta_i, \quad (4)$$

where a_j is the discrimination parameter for item j, b_{jk} is the difficulty parameter for response category k of item j.

As previously mentioned, P_{ijk} is obtained as the difference between adjacent cumulative probabilities, i.e.,

$$P_{ijk} = P(Y_{ij} = k|\theta_i, \xi_j) = \begin{cases} P^{+}_{ijk}, & \text{se } k = 1 \\ P^{+}_{ijk} - P^{+}_{ij[k-1]}, & \text{se } 2 \leq k < m_j \\ 1 - P^{+}_{ij[k-1]}, & \text{se } k = m_j \end{cases}. \quad (5)$$

2.2.2 Generalized Partial Credit Model

The GPCM is conceptualized as a generalization of the Partial Credit Model, which was derived from adapting the Rasch Model (Rasch, 1980) to polytomous items. This model was termed the Direct Model by Thissen & Steinberg (1986), as its probabilities are directly modeled.

The GPCM is based on the relationship given by the probability of a respondent choosing response category k over category $k - 1$ for an item j, following a conditional probability provided by the Two-Parameter Logistic Model, represented by

$$P(Y_{ij} = k|Y_{ij} = k-1) = P_{ijk|k-1} = \frac{P_{ijk}}{P_{ij[k-1]} + P_{ijk}} = \frac{\exp[a_j(\theta_i - b_{jk})]}{1 + \exp[a_j(\theta_i - b_{jk})]}. \quad (6)$$

Through this modeling, the probability P_{ijk} of the respondent i selects the category k in item j is given by

$$P_{ijk} = P(Y_{ij} = k|\theta_i, \xi_j) = \frac{\exp[\sum_{h=1}^{k} a_j(\theta_i - b_{jh})]}{\sum_{i=1}^{m_j} \exp[\sum_{h=1}^{i} a_j(\theta_i - b_{jh})]}, \quad (7)$$

where $\xi_j = (a_j, b_{j1}, ..., b_{jmj})$, $a_j > 0$ is the discrimination parameter of the item j, b_{j1} is fixed at 0, therefore, there are $m_j - 1$ step parameters, $b_{j2}, b_{j3}, \ldots, b_{jmj}$, which are the difficulty parameters to move from response category $k - 1$ to k in the item j.

In IRT modeling, evaluating the discrimination and difficulty parameters is crucial for understanding the characteristics and effectiveness of items in differentiating the levels of perception among respondents. Discrimination parameters represent the degree to which an item's response curve is sensitive to changes in the respondent's latent trait, or their underlying level of sustainability perception. Higher discrimination parameters indicate that an item is more effective in distinguishing between respondents with different levels of perception. Difficulty parameters represent the location of an item's response curve on the latent trait scale. Items with higher difficulty parameters require a higher level of sustainability perception to be correctly answered. By examining both discrimination and difficulty parameters, researchers can gain insights into the quality and appropriateness of items for assessing sustainability perception.

2.3 Computational resources

The R software environment (R Core Team, 2021) is a widely used and powerful tool for statistical computing and graphics. Through version 4.3.1, both data processing and analysis via IRT models were carried out in this study.

The "tidyverse" package collection (Wickham *et al.,* 2019) was adopted to facilitate data manipulation, cleaning, and visualization. For data analysis through GRM and GPCM, the "mirt" package (Chalmers, 2012) was used. This package supports a wide range of IRT models, including unidimensional, bifactor, and multidimensional models, carrying out the estimation process with an EM algorithm approach outlined by Bock & Aitkin, 1981.

2.4 Model comparison criteria

Both GRM and GPCM can be used to fit data with polytomous items. However, according to Da Silva *et al.,* 2019, the selection of the most suitable model among the GRM and GPCM should be guided by statistical considerations rather than subjective preferences. In this sense, it is essential to analyze some model comparison criteria that can assist in this process.

In this study, two model comparison criteria were used. The first criterion is the *Akaike information criterion* (AIC) proposed by Akaike (1973). It evaluates the goodness of fit of a statistical model for a given set of data and is defined as follows:

$$\textit{Akaike information criterion (AIC)} : (-2\log(L) + 2p), \tag{8}$$

where L is the maximum likelihood value and p is the number of model parameters. The Akaike information criterion (AIC) evaluates the goodness of fit of a statistical model for a given set of data. The first term, $-2\log(L)$, measures how well the model fits the data and the second term, $2p$, penalizes for overfitting by adding a value of 2 for each parameter in the model. A smaller AIC value indicates better predictive performance.

The second criterion is the *Bayesian information criterion* (BIC) introduced by Schwarz (1978). This criterion is an alternative model selection criterion that also balances model fit with its complexity and is defined as follows:

$$\textit{Bayesian information criterion (BIC)} : (-2\log(L) + p\log(n)) \tag{9}$$

where $n = N \times J$ is the total number of observations in the IRT models. For the GRM and GPCM, $p = N + \sum_{j=1}^{J} m_j$.

3. Results and Discussion

This section presents the application of sustainability perception data to both the GRM and GPCM. It specifically addresses: (1) the selection of the most suitable model for the data, (2) the examination of item parameters, and (3) the analysis of respondents' parameters, exploring the relationship between sustainability perception and other individual characteristics, such as city, gender, age, education, profession, and monthly income.

3.1 Choice of model

The model comparison criteria presented in Section 2.4 were used to determine the most appropriate model for the sustainability perception data. Table 2 presents the differences in AIC and BIC values across the GRM and GPCM.

Table 2. Model comparison criteria for the GRM and GPCM applied to the sustainability perception data

IRT models	Criteria	
	AIC	BIC
GRM	68,175.46	68,735.18
GPCM	68,561.74	69,121.46
Δ_{CRIT}	386.28	386.28

It can be observed that both criteria obtained lower values for the GRM. Furthermore, the differences obtained in the two criteria (Δ_{CRIT}) were substantial, confirming the suitability of the GRM compared to the GPCM when applied to the sustainability perception data.

3.2 Analysis of items' parameters

Estimates of discrimination and difficulty parameters related to the items selected in the final calibration in Vincenzi *et al.,* 2018 with their respective standard errors are presented in Table 3.

Table 3. Estimates of discrimination and difficulty parameters of the validated items with their respective standard errors (EP)

Items	Parameters						
	a	EP	$b1$	EP	$b2$	EP	b_{mean}
1	1.309	0.107	0.432	0.058	1.683	0.113	1.058
2	1.129	0.097	0.710	0.071	1.860	0.135	1.285
3	1.256	0.105	0.637	0.065	1.773	0.122	1.205
4	0.437	0.074	1.481	0.266	4.432	0.729	2.957
5	1.262	0.114	1.100	0.084	1.998	0.143	1.549
6	0.801	0.089	1.203	0.132	2.852	0.289	2.028
7	0.873	0.087	0.841	0.095	2.405	0.215	1.623
8	0.960	0.121	1.557	0.182	2.774	0.319	2.166
9	0.487	0.083	-2.155	0.357	0.901	0.213	-0.627
10	1.277	0.135	0.993	0.100	1.835	0.164	1.414
11	0.698	0.093	0.496	0.120	2.727	0.357	1.612
12	0.514	0.084	-0.404	0.140	2.302	0.394	0.949
13	1.683	0.185	0.949	0.087	1.886	0.152	1.418
14	0.683	0.091	0.195	0.109	2.522	0.338	1.359
15	0.682	0.099	1.197	0.195	2.882	0.411	2.040
16	0.944	0.082	0.171	0.064	1.187	0.100	0.679
17	0.756	0.072	-0.085	0.078	2.083	0.188	0.999
18	1.850	0.154	0.966	0.056	1.635	0.087	1.301
19	0.350	0.061	-1.377	0.283	3.252	0.567	0.938
20	1.027	0.100	1.071	0.092	1.772	0.143	1.422
21	0.507	0.066	-0.188	0.115	2.354	0.303	1.083
22	1.016	0.091	0.975	0.084	2.150	0.164	1.563
23	0.933	0.080	0.342	0.066	2.154	0.167	1.248
24	0.793	0.080	0.915	0.101	2.327	0.214	1.621
25	0.898	0.096	1.129	0.111	2.336	0.213	1.733
26	0.903	0.091	0.792	0.089	1.928	0.168	1.360
27	0.499	0.075	1.191	0.193	3.364	0.481	2.278
28	1.395	0.138	1.208	0.087	1.894	0.135	1.551
29	0.442	0.075	1.397	0.245	3.957	0.642	2.677
30	1.015	0.096	0.639	0.076	1.646	0.135	1.143
31	0.559	0.073	0.588	0.121	2.422	0.301	1.505
32	0.709	0.077	0.268	0.090	1.905	0.195	1.087

Table 3 shows that the estimates of the discrimination parameters (a) are close to those presented by Vincenzi *et al.,* 2018, ranging from 0.350 to 1.850. Item 19 corresponds to the lower limit of this range, while item 18 corresponds to the upper limit. Items with higher discrimination parameter values are desirable as they effectively differentiate between respondents with varying levels of perception.

The estimated difficulty parameters (b) exhibit a wide range, with difficulty 1 (b1) values ranging from -2.155 to 1.557, corresponding to items 9 and 8, respectively. Similarly, difficulty 2 (b2) values span from 0.901 to 4.432, with these extreme values associated with items 9 and 4. This substantial variation in both difficulty parameters is considered desirable as it covers the scale of the latent variable.

3.3 Analysis of respondents' parameters

The distribution of perceived sustainability levels among the respondents is shown in Figure 2. More than 70% of individuals obtained sustainability perception levels between 90 and 110, indicating a moderate level of perception (Vincenzi *et al.,* 2018). Additionally, individuals with a perception below 90, which corresponds to 13.1% of the respondents, have a low sustainability perception, suggesting a need for further sustainability education and awareness initiatives.

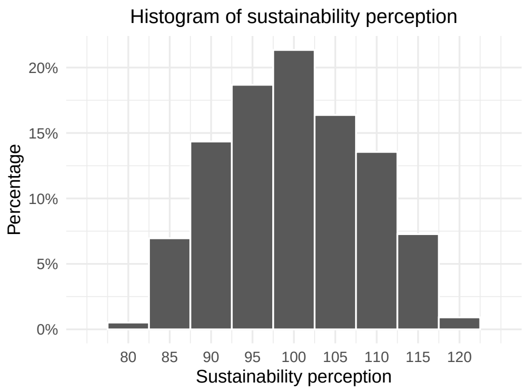

Figure 2. Histogram of the sustainability perception considering the complete dataset.

A study is conducted to analyze the relationships between the environmental sustainability perception and other characteristics of individuals, such as city, gender, age, education, profession, and monthly income. For this, some graphs are presented, as well as the results of the Kruskal–Wallis test, a non-parametric statistical test used to determine whether multiple groups of data come from the same underlying distribution (Kruskal & Wallis, 1952). To examine the particular sample pairs, the criterium Fisher's least significant difference was used for analysis (Conover, 1999). The assumptions for parametric tests of multiple comparisons were violated.

Figure 3 presents two groups of boxplots, one representing the data for the three cities considered in the study and the other representing the data for the genders of the individuals. The boxplots separated by city show that the first quartile and median for Cascavel and Foz do Iguaçu are close and higher than those for Toledo. Furthermore, the average sustainability perception in Cascavel is 102.0, in Foz do Iguaçu is 101.0, and in Toledo is 97.0. According to the Kruskal-Wallis test, the sustainability perception in the three cities has a significant difference at the 5% level, Cascavel being the city with the best perceptions and Toledo with the worst perceptions. The results suggest a significant progression in educational initiatives promoting sustainable practices in both Cascavel and Foz do Iguaçu, evident in the organization of festivals and campaigns designed to raise public awareness about sustainability. Nevertheless, the results indicate a potential gap in educational awareness within this sector in Toledo, despite ongoing discussions regarding the management, treatment, and conversion of solid waste produced by the region's agricultural industry, spearheaded by local government agencies (Agência Estadual de Notícias do Paraná, 2023). These deliberations underscore the need to carefully examine transformations in this sector and endeavor to align them with ecologically sound waste disposal principles, thereby fostering waste valorization, minimizing public health hazards, and mitigating adverse environmental impacts (Neves, 2013).

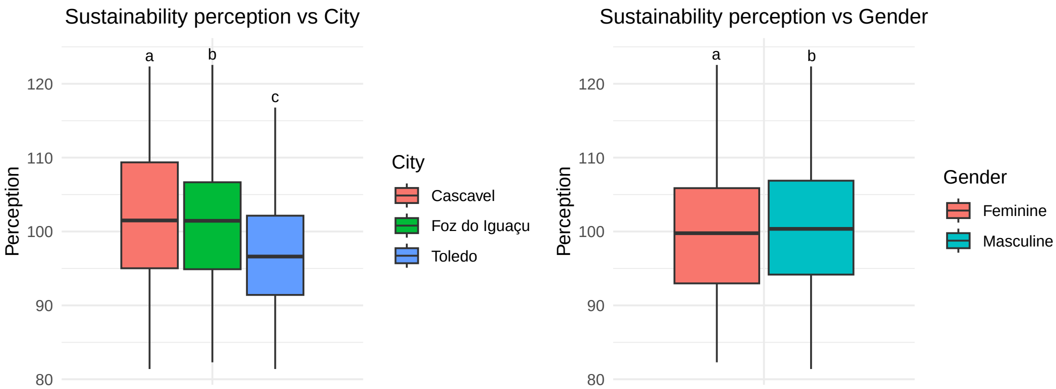

Figure 3. Distribution of environmental sustainability perception through boxplots separated by city (on the left) and by gender (on the right). Categories with the same letter on the boxplots are not significantly different at the 5% level.

The boxplots on the distribution of the sustainability perception separated by gender indicate that the perception is slightly higher in males. The average sustainability perception in males is 100.49, and in females is 99.59. According to the Kruskal-Wallis test, the sustainability perception in the gender has a significant difference at the 5% level. This result is not expected. As highlighted by Hartmann & Siegrist, 2017, a study examining the environmental impacts of consumer behavior on sustainable protein consumption and exploring gender-based perceptional differences revealed that women perceive meat consumption as having a more substantial environmental footprint compared to men (Cordts *et al.,* 2014; Tobler *et al.,* 2011). However, despite this elevated awareness among women regarding the environmental consequences of meat consumption, they still underestimate the detrimental effects of such dietary choices (Cordts *et al.,* 2014).

Two other groups of boxplots are presented in Figure 4. One represents the distribution of environmental sustainability perceptions across different age groups, while the other illustrates the data among individuals at different educational levels.

The boxplots separated by age reveal the strongest sustainability perception among individuals in the 50-59 age group, trailed by the 30-49 age group, 18-29 age group, and the 60+ age group. The average sustainability perception in the 50-59 age group is 100.52, in the 30-49 age group is 99.99, in the 18-29 age group is 99.68, and in the 60+ age group is 99.02. According to the Kruskal-Wallis test, the distribution of sustainability perception in the 50-59 age group differ from the distribution in the 60+ age group. No significant differences were found between the other categories, at the 5% level. Although they have direct exposure to the topic through the educational process, individuals in the younger group have yet to witness the direct and tangible effects of climate change and environmental degradation. However, as public policies become more comprehensive and inclusive, driven by different factors and in different spheres (Nogueira & Fagundes, 2017), linked to the maturity of individuals in this group, it is believed that sustainability perception rates will increase.

The boxplots on the distribution of the sustainability perception separated by educational levels indicate that the categories with the highest median are "Incomplete high degree", "Incomplete un-

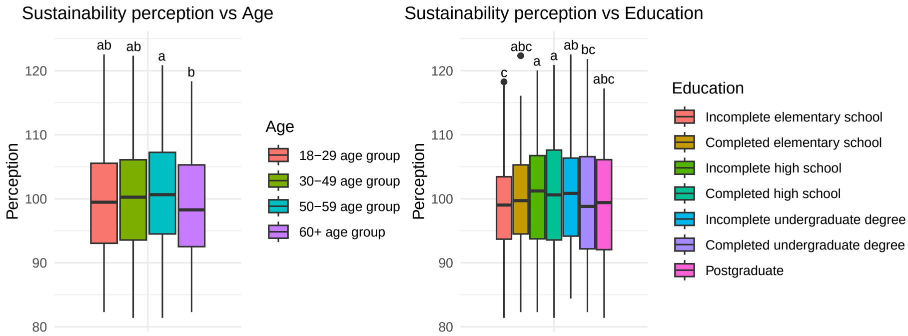

Figure 4. Distribution of environmental sustainability perception through boxplots separated by age (on the left) and by educational (on the right). Categories with the same letter on the boxplots are not significantly different at the 5% level.

dergraduate degree" and "Completed high school", while the categories with the lowest median are "Incomplete elementary school" and "Completed undergraduate degree". From the Kruskal-Wallis test, the distributions of sustainability perception in the "Incomplete high school" and "Completed high school" categories differ from the distributions in the "Completed undergraduate degree" and "Incomplete elementary school" categories. No significant differences were found between the other categories, at the 5% level. In general terms, the anticipated positive relationship between higher education levels and more favorable sustainability perceptions was not consistently observed.

Figure 5 presents boxplots representing the distribution of sustainability perception separated by professions and average monthly income.

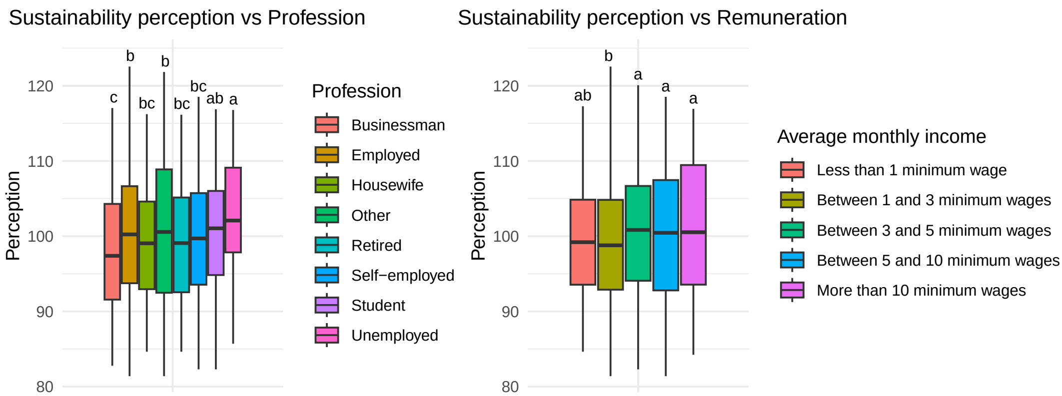

Figure 5. Distribution of environmental sustainability perception through boxplots separated by professions (on the left) and by average monthly income (on the right). Categories with the same letter on the boxplots are not significantly different at the 5% level.

The boxplots on the distribution of the sustainability perception separated by profession indicate that the categories with the highest median are "Unemployed" and "Student", while the categories with the lowest median are "Businessman", "Housewife" and "Retired". According to the Kruskal-Wallis test, the distribution of sustainability perception in the "Businessman" differ from the distribution in the "Other", "Employed", "Student" and "Unemployed", while the distribution in the "Retired", "Housewife", "Self-employed", "Other" and "Employed" differ from the distribution in the "Unemployed". No significant differences were found between the other categories, at the 5%

level.

In general, the boxplots separated by average monthly income show that as the average monthly income increases, the median of the sustainability perception also increases. From the Kruskal-Wallis test, the distributions of sustainability perception in the "More than 10 minimum wages", "Between 3 and 5 minimum wages" and "Between 5 and 10 minimum wages" categories differ from the distributions in the "Between 1 and 3 minimum wages" categories. No significant differences were found between the other categories, at the 5% level. The positive relationship between income and sustainability perception can be explained by the underlying connection between sustainability perception and quality of life. This connection is likely driven by the observed tendency for better financial conditions to enhance social well-being. According to Cavalcanti *et al.* (2019), based on Maslow's Hierarchy of Needs (Maslow, 1943), among the five human needs addressed in Maslow (1954), the need for self-actualization is the highest hierarchical level, representing the innate human aspiration to fulfill one's potential and become who one is destined to be. A higher quality of life typically leads to a stronger sense of self-actualization, which can directly manifest as a deeper connection to humanity and nature, motivating individuals to engage in sustainability-promoting actions.

4. Conclusions

In this paper, a comparison of the GRM and GPCM, two polynomial IRT models, using AIC and BIC measures revealed that the GRM provides the best fit for the data. This result validates the study in Vincenzi *et al.,* 2018, which also used the GRM for the analysis of sustainability perception data. Furthermore, IRT models for polytomous items were used to analyze residents' environmental sustainability perception in the Paraná Basin III, relating it to socio-economic and location characteristics. This approach contrasts with the research of Vincenzi *et al.,* 2018, whose goal was to develop a sustainability perception measurement scale.

Overall, the analysis of the relationship between the covariates city, gender, age, education, profession, and remuneration and the sustainability perception of respondents revealed some interesting results. First, the difference in the perception of sustainability in the three cities in the study. Toledo obviously had lower values than the other two cities. Second, unexpectedly, the study revealed a higher level of sustainability perception among males. Third, in general, individuals with higher remuneration demonstrated a greater sustainability perception.

This study ultimately seeks to facilitate the development of timely and effective public policies that can assertively raise the sustainability perception level. Finally, it is expected that the dissemination of this article will promote research fields in latent variable models and sustainability perception assessment.

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