IDR-CAR

Measuring socioeconomic development in the context of rural properties

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SUMMARY

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Socioeconomic indicators are central components in the context of public policy, as they enable measuring, qualifying, and informing aspects of a social group's reality, serving as a basis for planning, monitoring, and evaluating public actions. With its huge needs and complex public policy systems, Brazil is in great need of social indicators. It is no coincidence that the domestic public data infrastructure is becoming increasingly robust, with databases derived from government agencies' statistical surveys and administrative records, which seek to bring transparency to state actions. In nationwide data sets, the rural universe holds a prominent position, with records from a variety of sources, from the point of view of both the environment and natural resources, as well as agriculture and its interfaces. Despite this, availability of socioeconomic data for rural areas remains a significant challenge. Despite the importance of surveys such as the Agricultural Census (CA) in understanding the socioeconomic aspects of rural areas, their dissemination is limited to municipal level at most, preventing an in-depth understanding of the socioeconomic dynamics of more delimited territories or even rural properties. It is this gap that motivates this work: to find ways to obtain more granular socioeconomic information on rural areas that is compatible with the most detailed rural property database that exists, the Rural Environmental Registry (CAR). We therefore present the IDR-CAR, the Rural Development Index for the CAR, and the methodological approach that is used to obtain it. The indicator is based on a strategy of building dimensions, in light of the Sustainable Development Goals (SDG), using data collected by the 2022 Demographic Census for the IBGE sector grid. Once the indicators for the sectors have been built, they are assigned to the CARs using overlap criteria. This generated the indicator, ranging from 0 to 1, seeking to measure the economic development of more than 7.8 million rural properties in Brazil. The IDR-CAR demonstrated gains in terms of territorial differentiation, as well as convergence with indicators that are already established in the literature (R^2 = 0.73 with the Municipal Human Development Index). The indicator is an advance in territorial intelligence proposed by Agroicone, based on incorporating another analysis layer into the sustainable agriculture research agenda; perhaps the most neglected layer – people – is the most important one in the agenda for transition to a more sustainable world.

INTRODUCTION

Socioeconomic indicators are core components in the context of public policy, as they enable measuring, qualifying, and informing aspects of a social group's reality, serving as a basis for planning, monitoring, and evaluating public actions. Currently, indicators are increasingly standing out, given the increase in data collection and recording and the development of new technological solutions for producing information. In this process, they are decision-making benefits, increasing the chances of effective interventions in society.

According to Jannuzzi (2009), social indicators can be defined as mostly quantitative measures that are capable of expressing social meanings, being used to operationalize abstract concepts, which can meet both theoretical (e.g., research) and practical (e.g., public policies) needs. Indicators, as the author points out, differ from simple data or public statistics, since the latter represent a raw and decontextualized record of a social or programmatic theory, while indicators have a "contextual value" that is supported by the intention to understand and/or change a given reality. The relationship between the two elements, however, is direct, since statistics, by recording reality, become the basis for indicators, providing them with their informational value.

In practice, indicators generally materialize in simple mathematical operations, such as percentages or even counts considering some criterion (e.g., temporal, spatial, and others), and are expressed in rates, indices, and others. Infant mortality rate, per capita income, and the Human Development Index (HDI) are examples of indicators that are commonly used in public policy for quantifying socioeconomic aspects, enabling comparison of geographic units and following their evolution over time.

Indicator complexity and formulas vary according to need, but as Jannuzzi (2009) pointed out, some features are key to ensuring their value, namely: social relevance, validity, reliability, coverage, sensitivity, specificity, intelligibility, communicability, feasibility of obtaining, periodicity, disaggregability, and historicity. These quality requirements highlight the challenge and responsibility of both data production and indicator development, given their direct impact on decision-making.

With its enormous needs and complex public policy systems, Brazil is in great need of social indicators. It is no surprise that the national public data infrastructure is becoming increasingly robust, with databases derived from government agencies' statistical surveys and administrative records, which seek to bring transparency to state actions.

Examples of the profusion of data in the Brazilian experience include IBGE data on a broad range of topics (demographics, economics, agriculture, and others), data on health (DataSUS), education (School Census and a wide range of Inep databases), statistics on labor and employment (RAIS and Caged), among many others. In this context, a notable advance was the creation of dados.gov, the Brazilian Open Data Portal and National Data Catalog, which centralizes inputs from different sources in a single domain. This initiative contributes to streamlining the daily use of data and producing indicators, even as information needs grow ever faster in an era marked by the importance of data and the role of algorithms and Artificial Intelligence (AI).

In nationwide datasets, the rural universe stands out, with records from several sources, from the standpoint of both the environment and natural resources, as well as agriculture and livestock, and their interfaces. In environmental management, for example, the entire set of georeferenced data was highlighted, enabling an understanding of the dynamics of deforestation or natural asset conservation. The Rural Environmental Registry (CAR), an instrument of the Forest Code, is a central administrative record in this process, which, when combined with databases generated by satellite images (PRODES/INPE, MapBiomas, etc.), enables comprehensive analysis and provides a basis for decision-making. In agriculture and livestock, the importance of data from the IBGE (Municipal Agricultural and Livestock Research, Agricultural Census, and others) and Conab, which records supply, demand, prices, and productivity of a number of domestic crops, is recognized. In the industry, the foundations of agricultural policy and other public policies for the countryside, such as rural credit (Sicor/BCB), risk management policies (Proagro, rural insurance), and institutional procurement, stand out.

Despite the picture described above, availability of socioeconomic data for rural areas remains a significant challenge. The Agricultural Census (CA), the latest version that was conducted in 2017, is the main survey for socio-productive characterizing the countryside, with data on establishments' and producers' characteristics . Despite its importance in understanding the rural environment, its dissemination is limited to the municipal level at most, preventing an in-depth understanding of the socioeconomic dynamics of more outlined territories or even rural properties. In a country like Brazil, with a large territorial extension, this situation leads to gaps in information, given that even within a municipality, the socioeconomic situation varies, especially depending on the territory.

Other databases, such as those already mentioned on education and health, are also generally restricted by municipality, while microdata bases at the individual level do not always present the segmentation between urban and rural areas, or keys for cross-referencing with other rural property databases, such as the CAR registration code, a factor that prevents characterizing the rural population, as well as more in-depth statistical analyses.

The low granularity seen in socioeconomic data reflects similarly low granularity in developing rural indicators. The Rural Municipal Human Development Index (IDHM) is the most notable example. The index was presented by Pinto et al. (2018), and is the result of the Human Development in Brazil Atlas project, which was conducted by a partnership between the Applied Economic Research Institute (IPEA), the United Nations Development Program (UNDP), and João Pinheiro Foundation (FJP). The indicator was built considering only rural households in the census data. Despite this, its dissemination to rural areas occurs only at the state level. Other rural indicator initiatives also take place at the municipal level and can be noted in Souza (2018) and Moura and Sousa (2020), as well as in sample case studies, according to Targanski et al. (2017) and Farias et al. (2018), which does not enable broader analyses that can be extrapolated to the Brazilian rural world.

It is from this gap that the motivation for this work arises: to find ways to obtain more granular socioeconomic information on rural areas that is compatible with the most detailed existing rural property database, the CAR. We therefore introduce the IDR-CAR, the Rural Development Index for the CAR, and the methodological approach pursued for obtaining it. The indicator represents yet another advance in territorial intelligence developed by Agroicone, aiming to provide methodologies and useful information for understanding the reality in the countryside for several purposes, especially under the aegis of the triple axis of sustainability: environmental, social, and economic.

THE METHODOLOGY'S DATABASES

Scarcity of data and indicators leads researchers and decision makers to develop palliative solutions for their information needs. Given the high cost of producing large-scale primary data and this task being performed by specific organizations, such as research institutes and administrative bodies, meeting these needs often requires combining databases and using proxies[1] for achieving the desired representation.

When dealing with more granular public databases, whose recording units are households, businesses, rural properties, individuals, etc., there is often a gap in public information that characterizes such units from a socioeconomic point of view. This is due both to the need to protect sensitive data[2], whose public disclosure could cause harm to individuals (e.g., public exposure, scams, etc.), and to the record's purpose (e.g., databases such as rural credit seek to provide transparency about producers who have received public subsidies, without focusing on providing information about these producers' characteristics). These reasons tend to lead to losses for producing knowledge and evidence through scientific research, through problem modeling, as well as for the public policy formulation process and decision-making, in processes focusing on and characterizing a target audience.

The task pursued by this methodology arises in this context. Absence of socioeconomic data in the CAR[3] (data characterizing resident families and

[1]Proxies can be defined as variables that play the role of other variables that are not noticeable or that could not be measured, and I develop a good degree of correlation with them so that they can be used as substitutes (Wooldridge, 2010).

[2]A step forward in data regulation in Brazil was made by the General Data Protection Law (LGPD), Law No. 13.709/2018. The law brings gains such as defining rules for processing sensitive information, i.e., information that, if processed improperly, could lead to discrimination or violation of fundamental rights.

[3]CAR is an instrument of the Forest Code (CF) (Law No. 12.651/2012), provided for in Article 29, with "the purpose of integrating environmental information on rural properties and possessions, comprising a database for controlling, monitoring, environmental and economic planning, and combating deforestation". The CAR is managed through SICAR and its database is expressed in vector representations of polygons, in the following layers: i) Property perimeters; ii) Permanent Preservation Area; iii) Remaining Native Vegetation; iv) Consolidated Area; v) Resting Areas; vi) Hydrography; vii) Restricted Use; viii) Administrative Easements; iv) Legal Reserves. The data is related to provisions of the Federal Constitution and is for administrative purposes.

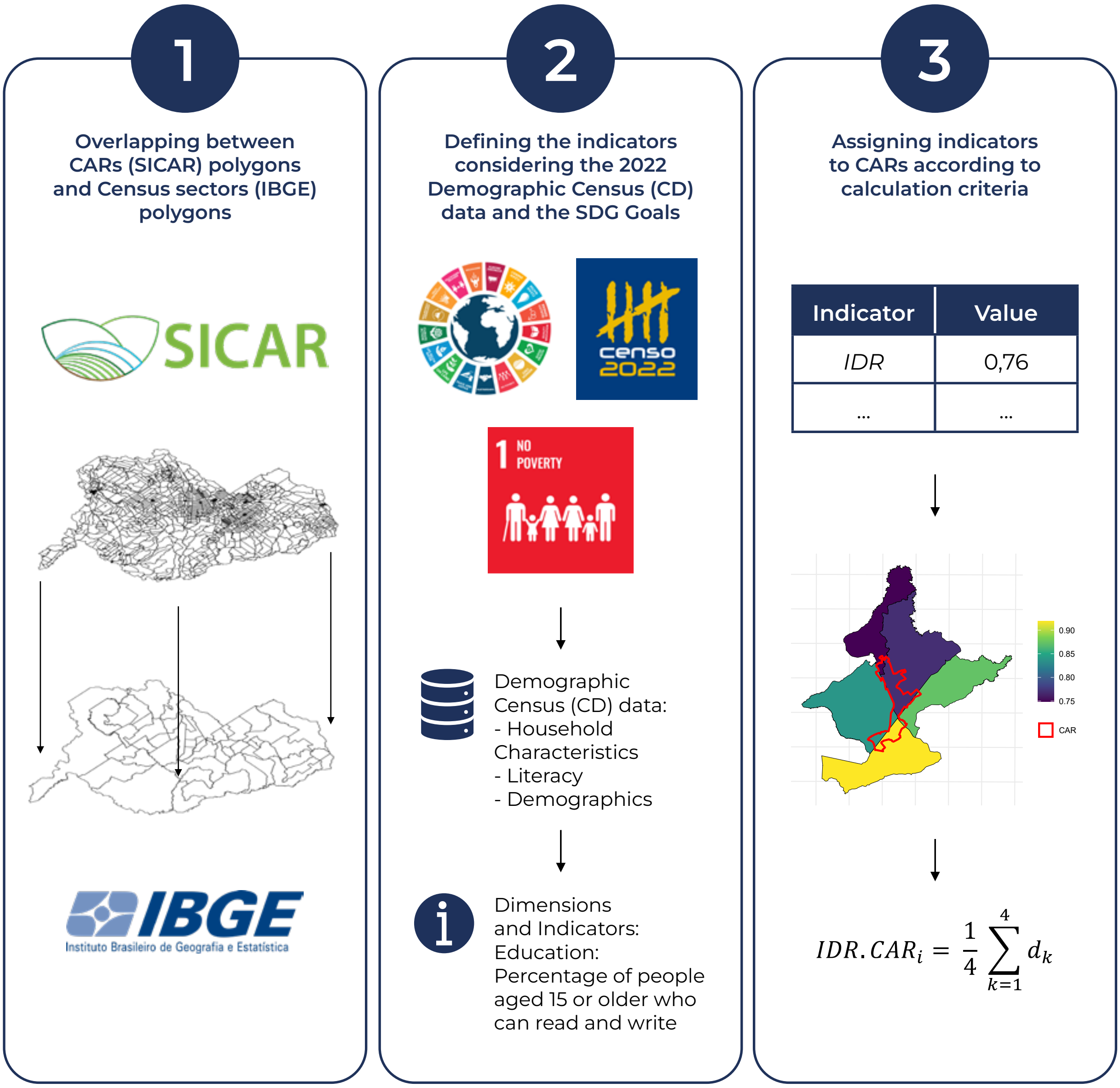
those responsible for rural properties) prevents more in-depth analyses and studies, as well as in planning public and private actions. For example, the opportunity to explore the relationships between individuals and natural resources, using socioeconomic factors (e.g., education, access to water and sanitation, income, and others) as explanatory elements, is lost. From the standpoint of inputs for decision-making, it becomes difficult to accurately understand rural producers' profiles, their vulnerabilities, and the required conditions for certain interventions to be effective.

The major challenge in searching for solutions through data cross-referencing is the fact that few socioeconomic records contain a unique identifier for the associated CAR, which makes characterization impossible. Combining municipal data would not lead to gains in the process either, given the enormous aggregation of the territory compared to the CAR, which is confined to a very specific and heterogeneous local reality.

Faced with this problem, the strategy developed in this study consists of exploring socioeconomic data at a more granular level for building indicators that can be attributed to CARs. The opportunity arises from the fact that CAR data is georeferenced and from the existence of a database that is also georeferenced and less granular than the municipality — the IBGE census tracts — which are used as a framework for collecting demographic census data. By overlaying these two vector databases and the 2022 Demographic Census data, it becomes feasible to build indicators for characterizing the reality behind each CAR.

Figure 1 provides an overview of the methodology. In summary, the process starts from a condition of feasibility: (1) gain in information granularity by means of the overlap between the CAR grid and the census sector grid (IBGE), which (2) filled with data from the 2022 Demographic Census and from the perspective of the Sustainable Development Goals (SDG), enables producing local socioeconomic indicators, which in turn (3) can be calculated and assigned to CARs based on defined criteria and assumptions.

Figure 1 - Methodology Stages



Source: Prepared by Agroicone

Before entering into each part of the process, it is important to recognize that the methodology is not without limitations and risks, but represents a palliative solution, which, based on understanding its elements and definitions, can produce useful inputs for filling this information gap. The next section explores the defined assumptions.

ASSUMPTIONS

Producing an indicator, as intended by this methodology, requires definitions that ensure the validity of the information produced, as well as its possible uses and limitations. To this end, assumptions were established that underpin the relevance of the analysis and procedures adopted in the process of ensuring database compatibility, aiming to guarantee the informational value of the created indicators. The assumptions are listed below:

1. The CAR's polygonal delimitation, despite not necessarily being linked to the place of residence of the person responsible for it (the owner/rural landowner is not required to reside on the land that is registered in their CAR), may contain households where the rural population resides[4];

2. The characteristics of the census sector(s) in which a given CAR is located are the most accurate approximations possible for the individual characteristics of the CAR and its residents, based on available data. The degree of accuracy tends to be higher when there are fewer CARs per census sector, meaning a higher degree of exclusivity of information for the CAR. However, gain in granularity may vary according to the land and census structures of the UF (Federal Unit/State) and the level of analysis of the CARs (only non-canceled CARs were used).

3. In some cases, independence between CAR and census sector grids causes the overlap of a CAR with more than one sector. This situation requires some criteria for calculating the indicators for these CARs. As neighboring sectors may have different characteristics, the weighted calculation of the indicator was used for such situations, using the percentage of the overlapping area as a weighting factor;

4. The indicator's accuracy tends to be more reliable the more "territorial" the raw data used as input is (e.g., a sanitation infrastructure data indicator for a census sector can be more accurately attributed to a CAR than a literacy indicator, given that sanitation services are collective, while the

[4] To obtain evidence of this assumption, the CAR grid was superimposed on the grid of address coordinates collected in the CD 2022 released by IBGE, in order to verify the percentage of CARs with a Private Residence (DP) within their perimeter. To deal with distortions in the analysis caused by specificities in the databases (i.e., 1. address coordinates distant from buildings found in satellite images and 2. coordinates obtained by IBGE on roadsides that are not covered by the CAR grid polygons), a 100-meter radius buffer was applied to each coordinate, thus incorporating a possible 100-meter error in positioning. With this procedure, it was noted that 71.9% of non-canceled CARs had an associated DP coordinate, with the smallest family unit having 46.1% and the largest having 91.1%. It should be noted that the analysis is only potential, given that the IBGE did not discriminate the category (use) of Private Residence, which can be Permanently Occupied, Occasionally Used, Vacant, or Improvised. Only Permanently Occupied Private Residences (DPPOs) have residents.

learning trajectories of people in a household may be more individual, although factors such as schools may condition collective patterns);

5. Given the possibility that a rural property may be segmented into several CARs due to more than one property registration, for example, not all CARs will represent a household. Segmentation of a property into several CARs is a situation that is already recognized in several analyses. From the point of view of using the indicators generated in this methodology, this condition requires caution, as not all CARs will represent a household. Furthermore, the CARs of a property may be located in different census sectors, leading to different values being assigned to the indicators;

Although it cannot be verified whether the household associated with the CAR under analysis actually belongs to the overlapping census sector, this analysis provides the socioeconomic characteristics of the territory in which this CAR is located. This provides relevant information for a number of purposes, as it relates to the surrounding conditions (e.g., education level, infrastructure, and income in that location), with potential for private decisions, such as investments in intensifying production, and public policies. Once the assumptions that enable the methodology have been defined, procedures in the first stage begin, which concerns the relationship between databases.

STAGE 1

OVERLAPPING BETWEEN CARS AND CENSUS SECTORS

As mentioned above, the first stage of building indicators for CARs involved assessing feasibility, in the sense of analyzing the data's ability to handle the granularity of CARs in the territory. Figure 2 helps to compare the degree of territorial delimitation, both for the municipalities grid and for census sectors grid. In large numbers, there are 5,571 municipalities[5] and 207,825 census sectors that intersect with non-canceled CARs[6], showing that the strategy has a national average granularity 37.3 times greater than at the municipal level, where most of the data and indicators are available.

[5] The IBGE includes the Federal District and Fernando de Noronha as municipal boundaries, but legally Brazil has 5,569 municipalities.

[6] For selecting census sectors, the criterion of intersecting with CARs not canceled in the SICAR database was used, on the May 30, 2025 access date. This criterion was adopted to prevent the sector grid — which has more than 450,000 sectors, most of them urban — from overestimating the database's granularity. The intersection was also chosen to prevent a sector filter based solely on rural status from leaving CARs in other situations out of the analysis.

Figure 2 - IBGE Municipality grid and IBGE census sector grid

2a - Municipalities

2b - Census sectors

Source: IBGE. Prepared by Agroicone

To validate the granularity subject and follow the relationships between municipalities, census sectors, and CARs, an analysis of the totals and proportions between these boundaries for each Federal Unit/State (UF) was also performed. Table 1 summarizes the data. States with a large number of census sectors used in the analysis by municipality (B/A), such as Rio de Janeiro, Ceará, and Pará, tend to gain significant information from the strategy, capturing the territories' particularities in a better manner. On the other hand, states such as Tocantins, Rio Grande do Norte, and Piauí, with the three lowest rates, are more aggregated.

Table 1 - Totals and proportions involving municipalities, census sectors, and CARs

UF/STATE	NUMBER OF MUNICIPALITIES (A)	NUMBER OF CENSUS SECTORS THAT INTERSECT WITH NON-CANCELED CARS (B)	CENSUS SECTORS BY MUNICIPALITY (A/B)	NUMBER OF NON-CANCELED CARS (C)	CARS PER CENSUS SECTOR (C/B)
Rondônia	52	1,913	36.8	170,284	89.0
Acre	22	1,170	53.2	52,536	44.9

UF/STATE	NUMBER OF MUNICIPALITIES (A)	NUMBER OF CENSUS SECTORS THAT INTERSECT WITH NON-CANCELED CARS (B)	CENSUS SECTORS BY MUNICIPALITY (A/B)	NUMBER OF NON-CANCELED CARS (C)	CARS PER CENSUS SECTOR (C/B)
Amazonas	62	3,947	63.7	91,203	23.1
Roraima	15	490	32.7	25,800	52.7
Pará	144	9,221	64.0	332,774	36.1
Amapá	16	528	33.0	15,139	28.7
Tocantins	139	2,300	16.5	96,334	41.9
Maranhão	217	11,471	52.9	371,744	32.4
Piauí	224	5,003	22.3	310,999	62.2
Ceará	184	11,864	64.5	387,460	32.7
Rio Grande do Norte	167	3,523	21.1	110,014	31.2
Paraíba	223	5,432	24.4	204,010	37.6
Pernambuco	185	9,238	49.9	409,353	44.3
Alagoas	102	4,576	44.9	134,030	29.3
Sergipe	75	3,229	43.1	114,935	35.6
Bahia	417	17,728	42.5	1,195,103	67.4
Minas Gerais	852	25,795	30.2	1,111,493	43.1
Espírito Santo	78	3,856	49.4	121,639	31.5
Rio de Janeiro	92	9,571	104.0	64,792	6.8
São Paulo	645	25,892	40.1	435,251	16.8

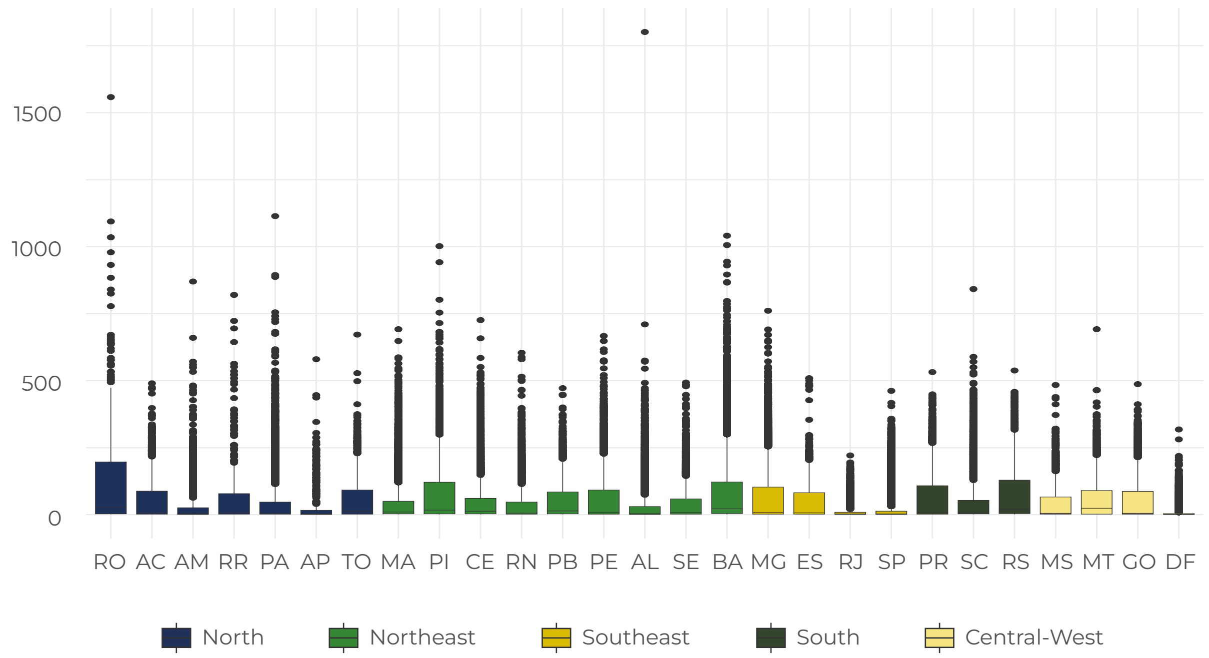
UF/STATE	NUMBER OF MUNICIPALITIES (A)	NUMBER OF CENSUS SECTORS THAT INTERSECT WITH NON-CANCELED CARS (B)	CENSUS SECTORS BY MUNICIPALITY (A/B)	NUMBER OF NON-CANCELED CARS (C)	CARS PER CENSUS SECTOR (C/B)
Paraná	399	12,546	31.4	533,772	42.5
Santa Catarina	295	9,783	33.2	406,303	41.5
Rio Grande do Sul	498	12,286	24.7	645,478	52.5
Mato Grosso do Sul	79	2,691	34.1	84,696	31.5
Mato Grosso	141	4,705	33.4	190,534	40.5
Goiás	246	5,976	24.3	227,440	38.1
Distrito Federal	1	3,091	3.091.0	19,476	6.3
Total	5,571	207,825	37.30	7,862,592	37.83

Source: Prepared by Agroicone. SICAR accessed on 30/MAY/2025

Looking at the ratio between CARs and census sectors (C/B), Rio de Janeiro stood out with the lowest value (6.8 CARs per census sector), followed by São Paulo (16.8) and Amazonas (23.1). The states with the highest ratios were: Rondônia (89), Bahia (67.4), and Piauí (62.2), indicating cases where the land structure is more granular in comparison with the census structure. It is noteworthy that considerations regarding the quality of the information attribution based on these proportions are of limited value, given that they represent a general view of the state. Thus, it is useful to examine the distribution of the number of CARs that intersect each state's census sectors.

Figure 3 provides this overview, showing a large number of outliers in all states, i.e., census sectors that intersect with many CARs. In Alagoas, for example, one census sector overlaps with 1,801 CARs. Although this analysis provides more elements for evaluating the granularity of the information and, therefore, the quality of the methodology, it must take into account the dependence on three factors related to the data: i) the influence of the land structure of each state; ii) the existence of a large number of CARs that have not yet been analyzed, which may distort some figures; and iii) variations in the IBGE census structure. In any case, analyzing the average of the third quartile of the total number of CARs per sector, we observe a value of 72.4. This means that, on average, among the states, 75% of their sectors overlap with up to 72.4 CARs.

Figure 3 - Distribution of the number of CARs intersected by census sectors by state



Source: Prepared by Agroicone

The findings in this first stage show that the proposed methodology for creating socioeconomic indicators by CAR is feasible in terms of gaining granularity. Once this condition is met, we move on to examining the available data and developing indicators using a theoretical framework on sustainable development.

STAGE 2

DEFINING THE INDICATORS CONSIDERING THE 2022 DEMOGRAPHIC CENSUS (CD) DATA AND THE SUSTAINABLE DEVELOPMENT GOALS (SDG)

Building an indicator by overlapping territorial units naturally depends on availability of corresponding data, enabling using criteria for assigning one layer to another. In the census sectors' case, the data used to fill them in is the result of the Demographic Census (CD) that is conducted every ten years by IBGE (the latest edition is from 2022). The CD is the broadest statistical survey conducted in Brazil, whose objective is collecting data for statistical purposes on the demographics and living conditions of all households and their residents. The CD 2022, for example, collected data on the characteristics of Brazilian households (access to water, sanitation, waste disposal, and others) and the characteristics of residents (education, work, income, marriage, disability, and others) (IBGE, 2022).

The CD is a household survey, which means that the data collection unit is the household. Individuals, in turn, are linked to their households. From an operational standpoint, data collection is organized by census sectors, which can be conceptualized as small divisions of the territory (such as neighborhoods), containing a number of households that can be collected by a census taker (IBGE collection agent) during the time set forth for conducting the survey[7]. The sectors also comply with criteria that differentiate them by their location (urban, rural, etc.) and type (varies according to the number of households, population group, and administrative aspects). Most sectors that intersect with CARs tend to be rural, with a larger area and fewer households compared to urban sectors.

Just as the collection of the CD is organized through census sectors, it is also the sector, the data dissemination unit, which is generally expressed in terms of the number of households or people; and in some specific variables, such as income, in monetary units. In the case of the CD 2022, the questionnaire data available at the census sector level are: i) Literacy; ii) Household Characteristics; iii) Color or Race; iv) Demographics; v) Deaths; vi) Kinship; and vii) Income of the Head of Household.

[7]CD 2022 was designed to be collected in about three months in 2020. However, the COVID-19 pandemic brought several challenges to the collection, with postponements, changes in population behavior (restrictions on human contact, refusals to be interviewed, etc.), budgetary problems, and others. Collection began in 2021 and ended in 2022.

Before entering the theoretical indicator definition process, it is important to clarify the logic used in this study. On a technical and scientific level, it is more appropriate to specify data and methods, having previously established the problem to be researched/solved. However, this is often frustrated by the fact that databases are not always available for performing the desired analyses, making it necessary to consider information constraints. In the case of this methodology, building indicators in the proposed granularity is by nature conditioned by CD data, the only data available for census sectors.

The first step in this process was, therefore, to examine the existing data and its ability to assess human development conditions for the intended purposes. The themes and questions that were selected as suitable were:

- Literacy: whether the resident can read and write;
- Housing characteristics:
  - Type of household (permanent or improvised);
  - Type of dwelling (house, apartment, degraded housing, etc.)
  - Type of water supply (public network, well, spring, etc.)
  - Level of access to water (inside the dwelling; on the land, etc.)
  - Sewage disposal (public network, ditch, river, etc.)
  - Waste disposal (collected by cleaning service, burned, etc.)
  - Access to bathroom (existence of bathroom in the household or on the land)
- Average income of the head of the household;

The condition of fitness (ability to assess human development) was noted in the sense of using only data that ensures a reliable qualitative view of the population's living conditions. For example, it is noteworthy that the presence of a bathroom in a home can indicate a condition for adequate human development, while its absence tends to indicate situations of vulnerability. It should be noted that this methodology can be adapted to different information demands using data from the CD 2022, which opens up a great opportunity for varied analyses. Assessing the living conditions of populations, especially in large territories such as Brazil, is not an easy task. Lifestyles, cultures, and trajectories vary, which can, by nature, make perceptions of human development and vulnerabilities among populations variable, making the assessment process complex. Unanimity therefore presents itself as a difficult challenge to overcome (IPEA, 2018).

Given this, it is necessary to seek consensus, and a good source for this can be found in the Sustainable Development Goals (SDG), a broad and detailed framework of objectives, targets, and benchmarks on the basic and desired conditions for the planet's sustainable development. The SDG are an update of the Millennium Development Goals that were established by the United Nations (UN) in 2000. The SDG were developed through a broad process of consultation with governments, society, the private sector, and research institutions, becoming part of the 2030 Sustainable Development Agenda signed by 193 countries in 2015 (Kronemberger, 2019). The process lead to 17 SDG, as shown in Figure 4, with the definition of 169 development targets and criteria.

Figure 4 - Sustainable Development Goals (SDG)

Source: SDG (UN)

The SDG are guided by an integrated vision of society, the economy, and the environment, representing a "global call to action to end poverty, protect the environment and climate, and ensure that people everywhere can enjoy peace and prosperity" (UN, 2025). During their implementation in Brazil, the goals and targets underwent a review and adaptation to local realities, a task carried out by IPEA, in an advisory capacity to the National SDG Commission (CNODS) (IPEA, 2018).

The IBGE, in turn, was responsible for monitoring the indicators[8] for each of the targets, quantifying the achieved progress, which is presented every year at the High-Level Political Forum on Sustainable Development Goals. The existence of a clear, well-founded conceptual framework with established practical guidelines on data and indicators is an important gain for public and private decision-making, as it enables harmonizing actions and monitoring them.

In the case of this indicator, based on selecting data, the process of alignment with the SDG was carried out by identifying the related goals. Table 1 demonstrates this relationship, showing how the data relates to each goal. The relationship is general in nature, with the data not necessarily being an input for expressing achieving the target, but with some possibility of pointing the way. Taking target 3.9 as an example – By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals, contamination, and air, soil, and water pollution; and its relationship with waste disposal data - it cannot be said that an indicator on waste disposal adequacy will measure reduction in deaths linked to pollution, but this goal is connected to the objective, with reducing pollution being a means to that end.

Table 1 also highlights the logic used in creating the indicator, namely its division by dimensions. It was decided to divide the indicator into the following dimensions: i) Education; ii) Collective infrastructure (with data capturing conditions related to public services and equipment in the territory); iii) Housing infrastructure (with data reflecting living conditions in households); and iv) Income. The multidimensional approach will enable the indicator to be broken down by dimension, which can contribute to specific analyses.

Table 1 - CD 2022 data, SDG target and the Indicator's Dimension

CD 2022 DATA	SDG	DIMENSION
Literacy	4.1 – By 2030, ensure that all girls and boys complete free, equitable, and quality primary and secondary education leading to relevant and effective learning outcomes	Education
	4.6 – By 2030, ensure that all youth and a substantial proportion of adults, both men and women, are literate and have acquired basic mathematical skills	
	8.6 – By 2020, substantially reduce the proportion of youth not in employment, education, or training	

[8]The Indicators dashboard can be accessed in: https://odsbrasil.gov.br/

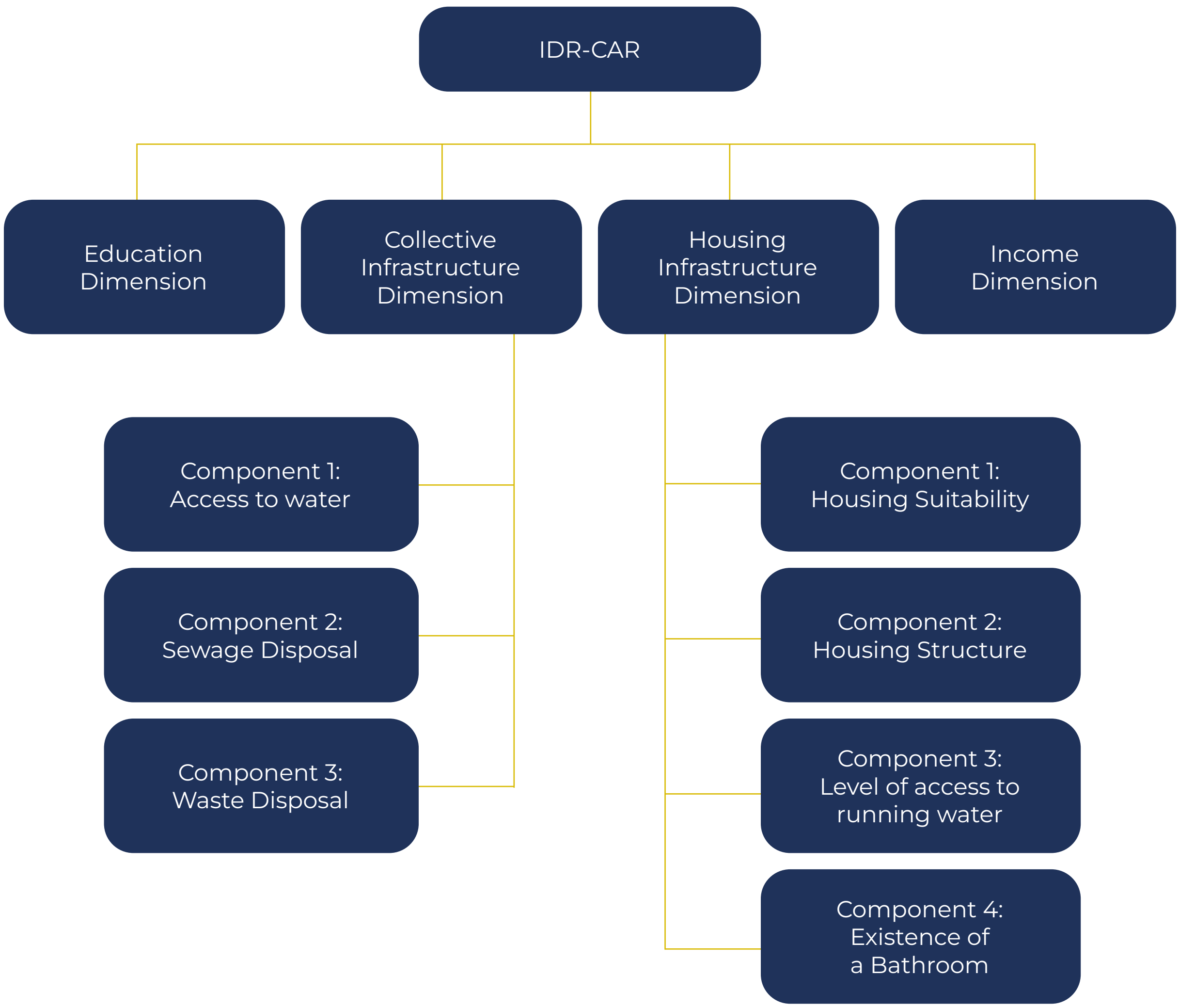
CD 2022 DATA	SDG	DIMENSION
Sewage disposal	6.2 – By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations	Collective infrastructure
	6.a – By 2030, enhance international cooperation and capacity-building support to developing countries in water and sanitation-related activities and programs, including water collection, desalination, water efficiency, wastewater treatment, recycling, and reuse technologies	
Waste disposal	3.9 – By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals, contamination, and air, water, and soil pollution	Collective infrastructure
	11.6 – By 2030, reduce the negative per capita environmental impact of cities, including by paying special attention to air quality, municipal waste management, and others	
	12.4 – By 2020, achieve the environmentally sound stewardship of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water, and soil in order to minimize their adverse impacts on human health and the environment	
	12.5 – By 2030, substantially reduce waste generation through prevention, reduction, recycling, and reuse	
	14.1 – By 2025, prevent and significantly reduce marine pollution of all kinds, especially from land-based activities, including marine debris and nutrient pollution	
Type of water supply	1.4 – By 2030, ensure that all men and women, particularly the poor and vulnerable, have equal rights to economic resources, as well as access to basic services, ownership and control over land and other types of property, inheritance, natural resources, appropriate new technologies, and financial services, including microfinance	Collective infrastructure
	6.1 – By 2030, achieve universal and equitable access to safe and affordable drinking water for all	

CD 2022 DATA	SDG	DIMENSION
Type of water supply	6.2 – By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations	Collective infrastructure
Type of water supply	6.3 – By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing the release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally	Collective infrastructure
Type of water supply	6.4 – By 2030, substantially increase water-use efficiency across all industries and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity	Collective infrastructure
Type of water supply	6.5 – By 2030, implement integrated water resource management at all levels, including through cross-border cooperation, as appropriate	Collective infrastructure
Type of water supply	6.a – By 2030, enhance international cooperation and capacity-building support to developing countries in water and sanitation-related activities and programs, including water harvesting, desalination, water efficiency, wastewater treatment, recycling, and reuse technologies	Collective infrastructure
Access to bathroom	6.2 – By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations	Housing infrastructure
Access to bathroom	5.6 – Ensure universal access to sexual and reproductive health and reproductive rights, as agreed in accordance with the Action Program of the International Conference on Population and Development and the Beijing Platform for Action and the outcome documents of their review conferences	Housing infrastructure
Type of residence	11.1 – By 2030, ensure access for all to safe, adequate, and affordable housing and basic services, and upgrade slums;	Housing infrastructure
Kind of type of residence	11.1 – By 2030, ensure access for all to safe, adequate, and affordable housing and basic services, and upgrade slums;	Housing infrastructure

Fonte: elaborado por Agroicone com base nos dados do CD 2022 e ODS

The Indicator's Collective Infrastructure and Housing Infrastructure dimensions are divided into components, as shown in Figure 5. It is also worth noting that the indicator was designed to be expressed as a value between 0 and 1, using simple proportions and data standardization. Therefore, the closer to 0, the worse the level of rural development; and the closer to 1, the better. Another point of emphasis is the fact that the indicator is calculated for the census sector, so that the rule for assigning it to the CAR will be explored in Stage 3. Details of each dimension, its components, formulas, and concepts used can be found below.

Figure 5 - IDR-CAR Structure



Source: Prepared by Agroicone

DIMENSION: EDUCATION

This dimension seeks to capture aspects related to education by measuring the literacy rate of residents in the census sectors in which the CAR is located. The dimension has a single component and reports the percentage of people aged 15 and over who can read and write, which, according to the IBGE, indicates literacy. The concept refers to the residents' ability to read and write "at least a simple message or note in the language they know" (IBGE, 2022). The data used were:

Table 2 - CD 2022 data on illiteracy

VARIABLE	DESCRIPTION	THEORETICAL-CONCEPTUAL ALIGNMENT
V00900	15 years or more, Resident can read and write	Aligned to SDG 4
V00901	15 years or more, Resident cannot read or write	Not aligned to SDG

Source: CD 2022 (IBGE)

The formula that is used for calculating the dimension:

$$I.educ_i = \frac{V00900_i}{V00900_i + V00901_i} \quad (1)$$

where i represents the census sector.

DIMENSION: COLLECTIVE INFRASTRUCTURE

This dimension seeks to measure the CAR's adequacy in terms of collective infrastructure, i.e., public water, sewage, and waste collection services. The dimension has three components, whose specificities are described below.

COMPONENT 1 – ACCESS TO WATER

The component unforms the percentage of Occupied Permanent Private Households (DPPOs)[9] whose type of access to water is aligned with the sources described in indicator 6.1.1. Proportion of the population that uses safely managed drinking water[10], as established by the IBGE, namely: i) general network; ii) artesian wells; iii) protected shallow wells; iv) protected springs; or v) stored rainwater. The data used for building the indicator are detailed in Table 3.

Table 3 - CD 2022 data on type of access to water

VARIABLE	DESCRIPTION	THEORETICAL-CONCEPTUAL ALIGNMENT
V00111	Occupied Permanent Private Household. Uses general distribution network	Aligned with SDG 1 and 6. Category aligned with indicator 6.1.1 established by IBGE
V00112	Occupied Permanent Private Household. Uses deep or artesian well	
V00113	Occupied Permanent Private Household. Uses shallow well, groundwater, or cistern	
V00114	Occupied Permanent Private Household. Uses a spring, source, or water mine	
V00116	Occupied Permanent Private Household. Uses stored rainwater	
V00115	Occupied Permanent Private Household. Uses a water truck	Not aligned to SDG
V00117	Occupied Permanent Private Household. Uses rivers, dams, streams, lakes, and creeks	
V00118	Occupied Permanent Private Household. Uses other types of water supply	

Source: CD 2022 (IBGE)

[9]Households "whose buildings were erected for housing, with the purpose of serving as a dwelling for one or more people" (IBGE, 2022a)

[10]The concepts can be accessed at: https://odsbrasil.gov.br/objetivo6/indicador611

The formula that is used for calculating the dimension:

$$I.access.water_i = \frac{V00111_i + V00112_i + V00113_i + V00114_i + V00116_i}{V00001_i} \quad (2)$$

where $V00001_i$ is the total number of DPPOs and represents the census sector.

COMPONENT 2 – SEWAGE DISPOSAL

This component informs the percentage of DPPOs whose bathroom or toilet sewage or pit latrine waste is disposed of in the general or storm sewer system or from a filter or septic tank connected to the sewer system. Selecting these two categories partially meets SDG 6 and Indicator 6.2.1 - Proportion of the population using (a) safely managed sanitation services and (b) handwashing facilities with soap and water[11].

In this indicator, "sanitary facilities connected to the collection network, provided that the sewage is sent for treatment" is aligned with sustainable development. However, the technical design of CD 2022 provides that the census taker should consider the "even if the system does not have a sewage treatment plant" option (IBGE, 2022b, p. 37). In other words, the condition of sewage treatment was not captured by the survey. As a simplification, therefore, the used criterion was to analyze compliance with the criterion of destination or some degree of sewage treatment. The data used can be found in Table 4.

Table 4 - CD 2022 data on sewage disposal type

VARIABLE	DESCRIPTION	THEORETICAL-CONCEPTUAL ALIGNMENT
V00309	Occupied Permanent Private Households, Disposal of sewage from bathrooms or toilets or latrines is via the general or storm sewage system	Partially aligned to SDG 6 and to indicators 6.2.1 and 11.1.1 established by IBGE
V00310	Occupied Permanent Private Households, Disposal of sewage from bathrooms or toilets or latrines is via a septic tank or filter tank connected to the sewage system	

[11] The concepts can be accessed at: https://odsbrasil.gov.br/objetivo6/indicador621

[12] The concepts can be accessed at: https://odsbrasil.gov.br/objetivo11/indicador1111

VARIABLE	DESCRIPTION	THEORETICAL-CONCEPTUAL ALIGNMENT
V00311	Occupied Permanent Private Households, Disposal of sewage from bathrooms or toilets or latrines is via a septic tank or filter pit not connected to the sewage system	Partially aligned to SDG 6 and to indicators 6.2.1 and 11.1.1 established by IBGE
V00312	Occupied Permanent Private Households, Disposal of sewage from bathrooms or toilets or latrines is via a rudimentary pit or hole	Not aligned to SDG
V00313	Occupied Permanent Private Households, Disposal of sewage from bathroom or toilet or pit for waste is a ditch	
V00314	Occupied Permanent Private Households, Disposal of sewage from bathroom or toilet or pit for waste is a river, lake, stream, or the sea	
V00315	Occupied Permanent Private Households, Disposal of sewage from bathroom or toilet or pit latrine is another method	
V00316	Occupied Permanent Private Households, Disposal of sewage is non-existent, as they had no bathroom or toilet	

Source: CD 2022 (IBGE)

The formula that is used for calculating the dimension:

$$I.sewage.disposal_i = \frac{V00309_i + V00310_i}{V00001_i - V00316_i} \quad (3)$$

where $V00001_i$ is the total number of DPPOs and i represent the census sector.

COMPONENT 3 – WASTE DISPOSAL

The component informs the percentage of DPPOs whose waste disposal is managed by a cleaning service. The logic of the component is aligned with SDG 11 and Indicator 11.6.1 - Proportion of municipal solid waste collected and managed in controlled facilities out of total municipal waste generated by cities[13], although this SDG refers to municipal waste management. Table 5 summarizes the data used.

Table 5 - CD 2022 on waste disposal

VARIABLE	DESCRIPTION	THEORETICAL-CONCEPTUAL ALIGNMENT
V00397	Occupied Permanent Private Households. Waste is collected from households by cleaning services	Aligned to SDG 11 and to indicators 11.1.1 and 11.6.1 established by IBGE
V00398	Occupied Permanent Private Households. Waste is deposited in cleaning service dumpsters	
V00399	Occupied Permanent Private Households, Waste is burned on the property	Not aligned to SDG
V00400	Occupied Permanent Private Households. Waste is buried on the property	
V00401	Occupied Permanent Private Households. Waste is thrown on vacant lots, hillsides, or public areas	
V00402	Occupied Permanent Private Households. Other waste disposal	

Source: CD 2022 (IBGE)

The formula that is used for calculating the dimension:

$$I.waste.disposal_i = \frac{V00397_i + V00398_i}{V00001_i} \quad (4)$$

where $V00001_i$ is the total number of DPPOs and i represents the census sector.

The dimension is calculated by the simple average between the components.

$$I.colletive.infrastructure_i = \frac{I.acesss.water_i + I.sewage.disposal_i + I.waste.disposal_i}{3} \quad (5)$$

where i represents the census sector.

[13]The concepts can be accessed at: https://odsbrasil.gov.br/objetivo11/indicador1161

DIMENSION: HOUSING INFRASTRUCTURE

This dimension seeks to measure the CAR's degree of adequacy in terms of housing infrastructure, i.e., the structure/equipment that is present in households. The dimension has three components, whose specificities are described below.

COMPONENT 1 – SUITABILITY FOR HOUSING

The component informs the percentage of DPPOs among Occupied Private Dwellings (DPOs), which can be Occupied or Improvised. According to the CD 2022 technical design, an Occupied Improvised Private Dwelling (DPIO) is one that may be "located in: i) a building that does not have rooms intended exclusively for housing (for example, inside a bar, a store, a warehouse, an office, etc.); ii) a mobile structure; iii) on sidewalks, squares, or overpasses; or in natural shelters (such as grottos or caves)" (IBGE, 2022a, p. 84). In other words, these are conditions that are not suitable for housing. This component is aligned with Indicator 11.1.1 - Proportion of urban population living in precarious settlements, informal settlements, or inadequate housing. The data used are described in Table 6.

Table 6 - CD 2022 data on waste disposal

VARIABLE	DESCRIPTION	THEORETICAL-CONCEPTUAL ALIGNMENT
V00001	Occupied Permanent Private Households	Aligned to SFG 11 and to indicator established by IBGE
V00002	Occupied Improvised Private Households	Not aligned to SDG

Source: CD 2022 (IBGE)

The formula that is used for calculating the dimension:

$$I.suit.housing_i = \frac{V00001_i}{V00001_i + V00002_i} \quad (6)$$

where *i* represents the census sector.

COMPONENT 2 – HOUSING STRUCTURE

This component informs the percentage of DPPOs whose type of household is not degraded, and whose structure is in normal condition. The component is related to Indicator 11.1.1, which deals with the suitability of households for dwelling. The calculation was based on the following data:

Table 6 - CD 2022 data on the type of household

<table>
<tr><th>VARIABLE</th><th>DESCRIPTION</th><th>THEORETICAL-CONCEPTUAL ALIGNMENT</th></tr>
<tr><td>V00047</td><td>Occupied Permanent Private Households. Type of dwelling is house</td><td rowspan="5">Aligned to SDG 11 and to indicator 11.1.1 established by IBGE</td></tr>
<tr><td>V00048</td><td>Occupied Permanent Private Households. Type of household is a close house or condominium</td></tr>
<tr><td>V00049</td><td>Occupied Permanent Private Households. Type of household is apartment</td></tr>
<tr><td>V00050</td><td>Occupied Permanent Private Households. Type of household is rooming house or tenement</td></tr>
<tr><td>V00051</td><td>Occupied Permanent Private Households. Type of household is indigenous hut with no walls, or a maloca</td></tr>
<tr><td>V00052</td><td>Occupied Permanent Private Households. Type of household is degraded or unfinished permanent residential structure</td><td>Not aligned to SDG</td></tr>
</table>

Source: CD 2022 (IBGE)

The formula that is used for calculating the dimension:

$$I.housing.structure_i = \frac{V00047_i + V00048_i + V00049_i + V00050_i + V00051_i}{V00001_i} \quad (7)$$

where $V00001_i$ is the total number of DPPOs and i represents the census sector.

COMPONENT 3 – LEVEL OF ACCESS TO PIPED WATER

The component informs the percentage of DPPOs with access to piped water, both in the household and on the property grounds. Piped water in such a way as to enable some manner of access by the household is an indicator of sustainable development, as defined by indicator 6.1.1. The data used are described in Table 7.

Table 7 - CD 2022 data on level of access to piped water

VARIABLE	DESCRIPTION	THEORETICAL-CONCEPTUAL ALIGNMENT
V00199	Occupied Permanent Private Households. Water is piped into the house, apartment, or dwelling	Aligned to SDG 6 and to Indicator 6.1.1 established by IBGE
V00200	Occupied Permanent Private Households. Water is piped in, but only to the property	
V00201	Occupied Permanent Private Households. Water is not piped into the dwelling	Not aligned to SDG

Source: CD 2022 (IBGE)

The formula that is used for calculating the dimension:

$$I.piped.water_i = \frac{V00199_i + V00200_i}{V00001_i} \quad (8)$$

where $V00001_i$ is the total number of DPPOs and i represents the census sector.

COMPONENT 4 – EXISTENCE OF A BATHROOM IN THE HOUSEHOLD

The component is used for informing the percentage of DPPOs that have an exclusive use bathroom. The consideration of exclusive use was based only on the previously mentioned indicator 6.2.1, whose criterion for establishing adequate sanitary facilities considers the bathroom's exclusivity for the household. The data used are described in Table 8.

Table 8 - CD 2022 data on presence of a bathroom in the household

VARIABLE	DESCRIPTION	THEORETICAL-CONCEPTUAL ALIGNMENT
V00232	DPPO. 1 bathroom for exclusive use with shower and toilet in the household	Aligned to SDG 6 and to Indicator 6.2.1 established by IBGE
V00233	DPPO. 2 bathrooms for exclusive use with shower and toilet in the household	
V00234	DPPO. 3 bathrooms for exclusive use with shower and toilet in the household	
V00235	DPPO. 4 or more bathrooms for exclusive use with shower and toilet in the household	
V00236	DPPO. Only a bathroom for shared use by more than one household	Not aligned to SDG
V00237	DPPO. Only a toilet or pit latrine, including those located on the property	
V00238	DPPO. No bathroom or toilet	

Source: CD 2022 (IBGE)

The formula that is used for calculating the dimension:

$$I.bathroom_i = \frac{V00232_i + V00233_i + V00234_i + V00235_i}{V00001_i} \quad (9)$$

where $V00001_i$ is the total number of DPPOs and i represents the census sector.

The dimension is calculated by the simple average between the components.

$$I.housing.infraestructure_i = \frac{I.suit.housing_i + I.housing.structure_i + I.piped.water_i + I.bathroom_i}{4} \quad (10)$$

where i represents the census sector.

DIMENSION: INCOME

This dimension aims to capture the profile of the census sector in which the CAR is located. It is a single component, whose data is expressed in terms of the average monthly nominal income of those responsible for the income of the DPPOs in the census sector. The dimension addresses SDG 1 and 8, which deal respectively with poverty and income, and the best alignment with indicators is provided by Indicator 8.5.1 - Average actual hourly earnings of persons aged 15 and over employed during the reference week with earnings from work, usually received in all jobs, by sex, age group, occupational group of main job, and existence of disability[14]. The data used is described in Table 9.

Table 9 - CD 2022 data on income

VARIABLE	DESCRIPTION	THEORETICAL-CONCEPTUAL ALIGNMENT
V06004	Average monthly nominal income of persons responsible for income per occupied permanent private households	Aligned to SDG 1 and 8 and to Indicator 8.5.1 established by IBGE

Source: CD 2022 (IBGE)

Since the component is a continuous value and not a tally (which makes it difficult to transform into a ratio), the alternative was to standardize the values between 0 and 1, thus creating a comparative scale between all census sectors. However, it was realized that the huge asymmetry of the income variable (fewer sectors with very high incomes and many sectors with low values) would produce a distorted indicator, taking the maximum (very extreme) value as the highest, and still high income values as negligible. For this reason, it was decided to apply the logarithmic transformation procedure to change the statistical distribution of income, helping to better address the variable's asymmetry. The transformation preserves the order of the values but changes their scale, reducing the distance between them. From a theoretical and practical point of view, this procedure is in line with the principle of decreasing marginal utility, which states that the higher the income, the smaller the effect of an increase in supplying basic human needs tends to be. (UNDP/IPEA/FJP, 2013).

[14]The concepts can be accessed at: https://odsbrasil.gov.br/objetivo8/indicador851

The logic proposed for calculating the dimension is aligned with the Human Development Index (HDI) formula, calculated by the UNDP[15]. The index takes into account the natural logarithm of the countries' Gross National Income per capita, using a maximum value of US$ 75,000 and a minimum value of US$ 100 for standardizing the indicator (UNDP, 2025). The Human Development in Brazil Atlas project, which is adapted to the national context for calculating the municipal HDI, followed the same methodological structure as the HDI, but assuming the lowest income of the last decile of the income distribution of individuals in the state (UF) with the highest average income in Brazil, according to 2010 census data, as the maximum reference value, reaching R$ 4,033.00 (in 2010). Meanwhile, the minimum income used was R$ 100, following the HDI calculation (UNDP/IPEA/FJP, 2013).

Based on these methodologies, for the IDR-CAR, the maximum value for the Income dimension was the lowest value of the last decile of the distribution of variable V06004, considering all census sectors of the CD 2022 (not only those with intersections with CARs): R$ 5,169.59. For the minimum value, a threshold was chosen that considered the international classification of extreme poverty established by the World Bank, which is US$ 2.15 per day, at 2017 purchasing power parity (PPP). Using procedures to adjust the value for the Brazilian context and for the CD 2022 reference date[16], the value of R$ 6.69 per day was obtained, which totals an income of R$ 200.7 per month. The formula was as follows:

$$I.income_i = \frac{\ln\,(V06004_i) - \ln\,(min.ref)}{\ln\,(max.ref) - \ln\,(min.ref)} \tag{11}$$

where i represents the census sector; *min.ref* is 200.7 and *max.ref* is R$ 5,169.59.

Once the theoretical and conceptual bases of the indicators have been clarified and their formulas are defined, calculations can be made that will enable their assignment to the CARs.

[15] The technical note on calculating the HDI can be found at: HDR25_Technical_Notes.pdf

[16] According to IBGE calculations, in the 2017 PPP, US$ was equivalent to R$ 2.32. Thus, US$ 2.15 for the international extreme poverty line was equivalent to R$ 4.98 in 2017. As the last PPC calculated was for 2017, the method used for updating this value is to inflate it over the period. This was done using the accrued IPCA index from January 2017 to May 31, 2022 (CD 2022 reference date).

STAGE 3

ASSIGNING INDICATORS TO CARS ACCORDING TO CALCULATION CRITERIA

Como As mentioned earlier, if a CAR has its area distributed across more than one census sector, the criterion adopted for such CARs was to weight the value of each dimension of each overlapping sector by the percentages of the overlapping areas, securing the territorial correspondence logic. Once this was done, the dimensions were calculated by the simple average of the components, giving them equal weight in the dimension's final value. The statements below express the mathematics of the calculation.

A CAR may overlap with census sectors, and each sector has a vector of indicators with four dimensions designated by $D_j=(d_{j1}, d_{j2}, d_{j3}, d_{j4})$. Given that the area of overlap between the CAR's i and the census sector is a_{ij}, the total area of overlap with the sectors can be expressed as:

$$A_i = \sum_{j=1}^{n} a_{ij} \qquad (12)$$

And each sector's fs_{ij} overlap fraction as:

$$fs_{ij} = \frac{a_{ij}}{A_i} \qquad (13)$$

In the case of a CAR i that overlaps with only one sector, the final IDR-CAR is calculated using the simple average of the four dimensions, according to the formula:

$$IDR.CAR_i = \frac{1}{4} \sum_{k=1}^{4} d_k \qquad (14)$$

where k represents the indicator's dimensions.

Meanwhile, in the case that the CAR i overlaps with more than one sector the calculation is weighted, according to the formulas:

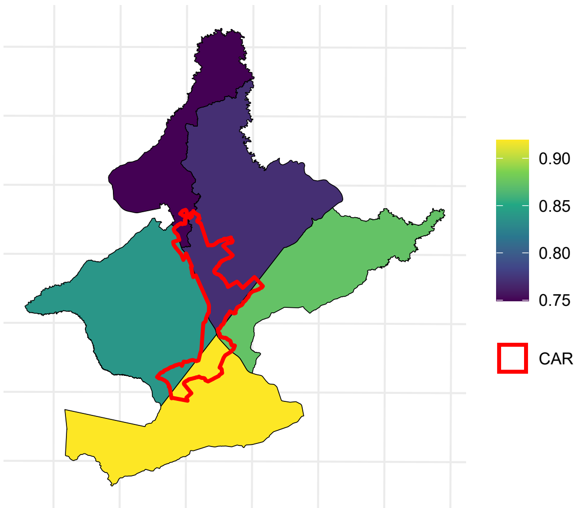
$$\tilde{d}_{ik} = \sum_{j=1}^{4} fs_{ij} \, . \, d_{jk} \qquad (15)$$

where $\tilde{d}_{ik}$ is the k dimension in CAR i obtained by the sum of the product of the CAR overlap fraction with the sector, shown in (13) by fs_{ij} with the value of sector j dimension k shown by d_{jk}. From this point onward, the calculation follows the same logic:

$$IDR.CAR_i = \frac{1}{4} \sum_{k=1}^{4} \tilde{d}_{ik} \quad (16)$$

Figure 6 helps to illustrate a concrete case of using the weighting criterion, showing a CAR that overlaps with five census sectors. The map shows the Income dimension. It is noteworthy that even neighboring sectors may have different characteristics in one dimension, showing how complex the socioeconomic reality is. The example also illustrates the importance of considering assumption 3, which deals with weighting dimensions by the percentages of the sectors' intersecting areas.

Figure 6 - Example of a CAR overlapping census sectors



Source: prepared by Agroicone

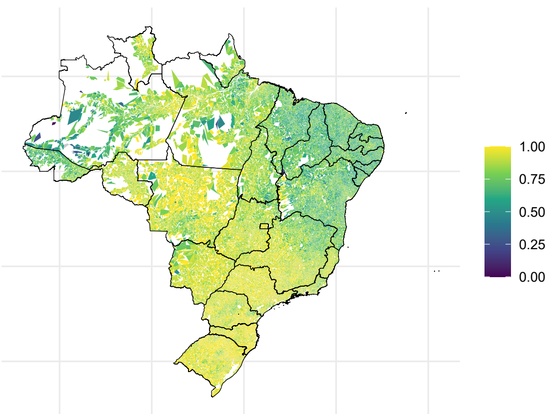
The next section presents the results of applying the IDR-CAR, discussing each of its dimensions, distribution by state, and its gain in terms of granularity.

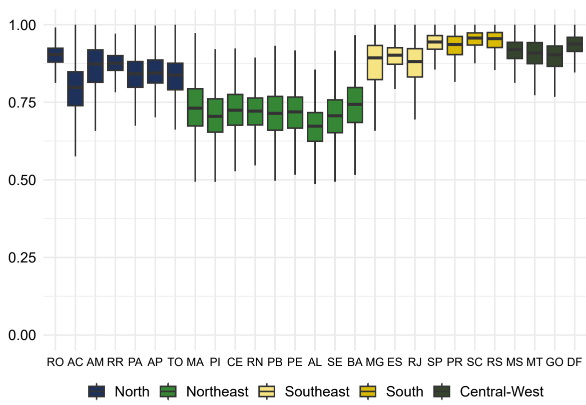
RESULTS AND VALIDATION

Applying the aforementioned procedures generated 197,339 sectors with indicators, out of 207,825 sectors with intersections with more than 7.8 million non-canceled CARs. The difference of slightly more than 10,000 sectors was due to situations such as absence of households in the sector (e.g., water bodies, Conservation Unit sectors, etc.) or low number of households, which leads to the omission of data by the IBGE in order to avoid the risk of identifying sensitive information about the sector's residents. The results of the indicators by census sector can be noted in the maps in Figure 7, as well as the distribution of dimensions for CARs by state in the boxplots.

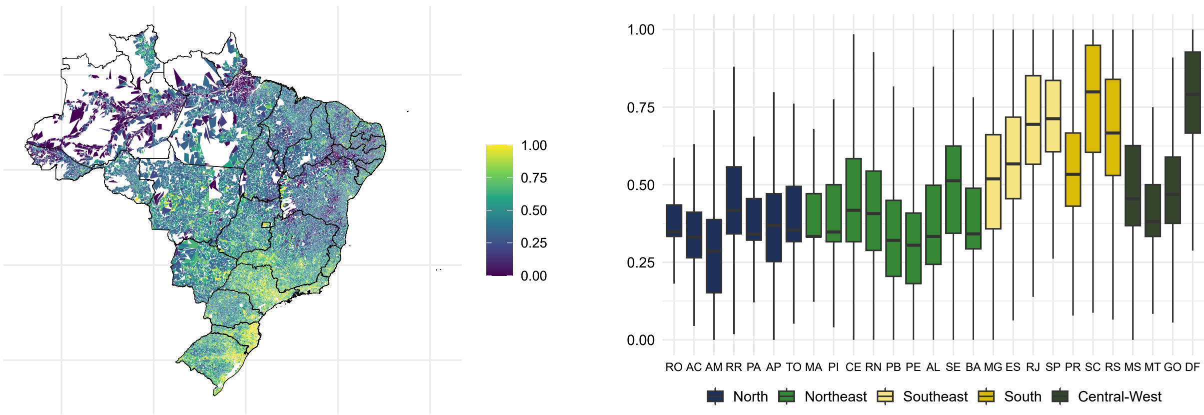
Figure 7 - Dimension maps by census sectors (rural areas) and boxplots for CARs by

7.a - Education Dimension

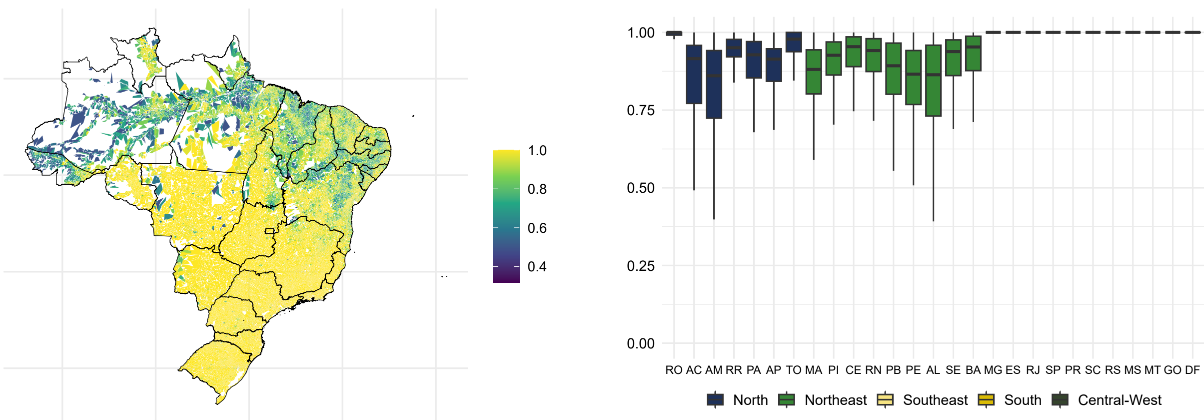




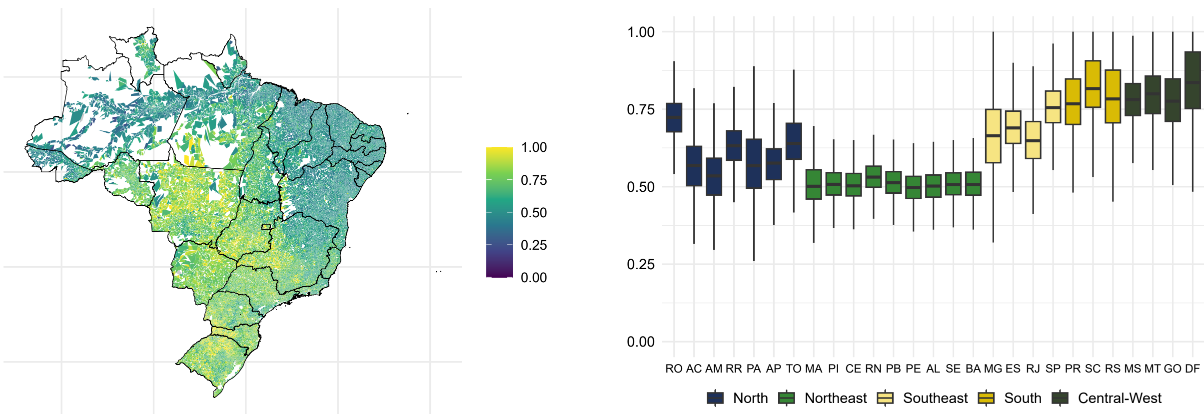
7.b - Collective Infrastructure Dimension



7.c - Household Infrastructure Dimension



7.d - Income Dimension



Source: Prepared by Agroicone based on SICAR and CD 2022 data

The results show patterns that are in line with the well-known Brazilian reality for these socioeconomic dimensions, which are the result of their historical trajectories: the difference between the Southeast, South, and Midwest regions, with higher scores in these dimensions, and the Northeast and North regions, which still have average or low scores. These two macro realities are most evident in the Education and Income dimensions, with greater geographical differentiation.

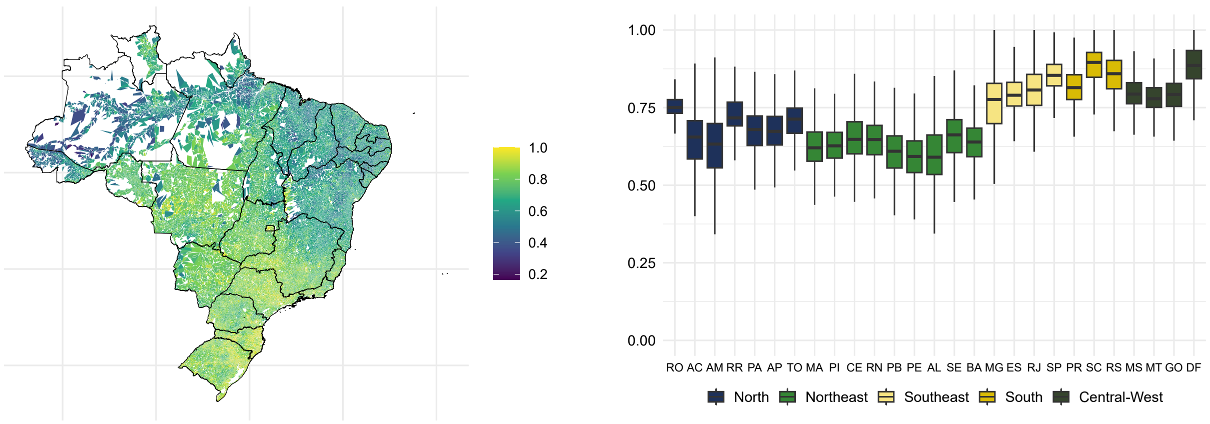
In these two dimensions, low but more homogeneous levels are seen among the Northeast states; unlike the North, where the distribution of the dimension varies more among states, especially in terms of income. This suggests a more unequal rural reality in the region. In terms of income, the Federal Units (UFs or States) in the South and Midwest stood out, with higher distributions, also reflecting the well-known reality of the rural environment in these locations, which is marked by a more vigorous production.

In the collective infrastructure dimension, the generally lower level of the indicator is noteworthy, with higher values only in São Paulo state and in parts of the South, signaling that infrastructure for access to water, waste disposal, and sewage is still generally scarce in rural areas in the rest of Brazil. The distributions of this dimension among the states show greater variation, suggesting greater inequality in this regard.

There is also greater contrast within the regions themselves. The household infrastructure dimension, which takes into account aspects such as adequate housing, also reveals interesting findings, showing a more asymmetrical distribution, in which the South, Southeast, and Midwest regions have practically maximum indicators, while several areas with average values can be seen in the Northeast, and areas with low values in the North. This result demonstrates the persistence of vulnerable situations in these regions, signaling deficiencies such as adequate housing, access to piped water, and the presence of a bathroom in the dwelling.

Consolidation of the dimensions in the IDR-CAR can be noted in Figure 8. Both the map and the boxplot distribution demonstrate the socioeconomic heterogeneity in the territory. The IDR-CAR in all states shows values, in general (upper three quartiles), above 0.5, but the presence of outliers was highlighted.

Figure 8 - Indicator maps by census sectors (rural areas) and the IDR-CAR boxplot by UF (Federal Units or States)



Source: Prepared by Agroicone based on SICAR and CD 2022 data

The analytical gains with IDR-CAR can also be noted from the municipality's point of view, understanding intra-municipal heterogeneity and its reflection in the proposed indicator for CARs. As mentioned, one of the gains in using the methodology is to assign more granular information to rural properties in the territory, enabling local realities to be captured. Figures 9 and 10 illustrate this argument.

The former stands out as it highlights the example of CARs in a municipality, graded on the indicator scale, enabling us to see the existence of great heterogeneity in the territory. Using municipal data for building an indicator would not enable us to visualize such differences.

Figure 10, in turn, highlights two metrics for assessing the degree of intra-municipal differentiation: i) the Gini Index[17] (it assesses inequality in distributing a variable) and ii) the Decile Interval (difference between the last and first deciles). According to the Gini Index, low values can be noted per municipality, with higher levels in the collective infrastructure dimension.

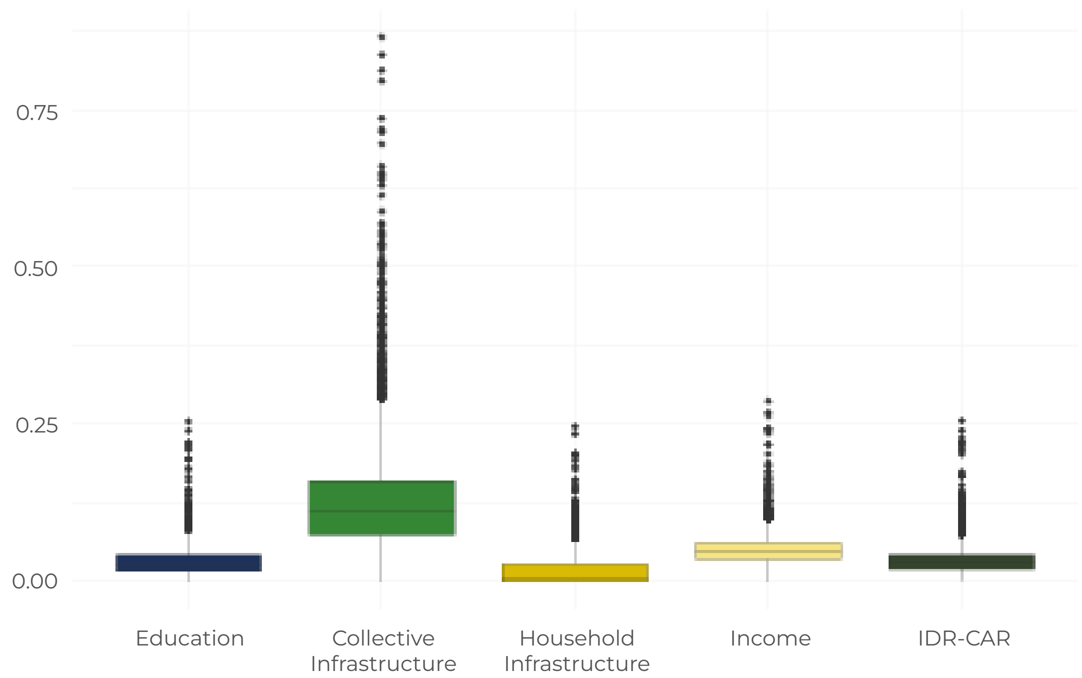
[17]The Gini Index measures the degree of income concentration among units, but can be applied to any variable. A value of 0 (minimum) indicates perfect equality and a value of 1 (maximum) indicates maximum inequality. The calculation is based on the Lorenz curve, which calculates the relationship between the cumulative distributions of the variable and its population. The Index is an analysis of how far the distribution of the Lorenz curve deviates from an equal distribution.

Figure 9 - Example of CARs in a municipality that were graded by IDR-CAR

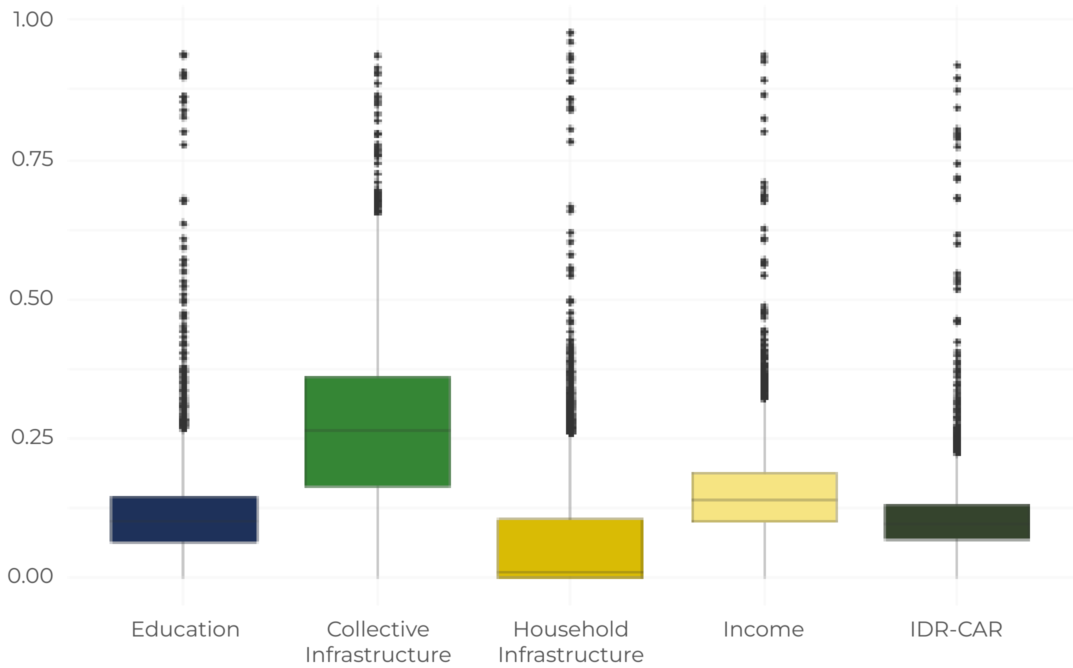
Source: Prepared by Agroicone based on SICAR and CD 2022 data

Figure 10 - Gini Index distribution and the interval between deciles (90% and 10%) in IDR-CAR by municipality

10.a - Gini Index



10.b - Interval between deciles



Note: only municipalities with more than 100 CARs were considered, totaling 5,423.

Source: prepared by Agroicone based on SICAR and CD 2022 data

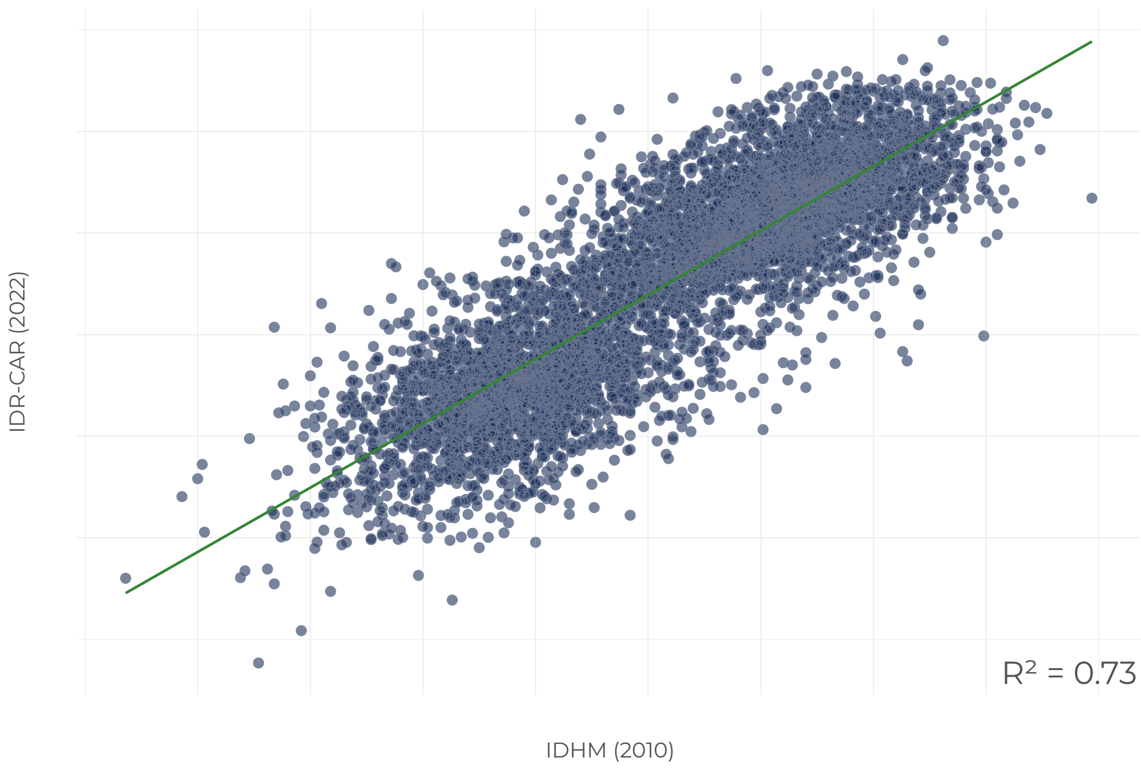
The low overall level of the Index between dimensions and the IDR-CAR does not necessarily mean low intra-municipal inequality and should be analyzed with caution. The very nature of the territorial division at the census sector level tends to make inequality indicators less sensitive, given that differences may be more subtle in smaller territories. In addition, the values are influenced by the specific characteristics of the intersections between census sectors and CARs, given that the greater the number of CARs per sector and the larger the sectors, the less differentiation there tends to be in the indicator from an intra-municipal standpoint, masking the differentiation.

Thus, the distribution of the IDR-CAR Gini indices at the municipal level indicates the presence of inequality among CARs within the municipality. The analysis of the Interval between deciles (90% - 10%) (Figure 10.b) helps to better understand this differentiation. It is worth noting that, even if a municipality presents a very homogeneous pattern of the indicator among its CARs, this situation can only be accurately verified using the proposed methodology; something that would not be possible simply by cross-referencing with the municipal layer.

To assist in the validation of the IDR-CAR, a comparison was also made between its municipal average and the 2010 Municipal HDI[18], a well-established indicator that seeks to capture the municipalities' level of development.

The results are shown in Figure 11, which presents the scatter plot and the explanatory power of the IDR-CAR by the IDHM. The result shows good alignment between the indicators, and the determination coefficient (R^2 = 0.73) can be considered high, given that the IDHM considers the municipality as a whole and not only (predominantly) the rural environment, as the IDR-CAR does. In addition, these are indicators with an interval of more than a decade, and changes in this environment are to be expected. Therefore, there is a secure basis for using the IDR-CAR.

Figure 11 - Comparison between the IDHM (2010) and the IDR-CAR (2022)



Note: only municipalities with more than 100 CARs were considered, totaling 5,387.

Source: prepared by Agroicone based on IDR-CAR and IDHM data

[18] As of the date of the study, the 2022 IDHM had not yet been published.

POSSIBILITIES AND LIMITATIONS

The IDR-CAR opens up new outlooks for research agendas, for the process of developing and analyzing the impact of public policies, and for private sector decisions, enabling the development of analyses that integrate different sustainability axes: environmental, productive, social, economic, and others. Thus, the indicator provides an opportunity for measuring rural properties' socioeconomic reality, which is useful for understanding the living conditions of producers, their families, and rural workers, whether from an aggregate perspective or locally, in smaller sections of the landscape. To illustrate the potential of the IDR-CAR results in these areas, three cases are presented:

CASE 1 – SOCIOECONOMIC ANALYSIS FOR DEFINING THE TARGET AUDIENCE IN ATER INTERVENTIONS IN THE CONTEXT OF PRONAF'S SUSTAINABLE LINES

Transition of family farmers to agriculture that is more resilient to climate change is a challenge for public policy. The reduced availability of their own financial resources to make the necessary investments in this regard, as well as situations of vulnerability, render these producers more exposed to climate risks, which can lead to a series of negative individual and social consequences.

To address this situation, the rural credit policy, through the National Program for Strengthening Family Agriculture (Pronaf), offers better financing conditions so that producers can make investments in productive transition, by means of subprograms such as Agroecology, Bioeconomy, Forests, and Semi-Arid. With the exception of Bioeconomy, all others require using ATER for credit contracting; and since ATER is a fundamental component for the effectiveness of such productive interventions, it is relevant for policy, or even for private or third sector organization projects, to know the socioeconomic profile of producers who contract these lines of credit.

An organization may, for example, develop actions for supporting ATER for this audience, wishing to know the most deprived locations in the Education dimension of the IDR-CAR. Identifying the educational level can be an important step in designing customized interventions, given that it influences producers' ability to understand, discuss, and disseminate instructions when in contact with technical assistants.

Table 2 provides a cross-reference between IDR-CAR data and rural credit microdata made available by the Central Bank (BCB) through Sicor, helping to identify locations that could receive ATER support.

Table 2 - Municipalities with CARs contracted for Pronaf subprograms with sustainable objectives in the 2024/25 harvest and with low scores in the Education Dimension of the IDR-CAR

MUNICIPALITY	CONTRACTED AMOUNT	IDR-CAR EDUCATION DIM. (AVG.)	CARS WITH CONTRACTS IN BIOECONOMY	CARS WITH CONTRACTS IN SEMI-ARID	CARS WITH CONTRACTS IN FOREST
Tutoia (MA)	807,550,00	0.6048	0	33	0
Acopiara (CE)	1,316,957,99	0.6382	14	28	0
Elesbão Veloso (PI)	1,349,106,63	0.6511	11	11	0
Mombaça (CE)	952,711,35	0.6525	2	28	0
Wenceslau Guimarães (BA)	1,602,969,58	0.6626	0	0	25
Boa Viagem (CE)	1,065,076,11	0.6761	12	17	0
Mauriti (CE)	1,190,262,44	0.6810	3	32	0
Serra Talhada (PE)	562,789,79	0.6906	5	17	0
Canindé (CE)	691,684,64	0.6955	0	22	0

Note: Municipalities with an average score in the IDR-CAR Education Dimension below 0.7 and number of contracting CARs above 20 were selected

Source: prepared by Agroicone based on Sicor/BCB and IDR-CAR data

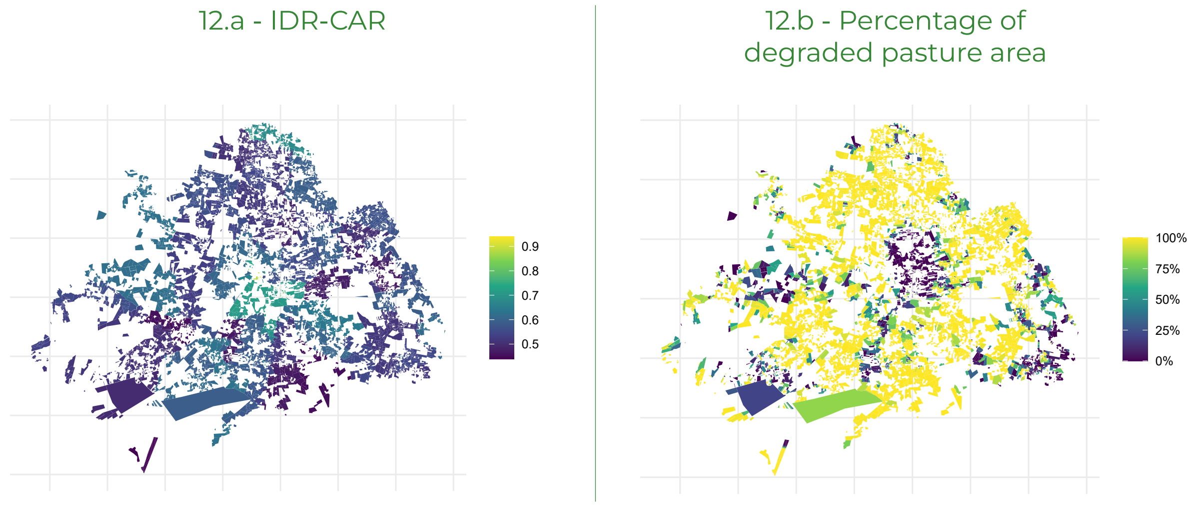
CASE 2 – SOCIOECONOMIC ANALYSIS FOR IDENTIFYING REGIONS WITH RURAL PROPERTIES WITH A HIGH PERCENTAGE OF DEGRADED PASTURELAND AND HIGH SOCIAL VULNERABILITY

Pasture degradation is a core problem in the context of cattle ranching, leading to environmental and socioeconomic effects with significant negative potential. On the environmental side, degradation resulting from inadequate soil stewardship leads to loss of nutrients and the consequent ability to provide food for animals, contributing to lower carbon retention and generating pressure to open up new native vegetation areas. From a social and economic point of view, low supply of pasture for animals leads to low productivity in cattle ranching and/or dairy farming, which compromises family income and can lead to critical situations of inactivity, especially in the case of family farming.

Detecting pasture degradation situations is essential for designing actions that help change production trajectories and mitigate the aforementioned risks. Detecting this by characterizing the socioeconomic realities in the territory is an important strategic advance that can be achieved by using the IDR-CAR, which enables identifying the vulnerabilities of the populations behind this situation.

Figure 12 shows CARs with a high percentage of degradation of their pasture areas and very low IDR-CAR values, indicating high social vulnerability. In this case, contour conditions (investments in education and infrastructure) become necessary, given that their absence tends to limit the effectiveness of other agricultural policies, such as credit and ATER, for example.

Figure 12 - IDR-CAR and percentage of degraded pasture in CARs



Note: A municipality with a high percentage of degraded pastureland was selected for CARs of up to four fiscal modules and low average IDR-CAR.

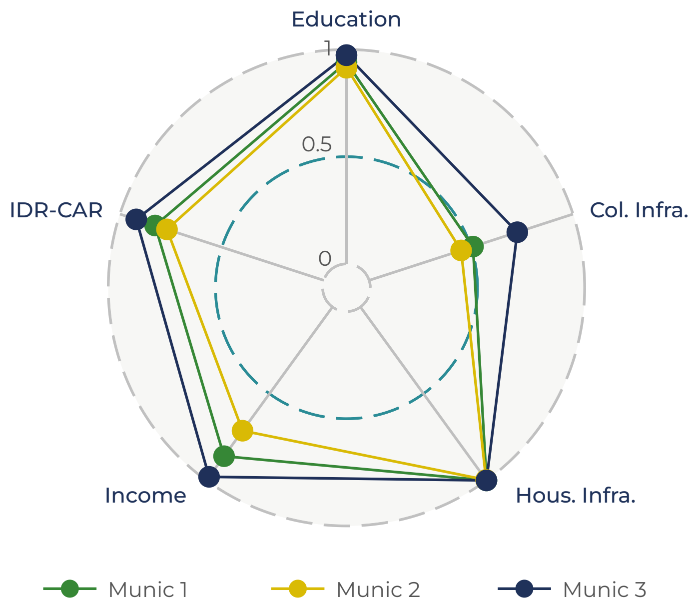
Source: prepared by Agroicone based on data from IDR-CAR and the Prioritization Plan for the National Policy for Degraded Pasture Conversion (PNCPD) (Brazil, 2024).

CASE 3 – SOCIOECONOMIC ANALYSIS FOR GUIDING FINANCIAL INSTITUTIONS' STRATEGIES IN THEIR RURAL CREDIT PORTFOLIOS

In addition to identifying vulnerabilities in the territory, the IDR-CAR can also be used for business decision-making, enabling opportunities in more developed regions to be identified. A financial institution, for example, who wishes to expand its operations in the territory can use the indicator and its dimensions to assess and compare municipalities according to their development levels.

Figure 13 shows a comparison based on the CARs of a financial institution's rural credit portfolio for the 2024/25 harvest. It can be seen that Municipality 3 (in blue) has the best scores in all dimensions, followed by Municipality 1 and then Municipality 2. For the financial institution, there is therefore better risk indication, since the IDR-CAR dimensions can serve as proxies for understanding the chances of default by producers in a region.

Figure 13 - Comparison of IDR-CAR between three municipalities



Source: prepared by Agroicone based on IDR-CAR and Sicor/BCB

It is important to stress the limitations of the indicator that was built. The main limitation concerns the fact that the IDR-CAR does not represent raw CAR data (e.g., whether the rural landowner/tenant can read and write), but rather a multidimensional metric on living conditions in the territory in which the CAR is located, which can be used as a proxy for independently capturing the situation of the people/families living on the property. This gives the indicator a natural inaccuracy when used individually, given that the CAR receives the average value of one or more territories, as has been demonstrated. Therefore, accuracy varies according to the IBGE census structure and the land structure based on the CAR. Analyses in Stage 1 showed that, on average, 75% of all sectors selected in the analysis, among the UFs, have less than 73 overlapping CARs, which can be seen as a reasonable value for differentiation in terms of data coverage.

Another natural limitation of the produced indicator is the fact that not all owners or squatters responsible for CARs reside in the location where the property is located. An owner, for example, may reside in an urban area and own a rural property. The property's territory may have inadequate infrastructure and be surrounded by illiterate, low-income people/families living in poor housing conditions, which would lead to a low IDR-CAR value, contrasting with the owner's potentially higher standard of living in their urban residence. In a situation like this, other standards related to CAR (e.g., environmental situation, credit intake, etc.) would not theoretically be correlated with situations of vulnerability.

The analysis conducted in previous sections showed that 71.9% of the CARs used in the analysis intersect with private households collected by IBGE in CD 2022. Although this figure does not distinguish between household occupation (given the IBGE's lack of discrimination between types of households), it enables us to conclude that most CARs have an associated household. This observation is particularly important in the case of family farming, which tends to be directly related to life in the countryside.

Finally, it is important to note that, in general, every indicator has several limitations associated with: i) data availability; ii) data quality and its ability to capture qualitative situations; and iii) the concepts and theories that the indicator seeks to capture. The IDR-CAR is no different, given that: i) it is conditioned by the 2022 CD data released at the census sector level (the territorial unit that enables the best approximation of CAR granularity); ii) it has qualitative limits (e.g., one may wonder whether an indicator of 0.8, for example, reflects the same quality of life in a CAR in Maranhão and another one in the Federal District) and iii) it expresses only socioeconomic dimensions and, even then, only some regarding rural development, which is a broader phenomenon involving productive aspects, transportation infrastructure, economics, access to markets, and others. Even so, given these caveats and the validations made, the indicator can be considered an effort in territorial intelligence, with potential for analysis and for informing public and private decisions.

FINAL CONSIDERATIONS

This study has sought to fill an important information gap in the data and indicators infrastructure that portrays rural Brazil: lack of more granular data at the intra-municipal level. Based on the IBGE census sector layer and data collected in the 2022 Demographic Census, we saw an opportunity to learn about the socioeconomic realities of rural properties, where millions of rural producers and workers live. Through georeferencing procedures, assumptions, and the theoretical framework of the Sustainable Development Goals (SDG), it was possible to build indicators and assign them to properties in the Rural Environmental Registry (CAR), aiming to measure their development level.

As evidence of the quality and relevance of the methodology developed for the IDR-CAR, we can list: i) the low average number of CARs per census sector in Brazil, which is 37.8 (with ratios ranging from 6.3 to 89 among the states), which enables a relevant informational gain when compared with cross-referencing with the second lowest granularity (municipal); ii) the high percentage of non-cancelled CARs intersecting with private household coordinates collected by the IBGE in CD 2022, 71.9%, which attests to the relationship between CAR and the aspects of residence in rural areas; iii) the general alignment of the indicator with a consolidated theoretical framework on human development (SDG/UN), seeking maximum convergence with established indicator methodologies such as the HDI (UNDP), the MHDI (UNDP/IPEA/FJP), and with the SDG indicators in Brazil developed by IBGE; v) the result converging with the well-known Brazilian social reality, further validated by comparison with the IDHM (R2 = 0.73). This evidence does not exempt the IDR-CAR from flaws and even limitations that have already been demonstrated, which are intrinsic to the data; but it provides sufficient points for assuming the resulting innovation gains and benefits for agendas that consider the triple axis of sustainability: environmental, social, and economic.

The IDR-CAR therefore represents an advance in territorial intelligence proposed by Agroicone, and it is hoped that it will be an important resource in the development of agricultural research, public policy, private decision-making, and climate change mitigation. Ultimately, the indicator represents the incorporation of yet another layer of analysis in this field;

IDR-CAR is a breakthrough in territorial intelligence proposed by Agroicone, which is based on incorporating another analysis layer into this environment; perhaps the most neglected layer — people — is the most important one in the agenda for transition to a more sustainable world.

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IDR-CAR

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