

## **(Un) sustainability in the lower course of São Francisco River in the States Sergipe and Alagoas (Brazil)**

*(In) sostenibilidad en la ribera baja del río São Francisco en los Estados de Sergipe y Alagoas (Brasil)*

*(In) sustentabilidade no baixo São Francisco em Sergipe e Alagoas (Brasil)*

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**Abstract** — *This article presents a tool, which if it is not a novelty, seeks to collaborate with discussions about sustainable development, identifying indicators and indexes for assessing the sustainability degree of human interventions in the lower course of São Francisco River in the States Sergipe and Alagoas (Brazil). The purpose of the research was to establish the influence of environmental parameters, specifically, the water flows of São Francisco River, in the socioeconomic indicators of the lower course of the river, related to rice production, not only by natural but also by irrigation flood. The documentary sources and statistics were the data basis that made it possible to explain the sustainability status of each of the municipalities. The methodological approach was attached to the procedures for calculation of Municipal Sustainability Indexes (ISM), represented by Anthropogenic Impact Polygons and exhibited in radar charts. Therefore, it was found that the low flow of the river, generated by the Xingó dam, and the saline intrusion has converted the São Francisco River into a large lake. In this context, the rice production of the region fell in the areas of natural flooding and increase in the irrigation model at the expense of the low sustainability of the environment.*

**Resumen** — Este artículo presenta una herramienta que, si no novedosa, busca colaborar con las discusiones sobre el desarrollo sostenible, identificando indicadores e índices para evaluar el grado de sostenibilidad de las intervenciones humanas en la ribera baja del río São Francisco en los Estados de Sergipe y Alagoas (Brasil). El propósito de la investigación fue determinar la influencia de los parámetros ambientales, específicamente, el flujo de las aguas del río São Francisco, en los indicadores socioeconómicos en la ribera baja del río, relacionados con la producción de arroz, tanto de forma natural como a través de la inundación artificial “modelo de regadío”. Las fuentes documentales y las estadísticas fueron la base de datos que permitió explicar el estado de sostenibilidad de cada uno de los municipios. El enfoque metodológico buscó procedimientos para el cálculo de los Índices de Sostenibilidad Municipal (ISM), representados por los polígonos de impacto antropogénicas y expuestos en gráficos de radar. Por lo tanto, se constató que el bajo caudal del río, generado por la presa de Xingó, y la intrusión salina ha convertido en un gran lago a la ribera baja del río São Francisco. En este contexto, la producción de arroz de la región cayó en las zonas de inundación natural y aumento en el modelo de regadío a costa de la baja sostenibilidad del medio ambiente.

**Resumo** — Este artigo apresenta uma ferramenta, que se não é nova, procura colaborar com as discussões a respeito do Desenvolvimento Sustentável, apontando indicadores e índices, que permitem avaliar o grau de sustentabilidade das intervenções humanas no baixo curso do rio São Francisco em Sergipe e Alagoas - Brasil. O propósito da pesquisa foi estabelecer a influência dos parâmetros ambientais, mas especificamente, a vazão das águas do São Francisco nos indicadores socioeconômicos da região do baixo curso do rio, relacionados à produção de arroz, tanto por inundação natural, quanto por irrigação. As fontes documentais e estatísticas, foram a base de dados que possibilitaram explicar o estado de sustentabilidade de cada um dos municípios. O enfoque metodológico se prendeu aos procedimentos de cálculos dos Índices de Sustentabilidade Municipal (ISM), representados pelos Polígonos de Impacto Antropogênico e apresentados em gráficos radar. Portanto, constatou-se que a baixa vazão das águas do rio, enclausurou o baixo curso do rio São Francisco entre a barragem de Xingó e a intrusão salina, transformando-o em um grande lago. Nesse contexto, a região apresentou queda na produção de arroz por inundação natural, aumento no modelo irrigado, com o custo da baixa sustentabilidade ambiental.

**Keywords:** Environmental impacts, Sustainability indicators, Flow regulation, Rice culture, São Francisco River

**Palabras Claves:** Impactos ambientales, Indicadores de Sostenibilidad, Regulación del flujo de agua, Cultivo de arroz, Río São Francisco

**Palavras Chaves:** Impactos ambientais, Indicadores de sustentabilidade, Regulação de vazões, Cultura de arroz, Rio São Francisco

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## INTRODUCTION

Technological advances promoted by modern society during the industrialization process in the period covered by the post Second World War to the contemporary, deepened the environmental crisis through which mankind is going through. On the other hand, the environmental awareness it is consolidated in the populations in general.

The environmental crisis brings along the need for paradigm changes regarding the world view, changes in development concepts, in the life quality concepts. Thus, in the 1990s, post ECO-92, the concept of sustainable development has gained more prominence as a way to replace the current hegemonic concept of Development and Economic growth, which was signed in the modern society foundations and the development parameters in the modern western world.

Despite the society legitimacy, the discourse of this new development model, did not bring along a way that creates a consensus on the sustainable development concept, on the contrary, what it is seen are different lines that discuss the issue, seeking a way out, but in the same development model.

In the same way, there are discussions regarding the tools or systems that are better suited to instrumentalize the development sustainability assessments and therefore the environment as a natural resources holder.

São Francisco River is born in the Serra da Canastra, south-west of Minas Gerais. It takes the South-North and then East-West directions, stretches 2.700 km, passes through the States of Minas, Bahia, Pernambuco, Alagoas and Sergipe and traverses three biomes –Cerrado, Caatinga and Atlantic Forest–. The hydrographic basin is located between 7° and 21° South Latitude and 35° to 47° West Longitude, runs 639.219 Km<sup>2</sup>, 7,5% of the national territory and with an average flow of 2.850m<sup>3</sup>/s that reaches the Atlantic Ocean. The drainage area covers seven States, occupying in Bahia 48,2%, Minas 36,8%, Pernambuco 10,9%, Alagoas 2,2%, Sergipe 1,2%, Goiás 0,5% and Federal District 0,2%. There are 504 municipalities, or 9% of Brazil<sup>1</sup>.

In Alagoas, it occupies an area of 14.286,56 km<sup>2</sup> (51,45%) of the territory of the State<sup>2</sup>. In Sergipe it occupies an area of 7.289,86Km, (33,06%) of the State<sup>3</sup>. The lower course divides the two States, travels 179 km, from the dam to the mouth. The Power plant, is located 12km from the municipality of Piranhas (AL) and 6km from the municipality of Canindé do São Francisco

(SE). The river has 168 tributaries among rivers, streams, and trails, out of which 99 of them are perennial and 69 are intermittent<sup>4</sup>.

Historically, the watershed of the São Francisco River is of fundamental importance in the peasants' economic life, being traditionally practiced the rice growing in the lagoons and floodplains, since the 19th century. The river flow regularization puts an end to the floods and the tides, and it was responsible for significant changes in its hydrological regime, causing bed sedimentation, margins erosion, fauna and flora reduction, sea wedge increase and salinization of water and soil, layer of water increase and water depth reduction, these effects become more radical in the region of the lower course<sup>5</sup>. These floods occurred from November/December to February/March, after the construction of Sobradinho Plant in the 1970s and Xingó Plant in the 1990s, directly influencing the rice production.

The lower course of the river, due to its geographical and strategic position acquires importance for environmental sustainability, since it is its last stretch after the last dam operated by São Francisco Hydroelectric Company (CHESF)<sup>6</sup>, Xingó Hydroelectric Plant in Sergipe, until it meets the Atlantic Ocean in its mouth, dividing the states of Sergipe and Alagoas in northeastern Brazil.

The lower course of São Francisco River is composed of 79 municipalities in the two states, whose relevance in socioeconomic terms is almost allied to the primary sector, and consequently to the environmental ecosystem, a fact confirmed by the great investments on the electric and agricultural sectors<sup>7</sup>.

Investments on the electric sector date from the 1950s to the 1990s, when the large hydroelectricity generating plants were built and installed along the physiographic regions of the São Francisco River bed, such as Paulo Afonso I Plant in 1954; Três Marias, in 1962; Paulo Afonso II, in 1965; Paulo Afonso III, in 1968; Apolônio Sales/Moxotó, in 1977; Sobradinho, in 1978; Paulo Afonso IV, in 1979; Itaparica, in 1988 and Xingó, in 1994.

Concerning the investments in the agricultural sector, the most important moments were the modernization projects of the colonization programs promoted by the Development Company of the São

<sup>1</sup> ANA, 2016.

<sup>2</sup> Assis et al, 2006.

<sup>3</sup> França et al, 2006.

<sup>4</sup> Medeiros et al, 2003.

<sup>5</sup> Fontes, 2011.

<sup>6</sup> The acronyms and abbreviations that appear in the text follow the original in Portuguese.

<sup>7</sup> Jesus & Gomes, 2012.

Francisco Valley and the Paraíba (CODEVASF)<sup>8</sup> in the 1970s, which contributed substantially to the environmental ecosystem degradation as well as disaggregated the existing social system, which traditionally lived on rice and fish farming<sup>9</sup>. Other projects were created, such as Califórnia (1985-1987), Neopolis Plateau (1990-1995) and Jacaré/Curituba (1997), for fruit and vegetables growing, the first two in the semi-arid and the third closer to the river mouth. These projects are projects from Government of the Sergipe State<sup>10</sup>.

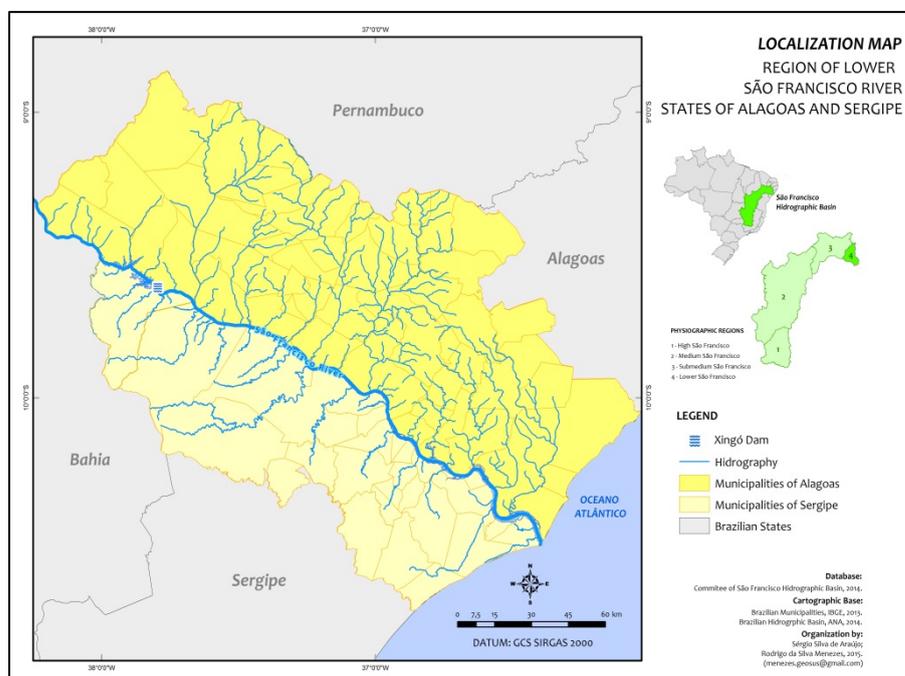
In March 1987, the construction of Xingó Hydroelectric Power Plant was started, managed by the São Francisco Hydroelectric Company (CHESF) between the States of Alagoas and Sergipe, 12 km from the city of Piranhas/AL, 6 km from Canindé do São Francisco/SE and 179 km from the river mouth, whose reservoir occupies an area of 60km<sup>2</sup> and drainage equal to 608,722 km<sup>2</sup>. In 1994 the Plant started to function partially, its full operation took place in 1997.

This paper deals with sustainability indicators and indexes in the time frame between (1990-2010), with spatial clipping, municipalities producing rice by natural flood and by irrigation in the lower course of the São Francisco River in Sergipe and Alagoas states.

The intention of this research is to demonstrate that the energy generation policies arising from the São Francisco River flow regulation, consequently changed the water regime of the river and the sea. This new operational arrangement was defined by the National System Operator (ONS)<sup>11</sup>, and executed by the São Francisco Hydroelectric Company (CHESF), more specifically, through the Sobradinho and Xingó hydroelectric plants.

In order to do this, tools and instruments were used, whose cross-referencing of social, economic and environmental indicators and indexes allowed to assess the degree of socio-environmental sustainability of the cities surveyed, based on human interventions in the environment, with results presented through calculation of the Municipal Sustainability Index (ISM)<sup>12</sup>, represented by the Anthropogenic Impact Polygon (PIA)<sup>13</sup> and General Anthropogenic Impact Polygon (PIAG)<sup>14</sup> exhibited in a radar chart. The addressed notion of sustainability implies on the combination of environmental, economic and social dimensions in a systemic way for each of the municipalities analyzed.

Figure 1. Location of the São Francisco River Basin in Brazil and the Lower Course of São Francisco River



Source: IBGE (2012), ANA (2014), Araújo & Menezes (2016).

## MATERIALS AND METHODS

The basin of the São Francisco River is of paramount importance to the low region sustainability due to its geographical and strategic position. This is the last stretch of the river after the last dam operated by CHESF, Xingó's Hydroelectric Plant in Sergipe, which

<sup>8</sup> The acronyms and abbreviations that appear in the text follow the original in Portuguese.

<sup>9</sup> Barros, 1985.

<sup>10</sup> Vargas, 2014.

<sup>11</sup> The acronyms and abbreviations that appear in the text follow the original in Portuguese.

<sup>12</sup> The acronyms and abbreviations that appear in the text follow the original in Portuguese.

<sup>13</sup> Polygon generated in the radar chart, whose specific area of the polygon quantifies the positive or negative impact that affects the region and defined a Sustainability Index. Calorio, 1997. Daniel, 2000 and Daniel et al., 2001.

<sup>14</sup> Souto, 2005.

meets the Atlantic Ocean at its mouth, divides the states of Sergipe and Alagoas in Brazil northeastern<sup>15</sup>.

The lower course of São Francisco River consists of 79 municipalities in two states, whose importance in socio-economic terms is related, to almost the whole primary sector, and consequently the environmental ecosystem. In this sense, it was measured the environmental sustainability from the selection of indicators, associating environmental impacts to stakeholders imposed by human actions, adding the social, economic and environmental dimensions, in order to set parameters and sustainability indicators that allow planning and management of natural resources in a balanced and sustainable way.

Adding environmental dimensions in assessments of social systems has been a concern on the agenda of socio-economic policies, both at national and international level, in academy, in the political and social environment, although the socio-economic indicators are presented "insufficient to assess the development degree of social welfare to countless levels of human aggregation"<sup>16</sup>.

This article consisted of giving a systemic approach in the analysis of social and economic data before the environmental data, i.e., it aimed to establish the environmental parameters influence, but specifically, the São Francisco River water flow in the socio-economic indicators, mainly concerning the rice production.

The definition of sustainability indicators follows a methodological framework<sup>17</sup>, whose conceptual parameters defined sustainability criteria for the cities of the Lower part of São Francisco River in SE/AL states, based on the dimensions of social, economic and environmental sustainability, whose the data matrix structure proposed, with eight (8) arranged variables arranged in the periods in 1990, 2000 and 2010, determined in official statistics<sup>18</sup>, i.e., in their pure form to compose the calculation of the Municipal Sustainability Index. The characteristics of these indicators were substantiated in the influence they exert

on the sustainability of the evaluated system and constituents of quantitative variables.

Calculation matrix indicators were distributed from three sustainability dimensions: social, economic and environmental, these were divided into Sector Indicators: Social Stratum, health and education, the social dimension, whose thematic indicators are: (S1) percentage (%) of extremely poor, (S2) Infant mortality per thousand, (S3) illiteracy rate; concerning the Economic Dimension, the Sectorial Indicators are: income and rice culture, whose themes are: (E4) per capita income, (E5) rice production; when it comes to the Environmental Dimension, the Sector Indicators are the hydric resources and basic sanitation, which unfold in the Thematic Indicators: (A6) maximum flow, (A7) percentage (%) of households with piped water, (A8) percentage (%) of households with inadequate sanitation as exhibited in Table 1.

This sequence is the same used on the radar chart, allowing the environmental indicator, water flow/Xingó -m<sup>3</sup>/s- (A6), interrelate directly to the economic indicators concerning the rice production -t/a- (A5), to

Table 1. It displays Sustainability dimensions, sectoral and thematic indicators

Sustainability Dimension	Leading Indicators	Thematic Indicators
S – Social	SEP – Social Stratum	S1 % Extremely Poor
	SD – Health	S2 – Infant Mortality;
	SE – Education	S3 – Illiteracy Rate - 18 years or more .
E – Economic	ER – Income	E4 – Per Capita Income in R\$
	ECA – Rice Culture	E5 – Rice Production - t/ty
A – Environmental	ARH – Water Resources	A6 – Water flow / Xingó - m <sup>3</sup> /s
	ASB – Basic Sanitation	A7 – % the domicile population with Piped Water; A8 – % the domicile population with Inadequate Sanitation;

Source: Prepared by the authors (2015).

measure the effects that the environmental dimension has on the economic output of the municipalities.

Generalizations of the individual values of sustainability indicators give an idea of the whole picture; however, there was the need to make individual analysis of each of them, in order to verify the changes in individual values and factors that directly influenced the Sustainability Indexes, according to Daniel<sup>19</sup>.

The methodology developed by Calorio<sup>20</sup> consisted of calculating the value of sustainability index from the radar chart area, through the combination of aggregate

<sup>15</sup> See Figure 1.

<sup>16</sup> Passos & Pires, 2008, 2.

<sup>17</sup> Camino & Müller, 1993.

<sup>18</sup> IBGE, 2013. ANA, 2014.

<sup>19</sup> Daniel, 2000.

<sup>20</sup> Calorio, 1997.

indicators. Daniel<sup>21</sup>, in turn, made adjustments for the purpose of simplifying the calculation. However, the use of the standard deviation (DESVPAD) as the denominator in the calculation of the equation, results in the emergence sustainability indexes with inverse values as it was expected<sup>22</sup>.

The calculation of the Municipal Sustainability Index took into account the scale of values transformation, the visual presentation of content through the radar chart area. As the variables have units of measures that do not allow aggregation in their dimensions, it was decided to substitute the first standardization phase (Vpn), the original formula by Calorio<sup>23</sup>, for the use of the normal values of the indicators.

Santos<sup>24</sup> reminds that the use of the division of indicators by 10 (ten) or one hundred (100) arises from the need to avoid excessive distortions on the radar chart, and also so that the values keep reasonable dimensions not to occur discrepancy in the comparative analysis. Thus, it was attributed scores with values observed in scales whose minimum value is 0 (zero) and the maximum value is 10 (ten), that is, it was divided the values of sustainability indicators already normalized by 10 (ten)<sup>25</sup>.

This reduction device to a range of values was given in a way that would allow a better assessment of the calculated sustainability indexes, and guaranteeing the importance of a particular indicator by its size compared to the other in the corresponding system<sup>26</sup> without interference and distortion indicators from different dimensions, scale and unit of measure. This was necessary for the variables chosen for forming the data array, taking dimensionless values, eliminating the effects of scale and measurement, and also maintaining the purest data by removing the effects of average and standard deviation, according to Daniel<sup>27</sup>.

The equations used for the calculus of Standard Indicators (Ip) followed the following methods: The dimensions variables are displayed in such a way that when they are positive- the higher the indicator the better the qualification, and when they are negative, positive, their qualification makes it better when the indicator has a bigger and worse value, when it is smaller, in the case of being negative, qualify

themselves in a better way, when the value is smaller, and worse when this is higher<sup>28</sup>.

Increasing values for all indicators were settled. In this context, the decreasing indicators, i.e. the ones that improve the quality as the value is reduced, or the quality worsens when the value increases, the score is inverse to the municipality indicator. Thus, the calculation adopted for the indicators (%) percentage of the population in extreme poverty (EP), infant mortality (MI), the illiteracy rate (TA) subtracting the value from the indicator 100 (one hundred), whose formula is (100-I) shown in Equation (1), (2) and (3), respectively.

$$Ip1 = \frac{(100 - EP)}{10} \quad \text{Equation (1)}$$

$$Ip2 = \frac{(100 - MI)}{10} \quad \text{Equation (2)}$$

$$Ip3 = \frac{(100 - TA)}{10} \quad \text{Equation (3)}$$

For the per capita income (RPC) the values of each State were used as reference, both Sergipe, US \$ 247,78 in 1990; R \$ 326,67 in 2000 and for 2010 the amount of R \$ 523,53 and Alagoas in 1990 was R \$ 211,98; in 2000 R \$ 285,29; and 2010 R \$ 432,56. After that, it was applied the formula from the Equation (4):

$$Ip4 = \frac{(Y)}{10} \quad \text{Equation (4)}$$

Where (Y) is the percentage (%) of the per capita income of the municipality analyzed in relation to the income of the corresponding state.

In the case of rice production, it was considered as a reference the highest production obtained by the municipality in the period between 1990-2010, being considered this as the highest yield capacity of those wetlands in natural conditions, although there may be higher values in earlier times. Therefore, it was used the Equation (5):

$$Ip5 = \frac{(\%p)}{10} \quad \text{Equation (5)}$$

Where (p) is the percentage (%) of rice production in the municipality of the year investigated in relation to the highest production in the 1990/2010 period of the corresponding municipality. However, to ensure the polygon construction, for the years when the rice production of the municipalities were equal to 0 (zero), it was considered the value of 0,01 (one-hundredth).

<sup>21</sup> Daniel et al., 2001.

<sup>22</sup> Daniel et al., 2001.

<sup>23</sup> Calorio, 1997.

<sup>24</sup> Santos et al., 2013.

<sup>25</sup> Santos et al., 2013.

<sup>26</sup> Van Bellen, 2004.

<sup>27</sup> Daniel et al, 2001.

<sup>28</sup> Martins & Cândido, 2012.

As for the reference flow it was used to the maximum registered in Pão de Açúcar/AL Station between the period from 1990 to 2010, whose result reached 10449,6m<sup>3</sup>/s<sup>29</sup>. And the flow rate used to calculate the sustainability index was the maximum flow rate of the year surveyed, measured at Pão de Açúcar/AL Station<sup>30</sup>. Thus, Equation (6) was used to calculate:

$$Ip6 = \frac{(Z)}{10} \quad \text{Equation (6)}$$

Where (Z) is the percentage (%) of the maximum flow rate of the year investigated in relation to the highest flow of the reporting period that is 10.449,6m<sup>3</sup>/s, the maximum flow rate of the 1990-2010 period.

For the indicators, houses with tapped water (AE), it was used the equation, in which (AE) percentage value of the municipality studied representing houses with tapped water, divided by ten (10) to form the scale (0–10) in Equation (7):

$$Ip7 = \frac{(AE)}{10} \quad \text{Equation (7)}$$

For households with inadequate health (SI) it was also necessary to establish an increasing value for the indicator due to a decreasing behavior, or that improves the quality as this reduces the value or worsens the quality when the value increases the score, therefore, it is inverse to the value of the city indicator. Whose Equation is (8):

$$Ip8 = \frac{(100 - SI)}{10} \quad \text{Equation (8)}$$

To check the dispersion degree among the standardized original indicators the variation coefficient through Equation (9) was calculated:

$$CV = \frac{DESVPADA (Bn; On)}{\text{Average } (Bn; On)} \times 100 \quad \text{Equation (9)}$$

To validate the use of the variation coefficient, it was used as a maximum degree of low dispersion for data consistency purposes, the values between (> 0 to 25 %) and values between (25 %–50 %), for medium dispersion and (> 50 %) for high dispersion<sup>31</sup>.

Then, the arithmetic average of a Sustainability Indexes dimension (social, economic and environmental) for the construction of Anthropogenic Impact Polygon on the radar chart, the municipalities of

the Lower part of São Francisco River in SE/AL states follows the Equations (10); (11) and (12):

$$IS(Social) = \text{Average}28\left(\frac{B1+\dots+B28}{28}\right) \quad \text{Equation (10)}$$

$$IS(Economic) = \text{Average}28\left(\frac{B1+\dots+B28}{28}\right) \quad \text{Equation (11)}$$

$$IS(Environmental) = \text{Average}28\left(\frac{B1+\dots+B28}{28}\right) \quad \text{Equation (12)}$$

All values of the equations were entered into a spreadsheet Microsoft Office Excel to calculate the index (Ip), coefficient of variation (CV), sustainability index (IS), the anthropogenic polygons development on the radar chart.

For classification of sustainability indexes levels of all the municipalities, there was adaptation of the Martins and Candido<sup>32</sup> criteria matrix, and it was used a range of values ranking municipalities from sustainability indexes, on a five (5) levels scale without using color: very low, for those who have obtained indexes (0–25); low to the indexes (25–50); Medium to (50–75) and high for those that are between (75–100) and very high for values (> 100).

As for individual sustainability levels by the size of municipalities' sustainability, it was used the same as Martins and Candido<sup>33</sup>, with scale modification values which classifies social, economic and environmental dimensions of the municipalities from sustainability indexes, on a scale of 5 (five) levels without the use of color: very low for those which obtained indexes (0 to 10); low to the index (10 to 20); medium to (20 to 30) and high for values between (30 to 40) and very high for values within (40 to 50).

For the procedures of analysis and evaluation of sustainability indexes it was chosen among the 79 municipalities that make up the basin of São Francisco, in the region of its lower course, 28 (twenty-eight), which are more directly linked to the rice production. Out of these, 14 (fourteen) were producers typically from natural flood plains, the ebbs and flows, and fourteen (14) make up the flood irrigation flood plains, and are listed below, according to Table 2.

The analysis and evaluation of the Municipal Sustainability Indexes (ISM), were made with the interaction among social indicators, economic and environmental, from the preparation of the graphic radar to define the anthropogenic polygons of the municipalities that have relationship between the flow of

<sup>29</sup> ANA, 2014.

<sup>30</sup> ANA, 2014.

<sup>31</sup> Guedes et al, 2015.

<sup>32</sup> Martins & Candido, 2012.

<sup>33</sup> Martins & Candido, 2012.

the São Francisco River before rice production<sup>34</sup>. According to Lightfoot<sup>35</sup>, this type of chart allows to make comparisons among systems, considering the time and space, facilitated also by the use of visual information that it exhibits, hence, enabling a comparative and more immediate analysis of the levels of sustainability that each of the cities are on the indicator system.

Table 1. Lower Course of São Francisco River's Municipalities in Sergipe and Alagoas States

Identifler	Municipalities Natural Flood	Municipalities by Flood Irrigation
1	Amparo do São Francisco/SE	Brejo Grande/SE
2	Canhoba/SE	Cedro de São João/SE
3	Gararu/SE	Ilha das Flores/SE
4	Nossa Senhora de Lourdes/SE	Japoatã/SE
5	Poço Redondo/SE	Neópolis/SE
6	Porto da Folha/SE	Pacatuba/SE
7	Belo Monte/AL	Propriá/SE
8	Campo Grande/AL	São Francisco/SE
9	Coruripe/AL	Santana do São Francisco/SE
10	Olho d'Água Grande/AL	Telha/SE
11	São Brás/AL	Igreja Nova/AL
12	São Sebastião/AL	Penedo/AL
13	Traipu/AL	Piaçabuçu
14	Pão de Açúcar	Porto Real do Colégio

Source: Prepared by the authors (2015).

Further, it was proceeded to the calculation analysis of the Sustainability Index (IS) in the municipalities of the basin of the Lower part of São Francisco River and with the individual rates of the municipalities involved in the research the Anthropogenic Impact Polygon (PIA)<sup>36</sup> was elaborated, addressing the dimensions of environmental sustainability and General Anthropogenic Impact Polygon (PIAG)<sup>37</sup> in each of the municipalities that make up the lower part of São Francisco River in Sergipe and Alagoas States (Brazil).

#### RESULTS AND DISCUSSIONS: VALIDATION OF THE THEMATIC INDICATORS THROUGH COEFFICIENT OF VARIATION

The arithmetic average of the calculated Sustainability Indexes for each sustainability dimensions variable helped to establish a single criterion in the districts from the Lower sector of São Francisco River in

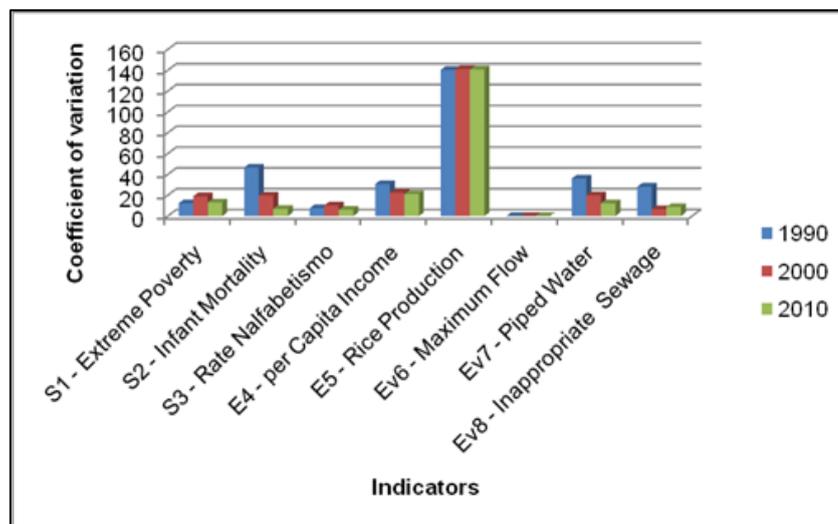
Sergipe and Alagoas States and it allowed to carry out analysis from the general to the specific.

In pictur<sup>38</sup> is observed that the dispersion degree of the indicators is uniform ranging below (25%), except in 1990 when the distortions ranged above (25%) for the indicators on infant mortality (S2), per capita income (E4) and to house with tapped water (A7). The variation in flow indicator (A6) was equal to zero, since the values remained constant for each year studied, measured in Pão de Açúcar/AL Station. Thus, the deviation and coefficient of variation of indicators, showed no major distortions, ensuring uniformity in the behavior of municipalities.

From 2002 on, several benefits have been adopted, such as Bolsa Escola, Vale Gás<sup>39</sup>, being unified from 2004, according to Law No. 10.836 from 2004<sup>40</sup>, which justifies more regularity on the indicators in the 2000's.

Regarding the indicator (E5) rice production, dispersion occurs due to the river flow regularization by dams that caused the drying up of ponds and marginal wetlands, areas where rice was cultivated by most of Lower Course of São Francisco River's cities, reason why the production was reduced to zero (0).

Figure 1. Coefficient of Variation of the indicators in the municipalities which produced rice by natural flood in the years 1990, 2000 and 2010.



Source: Prepared by the authors (2015).

In the years 2000 and 2010, the variation coefficients were below 25% in both municipalities which produced rice by natural flood, as those producing rice by surface irrigation. During this period, the public policy from the Federal Government subside transfer,

<sup>34</sup> Calorio, 1997. Daniel, 2000. Daniel et al., 2001. Lopes, 2001. Moura, 2002. Souto, 2005. Sepúlveda; Chavarria & Rojas, 2005. Passos & Pires, 2008. Mendonça, 2013. Van Leeuwen, 2013. Matos, 2014.

<sup>35</sup> Lightfoot et al., 1993.

<sup>36</sup> Souto, 2005.

<sup>37</sup> Souto, 2005.

<sup>38</sup> See Figure 2.

<sup>39</sup> Social and educational programs of the Federal Government.

<sup>40</sup> Rego & Pinzani, 2013.

such as Bolsa Escola, Brasil Sem Miséria<sup>41</sup>, minimum wage adjustments and their impacts were felt in people's lives. These policies impose a reduction regarding social and income inequalities, maintaining regularity in all municipalities.

#### SUSTAINABILITY INDEXES OF THE RICE PRODUCERS MUNICIPALITIES BY NATURAL FLOOD AND IRRIGATION

The results of the Municipal Sustainability Indexes, in relation to the average values of social, economic and environmental dimensions were classified by sustainability levels. Relative analysis on the sustainability indexes are followed to the methodological steps established. This approach made it possible to explain the state of sustainability of each municipality and focused on the procedures for calculation of Anthropogenic Impact Polygons. The parameters used were the data arising from rice producing municipalities by natural flood and irrigation in the lower course of the São Francisco River in Sergipe and Alagoas states - Brazil, as part of a monitoring process of sustainability in the period analyzed.

In 1990, the base year of the research in municipalities producing rice by natural flood, all sustainability indexes were at very low levels, with emphasis on those related to extreme poverty (S1), infant mortality (S2) and per capita income (E4), which had the worst performance with values of (3,81); (3,43) and; (5,9) respectively. However, the indexes related to the illiteracy rate (S3), rice production (E5), maximum flow rate (A6), households with piped water (A7) and households with inadequate sanitation (A8) indicated a better performance.

In the same period, the rates of municipalities producing irrigated rice compared to natural flood producers, had a similar behavior, highlighting the indexes related to extreme poverty (S1), infant mortality (S2) and per capita income (E4) and rice production (E5), with the worst performance in very low levels and values (4,64), (3,47), (2,33) and (2,56) respectively, the latter had a better performance in municipalities producing by natural flooding. As for the index on the illiteracy rate (S3), even being in a very low level, it has a value of (9,57). However, the rates related to maximum flow (A6), households with piped water (A7) and households with inadequate sanitary conditions (A8), had better performance, whose absolute values quadruple the contents of the first, but they are still at low levels.

In the period of 2000, both in municipalities producing rice either by natural flood, or by irrigation, the sustainability indexes associated with the economic dimension per capita income (E4) and rice production (E5) and environmental maximum flow (A6) were in very low levels, with values of municipalities: (a) (0,36), (0,16), (4,87) and (b) (6,20), (3,75), (5,42) respectively. The social indicators related to extreme poverty (S1), infant mortality (S2), illiteracy rate (S3), the environmental indexes concerning houses with tapped water (A7), and inadequate sanitation (A8) had equivalent performance in both groups evaluated. It should be noted that the rate of houses with tapped water (A7), in irrigation rice producing municipalities reached the highest level (21).

In 2010, both municipalities producing rice by natural flood and irrigation, had a similar performance, with social indicators of extreme poverty (S1), infant mortality (S2) and illiteracy (S3), at low levels, and environmental related to houses with tapped water (A7) and inadequate sanitary conditions (A8) were on the average. Noteworthy are the economic indicators per capita income (E4), rice production (E5) and environmental associated with to maximum flow (A6), which remained at very low levels, with values: (a) (0,02), (0,01), (6,28) and, (b) (3,19), (1,90) and, (6,51).

In the lower course of the São Francisco River, the Sustainability Indexes behavior for sustainability dimension in the period studied, both in municipalities producing rice by natural flood, and by irrigation, showed increasing values, not only for those related to social dimension, but also environmental, being the latter associated with basic sanitation. It was verified that the most impacting indexes are the maximum flow, per capita income and rice production that maintained at the levels of environmental sustainability "very low", except the maximum flow rate that in 1990 exhibited "low" level, putting at risk the São Francisco River's ecosystems.

These differences in the sustainability indexes are diluted as the indicators related to the social dimensions improve, due to the effects of inclusion public policies and income distribution from the Federal Government<sup>42</sup>, tend to standardize the economy of the poorest municipalities with the richest and, in 2010, these polygons became similar between the two groups of municipalities surveyed, with slight differences in economic indicators per capita income (E4) and rice production (E5). In picture<sup>43</sup> it is observed the Anthropogenic Polygon Impact, the average behavior of sustainability indexes by dimension of sustainability of

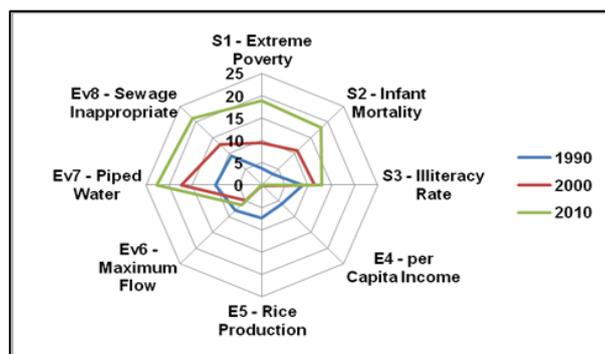
<sup>41</sup> Social and educational programs of the Federal Government.

<sup>42</sup> Rego & Pinzani, 2013.

<sup>43</sup> See Figure 3 and 4.

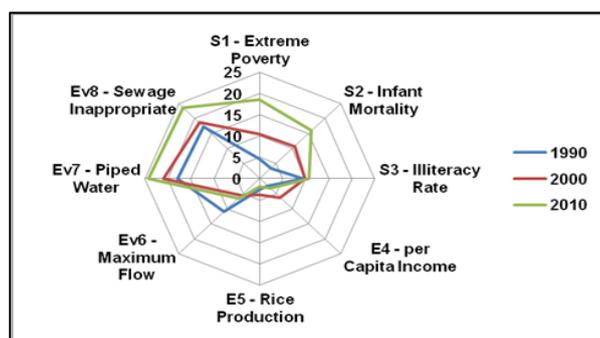
municipalities in the Lower São Francisco River in Sergipe and Alagoas states, considering these rice farmers by natural flooding and irrigation, in 1990, 2000 and 2010.

Figure 2. Sustainability Indexes by municipalities size in the Lower Course of São Francisco River's rice farmers by natural flooding



Source: Prepared by the authors (2015).

Figure 3. Sustainability Indexes by municipalities sizes in the Lower Course of São Francisco River's rice farmers by irrigation flooding



Source: Prepared by the authors (2015).

As for the Municipal Sustainability Indexes for the different municipalities rice producers by natural flood and irrigation for the year 1990, (50%) of the rice producing municipalities by natural flooding had levels of municipal sustainability index very low, (28,57%) low, (14,29%) on the average, and (7,14%) at high level. The municipality that had the lowest sustainability index was Olho d'Água Grande/AL with value (6,57), i.e., the largest negative environmental impact on the Lower Course of São Francisco Region, and Coruripe/AL, with the highest sustainability index, the value of (75,31).

In 2000, among the fourteen (14) municipalities analyzed, only (7,14%) were very low. In the range of low level of sustainability, (78,57%) of the municipalities were fit; while (7,14%) were found in mid-level sustainability; and (7,14%) at a high level. The municipality with the highest negative impact on municipal sustainability was Traipu/AL with the lowest

sustainability index, with a value of (17,97) and Coruripe/AL had the highest sustainability index, with a value of (74,37).

In 2010, the values of sustainability levels of fourteen (14) analyzed municipalities, (50%) were considered low sustainability levels, and (50%) at the average. The municipality of Olho D'Água Grande in Alagoas with the value of (31,32) presented the lowest sustainability index thus the highest negative impact and Coruripe/AL had the highest sustainability index-(67,72).

As for irrigation-producing municipalities, in 1990, (7,14%) of municipalities had a very low municipal sustainability index; (78,57%) with low index; (14,29%) with a medium environmental sustainability index. Santana do São Francisco/SE showed the lowest sustainability index, with a value of (21,01), therefore, being considered as a very low classification level, representing thus greater negative environmental impact; Cedro de São João/SE (61,90) and Piaçabuçu/AL which (71,92) had environmental sustainability index in the medium level.

The city of Santana do São Francisco/SE, stopped producing in 2011 and Piaçabuçu/AL in 2012. It allows to evaluate that in some municipalities due to the river flow reduction, "[...] resulting from dam, it caused losses to the irrigated areas, with soil losses [...]"<sup>44</sup> and consequently rice production.

In 2000, the values of sustainability indexes for fourteen (14) municipalities analyzed, (50%) had low index; with an average rate of (28,57%), while (21,43%) had high sustainability levels. The municipality with the greatest negative impact was Boley in Sergipe, which showed the lowest sustainability index, with value (34,30). The municipalities of Cedro de São João/SE, Propriá/SE and, Penedo/AL with values (70,59), (78,03) and, (87,92) presented the sustainability index at the toplevel.

In 2010, the values of sustainability indexes presented by fourteen (14) municipalities analyzed, were distributed as follows: environmental sustainability rate on the average, (64,29%), in the range of high sustainability index are found (28,57%) of the municipalities, while (7,14%) are found with sustainability indexes on very high level.

The municipality with the highest social and environmental negative impact this year was the city of Piaçabuçu/AL, with the lowest rate (52,17). The municipalities of Cedro de São João/SE; Neópolis/SE; Tile/SE and; Penedo/AL showed a high level of

<sup>44</sup> Aguiar Netto; Mendonça Filho & Rocha, 2010, 64.

environmental sustainability with values (95,82), (78,74), (80,95) and (96,71) respectively. Propriá/SE had the highest level of environmental sustainability with (107,42).

This period of the 1990s is considered as the lost decade in which social and income inequalities increased<sup>45</sup>. This is justified as a result of little or no public policy subsidies transfer in the period, under the responsibility of the Federal Government. However, in the year 2000s, the effects of public policies of inclusion and distribution of income from the Federal Government, are felt in the indicators, raising the sustainability indexes of the Lower Course São Francisco in Sergipe and Alagoas.

Whereas, in 2010, after establishing public policies the sustainability framework had more robust indexes. However, due to some social aspects, whose levels of environmental sustainability are "very low" or "low" have negative effects in certain municipalities.

As for the economic and environmental aspects of rice production and river flow respectively, these were quite affected in 2000, the economic indicator for the rice production showed low sustainability, due to the river's low flow, not allowing the flood of marginal wetlands and consequently this year nearly all the municipalities had their rice production reduced to 0 (zero). This scenario was also observed in 2010, when all these municipalities were outside of the rice production units due to natural flooding of marginal wetlands.

After the survey, it was found that indicators related to rice production and the flow of the river had interdependence. This was evidenced in municipalities producing rice by natural flood, because sustainability levels were shown between low and very low. Factors related to the river flow, according to Vasco, are linked to the hydroelectric plant operations of Xingó, so the author discusses:

"After HPP Xingó operation, only in 2004 the flow showed a greater amount equivalent to  $8089\text{m}^3\text{ s}^{-1}$ . The results shown in Pão de Açúcar Station [ ... ] reveals that since 1994 the flow was reduced and remained regularized on average  $1784\text{m}^3\text{ s}^{-1}$ , except for the year 2004. By observing the analysis of variations in flows, it was observed that in the period sampled the maximum peak flows were reduced immediately after the operation start of the hydroelectric plant of Xingó 1993, it was only possible to identify stream flow peaks in 2004 and 2007 with registered maximum flows of  $8089\text{m}^3\text{ s}^{-1}$  and  $6357\text{m}^3\text{ s}^{-1}$  respectively"<sup>46</sup>.

Associated with the flow reduction there are other environmental problems such as suspended sediment reduction and therefore nutrients that served as food for wildlife and flora, drying of lagoons; silting of the channel and bank erosion; degradation and change in the course of the mouth; retreat of the shoreline; depletion of fish stocks and increased maritime wedge<sup>47</sup>. Araújo, Aguiar Netto and Gomes, found that:

"The reduction of the interannual variability and flow magnitude proves that the São Francisco River suffered drastic decrease in seasonal flow variability. The flood peaks with high flow rates occurring naturally in the first months of the year (January to March) were remarkably reduced, with exceptions of flow that exceeded the control limit capacity of the dams, but this does not occur frequently"<sup>48</sup>.

Unlike with the revitalized river, it would enable to fill up the lagoons, and in consequence, recover the fauna and flora, allowing better performance in agriculture, thus Matos, discusses the issue:

"The increased flow results in the following: a. improved the condition of the oxbow lakes; b. rebalanced the mouth of the São Francisco River enabling better navigation; c. facilitated the entry of water in irrigated areas, attending rice producers; only in these three examples was possible to observe that the flow increase resulted in improved fishing, rice planting and navigation, therefore improving income in the lower course of São Francisco River region"<sup>49</sup>.

Low flow affected the fillers of oxbow lakes, therefore reflecting directly in the rice production by flooding in the municipalities. This phenomenon is perceived when assessing the sustainability framework from 1990 to 2010. Thus, the year 1990 was the period that social and income inequalities were higher than in the following years, and this is, due to little or no public policy income transfer in the period. However, in 2000, the effects of Federal Government's inclusion public policies and income distribution<sup>50</sup>, are felt in the indicators, raising the sustainability indexes of the lower course of São Francisco River region.

While, in 2010, after stabilized the mentioned public policy, the picture appears more robust. However, some negative effects are still perceived in certain municipalities, since some social aspects had low environmental sustainability levels.

<sup>45</sup> Neri, 2011. IPEA, 2012.

<sup>46</sup> Vasco, 2015, 58.

<sup>47</sup> Araújo, Aguiar Netto & Sales, 2016.

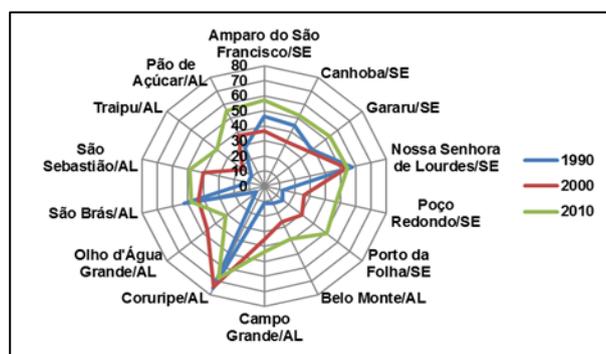
<sup>48</sup> Araújo, Aguiar Netto & Gomes, 2016, 243.

<sup>49</sup> Matos, 2014, 130.

<sup>50</sup> Rego & Pinzani, 2013.

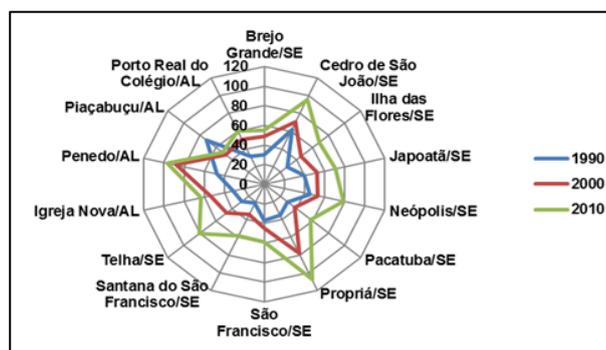
In picture<sup>51</sup> it is observed in General Anthropogenic Impact Polygon, the Municipal Sustainability Indexes for lower section of São Francisco River in Sergipe and Alagoas states, the rice farmers by natural flooding and irrigation respectively.

Figure 4. General Municipal Sustainability Indexes of the Lower Course of São Francisco River's rice farmers by natural flooding



Source: Prepared by the authors (2015).

Figure 5 - General Municipal Sustainability Indexes of the Lower Course of São Francisco River's rice farmers by irrigation flooding.



Source: Prepared by the authors (2015).

## CONCLUSIONS

Lower Course of São Francisco River's Municipalities in Sergipe and Alagoas States present social and environmental similarities, their indicators are constant with few distortions which allowed an assessment together.

Not only by municipality but also by region, it was noted that in the 1990s, the municipalities with rice production in lowland natural flood, child mortality and income per capita exhibited show the highest impact indicators in the region. However, child mortality also had its greatest negative impact on the region where the

production is by irrigation. From 2000 to 2010 the item Rice Production showed the greatest negative impact on the cities' sustainability, both regarding natural flooding and irrigation.

The social, economic and environmental characteristics of the municipalities that make up the lower course of São Francisco River, reflect the social and environmental conditions of the region. It was found that despite of the inclusion public policies, subsidies distribution and transfer that the Federal Government made in these first two decades of the twenty-first century, income concentration and social and economic inequalities still prevail. On the other hand, these improvements do not guarantee the sustainable development parameters, or address the needs of current generations without jeopardizing the ability of future generations to satisfy their own needs.

Negative impacts related to rice production and the river flow, follow the entire period studied, both in municipalities that produced by natural flooding, and those which produced by irrigation system. This was observed from the Sustainability Indexes calculation, either through the dimensions of sustainability, or through the individual indexes by municipalities.

In this sense, the proposed method was suitable for assessing the sustainability of municipalities regarding environmental, economic and social aspects. The characteristics of these indicators allowed an immediate response to perceived changes in the system, of easy application, exhibiting integrated approach when it was related to other indicators.

In view of the observed data, it was verified that the regularization of the water flows of the São Francisco River and its consequent reduction of the maximum values and increase of the minimum values caused changes in its lentic characteristics to the detriment of its lotic aspects. Enclosed between the Xingó dam and the saline intrusion, it becomes a large lake, victim of linear progress, of the precarious present, the river sees its autochthonous fauna and flora coming off its bed and its banks, which expand, in a future without horizon, fulfilling the mission delegated by modernity.

It is observed the maintenance of this model of natural resources appropriation, whose principles are the nature domination and destruction, without observing the capacity of resilience of the ecosystems involved. São Francisco River, mainly in its low course, which is affected with the flows regularized by the Hydroelectric of Xingó will be running the risk of not fulfilling its environmental functions, therefore social and economic.

Therefore, it is recommended that there are artificial floods that allow the ecological return of the river,

<sup>51</sup> See Figure 5 and 6.

recovering terrestrial and aquatic flora and fauna and the adoption of energy generation models with alternative technologies and guarantee a minimum of environmental sustainability. On the contrary, this nature exploitation process amplifies the environmental impacts, which will lead to the outbreak of new socio-environmental conflicts, or to radicalize the existing ones.

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