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Agriculture and Supporting Ecosystem Services: A Trade-off Analysis Using Open Data in Brazil

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Abstract

Open data are important for adding legitimacy and transparency to public sciences. These data have also a potential to be used as a first approach for scientific investigation, such as spatial evaluation of ecosystem services. This paper presents a methodological approach to evaluate the trade-offs between agriculture and supporting ecosystem services based on spatial analysis and open data. The study area is an important agricultural production region in Bahia State, Brazil. The framework was able to establish the spatial interactions between agriculture and ecosystem service provision, while the regional scale was useful in supporting guidelines regarding sustainable land use for agricultural areas.

Keywords: supporting ecosystem services, open data, spatial evaluation

1. Introduction

Open official data sets are a source of information produced by governments and readily available to the public; therefore, they can be useful for several applications, including scientific research as well as for crosschecking with other data or sources and the monitoring of environmental interventions (Open Data Handbook, 2012).

This type of information is a notable resource, since entities subordinated to the government collect significant volumes of data in order to issue publications, balance sheets, and research, among others. Generally, these data are used to guide public policies and to monitor societal development. In other words, the government plays a key role within the open data context due to the amount of information it gathers and centralizes within its structure (Open Data Handbook, 2012). Additionally, free access to information and the possibility of using and reusing this information (for example, data, content, etc.) are interlinked to democratic concepts like freedom of speech and, therefore, essential for development.

In the 2000s, governments made the first efforts to create web portals aimed at sharing official data. After these efforts started in the United States in 2009, other countries, including Brazil, adopted these practices in the following years (Archambault et al, 2014). This movement shows the commitment of governments to this issue. In 2011, Brazil enacted its Access to Information legislation (Brasil, Law Nº 12527/2011). This law states that public bodies and agencies should disclose information of general or collective interest regardless of request, except for data for which confidentiality is provided for in the legal text.

Regarding the use of open data in scientific research, it is possible to highlight its use as a strategy for a primary survey. The use of secondary data reduces survey time and cost, since these data are already tabulated and analyzed (Mattar, 2005). However, the same author highlights that for research subjects the reliability of such data should be taken into consideration. Therefore, these data may be used to reduce costs and to provide resources for the preparation of research, thus making it faster and more feasible.

Lokers, Knapen, Janssen, van Randen, and Jansen (2016) state that societal challenges, such as food security, ecosystem restoration, climate change, resource use efficiency, as captured in the United Nations' Sustainable Development Goals (SDGs) (https://sustainabledevelopment.un.org/topics/sustainabledevelopmentgoals) and the EU's societal challenges – Horizon 2020 (https://ec.europa.eu/programmes/horizon2020/en/h2020-section/societal-challenges) require increasingly complex approaches in terms of combining cross-sectoral and cross-discipline knowledge, information, and data. These assumptions are closely related to the capacity of a country collect, organize, and provide open data that monitors their performance, to propose actions and public policies regarding land use and governance, for instance.

Similar ideas are shared by Schmidt, Gemeinholzer, and Treolar (2016), who explain that the growth of extensive computing facilities and access to large datasets provides major opportunities for researchers to address complex, multi-dimensional questions dealing with urgent environmental issues, such as climate change, natural resource alterations, depletion, and biodiversity loss. Open data allows for model-field-laboratory inter-comparisons and facilitates multi-, inter- and trans-disciplinary analyses.

The generation and use of reliable open data create social and economic value. These data may reduce costs in the preparation of (public or private) tasks, enable new services, and improve the quality of existing services. In addition, they may indirectly help improve governance and governmental services by encouraging the dissemination of information among the civil society, thus strengthening society's participation and demonstrating transparency initiatives (Open for Business, 2014). However, data quality is relevant for making accurate decisions. If inaccurate or outdated data are available for use, damage can occur, thus fostering a lack of credibility with society (Martins, 2009).

Veracity, which addresses, among others, the integrity and accuracy of data and data sources, is closely associated with trust and with being confident that the quality of data is sufficient to serve as an evidential basis for critical decision making. With respect to the agro-environmental domain, a dataset's veracity is exceptionally critical when making decisions for research (Lokers, Knapen, Janssen, van Randen and Jansen, 2016)

However, the same authors suggest that metadata is key for addressing the confidence of provided data; while, data providers must trust that their data is properly used, which again can be facilitated by adequately documented datasets.

1.1 Ecosystem Services

Ecosystem services (ES) are goods and services provided by the environment and they directly or indirectly contribute to human welfare (MEA, 2005).

Life on earth is closely linked to continuous ecosystem service delivery capacity (Sukhdev, 2008; MEA, 2005). However, the demand for these services is growing faster than the ability of the environment to provide them. Thus, it is extremely important to understand the constituent elements of the ecosystems as well as their interaction mechanisms in order to achieve its sustainable and efficient management.

Agriculture is a priority for several countries due to its remarkable and vast impact on food production, land use, and climate change, as well as job opportunities, human health, and environmental health (Müller, 2005). Not only does the sector comprise 1.3 billion workers worldwide, it also plays an important role in supporting the quality of life for rural populations (FAOSTAT, 2013). In addition to the important role agriculture plays in today's society, studies indicate that crop production should double within a few decades in order to meet future demand for food and bioenergy (Foley et al, 2011).

Due to the growing and constant depletion and degradation of ecosystem services, monitoring and research are important tools facilitating a decision-making process seeking to achieve sustainable agriculture. These tools may use open data in order to incorporate information and generate value (Open Data Handbook, 2012).

FAO (2011) stresses that healthy ecosystems provide a variety of vital goods and services that contribute directly or indirectly to human well-being. Agroecosystems can provide a range of supporting, provisioning, regulating, and cultural services to human communities. Supporting services include nutrient cycling and primary production; provisioning services include food, wood, fiber, and fuel production, as well as, fresh water; regulating services from agriculture may include flood control, water quality control, carbon storage, and climate regulation through greenhouse gas emissions, disease regulation, and waste treatment (e.g. nutrients, pesticides); and cultural services includes scenic beauty, education, recreation, tourism, as well as traditional use (MEA, 2005; Power, 2010).

In this study, we focus on the so-called "supporting ES." These are the basis of all ecosystems and their services as they are closely linked to the characteristics of the landscape, including geological, geomorphological and pedological domains.

Supporting ES differ from “provisioning,” “regulating,” and “cultural” services in that their impacts on people are either indirect or occur over a very long time, whereas changes in the other categories have relatively direct short-term impacts on people (Boeckh and Huckauf, 2006):

- Soil formation: Humans do not directly use this as a service, but changes in soil formation would indirectly affect people through its impact on other services, such as the provisioning service of food production.
- Nutrient cycling: This indirect supporting service is required e.g. as the basis for crop production and plant growth.
- Biomass production: Primary production provides the base of the food pyramid for all higher consumers – herbivores as well as carnivores.
- Production of atmospheric oxygen through photosynthesis is often categorized as a supporting service since oxygen forms the basis for all animal life on earth. Any impacts on the concentration of oxygen in the atmosphere would only occur over an extremely long time.
- Habitat provision has important long-term effects on diversity and species richness.

Zhang, Ricketts, Kremen, Carney, and Swinton (2007) summarize the main ES connection to agriculture: *Soil structure and fertility* play a large role in determining where different kinds of farming take place as well as the quantity and quality of agricultural output; *Nutrient cycling* maintains soil fertility; *Crop pollination* regulates pest pressures among others. All of these provide supporting ES services. Thus, the understanding of the spatial interaction among the natural features – which can sustain the supporting ES – and the land use is core information for sustainable land use planning. It is also relevant for promoting resilient agriculture systems, since there are many close interactions between agriculture and the supporting ES.

The interactions between natural and anthropo-natural systems directly influence ES provision in both systems. In agricultural systems, the management practices are a driving force for these interactions, since it can intervene in the provision of some ES, thus providing trade-offs between ecosystem services. According to Rodriguez et al. (2006), trade-offs happen when the provision of an ES is reduced as a consequence of another being increased. Trade-offs can be the result of an explicit choice, for example when a forest area is cut for agricultural crops. This implementation may occur without forethought or even awareness of the reduction the other service. Unintentional trade-offs occur when the interactions between ecosystem services are ignored or when its functionalities are not well comprehended (Rodriguez et al., 2006).

Rodriguez et al. (2006) states that trade-offs can be analyzed based on three axes: spatial scale, time scale, and reversibility. The spatial scale refers to whether an effect of a trade-off is observed in a nearby or distant site; the time scale is related to the time it takes for the effects of the intervention on the ES to be perceived; and reversibility expresses the probability that disturbed services to return to its original state.

Thereby, the use of geotechnologies tools can support analyzing the trade-offs regarding their spatial scale. As the supporting ES is a combination of several geophysical and biological features, forming the diversity of ecosystems found in the environment, it is possible to map the ecosystems and their services by listing and associating variables of interest, including physical, geological and biological features, as well as spatial interactions (Atanazio, 2010).

Hence, this paper aims (i) to present a methodology based on open data to map and identify the trade-offs between the potential of supporting ES provision and agriculture at a regional scale; and (ii) to assess the feasibility of using the proposed methodology at this context and purpose.

2. Materials and Methods

The study area is the west region of Bahia State, specifically Barreiras, Correntina, Luís Eduardo Magalhães, Riachão das Neves, and São Desidério Counties (Figure 1). The huge investments in agribusiness in this region make it strategic in terms of land use planning.

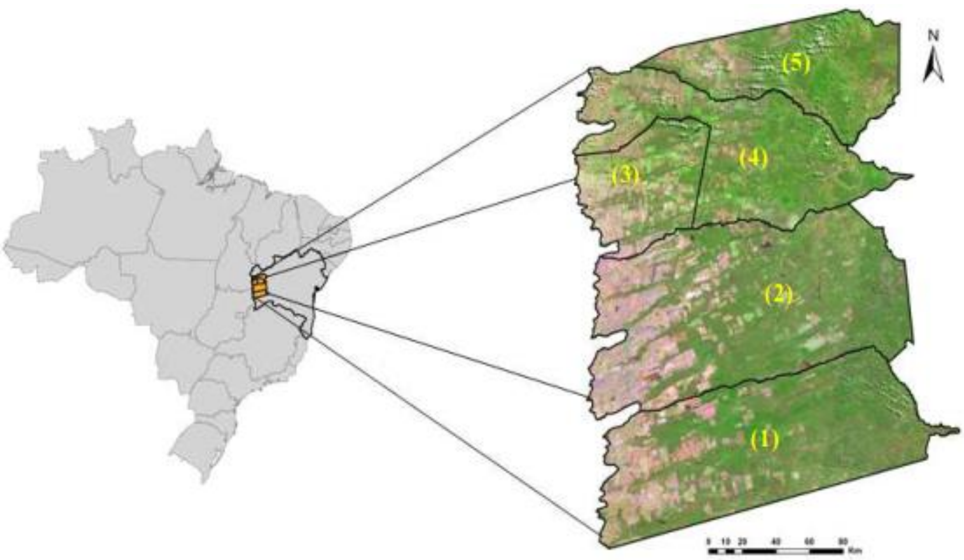

Figure 1. The west region of Bahia State: (1) Correntina, (2) São Desidério, (3) Luís Eduardo Magalhães, (4) Barreiras, and (5) Riachão das Neves municipalities

According to Crop Monitoring by CONAB (2019) for the 2018/19 season in Brazil, an estimated 62,200,000 ha are cropped, an increase of 2.4% over the previous season (2017/18). This is explained by increases in cotton, corn and soybean crops. In general, 4% of all Brazilian agriculture production is in Bahia State (Zanella, 2015).

The west of Bahia is a vast geographic region dominated by a sedimentary plain softly dissected by perennial rivers draining to the São Francisco River. The Province of São Francisco do Norte constitutes the substrate-geology with a diversity of lithological classifications; it expresses the presence of arenitic conglomerates from Mesozoic (Upper Cretaceous) Era (Souza, 2008).

The original vegetation is typical of the Cerrado biome (Brazilian savanna), while the climate is characterized by a dry season (May to September) and a rainy season (October to April), with an annual rainfall of 1,500 ± 500 mm. Dry periods of one to three weeks, may occur during the rainy season, especially in January and February. The average annual temperature ranges from 21.3 °to 27.2 ℃ (Souza, 2008). Soils are weathered, deep, well drained, with low natural fertility and marked acidity (Souza, 2008).

Open *shapefile* data - geological, geomorphological and pedological - mappings were obtained from the Brazilian Institute of the Environment and Renewable Natural Resources – IBAMA homepage (https://siscom.ibama.gov.br/); Landsat images were obtained from the National Institute for Space Research - INPE website (http://www.dgi.inpe.br/CDSR/) from 2010 and the land use/land cover map was generated. All the GIS tasks were processed using ArcGis®10.2 software.

In a second stage, the geological, geomorphological and pedological attributes obtained from the from the shapefiles were organized in a worksheet and sent by email to experts (15 in total, including agronomists, geologists, geographers, and biologists) to evaluate the potential of each attribute to support ecosystem services. The potential was classified as (1) low; (2) medium; and (3) high. Once the evaluations were returned, each layer was classified according to the experts' grades.

A map with potential areas to support ES provision was generated following the integration of the three layers, with an evaluation based on the land use/land cover map from 2010. Only agricultural areas were considered for this evaluation since the main research question is related to identifying overlap between food production and those areas strategic to the provision of supporting ES.

3. Results and Discussion

The experts were invited to attribute grades (as (1) low; (2) medium and (3) high) to the features of each thematic layer – Pedology, Geomorphology, and Geology – regarding their ability to provide supporting ES. From the fifteen experts who were invited to answer the survey, three sent their feedback. Despite the low response rate, we believe that the most important aspect was to test the whole methodology and verify its performance.

The average of the evaluations was considered to be the final score for each attribute (Table 1).

Table 1. Average of the experts' evaluation for each layer

Pedology (between halves the equivalent to soil WRB/FAO classification)	**Potential (N = 3)**
Neossolos Litólicos Distróficos - RLd (Leptsols)	1
Neossolos Litólicos Eutróficos - RLe (Leptsols)	1
Neossolos Quartzarênicos - RQ (Arenosols)	1
Neossolo Flúvico Tb Eutrófico – RUBe (Fluvisols)	3
Latossolo Vermelho Eutrófico – Lve (Ferralsols)	3
Latossolo Vermelho-Amarelo Distrófico – LVAd (Ferralsols)	2
Gleissolo Háplico – GXbd (Gleysols)	2
Cambissolo Háplico Tb Distrófico – CXbd (Cambisols)	2
Cambissolo Háplico Ta Eutrófico – Cxve (Cambisols)	3
Argissolo Vermelho-Amarelo Eutrófico – PVAe (Acrisols)	3
Geomorphology	**Potential (N = 3)**
Structural levels	3
Functional or retouched pediments by incipient drainage	2
Country pediplain	2
Sub-structural plain of Gerais	3
Accumulation zone	2
Geology	**Potential (N = 3)**
Slate, Metasiltstone, Marble, Metamarl, Metasandstone	2
Sand, Clay	2
Sand, Clay, Laterite	1
Argillite, Limestone, Marl, Varvite, Silex	2
Calcarenite, Dolomite	3
Metasiltstone, Marble, Metamarl	3
Metasiltstone, Meta-Arkose	3
Orthogneiss, Migmatite	2
Pelite, Sandstone, Conglomeratic Sandstone	1
Feldspathic Quartzite, *Metadiamictite*, Metamarl, Metasiltstone, *Mica-schist*	2

Then, these results were plotted and the final map with the potential of each layer to provide supporting ES was generated (Figure 2).

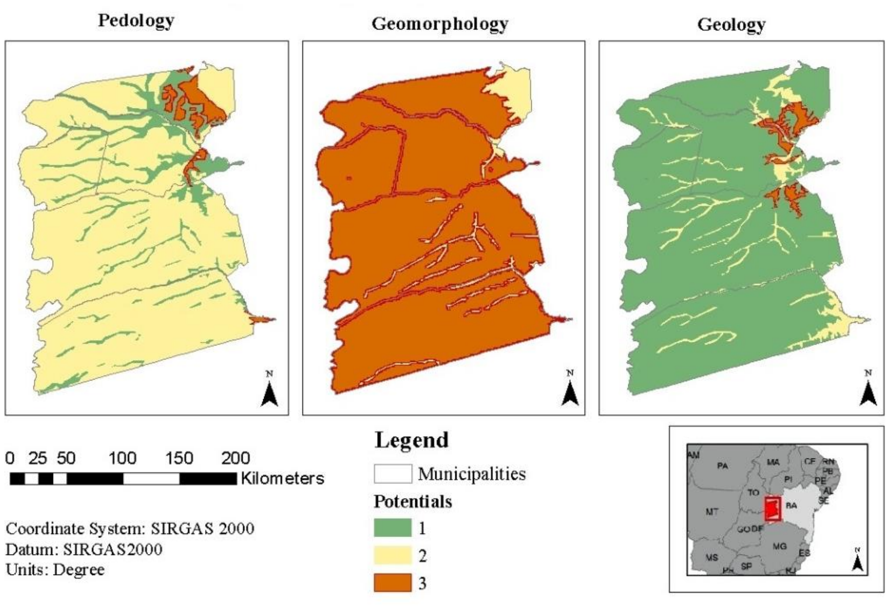

Figure 2. Potential of each layer to provide supporting ES: (1) Low; (2) Medium; (3) High

Geomorphology presented the highest potential to provide supporting ES. Santos and Castro (2016) state that the area is characterized by a wide flat area with sandy cover and an absence of rocky flowering, with dense vegetation of prickly shrub (caatinga). These smooth features give this layer high stability and connect it to some supporting ES, such as biomass production, soil formation, and nutrient cycling.

In contrast, geology offered the lowest potential. However, Bonfim, Janoni, Leite, Santos, and Carvalho (2016) highlight that the extensive plateaus found in the area were carved on the Arenitic sedimentary rocks of the Urucuia Group, associated with intense pedogenic and residual action; a feature that makes the occurrence of rocky outcrops impossible. These aspects link the area to supporting ES, especially soil formation. Thus, since this is a result of a consulted survey, it is possible that some subjective judgment has been inputted to this assessment. This is a weakness of this participatory approach. To overcome it, we suggest increasing the number of experts consulted; diversifying the experts' backgrounds and providing clear guidelines about the process, including the concepts providing the foundation for the study. Another premise is that the experts evaluated the geology by itself or in the context as origin material for soil. Since most of the geology in the area is derived from sandstone, the resulting soils are mostly low fertility soils.

Gama et al. (2018) state that the soils are mostly sandy, due its origins from Urucuia Group sandstones or from unconsolidated material that comes from the erosion and deposition of the sandstones. The soils present a wide distinction of colors, mainly from (red) and reduction (ashes) processes. The main variations among those sandy soils are due to the percolation of water, which depends on the permeability of the rocks and the relief (Gama et al., 2018).

With respect to this study, some specific misunderstandings about the types of ES may also have occurred. Fisher, Turner, and Morling (2009) highlight that while there have been several attempts to come up with a classification scheme for ecosystem services, there is not an agreed upon, meaningful, and consistent definition for ES. Reyers et al. (2013) also express concern about how ES – and particularly changes in those services – should be measured, which is directly linked with the idea of identifying potential areas for their provisioning.

Schröter et al. (2014) state that, although many authors have proposed ways to define ES more consistently, these attempts are criticized for being impractical, open to interpretation, and inconsistent (Nahlik, Kentula, Fennessy and Landers 2012). As a result of this ambiguity surrounding the concept, the term ES has become a popular "catch‐all" phrase that is used to represent ecosystem functions or properties, goods, contributions to human well‐being, or even economic benefits (Nahlik, Kentula, Fennessy and Landers 2012). Therefore, these disparate concepts appear to be reflected in the results obtained, especially in relation to geology.

To identify the spatial trade-offs between agriculture and supporting ES, a map for the general potential map was generated based on the overlap of the thematic layers. Thereafter, we used the land use map to identify agricultural areas and cross checked it with the potential map (Figure 3).

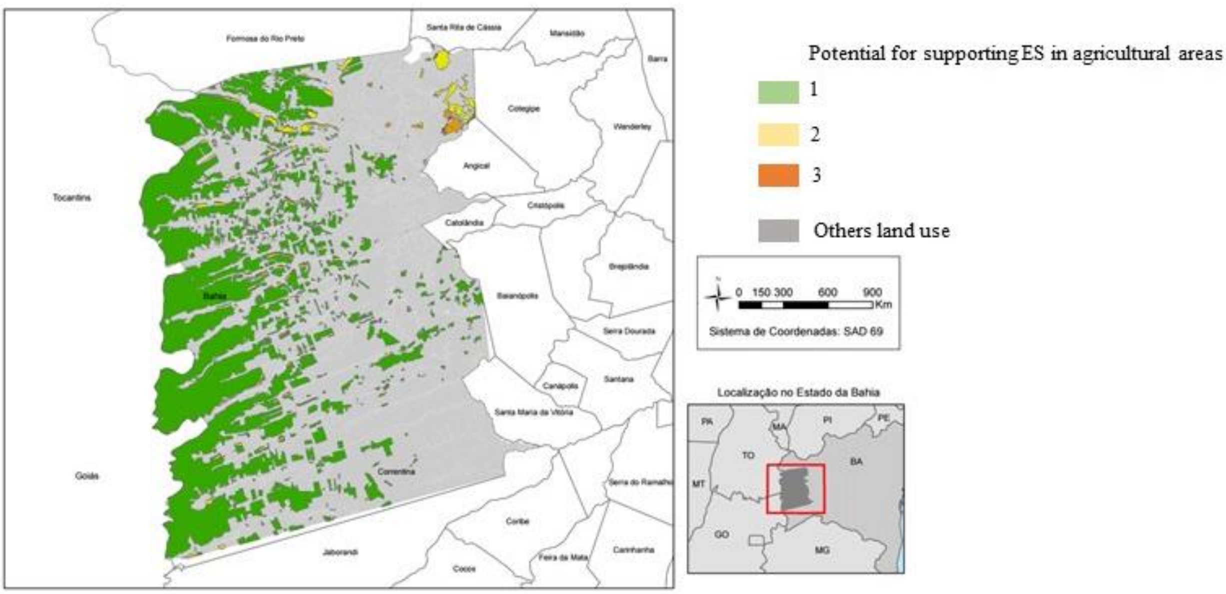

Figure 3. Potential for supporting ES in agricultural areas.

Thirty-six percent (36%) of the entire study area is associated with agricultural production, especially in the far west of the municipalities. However, 93% of the agricultural area is evaluated as having low potential for supporting ES (Table 2).

This result suggests a win-win scenario that occurs when there is no ES detriment in relation to another (Rodriguez et al., 2006). In this case, the largest area with low potential to provide supporting ES is used for “Food Production,” a provisioning ES. Moreover, Power (2010) highlights that the adoption of conservationist agricultural practices can reduce the trade-offs and, in some cases, increase win-win scenarios, since these practices can contribute improving the soil C stock and controlling erosion, two important ES (Feng, Zhao, Ding and Wang, 2017).

Gurgel et al. (2011), studying the same area, state that, considering the “Business as usual” scenario for the area, most of it seems to provide a low risk of erosion. However, the same authors stress that in a hypothetical scenario with vegetation removal and the absence of agricultural conservationist practices, the soil would be exposed and the risk for erosion would increase approximately 54%. Thus, the trade-offs impacts would also increase.

4. Conclusions

Open data shows its potential as a tool for regional spatial analysis, which allows for reducing costs due the reduced time needed to develop an analysis. The main outcome is the guidelines for socio-economic-environmental planning. However, following the identification of the target areas, a detailed analysis should be conducted according the goal of the intervention.

The Brazilian Access to Information law increases the flow of information between government and society, thus providing benefits beyond the scientific realm. Such action is very positive for government transparency and should be prioritized.

The methodological framework is proven useful for this purpose: to identify areas of trade-offs between agriculture and supporting ES on a regional scale. The expert’s low response rate did not prevent framework development and the results are coherent with the area’s characteristics. However, some strategies to improve expert consultation on the methodology would contribute to increase its reliability.

The methodological framework can be used as initial potential analysis for policy-societal dialogues to visualize ES potentials at a larger scale, thus guiding structured discussions within decision processes.

The concept of ES is demonstrated to be very complex, especially for subjects that traditionally are not conversant in this field, such as geology. It is a critical issue, especially considering decision making contexts.

The spatial analysis of trade-offs on a regional scale shows that it is possible to have win-win scenarios between agriculture and supporting ES. Nevertheless, it is mandatory that the agriculture activities follow conservationist principals and comply with the Environmental Legislation. Analyses at detailed scales and the monitoring of sustainability parameters are also recommended.

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