Title: *Transition to sustainability and the water-agriculture-energy nexus: exploring na integrative approach Cerrado e Caatinga biomes study cases*

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Project Title: *Transition to sustainability and agriculture-energy-water nexus: exploring an integrated approach with case studies in the Cerrado and Caatinga*

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Summary: The Cerrado and Caatinga biomes have the largest available stock of land for agricultural expansion in Brazil, besides having vast areas of high solar and wind potential. Their natural resources are also vital for climate regulation and for human survival and well-being. The general objective of this proposal is to explore how a participatory approach, integrating qualitative and quantitative methods of the natural and social sciences at multiple scales, could support the transition to a sustainable future in these two biomes, through the definition of scenarios and indicators that reconcile the economic, social and environmental (the three pillars of sustainability) in food production and use of natural resources. To achieve this purpose, the project is divided into phases with specific goals. **Phase 1** includes the organization and analysis of data on the social, economic, institutional and environmental dimensions of the study area to build sustainability indexes that reflect the current situation (*past and present*). **Phase 2** focuses on the future of the study area, by constructing qualitative and quantitative scenarios, built in a participatory manner. Elements of stories about the future will be quantified by generating spatially explicit projections of land use change, regional climate and its impacts (translated into a significant set of social-environmental indicators, including water, vegetation, biodiversity, agriculture, energy, lightning, biogeochemical cycles, among others). Finally, **Phase 3** involves the synthesis of activities between the scales, and the analysis of social transformation mechanisms to achieve sustainability (*trajectories*).

1. Rational

Humanity is facing unprecedented environmental challenges in both complexity and scope. We are in the 'Anthropocene", expression that frame the collective action of human kind into a geological forcing on its impact in the environment, changing how the geophysical and biological processes operate, imprinting the action in the Planet history. On the top of the large-scale threats are the climate change and degradation of natural ecological processes, essential for the maintenance of critical to the Nature Contribution to People, and well-being.

Currently, a substantial part of the Earth surface has passed by transformation in its natural ecosystems cover and biodiversity, by the increased demand of land for agriculture and expansion of urban areas (ELLIS, 2015). Challenges related to feed, and nourish a growing population, estimated to reach 10 billion people in 2050 (FOLEY *et al.* 2011, GODFRAY *et al.*, 2010). As well, the population growth trend poses pressure on the future demands for energy and water, as well as rates and country based emissions of greenhouse gases (GHG). The most recent global scientific assessment (e.g., IPCC) convey a quite clear message, global environmental changes are serious, disastrous and transversal in the global society, thus we need an urgent and integrated reaction. Central to this, are the pillars of the sustainable development goals: a) human well-being (related to social and political equality); b) social-financial inclusiveness; and c) environmental conservation.

The *Sustainable Development Goals* (SDGs) aim to inform and orient the public political arena of the United Nations member' Countries towards 2030 (http://www.un.org). The aim of the Goals is to improve lack of efficiency on the Millennium Goals, treating the environmental and economic goal in a holistic approach, including questions related to poverty, social equality and human rights. Considering this context, this project aims to support, based on sound science and communication, the process that Brazil has to endeavor to meet the SDGs in the country context, filling what we identified as an important lack of knowledge in the relation between the environmental scientific community and the decision-making processes. As well, based on understanding and recommendation for a stronger social engagement in these process, the project aims also on contributing to the national challenge on reconciling the abundance of natural resources to demands and needs of energy, water and health food

Therefore, we propose to explore the following scientific question: *how to evaluate pathways to sustainability, considering the variabilities of the natural system and the anthropogenic pressures, reconciling food, energy and water securities to human wellbeing?* This question is central on the discussion around the SDGs, reinforcing, within the scope of the project and its collaborations, the central adherence to the following Goals: No Poverty (SDG 01); No Hunger (SDG 02); Clean Water and Sanitation (SDG 06); Clear Energy (SDG 07), Sustainable Cities and Communities (SDG 11); Climate Action (SDG 13); Life on Land (SDG 15); Peace, justice and Strong Institutions (SDG 15). The SDGs are proposed at global level, but emphasizing the importance of, country based, national and subnational strategies for effective implementation.

Land available to agriculture expansion, at global level, are becoming scarce resource (LAMBIN & MEYFROIDT 2011; LAMBIN *et al.* 2013), with the recent expansion of the agriculture frontier, is concentrated in the tropical region (GIBBS *et al.* 2010; HANSEN *et al.* 2009). Due to its large territorial extension and abundance of natural resources, the country is a central player on the food and bioenergy production. The Cerrado e Caatinga biomes are considered regions with the largest areas available for agriculture expansion (SOARES-FILHO *et al.*, 2014, BOUCHLE *et al.* 2015) in the country, as well regions with, not only high potential for solar and wind energy production, but with the development of the commercial scale energy generation by these sources. The region known as MATOPIBA[1], distributed within these biomes is considered the most active agriculture frontier in Brazil.

However, planning on processes changing land use is critical. Transition from natural vegetation to other uses, is the primary driver for terrestrial biodiversity loss and has strong impact on the hydrological and climate systems. Pressures of un-planned land use changes, can also pose strong pressure on the local socio-economic systems and marginal areas expansion in in urban systems, derived among several drivers, on the land use change exodus (LAPOLA *et al*, publishing). The impact of drastic changes in the distribution of natural vegetation in the landscape can lead to strong impact on the shallow and deep ground water. RICHEY *et al.* (2015) observed a dramatic decline on the water stocks, in deep aquifer, in the Cerrado region, in special by irrigation in agricultural lands for commodities production.

By combining several relevant elements to the water-energy-food nexus, Cerrado and Caatinga, were chosen as focal area for this study. On top of the elements cited in this proposal thus far, one highlight the existence of areas susceptible to desertification and soil degradation in the Brazilian semi-arid region (MMA, 2005). This region is also listed as in high risk of changes due to changes in (OBERMAIER & ROSA, 2013). The persistence of these problem can worsen and already fragile social-environmental systems. (IBGE, 2013).

[1] Acronyms composed by the initials of States of Maranhão, Tocantins, Piauí e Bahia.

The water-food-nexus, being intrinsically complex, requires an innovative and multiscale research strategy. Therefore, the general objective of this proposal is: *to propose solutions using a novel participative approach, integrating quantitative and qualitative methods of natural and social sciences in multiple scales, to support the transformation to sustainability in the Cerrado and Caatinga biomes proposing pathways, scenarios and indicators reconciling the three pillars of sustainability for the use of natural resources, production of food and energy,*

The subjacent premise to this scientific challenge is that the transition to sustainability requires much more than technical solutions (PARK *et al.*, 2008). For that, profound and structural socio-political changes are required, including rethinking of current institutions, dominant standards (e.g., as in science the valuation of natural sciences in relation to humanities and arts, when looking to environmental issues), cultural options and the involvement of society in public decisions (DRYZEK, 2014). Building scenario based on normative and participatory approaches are gaining space on the environmental discussions towards a sustainable[2] future (VERGRAGT & QUIST, 2011). A recent example of this approach, was proposed by the *Global Environment Outlook – GEO5* (UNEP, 2012), where a 'traditional' exploratory approach (i.e., "where are we plausible going to*?*") migrate to a normative approach (i.e., "what do we want and what to do to get there*?*"), with a clear motivation to seek solutions and start a process toward transformation (IPCC, 2014). In the normative approach, the scenarios develop based on *trajectories*, linking the future to the present based on *backcasting* methods (VERGRAGT & QUIST, 2011). This approach is becoming a powerful when dealing, for instance, with climate change (GIDDENS 2009). This approach is the guiding principle of this proposal, by investigating the options associated to trajectories for a sustainable future, within the water-energy-food nexus, considering processes within and between rural and urban environment and the concept of "sustainable territories"[3]. For this, we will use a suit of approaches including mathematical modelling in different domains (land use, climate, vegetation, hydrology, agriculture, energy), field data and literature assessment for key parameters and participatory processes (citizen science).

[2] "*The essence of sustainability is to harmonize economic development with social goals and environmental preservation. At its core is the moral imperative that current generations should pass along an undiminished world to their descendants. To a large degree, sustainability is a challenge to think about the long-range future and, in so doing, to rethink the present. Sustainable development brings the question of the future to the strategic forefront of scientific research, policy deliberation, forward-thinking organizations, and the concerns of citizens*" (RASKIN, 2005).

[3] Sustainable territories are "*um mosaico de usos de terra complementares, gerenciados de forma integrada, que permitam conservar a biodiversidade e manter tanto a dinâmica dos processos ecológicos quanto a dinâmica socioeconômica de um determinado território*" (Viera et al., 2005).

The Center for Science of the Terrestrial System (CCST) of the National Institute for Space Research (INPE), institution that hosts this proposal, has the mission of conducting studies and evaluating the impacts of regional and global changes in social-economic-environmental systems. The CCST develops research that assists in the search for scientifically-based solutions that help Brazilian society to move towards a sustainable, safe and socially just development, regarding access to food, water resources, energy and health. Created in 2009, the Center is organized academically in three main thematic axes related to the monitoring of environmental variables, integrated data analysis, and modeling, resulting in diagnostic studies and scenarios in the various aspects related to the Terrestrial System

This project was strategically built as a coordinated and integrated action among the CCST researchers towards presenting diagnostics, prognostics and reflections on solutions to constructive development pathways from the natural science perspective, but with causal effects on the social arrangements and consequent territorial organization. CCST contributes to the definitions of new scientific paradigm which has being resented, at international level, within the scope of initiatives as the *Future Earth*, as scientific think tank, and the *Belmont Forum*, as important collaborative science funding scheme. An important collaborative network, with central presence and work in the focus areas, was organized and put together to the development of this proposal. This network includes the *CODEVASF (Companhia de Desenvolvimento dos Vales do São Francisco e Parnaíba), INSA (Instituto Nacional do Semiárido), EMBRAPA Semiárido, INPE's Northeast Regional Center (CRN/INPE) and regional Universities, as Universidade Federal de Alagoas, Universidade Federal do Ceará, Universidade Federal da Paraíba, Universidade Federal de Pernambuco, Universidade Federal Rural de Pernambuco, Universidade Federal do Rio Grande do Norte)*. As well, the network expands to other regions of the country, including researches from the *Universidade de São Paulo, Universidade Federal de São Paulo, Universidade Federal do Rio de Janeiro, Universidade Federal de Goiás, Universidade Federal de Minas Gerais, Museu Paraense Emílio Goeldi, Fundação Oswaldo Cruz, EMBRAPA Meio Ambiente and CEMADEN (Centro Nacional de Monitoramento e Alertas de Desastres Naturais)*.

To achieve the proposed objective, we planned a multiscale approach with research intervention and the biome scale (Caatinga and Cerrado), regional scale (watersheds) and local scale (selected municipalities). The study areas at biome and regional scale are presented in Figure 1, complimentary, Figure 2 present anthropic pressure and the environmental condition (related to the water-energy-food nexus)., highlighting the study regional scale

Biome Scale – Cerrado e Caatinga. The Cerrado is a global biodiversity *hotspots* but faces the strong agricultural expansion in Brazil (MYERS *et al.*, 2000), and the Caatinga, despite its uniqueness and specie endemism, holds the least extend are for conservation in the country (ICMBio, 2015; LEAL *et al.*, 2005). These biomes, in particular Cerrado, are critical for the hydrology of big river system in Brazil, as well as providing environment benefits to people (IPBES) and to other regions in the country (VALENTE *et al.*, 2013; MALHADO *et al.*, 2010). IBGE (2006) consider that 58% e 63% of Cerrado and Caatinga, areas are adequate for agriculture, however, climate change is seen as an emergent treat in the region, with increasing temperatures and reducing precipitation (FENG *et al.*, 2013). As a consequence, increasing of extreme events, leading, for instance, to increase in evapotranspiration and length of dry season, can drastically affect the Cerrado region (NOBRE *et al.*, 2007), can seriously affect agricultural production (both commodities and staple food), industrial production, use of energy and vegetation fires. The same authors suggest that the climate change impacts in the Caatinga biome, after 2050, might lead to increase of soils degradation in desertification processes, loss of biodiversity, reduction in the shallow aquifers recharge, and strong impact in food production, human health, human migration, tourism and unemployment (NOBRE *et al.*, 2007). This has serious consequences, also, for the country internal gross product, once agricultural commodities (e.g., soy, corn, sugar-cane, beef) are important component of the country commercial portfolio (IBGE, 2006; EMBRAPA, 2014). For instance, from the period of 2005-2014, the expansion of agriculture in the MATOPIBA region (which encompasses four states within, overall, the Cerrado, but also the Caatinga biomes), increased 89%, while at national scale this increase was just 29% (CONAB, 2015). Being under a semiarid environment, the large scale agricultural expansion in the Caatinga relies on irrigation, having the São Francisco river as the main water provider (ANA, 2012). Model's simulation suggested that the increasing demand, national and international, for agricultural commodities shall burst the land use change expansion in the area, for the next decades (DALLA-NORA *et al.*, 2014).

Regional Scale (São Francisco e Parnaíba river basins): for the regional approach, two contiguous areas, located within the interface of the two biomes were selected, those areas refers to the São Francisco e Parnaíba river Basins (Figures 1 e 2). River basins in Brazil are defined within political administration, called Hydrographic Regions (REHIDRO). This designation was defined by national legislation (Resolução n. 32/2003 from Conselho Nacional de Recursos Hídricos, CNRH), as "the territorial area comprised by a watershed, groups of watersheds or sub-watersheds, contiguous, with specific and homogeneous, or similar, natural, social and economic characteristics, with the objective to oriented public actions as planning and management of the water resources" (*[...]"<u>o espaço territorial brasileiro compreendido por uma bacia, grupo de bacias ou sub-bacias hidrográficas contíguas com características naturais, sociais e econômicas homogêneas ou similares, com vistas a orientar o planejamento e gerenciamento dos recursos hídricos</u>" [...])*. These watersheds are important areas for the logic of agriculture production and expansion in Brazil, face concerns on water availability and conflict on multiple needs and demands.; and are part of the MATOPIBA region, which encompass 18,11% of São Francisco e 20,16% of Parnaíba river basins (EMBRAPA, 2014). For both river basins, the processes associated to differentiation and intensification of socio-environmental inequalities are characterized by the duality between an immense majority of small municipalities with low demographic dynamics, which are predominantly rural and characterized by economic stagnation and, at the other end, by the consolidation of isolated poles of intense modernization, endowed with strong economic structures, typically aimed at the expansion of the agricultural and cattle frontier. In contrast to this dynamic, there are dozens of municipalities with potential for agroecological transition (MMA, 2011)[4].

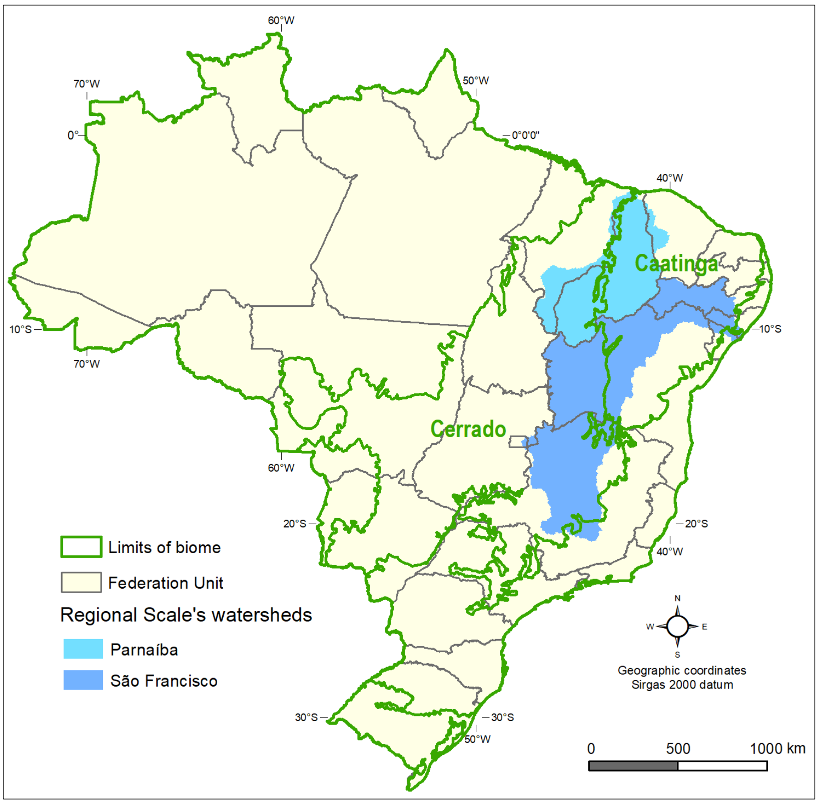

Figure 1 – Location of: Cerrado and Caatinga biomes and Parnaíba e São Francisco river basins.

[4] Exemplifying the diversity of the region, one can mention one more category of municipalities, besides these two types that represent agribusiness and the stagnant economy. This is the experience of communities in dozens of municipalities that are trained in agroecological transition. There are NGOs in Pernambuco (Centro Sabiá), Paraíba (ASPTA and ASA-PB), RN (SEAPAC and Dom Helder project) that promote adaptation actions to the semiarid in many cases based on sustainability principles. It is a participatory process that involves social organization of the communities.

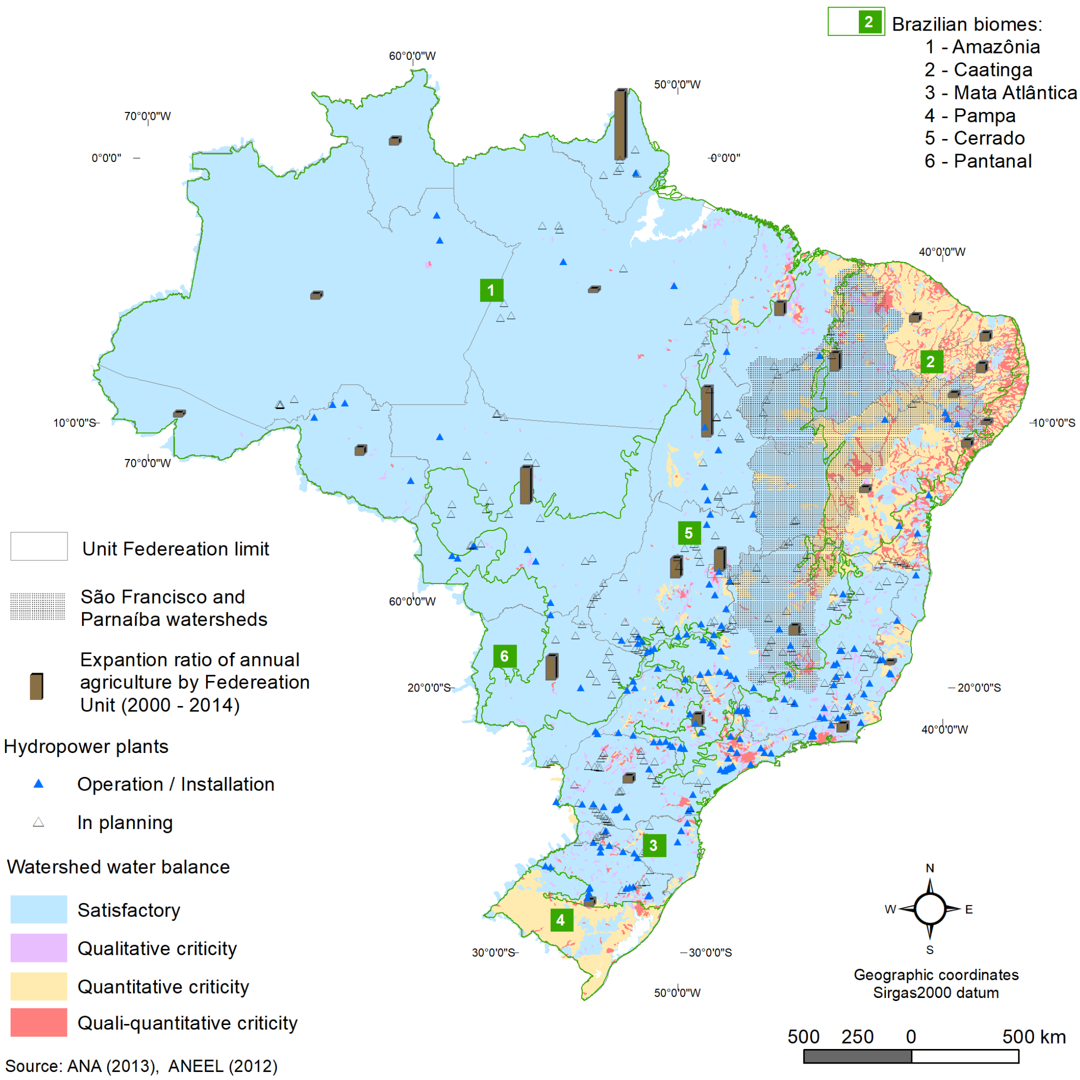

Figure 2 – Distribution of some anthropogenic pressure and the environmental status of the water-energy-food nexus in Brazil

Local Scale: In each of the hydrographical regions (São Francisco and Parnaíba), a municipality will be selected (with distinct socio-environmental characteristics) in which more specific analyses of social processes will be performed - through participatory activities. As well, evaluation for understanding the interactions between certain biophysical processes and social aspects on a more detailed scale. It should be noted that the objective of the selection of certain specific municipality is to bring the methodology at a local scale, being aware of the enormous diversity in the municipalities of the region.

In order to achieve the proposed general objectives, the project is organized in stages, with specific objectives in each of them, according to the structure shown in Figure 3. **Phase 1** will produce sustainability indices for the present, from the identification and production of an expressive quantity of indicators in the socio-environmental dimension, derived from secondary sources and observational models. In **Phase 2**, sustainability indexes will be generated for the year 2050 from the construction of participatory scenarios, updating indicators and quantitative models. "Sustainable" and "Conventional" futures will be represented. In **Phase 3**, the possible trajectories for sustainability will be interpreted in an analytical and synthetic way. In all these Stages, there will be interaction with the sectors of society (civil society, productive sector, and government agencies).

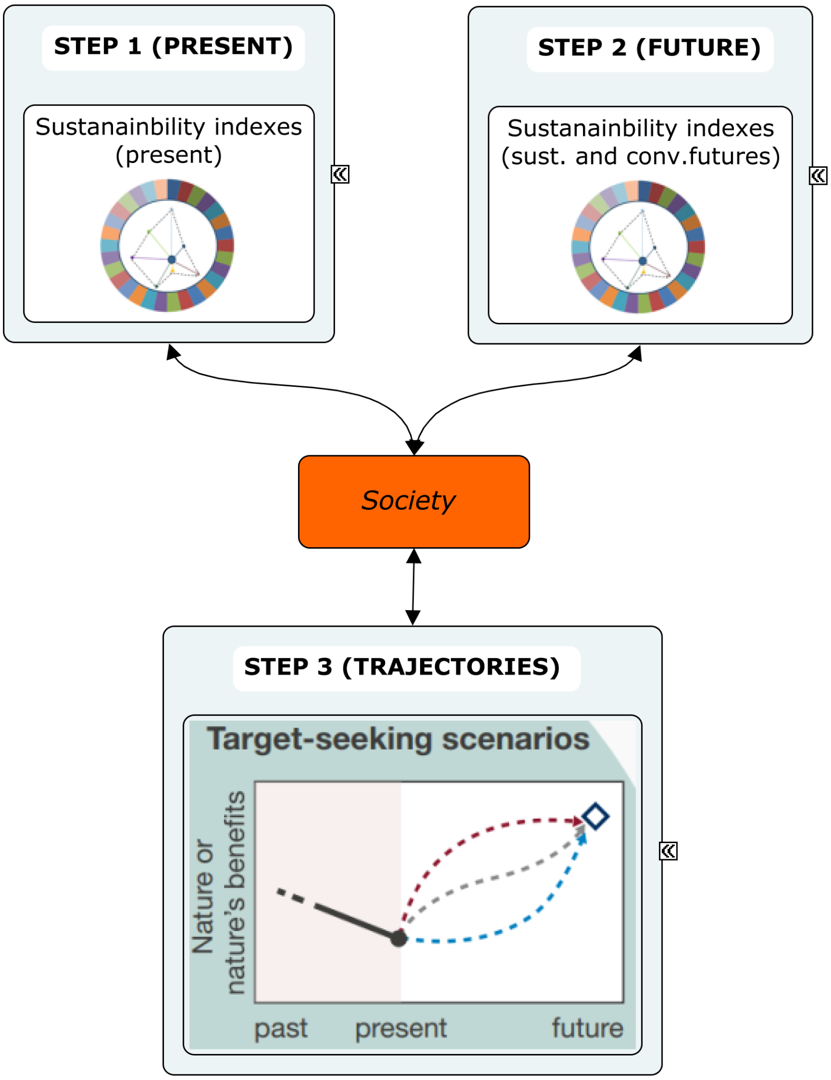

Figure 3 – Structure of the project Stages with their respective products

For the scientific coordination of the project, the logic of the institutional approach of the CCST, in relation to environmental problems and global changes, was considered. In this sense, the structuring of the project is linked to a systematization of scientific and operational coordination according to the logic of Principal Investigators (PP) of FAPESP, as listed below:

i. The **DIAGNOSTICS AND SCENARIOS** component will be the responsibility of the researcher Peter Mann de Toledo (CCST / INPE);

ii. The themes of **MODELING** of the various areas of focus will be under the coordination of the researcher Celso von Randow (CCST / INPE);

iii. The work involving **OBSERVATIONS** in the field and the supporting logistics infrastructure will be under the care of researcher Laura De Simone Borma (CCST / INPE).

iv. The structure and processes of **DISSEMINATION OF DATA**, including organization and processes of scientific dissemination, will be under the responsibility of researcher Pedro Ribeiro de Andrade Neto (CCST / INPE).

v. The **GENERAL COORDINATION** of the project will be conducted by the researcher Jean Pierre Henry Balbaud Ometto (CCST / INPE).

2. Expected Results

1) Methodology: development of a participatory method for defining scenarios and mechanisms of social transformation. The method shall combine qualitative and quantitative elements of the natural and social sciences, and be replicated in other geographical contexts.
2) The construction of locally desired and plausible scenarios for a sustainable future (considering the three pillars of sustainability: social, economic and environmental) for the area of study, at multiple scales.
3) Definition of useful sustainability indicators to guide and monitor actions to reach the desired scenarios, composed of indicators of social, economic, institutional and environmental dimensions. For the study area, the project will generate a set of indicators at the municipal scale, hydrographical region and biome, in the present and future, according to alternative scenarios.
4) Each of the Stages (Phases 1-3) will produce specific scientific, peer review articles, on the following topics:
    - Phase 1: sustainability indicators at multiple scales; development of environmental indicators; results of qualitative analyses, in particular field work on the local scale; regionalization method to identify homogeneous areas.
    - Phase 2: scenario building process; projections of land-use and climate change; impact of these changes on the indicators for the scenarios.

- Phase 3: integrated project results; multi-scale methodology; limits of participation and comparison of participatory methods for social transformation.

5) A data dissemination platform on the Internet that aims to make available to all scientific community and society the main data, products and results of the project.
6) Finally, the consolidation of an interdisciplinary / transdisciplinary research model, one of the challenges of current science, considering that: "*Science is expected, more than ever, to provide critical knowledge to help guide humanity's path towards plausible, desirable and novel futures in the Anthropocene*" (BAI *et al.* 2015, p.8)

3. Scientific and Technological Challenges and Methods for Overcoming them

The central scientific challenge of the project is the integration of the social and natural sciences, through qualitative and quantitative methods, into an approach applicable to the processes of social transformation in a given region. Therefore, we adopt a multi-scale perspective in the area selected for study - MATOPIBA region - which presents several conflicts in the water-agriculture-energy nexus, which may be enhanced by the impacts of climate change.

Integration between scales and disciplines can be mentioned as a second important scientific and technological challenge of the project, according to GALLOPIN (1996) in relation to sustainability indicators. KRONEMBERGER *et al.* (2008) stressed that these indicators are being used since the World Conference – ECO92, in Rio de Janeiro, as a metric to evaluate the progress of countries on sustainability measures. It should be noted that despite the increasing use of various methods and indicators for sustainable development evaluation, this process of analysis is still a challenge for research institutes and government agencies (KRAMA, 2009).

In addition to the indicators, two sustainability indices will be used, the **Sustainability Barometer** (BS) and the **Sustainable Development Indexes** (IDS). Developed by PRESCOTT-ALLEN (2001), the BS integrates two main axes: Human Well-Being (BEHum) and Environmental Well-Being (BEAmb). Each of these axes is subdivided into five dimensions. For society, it is considered: health and population, wealth, knowledge and culture, community and equity. For the environment, land, air, water, species and use of resources are included (VAN BELLEN, 2004). This method is versatile and has an open architecture, being possible to adapt to the local reality, since the choice of indicators is conditioned by the existence, consistency of the data and ease of measurement (KRONEMBERGER *et al.*, 2008).

In turn, the IDSs, developed by SACHS *et al.* (2017) were designed to instrumentalize and monitor the evolution of the ODSs for all UN member countries. More than 230 IDSs were recommended, of which 150 have consolidated definitions and many of them do not have sufficient data, from the member countries, for their respective calculations (SACHS *et al.*, 2017). In this regard, the UN recommends that member countries make investments in relation to their household sustainability statistics and indicators. The IDSs are subdivided and calculated according to the 17 ODSs (SACHS *et al.*, 2017), showing a variation of the number of indicators according to each MDS. ODS 3 is the one with the most recommended IDSs, whereas ODS 1, 10 and 11 have 3 IDSs recommended, respectively.

The following text will describe the main Stages and activities to achieve the proposed objectives. Its structure is shown in Figure 4.

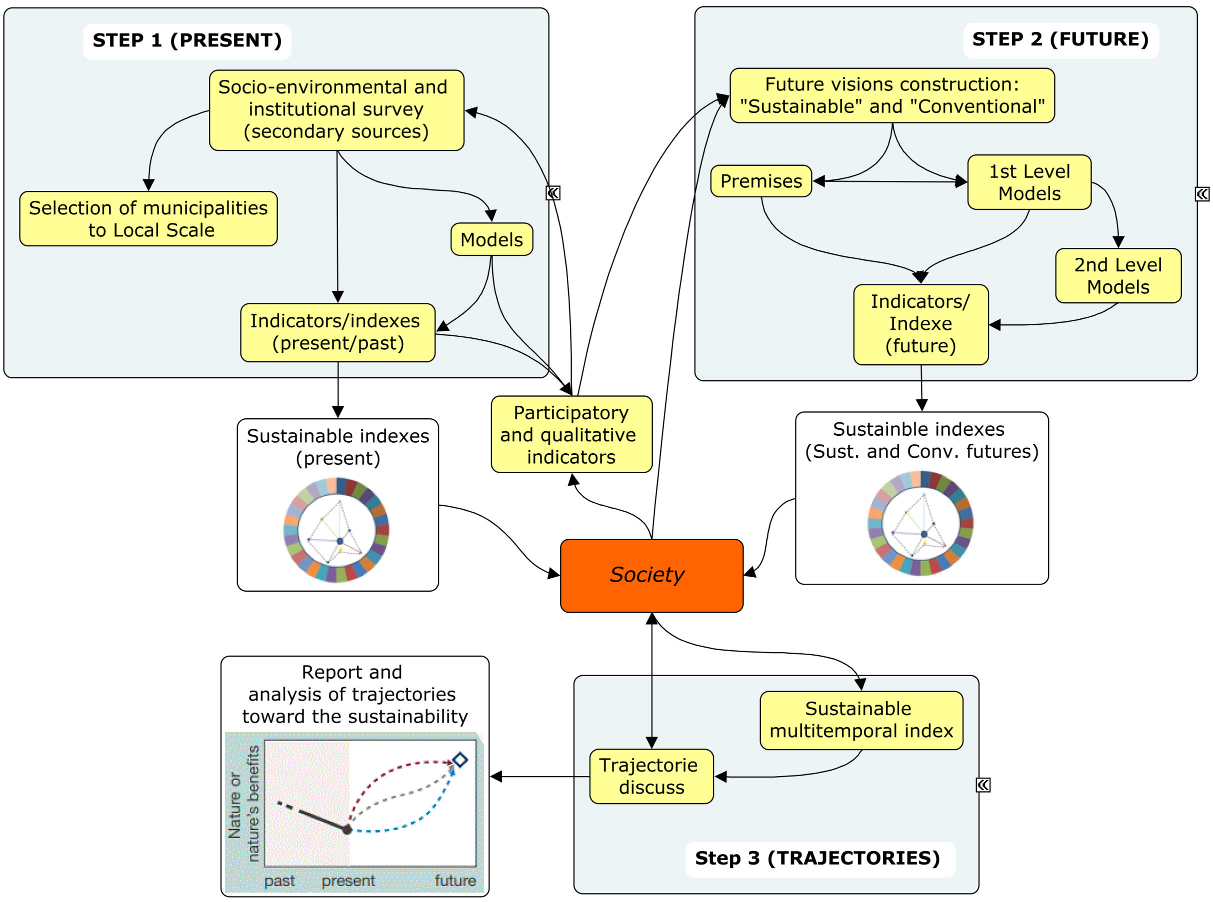

Figure 4 - Structure of the project stages with respective actions and products.

3.1. Stage 1 (Present): Social, environmental, economic and institutional survey on multiple scales

The general objectives of this stage include the collection of quantitative and qualitative information on social, environmental, economic and institutional dimensions at different scales. The processes identified in this Stage should elucidate the main issues to be addressed in the discussion of scenarios, including the identification of indicators, actors, and conflicts in the water-agriculture-energy nexus (Section 3.2.2). This Stage also includes the organization of a spatially explicit database for the design and selection of municipalities for analysis at the local scale. Previous experience in the region, on building a platform on land degradation data, (http://www.ccst.inpe.br/projetos/sap-sistema-de-alerta-para-seca-e-desertificacao/), and dealing with geospatial, environmental and socio-economic data, will be central in this Stage of Item 3.1.1 describes the construction of indicators for the Biomas scale and Regional scale. Section 3.1.2 describes the process of selecting areas of study at the local scale. Item 3.1.3 presents the objectives and methods for the collection of qualitative information, especially of field work, planned for this stage.

3.1.1 Social and environmental analysis at the Biomes and Regional scales

Socio-environmental indicators

The purpose of this research action is to generate an initial set of indicators that provide a holistic view of the current situation of the area of study in the Biomes and Regional scales. This is a first Stage in the construction of current sustainability indexes for these scales, whose territorial unit of analysis will be the municipality. Initially, workshops will be held with the sectors of society (civil, productive sector and government agencies) in order to guide the construction of the main indicators of sustainability in a qualitative way. Based on the benchmarks (acceptable limits), the qualitative indicators will serve as guiding principles for the collection of socio-environmental data from secondary sources, thus, delimiting new indicators, distributed in the following social, economic, institutional and environmental dimensions.

In addition to those collected from external sources, the project will build 27 socio-environmental indicators, organized in the following categories: Land Degradation (3), Water Quantity (3), Water Quality (1), Energy (3), Forest Conservation / Biodiversity (6), Greenhouse

Gas - GHG - and Biogeochemical Cycles (1), Atmospheric Electric Discharge / Urbanization (2) and Climatic Risks (1). Table 1 presents the description of the calculation method for each indicator. It is important to mention that the proposed methodologies combine the use of spatially explicit data (in situ data obtained in the present project and through local partnerships), remote sensing and the use/development of computational models in the several areas of knowledge of the researchers that integrate the project. The causal relationship and feedback among different physical and biological processes and human intervention will be analyzed in detail throughout the project. Extensive bibliography assessment supports the interpretation of a space in the territory in an integrated way, as summarized below.

Agriculture Expansion – Climate – Vegetation – Biodiversity

Land available for agricultural expansion has become an increasingly scarce resource in several regions of the globe (Delivering Food on Limited Land Project_FAPESP). In practice, the expansion of the agricultural frontier is already concentrated primarily in the tropics, and in Brazil, the Cerrado and Caatinga biomes are the main stocks of land available for conversion. Considering that the transition from natural areas to agricultural and urban systems can have greater implications for the loss of biodiversity, regulation of the hydrological and climatic regime, besides affecting local socioeconomic relations, the choice of a large volume of indicators to better represent and understand the processes that act during the dynamics of the use and modifications of the ground cover becomes necessary. This approach contributes to a multidimensional and multidisciplinary approach aimed at solving environmental problems and regional sustainability. For example, one of the points of interest will be to understand the processes and causes of the occurrence of fire, a factor related to the degradation process of natural systems and production systems. This process is centrally related to the advance of human activities on areas of native vegetation, increase of atmospheric pollutants, occurrence of atmospheric electric discharges (LYONS *et al.*, 1998) and important modifications in carbon and nutrient cycles linked to future climate conditions.

Climate, especially precipitation, in tropical ecosystems, such as Caatinga and Cerrado, influences the spatial and temporal distribution pattern of vegetation, which in turn influences the climate through feedback mechanisms of energy and water flows. In order to analyze the spatial and temporal variability of the vegetation in the region, remote sensing data allow elaborating indices of vegetation and humidity of the vegetation to detect, for instance, the photosynthetic activity and moisture content.

According to the Brazilian Ministry of the Environment (MMA), 431 priority conservation areas were identified in the Cerrado, of which 181 are already protected areas (conservation units and indigenous lands). Current species patterns and ecosystem structure are relatively recent, with current standards established only in the late Glacial period. The presence of a variety of forest formations interspersed with open areas, and distributed along different physiographic conditions, allows the presence of a great mammal richness. It is important to analyze the conservation status of the biodiversity of the study region and respective areas of local scale and to relate information indicative of food standards, such as using a methodology based on stable isotope analyzes on bats related to environmental and climatic patterns.

Soil – Climate – Water – Agriculture

Soil moisture is a key variable of the climatic system, impacting environmental aspects of relevance, such as water availability, energy balance and biogeochemical cycles, being also a potential indicator of the occurrence of droughts, desertification and fire. Given the great interdependence between soil moisture-precipitation-temperature, it can be expected that, in situations of climate change, the availability of soil water will be altered, influencing all the components of the system, depending on it. Similarly, the same can be said about changes in land use and land cover, due to their potential influence on the local climate (DIRMEYER *et al.*, 2006).

The development vision based on the intensive agricultural exploitation of the lands over the last decades has allowed the exponential increase in human population in the last century, but it has had severe consequences for the planet's biodiversity and climate. The increase in food and bioenergy demand should lead to increased productivity and expansion in the area of grain production and bioenergy crops in Latin America. Considering the expansion of non-conservation agriculture and livestock, combined with the effects of climate change, soil degradation processes can be potentiated, as observed in some regions of the Caatinga (SAP_www.sap.ccst.inpe.br). Considering the intrinsic relationship between soil degradation, agricultural productivity and food security, it is necessary to develop tools with potential to indicate areas where degradation compromises the development of crops, pointing to the behavior of agricultural productivity in the present and in the context of changes climate change.

The Caatinga biome, centrally distributed in the Brazilian semiarid region, is the most vulnerable to the desertification processes in the country. Global climate change processes tend to aggravate drought periods in semi-arid regions in Brazil, which, together with degradation and inadequate land use, are the direct factors that contribute most to the desertification process.

Competition for resources

In a scenario where the use of natural resources is limited, society's ability to make the most of a particular energy resource for a specific benefit is defined as energy efficiency. From another point of view, since energy is an essential input to maintaining a minimum level of comfort and meeting the basic needs of the individual, thus reducing their social vulnerability, per capita energy demand is a relevant indicator. In a spatial approach, indicators can be established regarding energy security, i.e. the risk of energy shortage through a regional energy balance, accounting for the balance between energy produced and consumed by a given region, defining the degree of energy autonomy of the territory. On the other hand, population supply, crop irrigation, and power generation compete for water resources in a basin. For example, an important element of water availability assessment is the relationship between demand and the volume of water not used for energy production, which is replaced by solar and wind generation.

The multiple use policies of the resources are based on the balance and negotiation, among different sectors demands, to resolve conflicts of interest. TUCCI *et al.* (2000) undertook a prediction exercise of the water resources situation in the country, considering three scenarios of socioeconomic development. The authors highlight problems related to the management of water resources, associated with the regulation of conferment, pollution and the negotiation of multiple uses, such as human supply, agriculture, and energy production, as well as problems related to the occurrence of extremes and the exposure to floods and droughts. In the evaluation, elements such as the preservation of the environment and the landscape, ensuring the maintenance of the hydrological regime necessary for the maintenance of biodiversity and the characteristics of the environment, should also be considered in the management of water resources.

Vulnerability analyses should include such constraints, which may be aggravated by the effects of climate change. Sustainability in the use of the water resource can be evaluated considering the production of water in the basin together with the demand exerted by the different uses. Thus, water availability should also summarize the effect of climate change and land use and coverage on the main uses of water in each basin.

Atmospheric extremes events

Extreme climatic events can seriously affect communities, impacting housing, public infrastructure, roads, work availability, disease occurrence, and epidemics, accentuating poverty and affecting the sustainability of their lifestyles. The characterization of the extreme hydrological events that result in these disasters is determined by the meteorological patterns of the region and the geomorphological and land use and cover characteristics. Thus, changes in the frequency of occurrence, magnitude, and duration of these events are related to climatic variability and to anthropic interventions that modify the landscape of a specific region, such as a drainage basin. Therefore, situations of vulnerability to climate change, mainly due to the increase in the intensity and frequency of extreme weather events, could become very serious, especially for the low-income population groups (UNFPA, 2007). Thus, this proposal will use a set of variables related to the characteristics of the natural environment in which the biomes are inserted, and which are potentially dangerous to the population (MOSER & SHRADER, 1999). Starting from this assumption the climatic variables used will be related to the occurrence of extreme events (precipitation, temperature, wind and atmospheric electrical discharges).

Urban climatology is defined as a methodology for studying the results of industrialization and urbanization in that region. At present, it is known that the construction and expansion of cities alter the local environment, affecting energy balance, humidity and near-surface atmospheric circulation regimes. Some of the differences between urban and rural climates include air quality, wind circulation, changes in precipitation patterns, heat island effect (OKE, 1982) and the increase in the incidence of atmospheric discharges (NACCARATO *et al.* 2013). Most of these modifications are related to pollution emissions, anthropogenic sources of heat, waterproofing of surfaces, thermal properties of materials, plant suppression and urban morphology (spacing, height, orientation of buildings). Other factors that influence local urban climate are topography, proximity to water bodies, size of the city, population density and the form of land use.

From the climatic projections, it is also possible to estimate the incidence of atmospheric electric discharges, which are events produced by storm clouds (ROMPS *et al.*, 2014). This parameter can then be used, together with the wind and / or precipitation information, to characterize the occurrence of the extreme events (HANSEN *et al.*, 2012; PINTO JR. *et al.*, 2013; PINTO JR., 2014).

Table 1 – Synthesis of socio-environmental indicators generated by this project and associated Sustainable Development Goals (SDG)

Category	Indicator	Description and Development	SDG
Soil Degradation	Soil Degradation index	Exploration of the soil resource with a view to its conservation. Initially, the rate of soil loss obtained through the Universal Soil Loss Equation (USLE) - methodological adaptation for regional scale as performed by MEDEIROS *et al.* (2016a). Pedological and climatic aspects, crop practices, among other factors will be considered in this evaluation. Then, the Soil Useful Life Index (or here called the Soil Degradation Index - SDI) will be calculated, which refers to the diagnosis of soil degradation according to the concept of soil loss tolerance (MEDEIROS *et al.* 2016b) and the estimated rates of soil loss	02 13 15
	Desertification Susceptibility Index	For the Biomes and Regional Scales, it is proposed the generation of an index of susceptibility to desertification, adapted from KOSMAS *et al.* (1999) and VIEIRA (2015). The following sub-indices will be considered: pedological, climatic, vegetation, management and socioeconomic. The generation of sub-indices will be performed by calibration and multi-layer neural network processing. The information that will feed this network, and in turn the sub-indices, will be collected in nuclei where it is known stages of degradation. In these nuclei will be considered information of specialists, census socioeconomics and biophysical status. In the latter case, the data will be extracted by remote sensing and in-situ stations/collections already available and/or instrumented by the project (bottom-up approach). On a local scale, the sub-indices considered will be composed of hydric-vegetative, management and socioeconomic conditions. These will be fed by biophysical data collected in-situ, information from census tracts and by interviews with passive and active actors regarding management in the respective municipalities.	01 02 08 13 15
	Time delay of vegetation related to rain	Indicator of vegetation quality, based on the climate-vegetation interaction. It measures the response time of the vegetation in relation to the precipitation, taking into account the difference in time between the date of maximum precipitation recorded in the annual cycle and the date of maximum vegetation development. Unity is "time" in days. The calculation of this indicator follows the procedure described by BUSTAMANTE-BECERRA *et al.* (2014).	13 15
Water Quality	Water quality	As an indicator of surface water quality, an index (QA) will be adopted based on the method recommended by the National Water Agency (ANA): http://portalpnqa.ana.gov.br/indicadores-indice-aguas.aspx. To calculate this index, we will adopt a linear combination, whose sum of the coefficients will be the unit, using the following parameters for its calculation: dissolved oxygen (OD), hydrogen ionic potential (pH), biochemical oxygen demand five days (BOD5) (T), total nitrogen (N), N-nitrate, N-ammonium, phosphorus-phosphate, conductivity / total dissolved salts and total residue. To carry out these determinations, a multiparameter probe of the Horiba U51 brand will be used to determine the following parameters in the field: dissolved oxygen, temperature, pH, total solids and conductivity (STD). The measurement of total nitrogen and its oxidized and reduced forms will be performed using a Shimadzu (N) brand TOC-N meter and a LACHAT brand (ammonium, nitrate and nitrite) FIA (flow injection analysis); phosphate as phosphate will be determined using a Metrohm Professional 850 liquid chromatograph. The solids (total, dissolved and suspended) will be determined by gravimetry (Mettler XP6 brand micro analytical balance). The BOD5 will be measured with a BOD meter.	06

Water availability	Soil humidity	This indicator will evaluate the soil moisture content for the study region and possible changes in this index due to changes in land use and land cover and climate change. The value of the moisture content will be obtained from 3 different approaches: (a) remote sensors; (b) using the combination of surface temperature data and NDVI and (c) from the hydrological modelling results.	06 15
	Water availability	Sustainability in the use of the water resource can be evaluated considering the production of water in the basin together with the demand exerted by the different uses. Productivity will be evaluated from distributed hydrological modelling. Climate change and changes in land use that may alter water availability conditions will be incorporated into these simulations (SIQUEIRA JR *et al.*, 2015). In this way demands by the natural vegetation (maintenance of ecosystems) and agriculture will be explicitly evaluated by the modelling. The demands for human supply, irrigation of plantations and energy generation will also be analyzed considering the land use scenarios developed in the project, population growth projections in the different regions up to 2030 provided by the Brazilian Institute of Geography and Statistics (IBGE 2013)) and installed capacity for hydroenergy production in the basin (MOHOR *et al.*, 2015).	06
	Hydrological Extremes	The environmental indicator that summarizes the effects of hydrological extremes should consider variables that quantify the potential impacts. In the case of extreme floods, these quantifiers can be given by the extent of the affected areas and the type of occupation in them, also producing estimators of the affected population. On the other hand, the impacts of extreme droughts can be quantified through their effects on water supply, reservoir and power generation, and irrigated agriculture.	06
Energy	Suitability Index for Solar and Wind Generation	The ability of a region for solar and wind generation can be spatially modelled by combining allocation factors such as road infrastructure, transmission networks, relief maps and radiation and wind potential maps, legal and environmental character, as demonstrated by JANKE (2010). Using the LuccME explicit spatial modelling tool and using relationships obtained from a spatial regression model based on past data on the evolution of solar and wind power generation in Brazil (2005 to 2015), the Aptitude Index for Solar and Wind Generation. This index assumes that the generating units are allocated hierarchically and progressively according to the potential of each cell in order to meet a defined demand.	07
	Energy Security	Population supply, crop irrigation and power generation compete for water resources in a river basin. Thus, water availability should consider the volume of water saved from the contributions of solar and wind generation. This indicator allows quantifying the complementarity between the different sources in an electrical matrix, which contributes to the increase of energy security insofar as it promotes gains in terms of the physical guarantee of hydroelectric reservoirs. It will be obtained from the projections of the a regional climate model + scenarios for the use of energy sources.	07 11

	Power robustness	Atmospheric electrical discharges cause damage to the electrical system leading to power outages and eventually to large blackouts with considerable social impacts. Such events are linked to the strength of the system against discharges. Quantifying and monitoring the vulnerability of these systems, allowing preventive actions, is strategic. An indicator will be developed to monitor the robustness of the electrical system against atmospheric electric discharges. This index will be based on the correlation of time between the occurrence of discharges and the FEC (Equivalent Frequency of Interruption per Consuming Unit) index of energy services quality. Data from the last 15 years will be used to define the degree of correlation. Future scenarios of this index will also be generated through the generation of climatic projections of the incidence of atmospheric discharges to the country and the evolution of the electric system based on the National Electricity Plan (PNEE).	07
Environmental Conservation and Biodiversity	Deforestation Risk	This indicator will be used to determine the risk of deforestation in a given area as a function of the potential demand for agricultural commodities, as well as of the biophysical, socioeconomic and institutional characteristics of the local area (AGUIAR, 2015, DALLA-NORA *et al.*, 2014). In order to construct this indicator, the agricultural expansion projections generated by the LuccME model. It will be possible to quantify and locate legally available, agronomically viable areas, with greater conversion risk at each (annual) time step.	15
	Potential occurrence of fire in the vegetation	The occurrence of fire is among the SDGs defined by the Brazilian Institute of Geography and Statistics (IBGE 2013). For the calculation of this indicator the combined use of field data, remote sensing and computational modeling is proposed. These techniques seek to find relationships between the occurrence of fire and other environmental variables linked to climate, land use and coverage, and landscape structure. These relationships will be used in equations to quantify the potential occurrence of fire (CARDOSO *et al.* 2003, 2008).	15
	Vegetation Seasonal Responses	For this, we will build a set of indicators that measure vegetation phenology parameters (such as amplitude and length of the vegetation growth cycle), based on the climate-vegetation interaction. The calculation of these indicators follows the procedure described by EKLUNDH & JÖNSSON (2004) and BUSTAMANTE-BECERRA *et al.* (2014) from the integration of the accumulated values of vegetation indexes (NDVI and LSWI) over the annual cycle.	15
	Native Remaining Vegetation	Based on data from public Institutions (present) or scenario assumptions, this Indication indicates the percentage of remaining vegetation and protected areas as indigenous lands, protected areas of integral protection and sustainable use.	15
	Endemism areas and species extinction risk	This Indicator is calculated based on the definition of endemic areas for species and the evaluation of anthropogenic forcing on changing habitats.	15
	Specie distribution modelling and extinction risk	This Indicator is calculated based on the definition of areas of potential distribution of species, in space and time, using physical variables of the ecosystem and evaluation of the conversion of natural areas in use for agricultural production.	15

GHG e Biogeochemical cycles	GHG emission levels	This indicator will allow us to: (a) establish, at specific sites and representative on the local scale, the emission standards of gases (CO_2, N_2O and CH_4) of the soil under different uses and coverage. Environmental parameters data will also be incorporated into the analyses, as well as the determination of nitrate (NO_3^-) and ammonium (NH_4^+) contents in soil and aquatic environments; (b) survey of GHG emissions from water bodies; (c) determine the emission balance at different scales by defining homogeneous zones, including emissions from the energy sector and environmental degradation, extracted from other project indicators.	13
Electric atmospheric discharges and urbanization	Urban atmospheric discharges occurrence	This indicator represents how much an urban center is able to intensify the occurrence of atmospheric discharges in relation to its neighborhoods (NACCARATO *et al.*, 2003). As a metric, the urban density of atmospheric discharges corresponds to the number of events per km2 of urban area per year and is directly related to the size of the urban heat island, the pollutant emissions, and atmospheric chemical composition.	13
	Lightning flashes of positive polarity (in %)	It measures the effect of the urban area on the physical characteristics of the atmospheric discharges, making it possible to identify how the anthropogenic action (emission of pollutants) affects the microphysics of the clouds (NACCARATO *et al.* 2003) As a metric, the percentage of discharges with positive polarity represents the ratio between the number of discharges with positive polarity in relation to the total number of discharges.	13
Climatic risks	Atmospheric extreme events	Identification and characterization of the areas with higher risk and the most vulnerable population groups to climate change. We propose to use a set of variables related to the characteristics of the natural environment in which the biomes are inserted and that is potentially dangerous to the population (MOSER & SHRADER, 1999). Based on this assumption, the climatic variables used will be related to the occurrence of extreme atmospheric events (precipitation, temperature, wind, electric discharges).	13

All proposed indicators will be calculated for the present (the base year 2010) and will feed at least two sustainability indices: BS and SDG. These indicators will then be recalculated based on the scenarios defined in Stage 2 (annually by 2050), reflecting the climate and land use projections to be produced (Section 3.2), as well as other scenario assumptions (such as the population growth), as shown in Figure 4.

Aggregated sustainable indicators

Individual indicators obtained for the Regional and Biomes scales (generated for all key municipalities in the study areas of the Cerrado and Caatinga biomes) will serve as a basis for the composition of aggregate sustainability indicators for the different scales (Local, Regional and Biomes). As already discussed, these indicators have been used since ECO-92 and help in assessing development towards sustainability. The Table 2 presents such indicators available from external sources and institutions with their SDG.

As an important part of the discussion and results from a multidisciplinary approach, it is expected that the project will create customized sustainability indicators with the issues under analysis. One aspect to be investigated is the incorporation of indicators of vulnerability[5] to climate change from the social, economic and environmental dimensions (Table 2) into more general indicators of sustainability (ADGER *et al.*, 2006; ERIKSEN *et al.*, 2005; LINDOSO *et al.* 2011; PEDROSO *et al.* 2013; TURNER *et al.* 2003). The indicators (individual and aggregate) generated at this step will be presented and discussed in participatory scenario workshops (Section 3.2.1).

Table 2 – The potential list of indicators collected in Stage 1 in various institutions and sources, their respective dimensions and related SDGs.

	Indicator - External sources	**SDG**
Social	Population	11
	Population Growth Rate	11
	Unemployment Rate	1, 8, 10
	Gini Index	10
	Average Monthly Income	1, 8, 10
	Percentage of People Who Earn Minimum Wages	1, 10
	Reason for Income by Gender	5, 10
	Ethnic Color Yield Ratio	5, 10
	Life expectancy at birth	3
	Child mortality rate	3
	Immunization against Infectious Childhood Diseases	3
	Number of Hospital Beds per Thousand Inhabitants	3
	Average Schooling	4
	Schooling Fee	4
	Households with Access to the General Water Network	6
	Households with Access to General Sewerage or Septic Tank	6
	Electrical Network Households	7, 9
	Density of Residents per Domicile	11
	IDH-M	3, 4, 8
Economical	Municipal GDP per Capita	8
	Municipal Participation Fund	8
	Investment Rate for Sustainability	17
	Municipal Trade Balance	8
	Degree of Indebtedness	8
	Power consumption per capita	7, 12
	Energy Intensity	7
	Participation of Renewable Sources of Energy Supply	7, 12

[5] Vulnerability is the level of susceptibility and inability of a system to deal with the adverse effects of climate change, including climate variability and extreme events (BRASIL, 2014).

Institutional	Existence of Municipal Councils for the Environment	16, 17
	Representation of Civil Society in the Environment Council	16
	Existence of Local Agenda 21	17
	Participation of the Municipality in River Basin Committees	17
	Interinstitutional Articulation of Municipalities (Participation in Public Consortia or Partnership Agreements with the Private Sector or Communities)	17
	Civil Society Organizations	16
Environment	Industrial Consumption of Ozone-Depleting Substances	12, 13
	Firewood Extraction and Coal Production	15
	Number of Vehicles Per Capita	9, 11, 13
	Burns and Forest Fires	1, 13
	Use of Agrochemicals	3, 6, 9, 15
	Garbage Collected (Rural and Urban)	3, 6, 12
	Recycling	12

3.1.2. Identification and selection of study areas (local scale) to build indicators in a participative approach

Concerning the construction of indicators in a participatory approach, there should be common municipalities for this task, therefore, such selection will be carried out by common methodology. Based on the qualitative indicators and on the collection of spatially explicit secondary data for the Regional scale, the delimitation of areas at Local scale will be carried out. In order to do so, areas with unique patterns and representative of the processes of transformation of the socio-environmental space at specific Hydrographic Regions (Rehidro) will be delimited, on which, for each one, a municipality will be selected. The selection of these will be done by considering the socio-environmental representativeness and the conflict in the water-agriculture-energy nexus at the Biomes and Regional scales. In order to subsidize the selection, computational processing will be carried out for the generation of agglomerates of municipalities with unique and representative characteristics of each Rehidro.

Computational method for generating clusters

The computational processing for clustering will be performed by a technique of patterns recognition, artificial neural networks of self-organizing maps, also known by the acronym SOM (Self-Organizing Maps) (KOHONEN, 1982). SOM has, as benefit, the not necessary linearity of the data and knowledge of the behavior of the variables, besides the possibility of visualizing their proportionality (GIRAUDEL & LEK, 2001). SOM is based on competitive and unsupervised learning, in which each variable is mapped into a finite space of nots organized, usually two-dimensional arrangements, representing the behavior of the variables (Kohonen Map or Component) (ARCOVERDE *et al.*, 2011).

3.1.3 Survey of qualitative information on different scales

Qualitative methods consist of a systematic and rigorous investigation integrating methods of data collection such as in-depth interviews, group discussion, participatory observation (ethnography), document analysis. These methods explore contexts and human experiences in each context (meanings). At this stage of the project, at the three spatial scales, activities will be carried out to identify actors and conflicts in the water-agriculture-energy nexus, to understand power relations, as well as the possible limits of participation in different contexts. These activities are:

Scientific Literature assessment on the areas and analysis of the databases. The information generated will allow identifying the major users of natural resources, economic divergences, among others. This information is key to identifying conflict "hotspots" or, at the very least, conflicting interests from a (more) equality point of view. This activity will include the analysis of access to natural resources through analysis of scientific literature and government reports and relevant financial and development institutions (e.g. CEBDS / GIZ, 2015). The theoretical framework will be based on environmental sociology (BUTTEL, 2003; FREUDENBURG 2005).

Sampling/Preparation of brief presentations (5-8 minutes each) on key dimensions of the water-food-energy nexus, from the largest to the smallest scale. We will survey, invite and record filmed testimonies from natural and social science experts on key issues (e.g. legal frameworks, energy sources, trade-offs, SDG). Under authorization, the films/presentations will be publicly accessible unless they have sensitive information about the target locations. They will serve to present to the general public the challenges of nexus - specifically those involved in the participatory activities of the project.

Field work using qualitative methods, in particular semi-structured interviews and focus[6] groups. Empirical data will be collected on: (a) perceptions of nexus and conflicts or other

[6] Focus group is a qualitative form of research in which a group of people is questioned about their perceptions, opinions, beliefs, and attitudes towards a product, service, concept, behavior. The questions are asked interactively in the group environment where participants are free to talk with other members of the group. Benefits and strengths of this method are that group discussions produce not only information for researchers, but also an

associated socio-political divergences; (b) local and supralocal social arrangements, including precedents/traditions and obstacles to participation. The semi-structured interviews will be conducted with key stakeholders representing different sectors of society (civil society organizations, productive sector, government) at the Biome, Regional, and Local scales. The use of focus groups will occur on the Local scale. Qualitative methods aim to understand the "why" and the "how" of sociocultural perceptions and decisions, not just "what", "where" and "when." Therefore, they are often based on small samples, and not on large samples counting, which justifies the use of focus groups. We will use focus groups of approximately ten selected people following recommended procedures to have a variety of perspectives (TRACY, 2013). Following the recommendations for reliable data, we will study a number of focus groups at various locations and cross-check the results with other data sources, following the recommendations of RAYMOND *et al.* (2010) and KIDD & PARSHALL (2000).

The results of these investigations will be considered in conjunction with the databases generated in Section 3.2.1.1. If a lack of perception of risks and negative impacts in the scientific literature or databases is identified, additional investigations will be carried out to identify their cultural and informational roots (main sources of individual information shall be identified).

3.2. Phase 2 (Future): Building scenarios on multiple scales

Raskin *et al.* (2005) define scenarios as "plausible, challenging and relevant stories about how the future can unfold, which can be told in both words and numbers. Scenarios are not predictions, predictions or recommendations. They are about sketching future pathways and taking into account critical uncertainties. " Thus, scenarios are used in situations where the factors that influence the future are highly uncertain, uncontrollable and insufficiently known. They can be used to improve understanding of the relationships between causes and consequences that often flea’s people attention, especially in today's world, marked by globalization and anthropogenic environmental changes. A scenario is not a description of an endpoint in time but a story (told in numbers or words) about a series of possible events within the time horizon established for it (ALCAMO, 2008; WILKINSON & EIDINOW, 2008).

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understanding of the collective through interaction among group members, as well as providing an opportunity to listen to individual perceptions; listening to others, verbalizing experiences stimulates memories, ideas, and experiences among participants (BERNARD 2011). Similar methods will be used in scenario workshops in Stage 2 (Section 3.2.2).

Several typologies were proposed to classify the scenarios, with many nuances and differences between them (VAN NOTTEN *et al.*, 2003; BÖRJESON *et al.*, 2006; PULVER & VAN DEVEER, 2007). For environmental scenarios, the following authors provided an important contribution to the evolution of this science ALCAMO (2008), RASKIN *et al.* (2005), PARSON (2008) and Wilkinson & EIDINOW (2008). Aguiar *et al.* (2015) synthesize the main variations found in the literature on environmental scenarios, through a four-way organization: (a) qualitative and / or quantitative scenarios; (b) normative and / or exploratory scenarios; (c) single-scale or multi-scale scenarios; and (d) participatory or expert-driven scenarios. We propose a multi-scale, qualitative/quantitative, participatory and normative approach in this project.

Normative scenarios are conceived from a "vision of the future,"[7] which can be positive, negative or neutral and develops in the discussion of confronting people's expectation with concrete conditions, by constructing a path of the 'future to the present', through *backcasting* methods.

For example, scenarios in the Fifth Global Environment Outlook (GEO-5) produced by UNEP, have been developed by a combination of the exploratory and normative approaches. Two scenarios were adopted. The first represents a vision of the world in 2050 assuming "*business as usual*" trajectories and behaviors, called "Conventional World". An alternative vision was then constructed, consistent with the current understanding, and the objectives and goals of 2050, called "Sustainable World". The difference between the two scenarios can define the depth of the necessary social transformation, allowing the emergence of new trajectories, as shown in Figure 5. Following this same line, the challenge of this project is to adapt and extend the approach developed for the construction of multi-scale and participatory scenarios in the Amazon, as reported in FOLHES *et al.* (2015) and AGUIAR *et al.*, (2016), for the reality of the study areas of the project, mainly exploring and improving participation mechanisms that effectively promote the transformations necessary for the construction of "sustainable territories". We intend to use the framework of SDGs to support the discussion. As described in FOLHES *et al.* (2015), the discussions will take place in workshops, with invited representatives from different sectors of society (civil, productive sector, government). Each workshop will be structured around the social, economic, institutional and environmental dimensions. The same workshop structure will be repeated, aiming on representing each scale/location of the project. The results will be integrated into Stage 3. The indicators generated

[7] The vision of the future should not be confused with the scenario itself, which contemplates the Stages to achieve this vision.

in Stage 1 will be presented as the starting point of the workshop discussions.

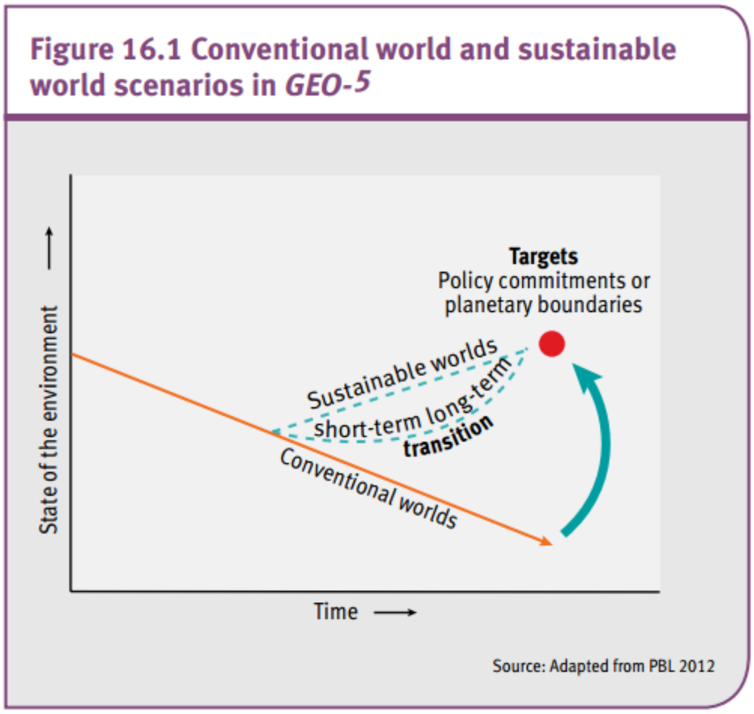

Figure 5 – Schematic representation of the difference between the "Conventional" and "Sustainable" scenarios. Source: GEO-5 (UNEP, 2012)

3.2.1. Quantification of the scenarios

Once the "conventional" and "sustainable" scenarios have been defined, we will quantify story elements, following the methodology proposed in the literature (e.g., AGUIAR *et al.*, 2016). The elements of the scenarios necessary to generate projections of land use and climatic projections will be selected and quantified. The land use and climate models will be referred to in this project as the first layer. The other models that receive outputs from the first layer models will be called 2nd layer models, for example, the hydrological model and the agricultural model. In addition to these models, premises will also be identified that should fit into a compatible "sustainable" or "conventional" future, for example, identification of policies, legislation, demands for population growth and energy, as pointed out by official bodies. The model layers and assumptions will feed and update the calculation of indicators in different dimensions (social, economic, institutional and environmental), as well as the identification and selection of more meaningful indicators that indicate the "sustainable" or "conventional" trajectories. This process will include, for example, projections of socioeconomic variables using existing data and/or extensions of IPCC Shared Socioeconomic Pathways (SSPs). The activities are divided into three parts. Section 3.2.1.1 describes the method for generating land use projections, section 3.2.1.2 presents how climate projections will be generated and section 3.2.1.3 summarizes the generation of indicators from these projections (ALCAMO, 2008; RASKIN *et al.*, 2005).

3.2.1.1. Spatially explicit projections of land use changes

The Cerrado and Caatinga biomes, as well as the São Francisco and Parnaíba hydrographic regions, present an enormous diversity of land-use and land cover processes linked to the water-agriculture-energy nexus. It includes, for example, the expansion of grain farming in MATOPIBA; the expansion of irrigated fruit production in the São Francisco; the desertification process in semi-arid regions affecting more traditional and smallholder agriculture, highly subject to climate change in the Caatinga; the expansion of biofuels; deforestation for both agricultural expansion and firewood, and recently the expansion of the wind and solar park that competes with agricultural uses.

The objective of this activity is to represent part of this process diversity, producing spatially explicit projections that correspond to the qualitative scenarios generated in the previous project activity and meet the requirements of the indicators described in Table 1. In this proposal, we will use the modeling framework LuccME (AGUIAR *et al.*, 2012, 2016) developed by INPE / CCST (http://luccme.ccst.inpe.br/). The LuccME is a spatially explicit land-use modeling framework that allows for easy construction of models of deforestation, agricultural expansion, desertification, forest degradation, urban growth, and other land use and land use change processes at different scales and areas of study, combining the components of allocation, potential, and demand. Using the LuccME, models are organized so that each year the demand for change is spatially allocated according to the potential of the cell.

Considering that changes in land use are influenced by local, regional and global factors (such as global demand for food and national policies), the implementation of land use models for the Biomes and Regional scales will be integrated into a modeling framework covering the national territory, in regular 10x10km cells, which, in turn, will receive results from global economic models projecting the demand for different uses. The strategy for implementation will depend on the consensus and divergence between scales. A specific workshop will discuss these consensus / divergences in order to build quantitative projections. In the Local Scale (for the selected municipalities), the implementation will possibly require a finer resolution and a specific approach to address divergences.

3.2.1.2. Spatially explicit projections of climate change

To observe how climate change occurs on a regional scale, more detailed information is needed. In this sense, it is necessary to use regionalization techniques (known as downscaling) to translate the information provided by global climate models into a more refined spatial scale. Regional climate models are widely used to produce high-resolution climate simulations at regional scales for impact and vulnerability assessment, as they may represent important local climate forcing such as complex topography, land surface heterogeneity, shoreline and lakes, helping to better capture inter-annual climate variability.

Thus, it is predicted in this project, the use of regional climatic models, potentially Eta and HadRMP3. The first one presents spatial resolution of 20x20km and has been used operationally in INPE since 1996 (CHOU *et al.*, 1996) for weather forecasting and, in recent years, for long integrations of climatic changes, after adaptations (PESQUERO *et al.*, 2009 (Roche *et al.*, 2004). The second presents 25x25km spatial resolution, being nested to the global model HadGEM2-ES, and two Representative Concentration Pathways (RCPs) 4.5 and 8.5. The latter is a product of CCST / INPE in partnership with UFPA.

Climate projections are subject to a number of uncertainties, which are generally associated with several factors such as future emissions of greenhouse gases and aerosol concentration, natural variability of weather and climate, construction of climate models (DESSAI *et al.*, 2009 DESSAI & HULME, 2004). MARENGO *et al.* (2010, 2012) suggest that uncertainties could be reduced with advances in the knowledge of the climate system and its better representation in the models. In addition, the use of a set of global or regional scenarios could generate added value in climate projections. This project will benefit from the outputs of the global models that have been run under the CMIP6 (Coupled Model Intercomparison Project Phase 6). The uncertainties associated with climate projections will be taken into account when making decisions for mitigation and adaptation actions. This highlights the need for an uncertainty and risk approach, incorporating results from different climatic scenarios in the impact studies (Nóbrega *et al.*, 2011).

We propose to study the climate sensitivity using three regional integration methodologies, a 20x20km resolution, nested to the HadGEM2-ES model (COLLINS *et al.*, 2011):

1. The first called control (CTRL1), will be the simulation of the present climate (1970-2000) and projections (2020-2050) from two contrasting emission paths (RCPs) adopted by AR5 (IPCC 2014): RCP 4.5 (CTRL2) and RCP 8.5 (CTRL3).

2. The second will consist of replacing the vegetation map of the regional model with the data and land use projections (in particular, results on deforestation) generated by the project for the area of study (regional scale) described in the previous section. Table 3 presents an initial proposal for the use of CPRs for the construction of the project scenarios. These combinations can be changed during scenario workshops.

Table 3 – Proposed combinations between CPRs and regional project scenarios.

		Sustainability	**Conventional**
Climatic Projections	RCP 4.5	**X**	
	RCP 8.5		**X**

3.2.1.3. Indicators derived from climate projections and land use

The results of climate projections, land use and other variables quantified from the scenarios (for example, population growth) will be used to generate socio-environmental indicators, detailed in Section 3.1.1 (Table 1), full-filling the quantification of scenarios

3.3. Stage 3 (Trajectories): Synthesis and analysis of trajectories for sustainability

3.3.1. Synthesis of the results from previous project Stages

The qualitative and quantitative results of the previous stages will be analyzed by the project researchers, seeking consensus and divergence. The results in the different scales will be analyzed independently, afterward seeking to map consensus and divergences (FOLHES *et al.*, 2015; BIGGS *et al.*, 2007). We will compare the results between scales with an analytical perspective, without seeking generalizations from local to regional scales, as proposed by Geist & Lambin (2002) and Gibson & Ostrom (2000). This activity will aim to prepare the last round of workshops, described in the next section.

3.3.2. Trajectories to Sustainability

This activity consists of the exploration of participatory methods to discuss trajectories for sustainability and social transformation in each scale, based on the results of the previous stages. It will broaden and deepen the discussion on trajectories (actions and obstacles) to achieve the "Sustainability" scenario. In **Stage 3**, this discussion will be marked by the quantitative results of the sustainability indices (present and future) and their respective indicators.

This component of the project will be based on theories of participatory processes (HICKEY & MOHAN, 2004) and will try to overcome common obstacles to their impact pointed out by them. In addition to the approach based on FOLHES *et al.* (2015) to discuss trajectories (with the same participants in **Stage 2** workshops), will experiment with a combination of "Wisdom Councils" and "Citizen Juries", two established models for involving citizens in deliberation and political decision-making (ATLEE, 2012). These panels will meet for two days and will be composed of ordinary citizens, not stakeholders. They will be asked to discuss the obstacles to achieve the scenarios defined in **Stage 2** and ways to overcome them. Such an iterative conception, going beyond the mere definition of recommendations, is one of the factors hitherto absent in experiments with such participatory processes (ATLEE, 2012).

4. Project Execution Schedule

		Year 1				Year 2				Year 3				Year 4				Year 5			
	Activity	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
	Selecting Local Scale Areas (Sites)	■	■	■																	
Stage 1	Database (Regional scale)	■	■	■																	
	Field Activities (Regional scale)		■	■	■	■															
	Models' calibration and generation of present indicators			■	■	■	■														
	Workshops: Scenarios							■	■	■											
	Scenarios - Quantification (projections and indicators)									■	■	■	■	■	■	■					
Stage 2	Instrumentation of the local scale areas			■	■	■	■														
	Literature review and preparation for field activities					■	■														
	Database (Local scale)						■	■	■												
	Field Activities (Local scale)						■	■	■	■	■	■	■	■							
	Workshops: indicators (Local scale)											■	■	■	■	■					
Stage 3	Synthesis of Stages 1 and 2																■	■			
	Workshops: trajectories																		■	■	
	Synthesis of trajectories																				■
	Dissemination of information (Communication)							■	■	■	■	■	■	■	■	■	■	■	■	■	■

5. Dissemination and Evaluation

5.1. Rating criteria

- **<u>Stage 1</u>** – Social-environmental indicators generated for the present;
- **<u>Stage 2</u>** – Social-environmental indicators generated for the future (scenarios);
- **<u>Stage 3</u>** – Cycle of workshops concluded with the discussion of the trajectories in multiple scales.

5.2. Dissemination

The project will seek to engage digital media in an innovative way to attract the attention of a large part of society to the project, disseminating knowledge through the production of material in the online media. The objective will be to disseminate not only the qualitative and quantitative results of the project (Stages 1 and 2) but also the possibility of innovative processes for deliberation and decision making (Stage 3). A web platform will be developed for publishing and disseminate spatially explicit data and scenarios. The possible users of this tool are both the scientific community and society in general. We plan to publish:

1. Quantitative data resulting from field work;
2. Spatially explicit results of computational models;
3. Social, economic, institutional and environmental sustainability indicators for the study areas, in different scenarios and at different scales;
4. Reports for each of the municipalities located in the Cerrado and Caatinga biomes, containing the results of the indicators developed under this project;
5. Journalistic texts of scientific divulgation to subsidize the dissemination of the knowledge by the printed and digital media;
6. Dissemination materials (printed and digital) of the results, addressed to policy makers and decision makers at the various levels (federal, state and municipal).
7. Peer-review manuscripts in high ranked journals relevant for the thematic
8. Engagement and collaboration of PPG-CCST with post-graduation programs from several partner institutions, aiming on the training of masters and doctors

The tool will establish a series of processes for importing and viewing the data. Project researchers will be able to define the areas to be viewed, import the data from their searches and how this data will be visualized by the end user. In turn, the end user of this tool can interactively view all the data published by the project researchers, as well as compare the results of the different scenarios, through an application on the Google Maps platform.

6. Another support

The researchers already participate in the following projects that show synergy with the theme of this proposal:

- DEVIL (*Delivering Food Security on Limited Land*) – Thematic Project FAPESP/Belmont Forum/FACCE-JPI (Process FAPESP 2014/50627-2). *Food Security and Land Use Change*.
- REDE CLIMA (Brazilian Research Network on Global Climate Change) - Established by the Ministry of Science and Technology (MCT) in November 2007 (http://redeclima.ccst.inpe.br/) In particular, within the Network, the integrative projects: (a) **Socio-environmental Security (PI-SSA)** with the activity "*Survey of public policies and key actors in the São Francisco river basin: analytical framework of its integration aimed at adaptation to climate change*" and (b) **Food Security, Water Security and Energy Security (PI-SHAE)**, also in the São Francisco Basin.
- **Forest2020** - CCST / INPE in partnership with Key Associates and IPAM, with funding from the UK Space Agency and ECOMETRICA, has the particular focus on improving forest and land use change monitoring systems through better applications of satellite data, with focus on the Brazilian Closed region.

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