LUIZ OTÁVIO MORAS FILHO

CONTRIBUIÇÕES DA AVALIAÇÃO AMBIENTAL ESTRATÉGICA PARA O PLANEJAMENTO ESPACIAL DE BACIAS HIDROGRÁFICAS NO BRASIL

LAVRAS-MG
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Prof. Dr. Luís Antônio Coimbra Borges
Orientador

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CONTRIBUIÇÕES DA AVALIAÇÃO AMBIENTAL ESTRATÉGICA PARA O PLANEJAMENTO ESPACIAL DE BACIAS HIDROGRÁFICAS NO BRASIL
CONTRIBUTIONS OF THE STRATEGIC ENVIRONMENTAL ASSESSMENT FOR SPATIAL PLANNING OF WATERSHEDS IN BRAZIL

Tese apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-Graduação em Engenharia Florestal, área de concentração em Ecologia Florestal, para a obtenção do título de Doutor.

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À minha mãe, grande amiga e companheira, por cada conselho, conversa, carinho, cuidado e dedicação.

Ao meu pai, exemplo de força, dedicação e competência.

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E a todos os amigos que compartilharam inúmeros momentos, sucessos e fracassos, sem perder o bom humor.

Dedico

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“Quando a maldade aqui passou
E a tristeza fez abrigo
Luz lá do céu me visitou
E fez morada em mim

Quando o medo se apossou
Trazendo guerra sem sentido
A esperança aqui ficou
Segue vibrando

E me fez lutar para vencer
Me levantar e assim crescer
Punhos cerrados, olhos fechados
Eu levanto a mão pro alto e grito

Vem comigo quem é do bonde pesadão”.

(Isabela Lima, Marcelo Falcão e Pablo Bispo)

RESUMO

Apesar da Avaliação Ambiental Estratégica (AAE) já estar sendo aplicada no Brasil, esse processo ainda é voluntário e carece de diretrizes que o conduzam de acordo com as necessidades e peculiaridades do país. Neste estudo, buscamos discutir as oportunidades e os desafios para a implementação da AAE no processo de planejamento do uso da terra no Brasil por meio de I. uma ampla revisão da literatura, e II. propondo um método baseado em um método multicritério para apoio a tomada de decisão por para subsidiar a etapa de diagnóstico da Avaliação Ambiental Estratégica Regional de uma bacia hidrográfica, mais precisamente da bacia do rio Doce. A AAE pode ajudar no processo de planejamento do uso da terra, fornecendo uma estimativa sobre o uso futuro de um território e levando em conta os ajustes que seriam necessários para garantir que as metas de desenvolvimento sustentável sejam alcançadas. Apesar de algumas experiências voluntárias, as AAE realizadas no Brasil foram consideradas fracas, principalmente por causa da falta de obrigação legal, falta de diálogo com outras políticas públicas, falta de continuidade na gestão política e necessidade de mais transparência e melhor governança. No entanto, o Brasil tem potencial para aplicação de AAE em diversos setores e é necessário adaptar este instrumento para melhor atender suas demandas. Acreditamos também que a AAE Regional é a categoria mais adequada de avaliação ambiental para o ordenamento do território brasileiro, apoiada pelo método proposto.

Palavras-chave: AAE. Planejamento Espacial. Gestão ambiental. Políticas Ambientais.

ABSTRACT

Despite Strategic Environmental Assessment (SEA) is taking place in Brazil, this process is still voluntary and lacks directives that lead it according to the needs and peculiarities of the country. In this study, we aimed I. to discuss opportunities and challenges to implementing SEA to Brazilian land-use planning process through a wide literature review, and II. to propose a method based on multi-criteria decision aid (MCDA) to support the diagnosis stage of the Regional Strategic Environmental Assessment (R-SEA) of a watershed, more precisely, the Doce river basin. SEA can help to hold the land-use planning providing an estimation about the future use of a territory and bringing into account the adjustments that would be necessary to guarantee that sustainable development goals are reached. Despite some Brazilian SEA voluntary experiences, the capacity of the performed SEA in Brazil is considered weak, mostly because of lack of legal obligation, lack of dialogue with other public policies, lack of continuity in political management, and the need for more transparency and better governance. However, Brazil has potential for SEA application in many sectors and that is necessary to adapt this instrument to better attend its demands. We also believe that premises of Regional SEA are the most suitable category of environmental assessment for the Brazilian land-use planning, supported by the proposed MCDA method.

Keywords: SEA. Spatial planning. Environmental management. Environmental policies.

SUMMARY

FIRST PART

1 GENERAL INTRODUCTION

The Environmental Impact Assessment (EIA) was established in Brazil by the National Environment Policy aiming to provide information to assist the licensing process of enterprises that may potentially cause environmental impacts. However, due to its focus on projects, it is necessary to use a more comprehensive evaluation instrument, reaching the level of policies, plans, programs (PPPs) and even structuring projects that "trigger effects on the environment, at the stage of designing its proposals, before irreversible decisions have been taken" (MINAS GERAIS, 2017), where Strategic Environmental Assessment (SEA) stands out.

SEA is "a systematic process of evaluating the environmental consequences of a proposed policy, plan or program to ensure that the consequences are fully elucidated in order to address them appropriately at the earliest stage possible" (GAO et al., 2017). Sánchez (2017) further adds that SEA refers to "the assessment of the environmental consequences of PPPs, generally within the framework of government initiatives, although it may also be applied in private organizations". Partidário (2012) also states that SEA is an instrument capable of anticipating political priorities, establishing dialogues and communicating long-term risks and opportunities, thereby establishing opportunities for development, including conditions for project licensing, through guidance and early clarification of restrictions.

SEA arose from Environmental Impact Assessment (EIA) and was based on its same steps, but with a "more strategic" function, where federal policies represent the highest planning levels subject to SEA (REHHAUSEN et al., 2018). Despite a number of past voluntary applications, SEA was legally consolidated in 2001 in Europe through Directive 2001/42/EC, establishing the assessment of the effects of certain plans and programs on the environment. According to Souza (2007) and Oberling (2008), there is a European leadership in this evaluation process, but there is a great international movement around the adoption of the instrument, as in the United States, Canada, Australia, South Africa, China, Chile, and Indonesia.

In Brazil, the first attempt to institutionalize SEA was made in São Paulo in 1994, as a consequence of an effort work to reform and update the EIA procedures led by the State Environmental Council (SÁNCHEZ, 2008). At the federal level, the same author mentions: the recommendation of SEA to Multi-Year Plan of the Union in 2001; the decision of the Court of Auditors of the Union in 2004 recommending the adoption of SEA in the preparation of Multi-Year Plan, and in the planning of sectoral PPPs; and the training course for federal and state agencies in SEA for the Pantanal region in 2006-2007. Pellin et al. (2011) also cite the SEA processes involving projects such as Bolivia-Brazil Gas Pipeline, Madeira River's Hydroelectric Complex, and São Paulo's Metropolitan Rodoanel (highway). Currently, the SEA in Brazil is a voluntary process and not yet regulated in federal legislation. For this reason, Draft Laws n. 261/2011 and n. 4,996/2013 were proposed to make SEA one of the instruments of the National Environmental Policy, as well as a mandatory step in the environmental licensing process.

According to Sánchez & Croal (2012), and to Oliveira (2014), evaluations using SEA are a worldwide trend, since they make the decision making process more responsible and transparent once possible environmental, social and economic consequences are considered in the decision-making process. SEA can improve the decision-making process at the planning level by: (a) supporting the integration of environment and development, (b) providing environmental evidence to support informed decisions, (c) potentiating identification of new opportunities, (d) preventing costly errors, (e) promoting public involvement in decision-making for better governance, and (f) facilitating cross-border cooperation (OECD, 2012). Pellin et al. (2011) also point out that "multilateral development agencies, such as the Inter-American Development Bank and the World Bank, have been encouraging the adoption of SEA in developing countries as a recommendation or requirement for investment approval".

SEA procedure includes the following stages: 1. Identification of broad plan alternatives; 2. Screening; 3. Situation assessment (Scoping); 4. Identification of sustainability objectives, criteria, and indicators; 5. Identification of environmental opportunities and constraints; 6. Formulation of sustainability parameters for the development of the policy, plan, or program; 7. Development and assessment of alternative policies, plans, or programs; 8. Decision-making; 9. Development of a plan for implementation, monitoring, and auditing; 10. Plan monitoring and auditing; 11. Implementation; 12. Auditing (MAKABA & MUNYATI, 2018).

SEA, according to Slootweg et al. (2006), should be outlined in accordance with the national context and the characteristics of the planning processes in which it will be applied. This evaluation is often used as a parallel process to support decision making only at the end of the planning process (Figure 1a). However, the same authors affirm SEA has been developed in an integrated way to planning, bringing together stakeholders during the main stages of the process and feeding the debate with reliable environmental information (Figure 1b), or even replacing the planning process (Figure 1c).

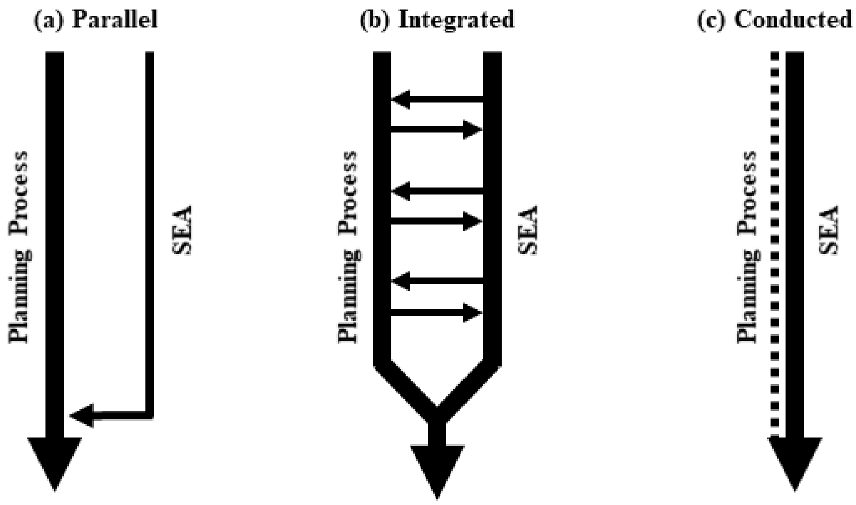

Figure 1 Combinations between Strategic Environmental Assessment and planning process (SLOOTWEG et al., 2006).

Partidário (2012) affirms there are four situations when SEA could be applied:

1. When the territorial area of intervention is known, but not sectoral proposals or intentions (e.g. national rural development plans);

2. When proposals or sector intentions are known without a territorial area for identified action (e.g. an implementation of wind farms in the country);

3. When the territorial area of intervention and sectoral proposals or intentions are known, however, there may be strategic dimensions capable of influencing the decision (e.g. port expansion of a given city to increase the region's import/export capacity); or

4. When sector policy is known, but there is no territorial materialization (e.g. health-related strategies, international trade, or emigration policies).

However, it’s important to highlight “there is no generalized SEA methodology applicable to all plans”, and that “SEA techniques and methodologies should be treated as a set of tools in a toolbox, out of which each user can choose their own tools depending on their particular needs" (Josimović et al., 2016). Noble & Nwanekezie (2016) also point out that each approach has its relative strengths and limitations, each one of then serves a different function and, for this reason, all of them are valuable and necessary to SEA process.

Josimović et al. (2015) consider SEA as "one of the key instruments for implementing sustainable development strategies in planning in general" especially in spatial planning. In this context, Thérivel & Partidário (2013), Gunn & Noble (2009), and Chen et al. (2018) bring the concept of Regional Strategic Environmental Assessment (R-SEA) that is "a process used to evaluate the potential environmental effects of strategic initiatives in a particular region". RSEA is a useful tool "for considering the benefits and consequences of the proposed changes in space, also taking into account the capacity of space to sustain the implementation of the planned activities" (JOSIMOVIĆ et al., 2015)

Spatial planning could be based on many factors, for example, water supply and demand. Gao et al. (2017) sustain that "water scarcity will eventually restrict industrialization and social and economic development, meaning that water may one day constrain the world's development". Besides lack of spatial planning, disasters such as rupture of Samarco's tailing dam in Doce river basin in 2015 could increase this risk. Doce River Basin has a drainage area of 86,715 km^2, of which 86% are in the eastern part of Minas Gerais state and 14% in the northeast of Espírito Santo state, in Brazil, with 879 km of extension. Its population floats around 3.5 million inhabitants distributed in 228 municipalities. There is strong pressure on water resources for many activities carried out in the region, mainly by mining, and the transportation of 50 million m^3 of iron ore tailings along more than 500 km in the basin in 2015 further aggravated the situation.

Based on those statements, this thesis aimed to approach strategic issues for the sustainable development of Doce river basin supported by RSEA experiences reported on scientific literature and by a case study using multi-criteria decision aid (MCDA).

2 OBJECTIVES

2.1 General Objective

In this study, we aimed to explore how Strategic Environmental Assessment (SEA) could be incorporated into the spatial planning process in Brazil, and we proposed a model based on multi-criteria decision aid (MCDA) to support SEA process in the spatial planning of Doce river basin.

2.2 Specific Objectives

I. To discuss opportunities and challenges to implement strategic environmental assessment in Brazilian spatial planning process through international experiences reported in the scientific literature.

II. To select sustainable development indicators that properly represent the study area, avoiding overlapping of information.

III. To propose a model based on multi-criteria decision aid to support Regional Strategic Environmental Assessment in the spatial planning of Doce river basin.

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SECOND PART - PAPERS

PAPER N. 1 – CONTRIBUTIONS FROM STRATEGIC ENVIRONMENTAL ASSESSMENT TO BRAZILIAN LAND-USE PLANNING

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ABSTRACT: Despite Strategic Environmental Assessment (SEA) is taking place in Brazil, this process is still voluntary and lacks directives that lead it according to the needs and peculiarities of the country. In this study, we aimed to discuss opportunities and challenges to implementing SEA to Brazilian land-use planning process through a wide literature review. SEA can help to hold the land-use planning providing an estimation about the future use of a territory and bringing into account the adjustments that would be necessary to guarantee that sustainable development goals are reached. Multilateral Development Agencies perform an important role to induce SEA to low- and middle-income countries but, by themselves, are unable to lead the SEA process that should be mandatory and regulated by law and conducted by an independent and well-capacitated agency. Despite some Brazilian SEA voluntary experiences, the capacity of the performed SEA in Brazil is considered weak, mostly because of lack of legal obligation, lack of dialogue with other public policies, lack of continuity in political management, and the need for more transparency and better governance. However, Brazil has potential for SEA application in many sectors and that is necessary to adapt this instrument to better attend its demands. We also believe that premises of Regional SEA are the most suitable category of environmental assessment for the Brazilian land-use planning.

Keywords: R-SEA. Spatial planning. Environmental management. Environmental policies.

1 Introduction

Land, according to Rozas-Vásquez et al. (2017), is “one of the most important and limited resources and provides a range of essential ecosystem services for human well-being”. A well-designed land-use planning could be considered, as stated by Sizo et al. (2015), as a “key policy instrument designed to direct future land use and development actions” towards sustainable development. However, the inefficiency or the lack of spatial planning can cause negative impacts related not only to the environment but also to social and economic issues, where strategic actions are necessary.

Mascarenhas et al. (2015) and Rozas-Vásquez et al. (2017) defend that spatial planning is crucial for decision-making process due to the capacity for coordinating human activities and their influences on land systems, which implies in substantial improvement on the quality, quantity, and spatial distribution of ecosystem services. Kazak et al. (2017) complement this statement affirming that the spatial planning needs to confront “the capacity of the environment in regard to the planned use of available environmental resources”, avoiding scarcity of resources and managing impacts that can be avoided, mitigated, or compensated. In an economic approach, Banhalmi-Zakar & Larsen (2015) also stated that if the potential environmental sensitivity of an area is previously known, financial risks could be avoided. Furthermore, a well-designed land-use planning provides “an integral view of future territorial development”, anticipating their efficiency and highlighting necessary future adjustments (Nenkovic-Riznic et al., 2016). To support this planning process arises the Strategic Environmental Assessment (SEA).

According to Gao et al. (2017b), SEA is “a systematic process of evaluating the environmental consequences of a proposed policy, plan or program (PPP) to ensure that the consequences are fully elucidated in order to address them appropriately at the earliest stage possible”. Nadruz et al. (2018)

also affirm that SEA is "an instrument for impact assessment that facilitates both the identification of opportunities and risks of strategic actions to sustainable development".

Fundingsland Tetlow & Hanusch (2012) stated that SEA basically takes place in 60 countries, and Caschili et al. (2014) identified 7,662 publications until 2012 where SEA was applied to fields like water resources, energy and fuels, forest management, biodiversity conservation, planning and development, and urban studies. In practice, Banhalmi-Zakar & Larsen (2015) affirm that SEA has been being applied as an assessment tool internationally in sectors such as agriculture, water, forestry, transport, oil and gas extraction, economic development planning, waste management, flood management, wind power, funding programs, industry, and land-use planning.

In this study, we aimed to discuss opportunities and challenges to implementing SEA to Brazilian land-use planning process through consultation of international experiences reported in the scientific literature.

2 Is there a SEA model that fits any situation?

SEA, according to Nadruz et al. (2018), was adopted by more than 60 countries at different planning levels, supporting the development of policies, programs, and plans. SEA was developed based on a "learning-by-doing approach" that, according to Jones (2018), created "considerable variation in frameworks, methods, and outcomes in attempts to improve the environmental sustainability of development". Regarding its methodological basis, Josimović et al. (2016) claim that their concept is fuzzy rather than precise and highly manageable, relying more on qualitative consideration and techniques than quantitative ones.

Basically, a SEA procedure includes the following steps: I. Screening, II. Scoping, III. Baseline Investigation, IV. Assessment, V. Report, VI.

Approval, VII. Monitoring, and VIII. Follow-up (Gao et al. 2017a). Although the SEA is not a mandatory formal document, a final report can be drawn up and be publicized. De Montis et al. (2016) assert this document should include: I. a description of relevant interactions of the proposal with the environment; II. a diagnose of the environmental components affected by the proposal; III. an evaluation of direct, indirect, cumulative and synergic impacts on the environment; IV. an indication of measures able to mitigate and compensate the impacts; and V. a prevision on the development of the monitoring phase. After the development of the report, Torrieri & Batà (2017) state it is crucial to lead public consultations, to appraise the report and the outcome of the consultations, to make a decision and to inform the interested public, and also to monitor the plan, program or police.

Noble & Nwanekezie (2017) suggested that SEA can be conceptualized as "operating along a spectrum from less to more strategic", being subdivided into two categories:

I. "Impact assessment-based SEA": that seek to appraise initiatives or to assess impacts of PPPs. This category could be divided in "Compliance-based SEA" (that ensures a PPP is in compliance with other policy and political objectives prior to its proposal or implementation), and "EIA-like SEA" (focused on the provision of information about the potential impacts of a proposed PPP and their mitigation); and

II. "Strategy-based SEA": this assessment has emphasis on PPP formulation, identifying and evaluating alternative futures or development intentions incorporated in PPP initiatives, and determining the necessary institutional context, and transformations, to facilitate desirable outcomes. It could be divided in "Strategic futures approach" (where SEA could help to shape or even formulate strategic initiatives or PPPs, particularly within the context of land use policies or plans in resource regions or sectors, usually described as R-SEA), and “strategic transitions approach” (focused on the institutional environment surrounding strategic initiatives and the conditions that either enable, or constraint, their success).

Regarding the SEA authority participation in the proposal appraising, Rega et al. (2018) came up with two different models: the independent (IM) and the subsidiary model (SM). The IM requires an external SEA authority, which adds credibility, impartiality, and efficacy to the process. The SM may lead to “auto-referential assessment” but helps to simplify communication and consultation, which hastens the process. The same scientists suggest that the authority responsible for appraising should be separated and be independent of the planning one, preferably at a higher level in the governance hierarchy. Wide public participation is also key to the success of this process.

The fact is, according to Noble and Nwanekezie (2017), “there is no one conceptualization of SEA that is ‘best’ for all decision contexts; rather, each approach to SEA is necessary and valuable – each serves a different function, and each has its relative strengths and limitations”.

3 How SEA can help land-use planning?

Menendez (2017) guarantees that some intrinsic advantages of SEA are: I. to enable compliance with government guidelines and policies; II. to promote accountability to the public since SEA incorporates public consultation; III. to avoid costly mistakes and missed opportunities by a previous identification of alternatives; IV. to improve government coordination and communication with departments, identifying opportunities for synergy and avoiding conflict areas; V. to establish clear rules for proposers and to improve project-level assessment; and VI. to provide an improved understanding of the cumulative and alternative effects of a wide range of projects and activities. Hegazy (2015) also highlighted some effectiveness factors, where SEA should be: I. directed towards sustainability; II. early involved and integrated with the planning process; III. flexible to better deal with uncertainties inherent to proposed actions; IV. focused on the key strategic issues; V. decision-centered, VI. participatory and transparent; and VI. accountable.

SEA is an extremely important instrument to effectively integrate the environmental issues into a spatial planning due to its capacity to predict environmental risks arising from a range of different projects proposed in the same area, which could reduce or neutralize adverse effects of spatial and sectoral planning (Hegazy, 2015; Banhalmi-Zakar & Larsen, 2015; Nenkovic-Riznic et al., 2016). SEA, according to Torrieri & Batà (2017) "takes into consideration the overall effects of management choices and territorial development using a multidimensional approach", including a participatory decision-making process seeking for a consensus among possible options that could be implemented in some area. Josimović et al. (2015) also stated that SEA considers "the benefits and consequences of the proposed changes in space, also taking into account the capacity of space to sustain the implementation of the planned activities", which is a characteristic greatly desired by spatial planners.

In Serbia, Nenkovic-Riznic et al. (2016) found good results about the integration of SEA into spatial and urban planning since it was possible to evaluate different territorial development options, which improves the quality of life and environment. With the aid of SEA, Indonesia, South Africa, Jamaica, Austria, Czech Republic, Egypt, and Italy government integrated climate change concerns in the spatial planning process, which lead to better management of environmental hazards and disaster risks reducing (Islam & Zhang, 2019). In South Korea, Um et al. (2018) presented an effective use of SEA to improve the waste management system, where important strategies were developed, such as the preservation of landfill area, stabilization, and removal of the hazardous substance in wastes, and optimal treatment for energy and material recovery from wastes.

SEA is more commonly applied in a "sector-based" approach, in other words, focused on solving problems related to a particular sector, such as energy, transportation or mining sector. However, faced with issues directly related to the development of a specific territorial space, regardless of a specific strategic sector, Chen et al. (2018) indicate a distinct SEA category: the Regional Strategic Environmental Assessment (R-SEA), considered a more appropriate approach in order to prevent and to mitigate adverse environmental impacts from the source and on a macro scale. According to Bidstrup et al. (2016), R-SEA (or land-based SEA, or area-based SEA) "has an explicit focus on identifying and evaluating the cumulative effects of a region in scope, and by such it applies wide topical boundaries and focuses on the receiving environment by default". Despite the similarity in the evaluation process, regional and sector-based SEA differ from each other in some characteristics described by Harriman & Noble (2008) and by Gunn & Noble (2009) in Table 1.

Table 1. Characteristics of sector-based and regional strategic environmental assessment

	Sector-based strategic environmental assessment	**Regional strategic environmental assessment**
Typical proponent	Single industry sector or government agency responsible for the sector.	Regional planning or administrative authority; public-private partnership; group of industry partners.
Trigger	Effects of proposed or existing sector-based plans or development initiatives.	Cumulative change or need for regional PPP development or review.
Alternatives considered	Sector development vision or plans.	Region-based alternatives or scenarios driven by broader regional, sustainability, or policy-oriented goals and objectives.
Scope	Stressors and effects of the sector.	Outward-focused, taking into account the combined effects of PPPs, projects, and exogenous factors.
Temporal bounds	Past, present, and planned sector activities.	Past, present, and longer-term futures of regional environments and economies.
Spatial bounds	Boundaries of sector initiatives (e.g. forest harvest area) or by sector-claims (e.g. oil and gas licensing block).	Planning region as defined by natural features such as watersheds or other ecoregions
Sources and pathways of effects	Activities of a single sector, often of a similar type and interacting with other similar sectoral activities or initiatives.	Activities of multiple sectors, often diverse and interacting with other regional activities, PPPs or developments.
Typical cumulative effects assessment questions	What are the potential cumulative impacts of each sector alternative? What are the opportunities and constraints on development?	What are the potential cumulative effects of alternative future scenarios? What are the opportunities and constraints to current and future developments?
Planning orientation	Industry planning and initiative prioritization.	Regional development or environmental management.
Management focus	Select preferred sector-based development strategy; risk reduction; regulate future project development.	Select preferred land use alternatives; enhance sustainability; risk reduction to regional environment; PPP development to manage future land uses.

Source: Adapted from Harriman & Noble (2008) and Gunn & Noble (2009).

About R-SEA methodology, Gunn & Noble (2009) defend that this assessment is based on “multiple criteria, cumulative effects, or broader sustainability objectives”, where there is no need for detailed impact predictions about environmental stressors, but for the identification and assessment of “opportunities, risks and threats of opting for a particular future or development scenario”. They also highlighted that regional context of the assessment allows identifying and addressing “meta-issues that would otherwise be missed through case-by-case project-level assessment, and thus requires an ecosystem perspective – adopting regional units defined by ecological relationships, such as watersheds, rather than political or administrative ones”.

Due to the extensive territorial proportions, high population plurality, and huge biodiversity, we believe R-SEA is the most appropriate assessment instrument to be implemented in Brazilian land-use planning, mainly in order to help regional development.

4 Is SEA regulated by law?

A well-established legal framework could substantially improve SEA application. Recently, same countries released specific legislation about SEA, such as Bulgaria, France, and the UK (2004), Sweden (2005), and Italy and South Korea (2006) (Makaba & Munyati, 2018). In Latin America, Bolivia (Law n. 1,333/1995), Peru (Law n. 28,611/2005 and Legislative Decree n. 1,078/2005) and Chile (Law n. 20,417/2010) established formal requirements of SEA, and Colombia set official methodological documents (Menendez, 2017). In 2015, Kenya’s Environmental Management and Coordination Act/ 1999 was amended to make explicit the mandatory character of SEA in PPP implementation (Walker et al., 2016).

Monteiro et al. (2018) bring some core legal documents about the SEA system:

I. in China: the Law of People Republic of China on Environmental Impact Assessment of 2002, the Plan Environmental Impact Assessment Ordinance of 2009, and the Revised Environmental Protection Law of the People's Republic of China of 2014;

II. in Vietnam: the Law on Environmental Protection no. 52/2005/QH11 2005 (repeal by Law on Environmental Protection no. 55/2014/QH13), the Decree no. 18/2015/ND-CP, and the Circular no. 27/2015/TT-BTNMT;

III. In Portugal: the Decree-Law 232/2007 (amended by Decree-Law 58/2011);

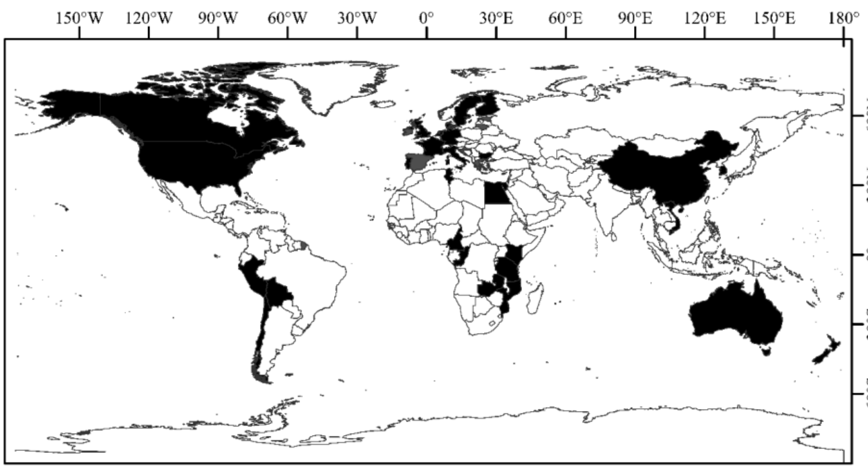
IV. In Denmark: the Executive Order no. 1533/2015, and Law no. 425/2016 (amended by Executive Order no. 448/2017); and

V. In the Netherlands: the Environmental Management Act amended in 2006, and the Environmental Assessment Modernization Bill of 2010.

In Figure 1 we highlighted countries where SEA is regulated in national legislation according to Thérivel & Partidário (2013), Walker et al. (2016), Menendez (2017), Makaba & Munyati (2018), and Monteiro et al. (2018).

In Brazil, the Ministry of the Environment published in 2002 a document bringing general recommendations for the establishment of SEA in the Multiyear Investment Plan, Electric Energy Sector, and Transportation Sector. Besides this effort, Brazilian legislation does not yet regulate SEA. In 2004, Santos & Teixeira (2017) related that SEA was suggested by the Brazilian Court of Auditors in the elaboration of the Multi-Annual Plan and in PPPs planning, through court judgment n. 464/2004.

At present, legislative proposals n. 2072/2003, n. 261/2011, and n. 4,996/2013 were submitted to the Brazilian Chamber of Deputies in order to make SEA one of the instruments of the National Environmental Policy and part of the environmental licensing process. However, SEA is still a voluntary process in Brazil and, usually, encouraged by multilateral development agencies (MDAs).



Australia	Canada	Denmark	Germany	Netherlands	South Korea	United Kingdom
Bolivia	Chile	Egypt	Italy	New Zealand	Sweden	United States
Bulgaria	China	Finland	Kenya	Peru	Tanzania	Vietnam
Cameroon	Congo	France	Mozambique	Portugal	Tunisia	Zambia

Figure 1. Countries where SEA is regulated by law (in gray we highlight countries belonging to the European Union that follow Directive 2001/42/EC but no information on specific national legislation were found).

5 Should multilateral development agencies lead the SEA process?

Multilateral Development Agencies (MDAs), in line with Tshibangu & Montaño (2016), are carrying the load SEA utilization in low- and middle-income countries. Josimović et al. (2015) also affirm that the number of international financial institutions that developed instruments and imposed requirements for the implementation of the SEA is getting bigger. Until 2015, Banhalmi-Zakar & Larsen (2015) reported that 78 financial institutions are operating in 35 countries based on equator principles (a risk management framework). But, how can SEA be advantageous for MDAs?

According to Banhalmi-Zakar & Larsen (2015), SEA provides “insights into the environmental risks for sectors which banks can utilize to identify target, restricted or excluded sectors and can incorporate into their credit policies”. These researchers categorized environmental risks in four categories:

I. direct risk: “when banks become directly liable for cleaning up contamination on a site taken over when the borrower defaults on the loan”;

II. indirect risk: “when a borrower’s ability to repay a loan is hindered as a result of environmental issues, such as when a borrower incurs costs to upgrade existing facilities to meet more stringent environmental standards”;

III. reputational risks: “when a lending institution is perceived in a negative light because the project is perceived to have a harmful effect on the environment and society”; and

IV. regulatory risk: “risk of non-approval by the relevant authorities (environmental or other development authorities)”.

Banhalmi-Zakar & Larsen (2015) affirm “SEA can identify possible and significant environmental impacts likely to result from PPPs and can be used to provide facts about the environmental risks connected to them”. The same researchers also suggest that SEA can provide information for MDAs about “environmental risks that stem from the potential impact of projects” (indirect risk) and “can indicate possible public controversy over proposed projects” (reputational risk exposure).

It is clear that the reputational risk of a project could be the main force for loan approval. In such a way, SEA could help MDAs to “identify not only the nature of potential opposition but also the groups (e.g. NGOs) that oppose PPPs and ensure that their concerns have been dealt with adequately by clients and regulators” (Banhalmi-Zakar & Larsen, 2015). SEA also could help with regulatory risk issues, since a well-established legal and institutional framework gives investors more security, guaranteeing the viability of projects, and also avoiding delays on execution.

In Brazil and in several other developing countries, the “main driving forces in the process of discussing, training and fostering practical experiences of SEA” is performed by the World Bank and the Inter-American Development Bank (Pellin et al., 2011). The MDAs act financing sectoral programs and projects, and advising activities, technical assistance, training and the insertion of concepts of SEA (Pellin et al., 2011). However, the same researchers affirm that SEA encouraged by these MDAs has a non-strategic nature since it has been used in a later stage of the decision-making process in order to present a “more comprehensive view of the social and environmental benefits, impacts and risks of individual projects, rather than PPPs”.

Besides the main objective is based on the economic security of the external investments, the MDAs has an important role in sustainability. However, a strict legal framework is key to guarantee that social and environmental issues will be considered equally. MDAs and international practice could help the Brazilian government to develop an effective SEA guidance guaranteeing that strategic thought leads the environmental licensing process.

6 Should Brazilians be concerned about any aspect of the SEA process?

As reported by Say & Okten (2017), SEA is quite a new and still-developing tool with a large scope, few practical studies in some fields – which demands new application methods and models, it has differences in administrative structures for planning and decision making in different countries, and differences in legal processing. For these reasons, SEA has been currently questioned about its effectiveness and about its value by planners and decision makers (Li et al., 2016).

In Portugal, Polido & Ramos (2015) detected “there is no evidence that scoping starts early in the decision-making process, or if it is done concurrently”. Kazak et al. (2017), citing the 2012 SEA Effectiveness Review Report prepared by the Irish Environmental Protection Agency, stated that the consideration of alternatives has not been being effective on SEA process. In Germany, Rehhausen et al. (2018) found that the alternatives assessment has been being restricted to macro-siting instead of “assessing scenarios of demand or system alternatives”. In Namibia, SEA failed to address alternatives to PPP assessed (Hipondoka et al., 2016), and in Botswana, the identification and formulation of alternatives to PPP have been carried out with “little rigor” (Makaba & Munyati, 2018). In Ecuador, Menendez (2017) defends that “a reasonable range of alternatives must be evaluated, as well as non-approval”.

About cumulative effects assessment, Rehhausen et al. (2018) reported that SEA is “limited to intra-plan effects” in Germany, and “follows a plan/program perspective instead of applying a resource/receptor-based perspective”. In Namibia, SEA struggle with addressing cumulative effects of the PPPs, paying “limited attention to synergies or antagonisms” (Hipondoka et al., 2016). In Kenia, Walker et al. (2016) highlighted as SEA main problems the “lack of direction on how to assess cumulative effects or to deliver the education component when engaging the public”. In Egypt, Hegazy (2015) affirms “there is no assessment of the possible future conditions of the sites based on different development scenarios”. Torretta & Capodaglio (2017) also stated that it is almost mandatory the definition of “specific standards and parameters in the presence of activities that may present risks of relevant accidents”.

De Montis et al. (2016) defends that SEA implementation quality depends on “a series of concerns including general context, impact definition, and follow up”. Makaba & Munyati (2018) stated there is a lack of “real fieldwork to determine baseline environmental conditions” in South Africa, witch possible is a struggle to many other countries. They also pointed out the "low technical quality in formulating sustainability measures as mitigation for the PPPs". In Bangladesh, Islam e Zhang (2019) inform there is a "lack of a requirement for short-, medium- or long-term development planning in addition to spatial planning".

Phylip-Jones & Fischer (2015) point out that impact prediction and mitigation are the weakest stages in UK and Germany wind energy sector. Rehhausen et al. (2018) and Makaba & Munyati (2018) reported a lack of real monitoring and auditing PPP implementation and Kazak et al. (2017) affirmed this is one of the weakest stages of the SEA in Ireland. In the Brazilian transportation sector, Rizzo et al. (2017) highlighted inexistence or non-transparency of this stage.

Regarding public participation on SEA, Hipondoka et al. (2016) reported inadequacy in Namibia, Makaba & Munyati (2018) detected low public participation in the scoping stage in Botswana, Polido & Ramos (2015) stated that it is an often discarded stage in Portugal, Menendez (2017) highlighted a need for effective transparency and citizen participation in Ecuador, and Rehhausen et al. (2018) stated that public participation is strict to consultation on the environmental report in Germany. In Bolivia, Santi et al. (2018) affirmed that the scarcity of political will, the lack of information available to the affected population and the weakness of the legislative framework are the most limiting factor for public involvement. Analyzing experiences from different countries, Rega & Baldizzone (2015) found that the main impeding factors for public participation on SEA are "lack of political willingness by proponents, insufficient information on the SEA process by the public, and weakness of the legal frames". They also suggested that public involvement has positive influences on SEA and on decision-making, mainly when supported be legal frames.

In the decision-making stage, Menendez (2017) defends that SEA should be "initiated along with the PPP planning process" and be "prior to the decision making" in Ecuador. Kazak et al. (2017) pointed out a weakness about "informed decision-making" in Ireland. Hipondoka et al. (2016) detected some influence of SEA on decision-making in Namibia, but that could be improved. In Brazil, Rizzo et al. (2017) mentioned deficiencies in "publicity of SEA results of decision-making".

Regardless of SEA stages, most issues observed in literature was related to legal and institutional framework. In Bangladesh, Islam e Zhang (2019) defend that SEA must be mandatory for "all development planning at the national, regional and local levels". In Ecuador, Menendez (2017) also defended the integration of existing policies or structures in the SEA process. In Egypt, Hegazy (2015) defends that a SEA legal framework SEA could be "easily shaped to be applicable to different sectors including spatial planning sector" and could provide "a minimum regulatory context or a more prescriptive set of procedures", which could help to create "basic SEA requirements and standards that can be implemented more effectively".

Makaba & Munyati (2018) affirms that "without legislation that makes SEA mandatory for PPPs, SEA becomes voluntary rather than a legal requirement", which could result in ineffective environmental management. In Brazil, where SEA is not a legal requirement, Nadruz et al. (2018) reinforce there is a need for a legal framework to define clear objectives and procedures for SEA, and Rizzo et al. (2017) affirm the performance of the SEA studies is basically related to requests from funding institutions, which prevents the verification of their influence in decision making.

About institutional framework, in Swedish municipal planning, Balfors et al. (2018) attested that there is an "uneven distribution of knowledge among practitioners on SEA processes and SEA regulations", a lack of municipal resources, and technical difficulties as determining the significance of some impacts. Hipondoka et al. (2016) reiterate the need to strengthen institutional and human capacity to sustain SEA in Namibia, and Islam e Zhang (2019) the need for “policy formulation, transparency, capacity building, gaps in data, information and research, funding, institutional frameworks and coordination” in Bangladesh.

In Lombardy Region, Italy, Torretta & Capodaglio (2017) highlighted issues about “the definition of players and stakeholders, variations and differences of the applied techniques, debatable role of both the public administration and the public, and varying costs of the procedure”. In Ecuador, Menendez (2017) insist that government must provide economic resources to train officials, to keep a specialized team, and to afford expenses of SEA process, including Makaba & Munyati (2018) complement this statement affirming that the low technical standards of various stages of SEA is directly related to the “lack of a central coordinating agency with trained and dedicated staff”. There is also a need to better assign task and action in each hierarchical level because, as set by De Montis et al. (2016), the institutional frameworks and procedures of each administrative hierarchical level are different, since “regional administrations address broad strategies over usually wide areas, while municipal bodies are responsible for detailed and operative plans concerning specific actions, areas, and communities”. In China, Li et al. (2016) also pointed out the lack of cooperation between different sectors as an administrative obstacle to the implementation of SEA.

Monteiro & Partidário (2017) argue that governance is “an essential dimension in SEA to enable sustainability”, since:

> 1) it allows the consideration of a wide range of perspectives and understandings in complex systems, positioning governance at the heart of the strategy itself;

> 2) it enables focusing on what is critical and what are root causes when addressing the policy and societal challenges; and
> 3) it provides the capacity to choose and learn when dealing with intended strategies (goal-rational oriented), with deliberative strategies (contextual-oriented) and with emergent strategies (learning oriented) in contexts of high interaction.

Aligned with the issues aforementioned, Rehhausen et al. (2018) mentioned that the main reasons for limitations in Germany SEA process are “prior policy-making, institutional settings, the institutions' (un)willingness to learn and limited quality assurance” by environmental agencies.

Monteiro et al. (2018) suggest that SEA could be not effective when a country just absorbs an imported model of SEA without “having installed capacities for practical implementation”. In Kenia, Walker et al. (2016) defend that training the competent agents, guaranteeing public education, early applying SEA to PPPs, and enhancing transparency will contribute to “the further evolution and strengthening of the national framework and practice”. In order to make SEA more effective in Botswana, Makaba & Munyati (2018) recommend reinforcing the institutional framework and increasing awareness of SEA, making SEA a legal requirement, training professionals from environmental agencies and other government departments, strengthening public participation, and including SEA in the strategies to achieve the commitments to international environmental conventions and protocols. Park et al. (2015) also highlighted that SEA awakens awareness of how to deal with negative public opinion before the implementation of a project, which encourages planners to seek more sustainable options.

7 Can SEA replace project-based environmental impact assessment?

The SEA process tries to overcome limitations of project-based EIA, including the need to consider “potential environmental impacts at earlier stages of decision making, to resolve longstanding concerns about how EIA approached cumulative environmental effects, and to set a better direction for project-level approval processes" (Noble & Nwanekezie, 2017). According to Makaba & Munyati (2018) and Hegazy (2015), some of the deficiencies of individual projects environmental impact assessment (EIA) "can only be remedied by extending the environmental assessment to earlier stages of the planning process", where SEA could help to streamline and strengthen the EIA.

As stated by Thérivel & Partidário (2013), EIA commonly "reacts to development proposals rather than proactively anticipating them", while SEA could act when strategic decisions are needed, addressing a broad range of alternatives and mitigation measures. The same researchers also stated that EIA ignores:

I. the additive effects of many small projects or management schemes that do not require EIA" (e.g. agricultural management schemes);
II. induced impacts, where one project stimulates other development;
III. synergistic impacts, where the impact of several projects exceed the sum of their individual impacts; and
IV. global impacts (e.g. biodiversity and greenhouse gas emissions).

Conforming to Bodde et al. (2018), EIA has focused on project approval and environmental licensing while SEA is "used by decision-makers, stakeholders, and environmental experts to develop, review", and discuss PPP options. The same researchers defend that "most environmental gains can be achieved at the strategic policy-making and planning phases" instead of project-level assessment. SEA provides greater flexibility and addresses large-scale and cumulative effects that are not addressed by project-focused EIA (Jones, 2018). SEA also "has long-term objectives, has uncertainty in its decision alternatives, and presents itself in a cyclical and continuous way, being ideal for the development of PPPs" (Santos & Teixeira, 2017).

According to Sánchez (2017), even the best project-focused EIA has struggled with deeply analyzing technological and locational alternatives and properly identifying indirect, cumulative, and synergistic impacts that require coordinated government action or even new laws and institutions. Hoffmann & Cardoso Junior (2018) suggest SEA must run in parallel to the preparation of the PPP ensuring that the environmental issues are prudently evaluated before the project-level planning while EIA should refine the project proposals that already meet the SEA parameters.

8 How is SEA being applied in Brazil?

In Brazil, according to Santos & Teixeira (2017), the application of sector-based SEA is more common, mainly in infrastructure sectors, with emphasis on the transportation, urban planning, and tourism sectors. Sánchez (2017) stated that the difficulty of environmental licensing of large projects, such as a set of hydroelectric that would be placed in the same river basin, was “a clear driver of the SEA in Brazil”. Nadruz et al. (2018) presented 35 SEA reports developed between 1997 and 2014 categorized into four planning categories, according to table 2: energy planning (1-11); regional development planning (12-19); transport planning (20-29); and tourism planning (30-35).

Table 2. Brazilian SEA reports developed between 1997 and 2014 grouped by sectors: energy planning (1-11); regional development planning (12-19); transport planning (20-29); and tourism planning (30-35). Source: Nadruz et al. (2018).

Strategic Environmental Assessment reports - Brazilian states	**Year**
1. Brazil-Bolivia Gas Pipeline (Mato Grosso do Sul, São Paulo, Paraná, Santa Catarina, Rio Grande do Sul)	1997
2. Chopim river basin (Paraná)	2002
3. Areia river basin (Paraná)	2002
4. Oil & Natural Gas Sector (Bahia)	2003
5. Northwest of Minas Gerais Rural Electrification Program (Minas Gerais)	2005
6. Verde river basin (Mato Grosso do Sul)	2007
7. Minas Gerais hydropower generation program (Minas Gerais)	2007
8. Petrobras Investment Program in Guanabara Bay (Rio de Janeiro)	2009
9. Turvo river basin (São Paulo)	2009
10. Planning of the Port, Industrial, Naval Offshore Dimension in the Sao Paulo Coast (São Paulo)	2010
11. Expansion Plans of Eucalyptus Forestry and Biofuel in the Extreme South of Bahia (Bahia)	2010
12. Portfolio of National Axes - Ministry of Planning (many states of Brazil)	2003
13. Social and Environmental Program of the Manaus Igarapés (Amazonas)	2004
14. Sustainable Development Program for the Sergipe Semi-Arid (Sergipe)	2005
15 Program for Improvement of the Urban Environmental Quality of Amapá (Amapá)	2006
16. Alto Paraguai river basin development (Mato Grosso e Mato Grosso dos Sul)	2008
17. Corumbá Mining-Industrial Pole and Influences on the Pantanal Plain (Mato Grosso do Sul)	2008
18. Development Industrial Plan for Espírito Santo (Espírito Santo)	2008
19. Conservation and Sustainable Management Planning for the Caatinga Biome (Ceará)	2010
20. Transportation Program by IDB II, 1st phase (Paraná)	2002
21. Roaring Program Mário Covas (São Paulo)	2004
22. Accessibility Program for Small-Scale Municipalities with Low Human Development by IDB (Minas Gerais)	2005
23. São Paulo Road Recovery Program (São Paulo)	2005

Table 2. (…)

Strategic Environmental Assessment reports - Brazilian states	**Year**
24. Minas Gerais Road Program (Minas Gerais)	2007
25. Integrated Brasilia Transport Program (Distrito Federal)	2007
26. Açu Industrial and Port Complex (Rio de Janeiro)	2009
27. Multimodal Transport and Mineral-Industrial Development Program of the Cacao Region (Bahia)	2010
28. Metropolitan Arch of Rio de Janeiro (Rio de Janeiro)	2010
29. Regional Integrated Development Plan for the Capricorn axis bioceanic corridor (some states)	2011
30. North Coast Tourism Development Program (Ceará, Maranhão e Piauí)	2007
31. Tourist Poles of the State of Rio de Janeiro (Litoral area) (Rio de Janeiro)	2011
32. Tourist Poles of the State of Rio de Janeiro (Mountain area) (Rio de Janeiro)	2011
33. Plan for the Integrated Development of Sustainable Tourism (Rio Grande do Norte)	2011
34. Regional Tourism Development Programs of Campo Grande area (Mato Grosso do Sul)	2014
35. Regional Tourism Development Programs of Serra da Bodoquema area (Mato Grosso do Sul)	2014

Recent studies ensure the possibility of using SEA in Brazil in areas such as the energy sector (Tshibangu & Montaño, 2016; Andrade & Santos, 2015), the transportation sector (Rizzo et al., 2017), river basin management (Avila et al., 2018), climate change policies and sectoral/regional planning (Nadruz et al., 2018), sugarcane expansion planning (Gallardo et al., 2016), and decision making about transgenic crops (Pizella & Souza, 2015).

Despite the aforementioned experiences, Sánchez (2017) called into question the capacity of the performed SEA in Brazil to actually influence the decision-making. This researcher affirms that academic research and industrialist's perception points out the "total inefficiency of SEA as practiced in Brazil". The most important factors pointed out by him for this failure was the lack of legal obligation, the lack of dialogue with other public policies, and the need for more transparency and better governance. Hoffmann & Cardoso Junior (2018) also affirms that the subjectivity of the political planning processes in Brazil directly affects SEA, as well as the lack of continuity in political management.

The performance of SEA in Brazil is, basically, related to requests from funding institutions (Rizzo et al., 2017), which often limits strategic thinking to the initial stages of planning, since sectoral intent has already been established. Apart from SEA is being started after relevant decisions, Tshibangu & Montaño (2016) affirm that SEA is being applied to actions without a clear definition of strategic dimensions, and also lacks a systematic assessment of alternatives. The same researchers indicate a "poor quality in baseline description, development, and assessment of alternatives and public participation" of SEA reports.

Sánchez (2017) mentioned that SEA should not be limited to PPPs in economic sectors, "but rather aimed primarily at public policies whose social and environmental consequences are barely known or largely ignored, such as macroeconomic policies". Hoffmann & Cardoso Junior (2018) claim that is necessary the articulation of public, private and society bodies in order to re-create the current model of SEA and make it more coherent and sustainable.

9 Final Considerations

Strategic Environmental Assessment (SEA) can help to held the land-use planning providing an estimation about the future use of a territory and bringing into account the adjustments that would be necessary to guarantee that sustainable development goals are reached.

There is no model of SEA that fits perfectly to any situation, what is not really something desired since SEA has to be flexible to better deal with uncertainties inherent to politics, programs or plans (PPPs) proposed.

Despite the important role of Multilateral Development Agencies (MDAs) in inducing SEA to, mostly, low- and middle-income co.untries, MDAs should not lead the SEA process. Researchers such as Hegazy (2015), Sánchez (2017), Menendez (2017), Rizzo et al. (2017), Makaba & Munyati (2018), Nadruz et al. (2018), and Islam e Zhang (2019), defend that SEA should be mandatory and regulated by law and conducted by an independent and well-capacitated agency

The most critical concerns about SEA for Brazilian taking to account in order to prepare a SEA guidance are: I. to present a reasonable range of alternatives, including the non-approval alternative for PPPs; II. to assess properly indirect, cumulative, and synergic impacts; III. to estimate possible future conditions of an area based on different development scenarios; IV. to define strategies for mitigation, compensation, and monitoring the impacts of PPPs; V. to guarantee widely public participation in all stages of SEA process; and VI. to reinforce the legal and the institutional framework to ensure the quality of the SEA information that should be taken to account in decision-making, which also help investors to deal with reputational risk and the risk of non-approval of a project.

Despite the 35 Brazilian SEA experiences presented by Nadruz et al. (2018), the capacity of the performed SEA in Brazil is considered weak, mostly because of the lack of legal obligation, lack of dialogue with other public policies, lack of continuity in political management, and the need for more transparency and better governance (Sánchez, 2017 and Hoffmann & Cardoso Junior, 2018). However, we defend that Brazil has potential for SEA application in many sectors and that is necessary to adapt this instrument to better attend Brazilian demands. We also believe that premises of Regional Strategic Environmental Assessment (R-SEA) are the most suitable category of environmental assessment for the Brazilian land-use planning.

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PAPER N. 2 – MULTI-CRITERIA MODEL FOR DIAGNOSIS STAGE ON REGIONAL STRATEGIC ENVIRONMENTAL ASSESSMENT OF DOCE RIVER BASIN

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ABSTRACT: Multi-criteria decision aid (MCDA) methods are often recommended to support the decision-making process for being able to point out multiple alternatives of development accessing sustainability indicators, characteristic extremely desirable to Regional Strategic Environmental Assessment (R-SEA). The aim of this paper was to propose a MCDA method based on indicators of sustainability to support the diagnosis stage of R-SEA of a watershed, more precisely, Doce river basin. Through Cluster and Redundancy Analysis we selected 32 of 60 indicators provided by Minas Gerais' environmental agency, that was classified in 5 levels quality degree, from very precarious to very favorable. Then we performed a Principal Components Analysis (PCA) and we used the scores of each indicator on the first axes of the PCA graphic to to build the vulnerability index for Doce river basin. DO4 and DO1 were the Unis of Planning and Monitoring of Water Resources considered less vulnerable, and DO5 was the most vulnerable area (among 14% of vulnerability). Overall, 6.6% of Doce river basin area was considered vulnerable, 62.6% average, 29.5% adequate, and 1.4% very adequate. The proposed method was considered adequate to spatial planning and it can be

adapted to any location or even sector where there is a need for a more strategic assessment.

Keywords: SEA. Spatial planning. Environmental management. Environmental policies.

1. Introduction

A well-designed land-use planning (including urban planning and development zoning) is considered by Sizo et al. (2015) as a "key policy instrument designed to direct future land use and development actions" of a region. However, to achieve this goal, Park et al. (2015) defend that is fundamental to reach a strategic approach towards the sustainable development that includes "consideration of environmental effects from the earliest stages of decision-making", including policy, plan, programs (PPPs) and Strategic Environmental Assessments (SEAs).

SEA is a preventive and participatory instrument designed to integrate the appropriate considerations into the decision-making process during the adoption and the implementation of specific PPPs (Li et al. 2016; and Torretta & Capodaglio, 2017). As stated by Torrieri & Batà (2017), SEA "takes into consideration the overall effects of management choices and territorial development using a multidimensional approach", including a "participatory decision-making process to protect legitimate interests and the creation of the conditions for consensus among stakeholders on actions to be implemented in a territory", considering also the interests of local population.

In order to evaluate the potential effects of strategic initiatives in a particular region, Gunn & Noble (2009) brought the concept of "Regional Strategic Environmental Assessment" (R-SEA). R-SEA, according to Chen et al. (2018) is "an effective method for both preventing and mitigating the adverse environmental impacts of human activities from the source and on a macro scale, thereby achieving sustainable development".

R-SEA could be applied to different levels of government competence: local, regional, national, or even international, and in different decisional levels (De Montis et al. 2016). At the highest level, SEA is used to focus on the valuation of policies according to a multisector approach involving economic, social, and environmental themes. At the intermediate level, programs and plans are subject to SEA. At the low level, SEA is useful to improve the performance of Environment Impact Assessment (EIA) of projects, as well as to analyze cumulative impacts of a group of companies of the same sector or placed in the same area, such as a river basin.

Regarding the SEA methodologies, Josimovic et al. (2016) affirm that they are not precise and highly operable; actually, they are quite fuzzy. There is no generalized SEA methodology because, in fact, SEA needs to be flexible to better deal with uncertainties inherent to the proposed PPPs. According to Noble & Nwanekezie (2017) "each approach to SEA is necessary and valuable – each serves a different function, and each has its relative strengths and limitations".

Multi-criteria decision aid (MCDA) methods are often recommended to support the decision-making process for being able to point out multiple alternatives of development accessing environment and socioeconomic indicators (Josimovic et al., 2015). According to Kim et al. (2015), MCDA is "one of the most flexible techniques that can be used to consider different kinds of impacts of a PPP", although just few studies have been applying it to SEA, such as: the waste management plan of Belgrade city, in Serbia (Josimovic et al., 2015); a long-term plan for dam construction in South Korea (Kim et al., 2015; and Park et al. 2015); a airport expansion plan of Tivat, in Montenegro (Josimovic et al., 2016); the urban plan of Marzano di Nola city, Italy (Torrieri

& Batà, 2017); and the land-use planning of Grande river basin, in Brazil (Ávila et al., 2018).

The use of a MCDA method to support the R-SEA process could help to “confront the capacity of the environment in regard to the planned use of available environmental resources” (Kazak et al., 2017). According to the same researchers, despite SEA lean more on qualitative consideration and techniques than a project-based EIA, the use of sustainability indicators could allow the quantification of states, processes, and phenomena, making SEA more objective.

The aim of this paper was to propose a multi-criteria decision aid (MCDA) method based on indicators of sustainability to support the diagnosis stage of the Regional Strategic Environmental Assessment (R-SEA) of a river basin, more precisely, the Doce river basin.

2. Methodology

2.1 Study area characterization

The Doce River Basin has a drainage area of 86,715 km^2, of which 86% are in the eastern part of Minas Gerais state and 14% in the northeast of Espírito Santo state, in Brazil, formed by the main watercourses Suaçuí Grande, Manhuaçu, and Doce River (Figure 1). Our focus in this paper was Minas Gerais portion of Doce River Basin.

The Doce river has 879 km of extension and its springs are in Minas, in the Sierras of Mantiqueira and Espinhaço. The relief of the basin is wavy, hilly and rugged. The Atlantic Forest biome covers 98% of its area, one of the most important and threatened in the world, and the remaining 2% are from Brazilian Savanna (Cerrado) biome (Doce River Basin Committee, 2019).

It is estimated that the population of Doce Basin is around 3.5 million inhabitants distributed in 228 municipalities (200 in Minas Gerais and 28 in Espírito Santo state). More than 85% of these municipalities have up to 20 thousand inhabitants and about 73% of the total population of the basin is concentrated in the urban area biome (Doce River Basin Committee, 2019).

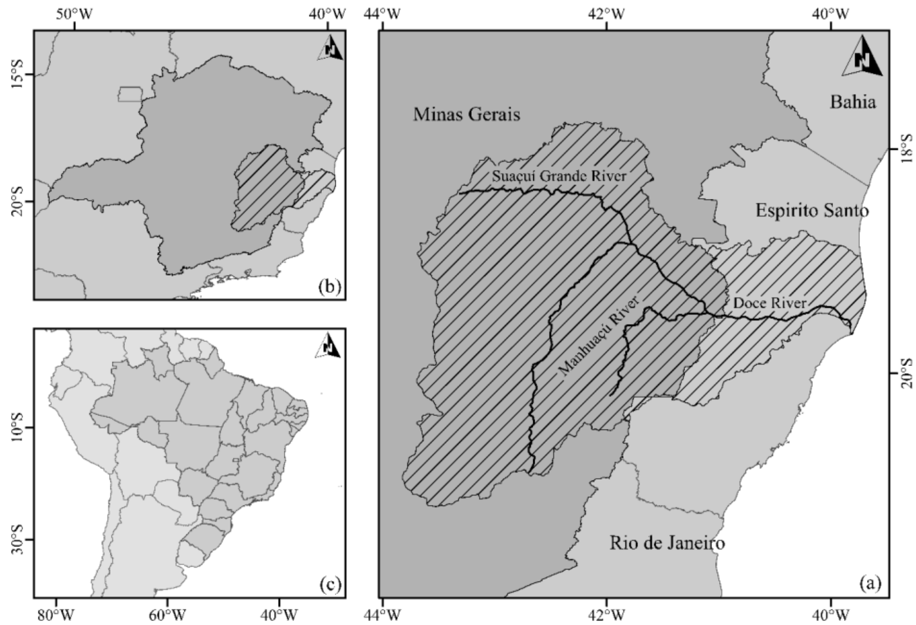


Figure 1. Location map of (a) Doce River Basin in (b) Minas Gerais and Espírito Santo states, (c) Brazil.

In November 5, 2015 Doce river basin was severely impacted by the rupture of Samarco's tailing dam (company formed by the partnership between Vale and BHP Billiton Brasil) in Mariana city, which promoted the transport of 50 million m³ of iron ore tailings along more than 500 km in the basin, affecting both states (Brazil, 2016).

From 2013 to 2017, Minas Gerais environmental agency (Secretary of State for Environment and Sustainable Development) licensed 201 potentially polluting activities, where 28% represents mining activities, 19% infrastructure activities, 15% food industry, 13% services and wholesale trade, 11% chemical industry, 7% agroforestry activities, and 7% metallurgical industry and others.

These activities are distributed according to Figure 2 and they are specified in Supplementary Material 1.

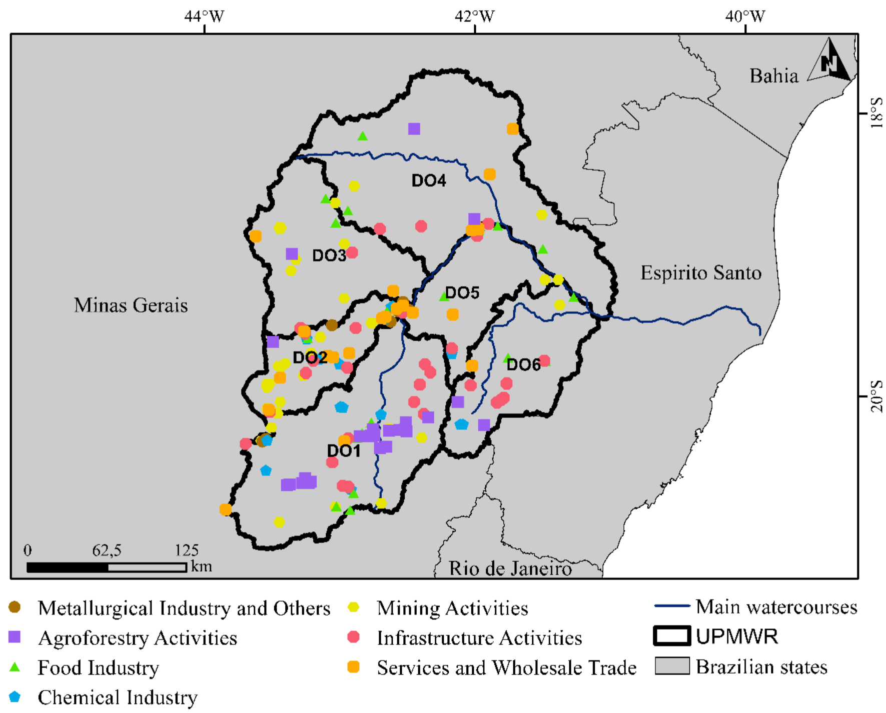


Figure 2. Location of the activities licensed by Minas Gerais environmental agency from 2013 to 2017 grouped by activity category in each Unit of Planning and Monitoring of Water Resources in Doce river basin (DO1 to DO6).

2.2 Methodology

We characterized the study area using 60 indicators provided by the Secretary of Minas Gerais State for Environment and Sustainable Development (Table 1). The database is derived from the Spatial Data Infrastructure of the State System of Environment and Water Resources. Each indicator was classified according to a quality degree as very precarious (1), precarious (2), average (3), favorable (4), very favorable (5), or not specified (0). Each indicator was represented by shapefiles (polygons) that we transformed into raster format. We extracted information from all pixels of the Doce river basin's rasters through 49,469 georeferenced points. We placed the information from each indicator in a spreadsheet (matrix) where the rows represent the coordinates of each Doce river basin's pixel and the columns represent each indicator's classification.

Through the indicators matrix, we performed a Cluster analysis using the script on Supplementary Material 2 on R computational environment. By the results of Cluster analysis we build a dendrogram on R (Figure 3) allowing us to partition the data into clusters (Table 1) after analyzing the graphic of stability of partitions (Figure 4), also built on R. In order to reduce collinearity, we chose in each cluster just the indicator with higher squared loading and higher correlation, according to Supplementary Material 5.

After the Cluster analysis, we performed a Redundancy analysis (RDA) using a R script detailed in Supplementary Material 3 also in order to reduce collinearity. With the scores of each indicator on the first and second axes of RDA graphic (Figure 5), we could remove four indicators that present collinearity, allowing us to reduce our database (Table 1).

By the 32 indicators selected through Cluster analysis and RDA, we performed a Principal Components Analysis (PCA) through the R script described on Supplementary Material 4. With the scores of each indicator on the first axes of the PCA graphic (Figure 6), we relativize the importance of each indicator in percentage to build the vulnerability index for Doce river basin (Equation 1), based on MCDA.

Equation 1. $$\text{Vulnerability Index} = \sum_{\text{indicator}=1}^{32} (\text{score}_{\text{indicator}} \times \text{quality degree}_{\text{indicator}})$$

By the Vulnerability Index results for each indicator, we plot a map on ArcMap 10.3 where each pixel of Doce river basin represent the vulnerability of the area (Figure 7).

Table 1. List of sustainability indicators considered to the characterization of Doce River Basin and selected indicators after Cluster Analysis (CA) and after Redundancy Analysis (RDA).

Indicators	**Code**	**CA**	**RDA**
1 Geobiophysical and Biotic component			
1.1 Flora			
Conservation Degree of Native Vegetation	CDNV	X	
Spatial heterogeneity of phytophysiognomies	SHPH	X	X
Priority for Flora Conservation	PFLC		
Integrity of Flora	IFL	X	X
1.2 Fauna			
Priority for Herpetofauna Conservation	PHEC		
Priority for Avifauna Conservation	PAVC	X	X
Priority for Ichthyofauna Conservation	PICC	X	X
Priority for Invertebrates Conservation	PINC	X	X
Priority for Mastofauna Conservation	PMFC		
Integrity of Fauna	IFA	X	X
1.3 Water resources			
Natural Availability of Groundwater	NAGW	X	X
Natural Availability of Surface Water	NASW	X	X
Potential Contamination of Aquifers	PCAQ	X	X
1.4 Soil			
Probability of Environmental Contamination by Land Use	PECLU		
Potential Erosion Risk	PER		
Susceptibility of Soil Structural Degradation	SSSD	X	X
Decomposition Rate of Organic Soil Material	DROSM		
Erodibility	ERO	X	X
Current Erosion	CERO	X	X
Solo Exhibition	SOE	X	X
2 Economic Component			
2.1 Infrastructure			
Density of the Railroad Network	DRAN		

Table 1. (…)

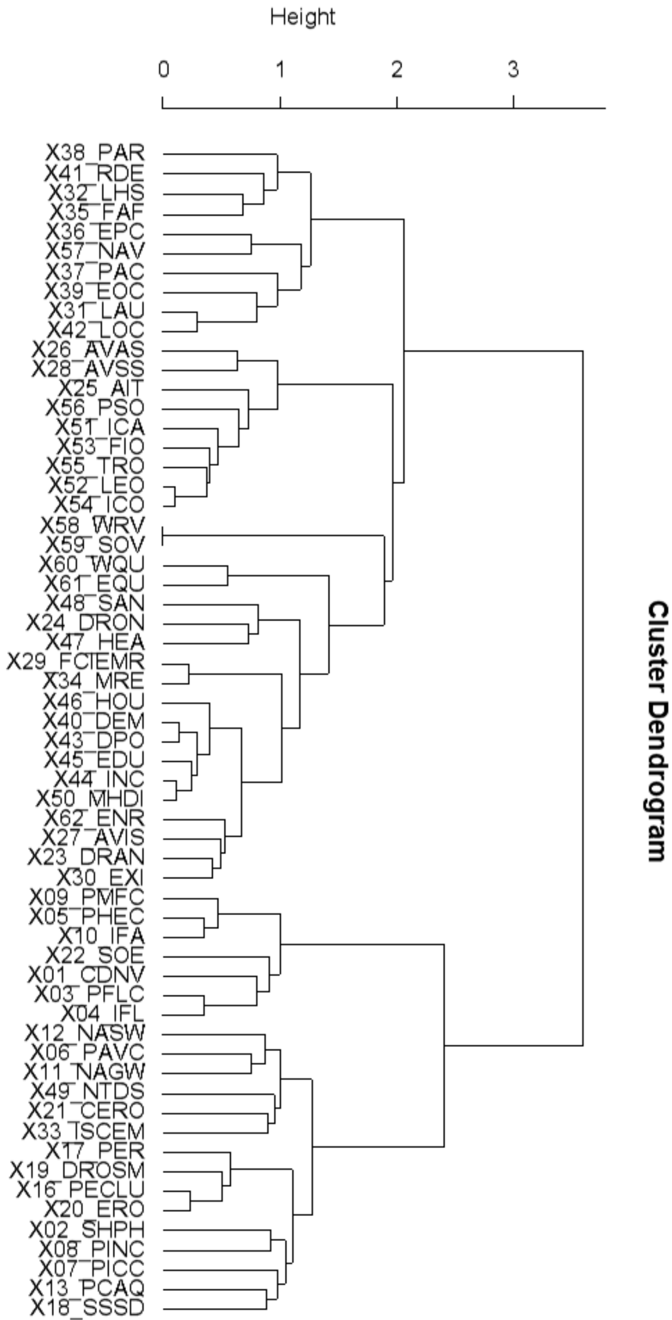
Indicators	**Code**	**CA**	**RDA**
Density of the Road Network	DRON	X	X
Air Transport	AIT	X	X
2.2 Economic Activities			
Added Value of the Agricultural Sector	AVAS	X	X
Added Value of the Industrial Sector	AVIS		
Added Value Of Service Sector	AVSS		
Financial Compensation Index for Exploration of Mineral Resources	FCIEMR		
Exportation Index	EXI	X	
3 Natural Component (In Social Potentiality)			
Land Use	LAU		
Land Holding Structure	LHS	X	X
Index of Sugar Cane and Eucalyptus Monoculture	ISCEM	X	X
Mineral resources	MRE	X	X
Family Farming	FAF	X	X
Eucalyptus Production Capacity	EPC	X	
Priority Areas for Conservation	PAC	X	X
Priority Areas for Recovery	PAR	X	X
4 Human Component			
Economic Occupation	EOC	X	X
Demography	DEM		
Rural Development	RDE	X	X
Land Occupation	LOC	X	X
Distribution Population	DPO		
Income	INC	X	X
Education	EDU		
Housing	HOU		
Health	HEA	X	X
Sanitation	SAN	X	
Need to Treat Domestic Sewage	NTDS	X	X

Table 1. (…)

Indicators	**Code**	**CA**	**RDA**
Municipal Human Development Index	MHDI		
5 Institutional Component			
Institutional Capacity	ICA		
Legal Organizations	LEO	X	X
Financial Organizations	FIO		
Inspection and Control Organizations	ICO		
Teaching and Research Organizations	TRO		
Public Safety Organizations	PSO		
6 Vulnerability Indicators			
Natural Vulnerability	NAV	X	X
Water Resources Vulnerability	WRV	X	X
Soil Vulnerability	SOV		
7 Quality Indicators			
Water quality	WQU		
Environmental Quality	EQU	X	X
Environmental Risk	ENR		

3. Results and Discussion

Through the dendrogram (Figure 3) provided by the Cluster analysis and through the stability of partitions graphic (Figure 4) we could reduce the collinearity of the database removing 24 indicators (Supplementary Material 5). By the scores from the first and second axes from RDA (Figure 5) we also reduce the collinearity of the database removing more four indicators, which allowed us to work with 32 indicators (Table 1). A PCA was performed using the 32 indicators, and the scores obtained on the first axe (Figure 6 and Table 2) were used to build the Vulnerability Index of Doce river basin, plotted in a map represented by Figure 7.


Height
0
1
2
3
Cluster Dendrogram
X38_PAR
X41_RDE
X32_LHS
X35_FAF
X36_EPC
X57_NAV
X37_PAC
X39_EOC
X31_LAU
X42_LOC
X26_AVAS
X28_AVSS
X25_AIT
X56_PSO
X51_ICA
X53_FIO
X55_TRO
X52_LEO
X54_ICO
X58_WRV
X59_SOV
X60_WQU
X61_EQU
X48_SAN
X24_DRON
X47_HEA
X29_FCIEMR
X34_MRE
X46_HOU
X40_DEM
X43_DPO
X45_EDU
X44_INC
X50_MHDI
X62_ENR
X27_AVIS
X23_DRAN
X30_EXI
X09_PMFC
X05_PHEC
X10_IFA
X22_SOE
X01_CDNV
X03_PFLC
X04_IFL
X12_NASW
X06_PAVC
X11_NAGW
X49_NTDS
X21_CERO
X33_TSCEM
X17_PER
X19_DROSM
X16_PECLU
X20_ERO
X02_SHPH
X08_PINC
X07_PICC
X13_PCAQ
X18_SSSD

66

Figure 3. Cluster dendrogram of the sustainability indicators of Doce river basin.

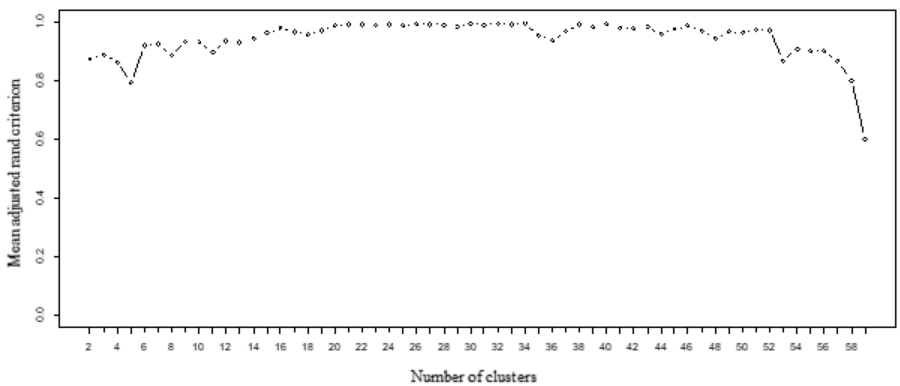


Figure 4. Stability of partitions based on the Cluster analysis applied to the sustainability indicators of Doce river basin.

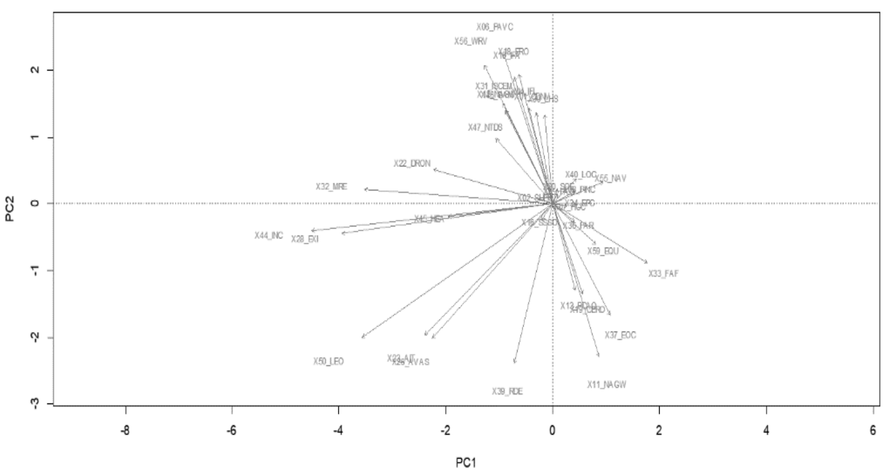


Figure 5. Graphic demonstration of scores obtained on the first two components (axes) from the Redundancy Analysis (RDA) applied to the indicators selected after Cluster Analysis (CA).

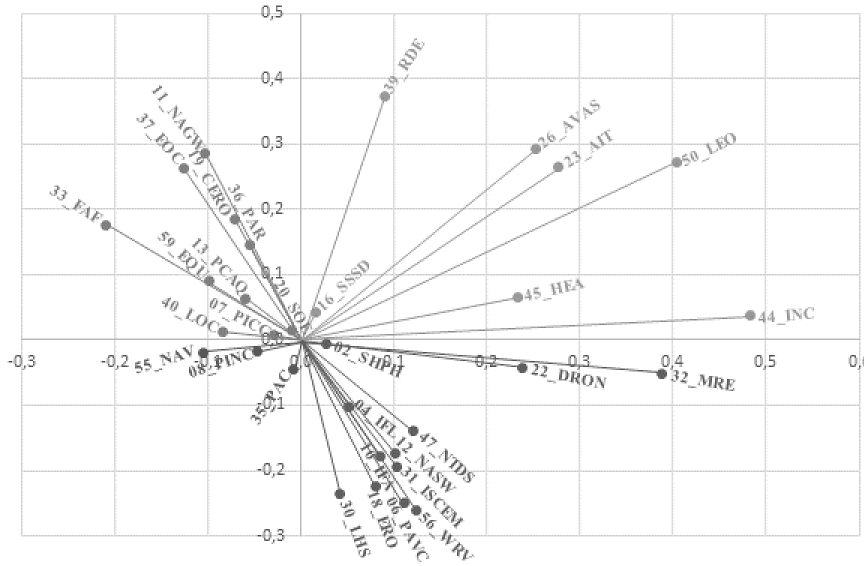


Figure 6. Graphic demonstration of scores obtained on the first two components (axes) from the Principal Components Analysis (PCA) applied to the indicators selected after the Redundancy Analysis (RDA).

Table 2. Scores and percentage contribution of each indicator from Principal Components Analysis (PCA).

Indicators	Scores PCA1	Contribution (%)
INC	0.482930	11.42
LEO	0.402700	9.52
MRE	0.388360	9.18
AIT	0.276600	6.54
AVAS	0.251440	5.95
DRON	0.238880	5.65
HEA	0.232150	5.49
FAF	0.209570	4.96
EOC	0.125410	2.97
WRV	0.123910	2.93
NTDS	0.121140	2.86
PAVC	0.110450	2.61
NAV	0.105360	2.49
NAGW	0.103110	2.44
ISCEM	0.102940	2.43
NASW	0.100600	2.38
EQU	0.098590	2.33
RDE	0.089270	2.11
IFA	0.085600	2.02
LOC	0.083810	1.98
ERO	0.080000	1.89
CERO	0.071670	1.69
PAR	0.059520	1.41
PCAQ	0.054780	1.30
IFL	0.051250	1.21
PINC	0.047130	1.11
LHS	0.042280	1.00
PICC	0.029430	0.70
SHPH	0.027380	0.65
SSSD	0.015620	0.37
SOE	0.009930	0.23
PAC	0.007580	0.18

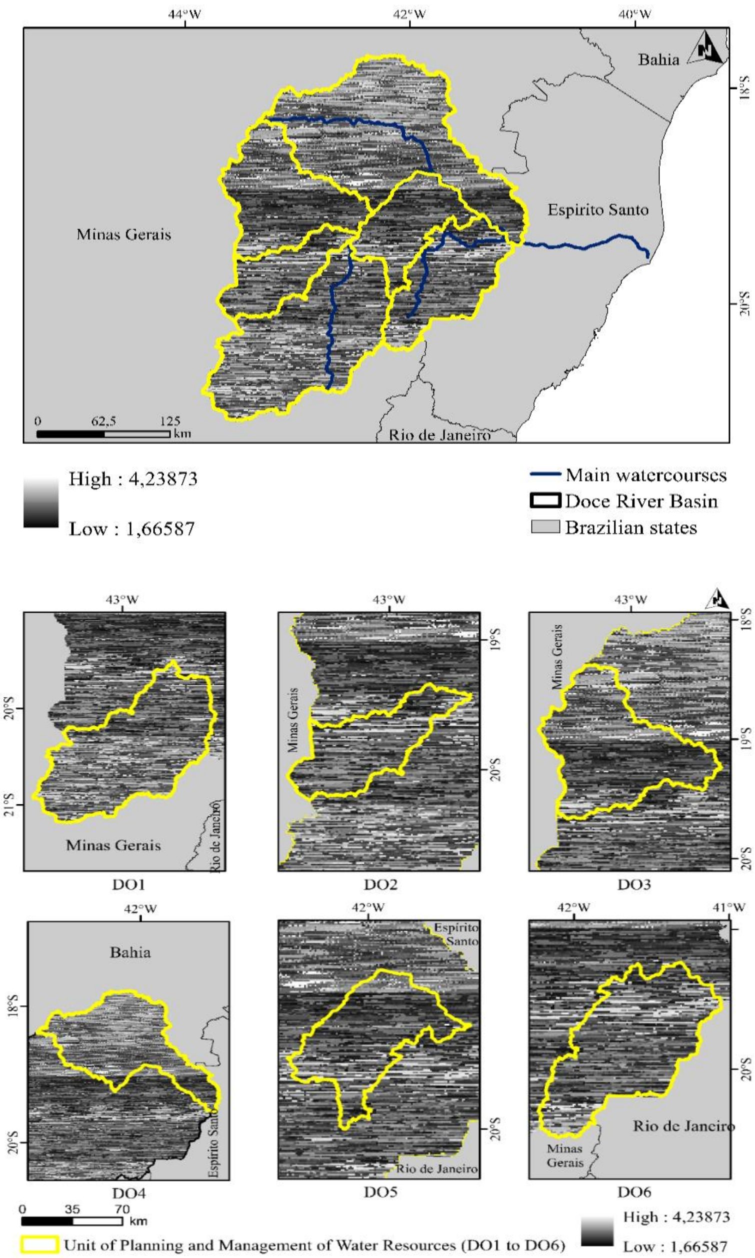


Figure 7. Vulnerability map of Doce river basin based on the proposed Vulnerability Index highlighting each Unit of Planning and Monitoring of Water Resources in Doce river basin (DO1 to DO6) where darkest pixels represent areas that are more vulnerable.

Trough the Vulnerability Index it was possible to realize a diagnose of each Unit of Planning and Monitoring of Water Resources (DO1 to DO6) in Doce river basin (Figure 8). DO4 and DO1 were the less vulnerable presenting, respectively, among 3 and 4% of vulnerability. DO5 was the most vulnerable area (among 14%). Overall, 6.6% of Doce river basin area was considered vulnerable, 62.6% average, 29.5% adequate, and 1.4% very adequate.

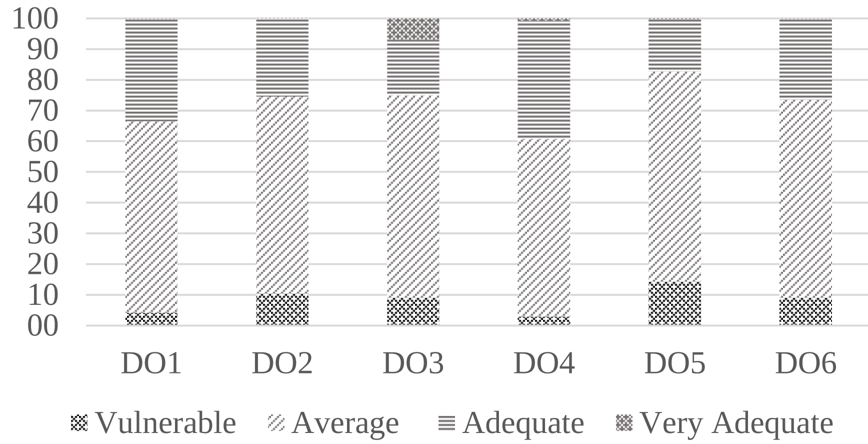


Figure 8. Vulnerability graphic of each Unit of Planning and Monitoring of Water Resources (DO1 to DO6) in Doce river basin based on the proposed Vulnerability Index.

In DO1 the most licensed activities are livestock (28.8%), energy infrastructure (12.3%), food industry (11%), open-pit mining (9.6%), and operating units in mining area, including mineral treatment units (9.6%). Although DO1 was considered less vulnerable, there is high erodibility there and it presented significant priority areas for mastofauna, herpetofauna, and flora conservation.

In DO2 predominates open-pit mining (16.7%), operating units in mining area (16.7%), and aviation fuel retailers activities (11.7%). This area presented the highest amount of natural availability of surface water, the highest exportation index, and the highest index of sugar cane and eucalyptus monoculture. However, economic occupation is considered precarious in general, there is high erodibility, and it presented significant areas with priority for avifauna, and herpetofauna conservation.

In DO3 the dominant activities are open-pit mining (33.3%), food industry (11.1%), and operating units in mining area (11.1%). The economic occupation was considered precarious, and it presented significant areas with priority for mastofauna, herpetofauna, ichthyofauna, invertebrates, and flora conservation.

In DO4 predominates food industry (30%), followed by forestry activities and wood processing, energy infrastructure, open-pit mining, transport and storage of dangerous products and waste, and aviation fuel retailers, each one representing 10% of the licensed activities. The economic occupation was considered precarious, and it presented significant priority areas for ichthyofauna conservation.

In DO5 the dominant activities are food industry and aviation fuel retailers (each one with 21.4%), and Rubber Industry 14.3%). DO5 was considered the most vulnerable sub-basin and presented the lowest standards about flora integrity.

In DO6 predominates energy infrastructure (37.5%), and food industry (18.7%). The current erosion there was considered the highest, and it also presented significant areas with priority for mastofauna, and herpetofauna conservation.

Overall, Doce river basin presented high susceptibility of soil structural degradation, precarious land holding structure, a high amount of priority areas for recovery, favorable rural development, average land occupation, precarious income, very precarious sanitation, average need to treat domestic sewage, precarious legal organizations, and average environmental quality. It was considered favorable the distribution of mineral resources along the river basin, family farming, and the institutional capacity, and the area also presented low natural vulnerability.

Regarding the context of RDA application, Lim et al. (2017) proved that this kind of analysis could be helpful and efficient to the identification of potentially hazardous elements in soil in Beijing, China. Shangguan et al. (2016), Song et al. (2016), and Gabarrón et al. (2018) also affirm that RDA could be successfully used in environmental assessments, whether related to soil aspects or to any environmental variable.

About the PCA application, Jolliffe & Cadima (2016) affirm that PCA is "a widely used and adaptive descriptive data analysis tool", adjustable to a wide variety of situations and database. This technic is widely recommend in studies about environmental vulnerability evaluation (Zou & Yoshino, 2017), tourism development (Zaman et al., 2016), desertification process (Zhang et al., 2017), waste management (Qi & Roe, 2016), watershed management (Farhan et al., 2017), and land-use planning (Li et al., 2018).

MCDA methods represent an important assessment tool towards a sustainable land-use but, sometimes, they struggle with data scale. According to Chen et al. (2018), "the spatial extent and resolution of prediction and assessment directly affect the selection of prediction models", which affect directly in the results of the modeling. They also affirm that spatial variability has "a large impact on model response, as in hydrologic, bioclimatic, and soil erosion modeling". On the other hand, SEA does not require a finer scale as project-based EIA since their focus on higher levels of planning. In a macroscale, SEA performs an important role to guide the decision-making comparing multiple alternatives, for instance, in river basin management. However, in a microscale, SEA could be less efficient, requiring the use of other forms of assessment, such as EIA.

According to Ávila et al. (2018), SEA should be used in land use planning by “replacing isolated actions with integrated management across several government agencies, thus resulting in higher viability in socioeconomic development and environmental protection”. These researchers applied a MCDA method in Grande river basin management, in Brazil, and they proved its efficacy to support future SEA of PPPs related to the integrated management of water resources.

For measuring wetland sustainability in Saskatoon, Canada, Sizo et al. (2016) adopted the following landscape indicators: total built-up area, wetland area, number of wetlands within the water catchment, wetland density, ratio between wetland area and total water catchment area, wetland size, and ratio between wetland and built-up area. The MCDA method applied by them allows offering “recommendations for strategic decisions for wetland conservation through urban land-use and planning processes”.

In Korea, Kim et al. (2015) assess some criteria in order to exanimate of potential areas for dam construction: landscape and geology, ecological value, water quality, and environmental toxicity. The researchers confirm that the MCDA methods are apt to develop decision support systems for SEA practices.

In order to support the elaboration of the Belgrad’s Waste Management Plan (BWMP), in Serbia, Josimović et al. (2015) proposed an MCDA method that considered indicators related to water (surface water and groundwater), air and climate change, soil, biodiversity, landscape, cultural and historical heritage transportation, population, human health, socioeconomic development, and institutional capacity in waste management. They affirm that the method was very convenient for the identification of strategically significant impacts of the BWMP and it could be widely applicable to aid SEA process.

In the cities of Polna (Czech Republic) and Wrocław (Poland), Kazak et al. (2017) appraised and local spatial development plan by the following indicators: number of residents, water consumption, sewage discharged, landfilled waste, surface runoff, and biologically active area. The MCDA method applied by these researchers was considered useful in the process of "ensuring spatial information regarding the area and layout of future land development, as well as statistical data characterizing the manner of development and the unit consumption of environmental resources".

Torrieri & Batà (2017) also proposed a MCDA method applied to urban plan in Marzano di Nola, Italy, using indicator grouped related to agriculture, forestry, tourism, industry, atmosphere, waste, natural hazards (geological-hydrological), and natural hazards (seismic-volcanic). Their proposed methodology proved to be a "useful decision support tool for a complex environment", able to provide "a rank order of the alternative scenarios from a multidimensional perspective, taking into consideration and controlling the sustainability of the future scenarios proposed in a direct and quantitative way".

The proposed MCDA method demonstrates to be adequate to support the diagnosis step in the R-SEA process, as well as the sustainability indicators used to characterize Doce river basin. The Cluster analysis, the RDA, and the PCA adjusted to this propose was efficient and the Vulnerability Index can be adapted to any location or even sector where there is a need for a more strategic assessment.

4. Conclusion

Through the Vulnerability Index, it was possible to realize a diagnose of each Unit of Planning and Monitoring of Water Resources (DO1 to DO6) in Doce river basin, where DO4 and DO1 were the less vulnerable presenting, and DO5 was the most vulnerable area (among 14% of vulnerability). Overall, 6.6% of Doce river basin area was considered vulnerable, 62.6% average, 29.5% adequate, and 1.4% very adequate.

The proposed MCDA method and the use of sustainability indicators were widely supported by literature, such as Josimović et al. (2015), Kim et al. (2015), Sizo et al. (2016), Kazak et al. (2017), Torrieri & Batà (2017), and Ávila et al. (2018), mainly when applied to spatial planning. This methodology can be adapted to any location or even sector where there is a need for a more strategic assessment. However, the results could be influenced by the scale of the database, which generally is available for a macroscale application.

In the future, we aimed to aggregate scenario analysis based on the same sustainability indicators to better support R-SEA studies. We recognize that there is a lack of studies about R-SEA in the country, mainly supported by MCDA methods. That instrument could be helpful in spatial planning, mainly applied to watershed management.

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Supplementary Material

Supplementary Material 1. Number of enterprises by activity category licensed by Minas Gerais environmental agency from 2013 to 2017.

Activity category	Number of enterprises
Services and Wholesale Trade	
Deposits and Wholesale Trade	1
Transport and storage of dangerous products and waste	3
Community, social and safety services (excluding dental and veterinary medical services and education)	1
Processing, Improvement, treatment and/or Final Disposal of Waste	6
Replacement stations, filling stations or points, retail installations, floating fuel stations and aviation fuel retailers	11
Industrial laundries with dyeing, softening and other finishes on clothes, garments and various fabrics.	2
Chemical industry	
Rubber Industry	4
Leather and Fur Industry and Similar Products	1
Chemical Industry	4
Pharmaceutical and Veterinary Products Industry	1
Perfumery Industry and Candles	2
Textile industry	1
Clothing, Shoes, Fabric and leather Artifacts Industry	1
Plants for the production of common or asphalt concrete	6
Metallurgical industry and others	
Non-Metallic Mineral Products Industry	1
Iron ore reduction	2
Metallurgical industry - Ferrous Metals	3
Metallurgical Industry - Non Ferrous Metals	1
Metallurgical Industry - Manufacture of artifacts	3
Wood and furniture industry	3
Food industry	
Food Industry	24
Alcohol and Beverage Industry	3
Mining Activities	
Underground mining	2
Open-pit mining	26
Extraction of Sand, Gravel and Clay, for use in civil construction	1
Extraction of mineral water or table drinking water	2
Operating Units in mining area, including mineral treatment units	19

Supplementary Material 1 (…)

Activity category	Number of enterprises
Mineral search	3
Infrastructure Activities	
Transportation Infrastructure	4
Energy Infrastructure	20
Sanitation Infrastructure	9
Land Parceling	2
Dams for protection of watercourse banks	1
Agroforestry Activities	
Livestock activities	23
Forestry Activities and Wood Processing	5

Supplementary Material 2. R script for Cluster analysis

```
require(ClustOfVar)
require(FactoMineR)
require(usdm)

# Selecting the directory
setwd(choose.dir())

# To load any matrix:
env1<-read.table(file.choose(),header=T,sep=";")
dim(env1)

# Confirming the real need to reduce dimensionality:
pca <- PCA(env1,graph=FALSE)
plot(pca, choix="var")
vif(env1)

# Reducing the dimensions of predictor variables:
tree <- hclustvar(env1)
plot(tree)

# Selecting the number of partitions.
stab <- stability(tree,B=10)
P36<-cutreevar(tree,36,matsim=TRUE)
cluster <- P36$cluster

X <- env1
princomp(X[,which(cluster==1)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==2)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==3)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==4)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==5)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==6)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==7)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==8)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==9)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==10)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==11)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==12)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==13)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==14)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==15)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==16)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==17)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==18)],cor=TRUE)$sdev^2
```

```
princomp(X[,which(cluster==19)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==20)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==21)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==22)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==23)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==24)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==25)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==26)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==27)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==28)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==29)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==30)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==31)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==32)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==33)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==34)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==35)],cor=TRUE)$sdev^2
princomp(X[,which(cluster==36)],cor=TRUE)$sdev^2

P36$cluster
clusterID <- P36$var
clusterID
write.table(P36$scores,"PCAScores.csv")

env2 <- read.table("PCAScores.csv",row.names=1,header=T,sep=" ")
dim(env2)
edit(env2)
vif(env2)
env3=env2
names(env3)
```

Supplementary Material 3. R script for Redundancy analysis (RDA)

```
# Selecting the directory:
setwd(choose.dir())

# Importing data to RDA
doce<-read.table(file.choose(), header=T, sep=";")
dim(doce)
options(max.print=10000000)

# RDA
require(vegan)
rda<-rda(doce,scale=T)
rda

head(summary(rda))
biplot(rda,display="sp")

srda<-summary(rda)
sitios<-data.frame(srda[2]) # sitios. Pode ser acessado por srda$
write.table(sitios, "score_sitios.csv", sep = ';')
especies<-data.frame(srda[1]) # espécies. Pode ser acessado por srda$
write.table(especies, "score_specie.csv", sep = ';')
```

Supplementary Material 4. R script for Principal Components Analysis (PCA)

```
# Selecting the directory:
setwd(choose.dir())

# Importing data to PCA
doce<-read.table(file.choose(), header=T, sep=";")
dim(doce)
options(max.print=10000000)

# Loading the package "Vegan":
require(vegan)

#PCA

# Running the analysis and view the contribution of each variable in the component:
prc.doce <- prcomp(doce, scale=TRUE); prc.doce

# Accessing the structure of the element "prc.doce":
str(prc.doce)

# Viewing the number of components and their contributions to the total variance:
screeplot(prc.doce)

# Showing the percentage of variance captured by each axis:
summary(prc.doce)

# Plotting PCA:
biplot(prc.doce)

# Accessing scores from PCA:
prc.doce$x
```

Supplementary Material 5. Squared loading and correlation of indicators by cluster.

Indicators	Squared loading	Correlation
04_IFL	0.8243533	-0.9079390
03_PFLC	0.8243533	-0.9079390
10_IFA	0.8089364	-0.8994089
05_PHEC	0.6920487	-0.8318946
09_PMFC	0.6799456	-0.8245882
20_ERO	0.8865294	-0.9415569
16_PECLU	0.6499127	0.8061716
19_DROSM	0.6116181	-0.7820601
17_PER	0.5407594	0.7353634
30_EXI	0.6880493	-0.8294874
23_DRAN	0.6580945	-0.8112302
27_AVIS	0.6010414	-0.7752686
62_ENR	0.5939915	0.7707085
26_AVAS	0.6793966	-0.8242552
28_AVSS	0.6793966	-0.8242552
34_MRE	0.8861281	-0.9413438
29_FCIEMR	0.8861281	-0.9413438
42_LOC	0.8540858	0.9241676
31_LAU	0.8540858	0.9241676
44_INC	0.8930775	-0.9450278
40_DEM	0.8872495	-0.9419392
50_MHDI	0.8483401	-0.9210538
45_EDU	0.7660611	-0.8752492
43_DPO	0.7518442	-0.8670895
46_HOU	0.6563793	-0.8101724
52_LEO	0.8750399	-0.9354357
54_ICO	0.824626	-0.9080892
53_FIO	0.6438404	-0.8023966
55_TRO	0.6434421	-0.8021484
51_ICA	0.5853361	-0.7650726
56_PSO	0.4192589	-0.6475021
58_WRV	1.0000000	1.0000000
59_SOV	1.0000000	-1.0000000
61_EQU	0.7224585	-0.8499756
60_WQU	0.7224585	-0.8499756