LARGE-SCALE SOLAR PHOTOVOLTAIC IMPACT ASSESSMENT IN THE CONTEXT OF THE BRAZILIAN ENVIRONMENTAL AND ENERGY PLANNING

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Orientador(es): David Alves Castelo Branco
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“Até aqui o Senhor nos ajudou” 1 Samuel 7:12
“Thus far the Lord has helped us” 1 Samuel 7:12

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AVALIAÇÃO DE IMPACTOS DE USINAS SOLARES NO CONTEXTO DO PLANEJAMENTO AMBIENTAL E ENERGÉTICO NACIONAL BRASILEIRO

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A energia solar está crescendo em todo o mundo, especialmente através de instalações fotovoltaicas de grande escala (IFVGE). Há, no entanto, uma discussão entre diferentes partes interessadas e profissionais sobre os reais benefícios e impactos ambientais dessas instalações. A discussão aborda o papel principal do licenciamento ambiental (LA) para instalações de energia renovável considerando os impactos reais de tais projetos, assim como os critérios usados para licenciar e orientar os estudos ambientais e os métodos usados na avaliação de impacto e processo de tomada de decisão. Esta dissertação apresenta três artigos que analisam coletivamente os impactos ambientais de IFVGE em três esferas: aspectos legais, importância dos impactos ambientais e abordagens atuais de avaliação de impacto no contexto brasileiro. O primeiro trabalho estuda as atuais regulamentações ambientais para o licenciamento de IFVGE no Brasil e conecta seu papel no planejamento energético do país. O segundo artigo descreve os potenciais impactos ambientais causados pelas IFVGE, comparando sistemas montados no solo com sistemas flutuantes. O trabalho final aborda os métodos de avaliação de impacto utilizados na Avaliação de Impacto Ambiental. Além disso, uma metodologia multicritério é proposta para melhorar o atual processo de avaliação.

Abstract of Dissertation presented to COPPE/UFRJ as a partial fulfillment of the requirements for the degree of Master of Science (M.Sc.)

LARGE-SCALE SOLAR PHOTOVOLTAIC IMPACT ASSESSMENT IN THE CONTEXT OF THE BRAZILIAN ENVIRONMENTAL AND ENERGY PLANNING

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March/2019

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Solar energy installations are growing worldwide, especially through large-scale photovoltaic installations (LSPVI). There is, though, a discussion between different stakeholders and professionals about the real environmental benefits and impacts of LSPVI. The discussion addresses the main role of environmental licensing (EL) for renewable energy installations considering the real impacts of such projects, criteria used to license and drive the environmental studies, and methods used to assessment and judge impacts and aid the decision-making process. This dissertations presents three papers that collectively examine the environmental impacts of LSPVI in three spheres: legal aspects, likely environmental impacts and their significance, and current impact assessment approaches in the Brazilian context. The first paper study the current environmental regulations for licensing LSPVI in Brazil and connect its role in the country's energy planning. The second paper outlines potential environmental impacts caused by LSPVI comparing ground-mounted to floating systems. The final work analyses the impact assessment methods used in the Environmental Impact Assessment. Moreover, a multicriteria approach is also proposed to improve the current assessment process.

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List of acronyms

AHP - Analytic Hierarchy Process

ANEEL - Brazilian Electricity Regulatory Agency

CNPE - National Council for Energy Policy

CONAMA - National Environmental Council

EIA - Environmental Impact Assessment

EL - Environmental License

ENP - Energy National Plan

EPE - Energy Research Office

FPV - Floating photovoltaic

GIS - Geographic Information System

GW - Giga-watts

ha - hectare

IAIA - International Association for Impact Assessment

IAPA - Impact Assessment and Project Appraisal

LP - Licença Prévia

LEA - Local Environmental Agency

LSPVI - Large-scale solar photovoltaic installations

MCDA - Multicriteria decision-making analysis

MME - Ministry of Mines and Energy

MW - Megawatts

O&M - Operation and maintanance

PDE - Decadal Energy Plan

PV- photovoltaic

SAMAMBAIA - Multicriteria Analysis System applied as a Baseline Method to Assess Environmental Impacts

SEA - Strategic Environmental Assessment

SEPA - State Environmental Protection Agency

USSE - Utility-scale solar energy

USSPV - Utility-scale solar photovoltaic

Declaration of previous publications

This thesis includes three original papers that have been previously published/accepted in the Impact Assessment and Project Appraisal journal, as follows:

THESIS CHAPTER	PUBLICATION	PUBLICATION STATUS
CHAPTER I AND V	Large-scale solar photovoltaic impact assessment in the context of the Brazilian environmental and energy planning	might turn into a submission as letter to the editor
CHAPTER II	Da Silva, GDP, Magrini, A, Tolmasquim, MT, Branco, DAC. Environmental licensing and energy policy regulating utility-scale solar photovoltaic installations: current status and future perspectives. Impact Assessment & Project Appraisal, 2019. DOI: 10.1080/14615517.2019.1595933	Accepted
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CHAPTER IV	Da Silva, GDP, Magrini, A, Branco, DAC. A multicriteria proposal for large-scale solar photovoltaic impact assessment. Impact Assessment & Project Appraisal, 2019. DOI: 10.1080/14615517.2019.1604938	Accepted

Chapter I

Introduction

In spite of the current public view associating solar PV panels with residential rooftop installations, the first PV panel applications did not include residential purposes. Extremely expensive manufacturing costs and low efficiency (below 10%) limited their uses to space missions and research purposes. Further research increasing the solar PV efficiency and decreasing manufacturing costs enabled the installation of ground-mounted plants such as the 1 MW (megawatt) plant at Hisperia, California, the first megawatt solar PV in the world [1]. Other projects were installed from 1985 to 2008, though their capacity did not exceed 14 MW; the biggest plant was the Nellis Air Force Base solar Plant in the USA, covering roughly 56 hectares (ha) [2]. Large projects with significant installed capacity were completed after 2008, such as the 60 MW Olmedilla PV plant in Spain (2008), the 90 MW Sarnia PV plant in Canada (2008) [3], [4], the 200 MW solar PV in Golmud, China (2011), and several other above 100 MW PV projects [5]. Currently, there are many multi-megawatt solar PV farms that have been commissioned, including a 1 GW in China; see a current list in [6]. The trend is to continue building large-scale solar photovoltaic (LSPV) installations for at least the next 5 years [7]. The main reasons for deployment of utility-scale projects over residential applications are economy of scale and lack of incentive for residential rooftop installation. Therefore, solar PV farms have been a reality in many countries and shall become extremely important worldwide as an alternative to mitigate CO_2 emissions. However, researches should not focus only on economic and technical impacts of the technology; environmental aspects must be part of the feasibility assessment as well.

Utility-scale PV plants cover hundreds of hectares (ha) and can significantly change the local physical environment, see figure 1. As example, the energy density reported varies from 5.4 W/m^2 [8] to 100 ha to every 20-60 MW [9]. With the emergence of multi-megawatt PV plants, the scholarly literature began to contain examples of disadvantageous aspects of renewable solar energy. The technology might be less impactful and preferred by the public in comparison to traditional sources such as coal burning thermal facilities and nuclear plants [10]. Some environmental impacts are considered negligible in small-scale PV away from fauna and flora and covering non-significant areas such as rooftop installations. This view is not always shared among researchers and Environmental Impact Assessment (EIA) practitioners for large-scale ground-mounted plants. There is, therefore, a discussion between different stakeholders and professionals about the real environmental benefits and impacts of utility-scale renewable solar energy. Will the transition from traditional coal and nuclear to renewable electricity generating occur at any costs for the environment? Are people underestimating environmental degradation from renewable energy, in this case, solar PV?

Figure 1. Utility-scale solar photovoltaic land coverage. Sources: [11]–[14].

In this scenario, the importance of researchers and EIA practitioners view is associated with the fact that EIA is the legal instrument designed to assess the likely adverse impacts on biophysical environment (fauna, flora, soil, water, and air) and social aspects of projects [15]. Governments usually use the EIA reports to issue an Environmental Permit (EP) that authorises installation and operation of the facility.

The uncertainties regarding potential environmental impacts, the impact assessment method (how to measure the significance of each impact and integrate the overall risk), and role of this analysis for environmental governance are under debate. Several stakeholders believe that large-scale PV impacts are not significant enough, and hence there is no need to request a detailed full EIA to support any environmental permits. Many countries' legislation mandates the production of EIA to support decision-making regarding projects with high potential to impact the area. In the circumstance of projects posing "low environmental degradation", a simplified EIA version might be required to issue the environmental license. Simplified EIA and fast track licensing is often appealing for LSPV as the public view is of an environmentally-friendly technology. However, studies stress several environmental and social impacts from PV plants, demonstrating that renewable energy does not mean "impact free" energy [10], [16]–[21]. Regarding the studies used to approve a project's installation, there have been international debates towards the quality of EIA and the effectiveness of the methodological approaches to assess and measure impacts [22]–[24]. Therefore, the techniques used to conduct the analysis, measure the impacts, and integrate the different areas of interest, will also play an important role in preventing conflicts and securing a sustainable energy transition from traditional to renewable sources. In summary, the three questions for environmental governance towards large-scale renewable solar PV are: Why is EIA important for decision-making? How are environmental impacts are being measured? And how can EIA contribute to sustainable renewable energy expansion? The overall analysis is not simple as it concerns environmental policies, the understanding of the real benefits and constraints of LSPV, and a technical investigation to asses and evaluate the approaches used.

A country-specific examination of the three questions for LSPV can bring a deeper understanding of the relationship between environmental aspects, energy planning, and decision-making. More specifically, it can illuminate the real role of EIA in decision-making for centralised renewable energy expansion. Moreover, as utility-scale solar photovoltaic is new in many countries, a local analysis can demonstrate the performance of the EIA methodological approaches to integrate complex decision-making aspects for predicting and preventing impacts. In this perspective, Brazil is a suitable candidate for which to undertake the analysis. Solar resource is widely available in the entire territory and large-scale PV installations have been emerging since 2014 with the first solar-specific energy auction. It is noteworthy that the Energy Research Office (EPE) estimates that LSPV will be one of the three main future electricity generating systems, third only to hydropower and wind farms [25].

With regards to EIA, a current study by [23] contrasted environmental regulation in the Latin America countries. The study found that although Brazil is one of the most advanced countries in EIA screening and scoping in South America, the real practice demonstrates that most EIAs have not prevented some major impacts. Furthermore, big energy projects have been the target of stringent EIA processes, mainly due to the previous hydropower experience [26]. As large solar energy projects are particularly new in Brazil, EIA practitioners might not have long-term experience in assessing and evaluating the real risks of multi-megawatts PV projects. The impact assessment reports can potentially lack relevant information regarding environmental impacts and possible conflicts. Additionally, there is not a specific national regulation to guide EIA screening or scoping for such projects. State Environmental Protection Agencies (SEPA), which are responsible for issuing permits for solar PV, might not have enough experience to determine the significance of environmental impacts either. In the context of energy planning, EIA is used to issue the environmental license, a document required to participate in the auctions. Even though the projects might have the required license approving their installations, the studies might contain flaws in the assessment of impacts; the methodology might easily lack the integration of multi-aspect environments. This scenario might lead to long-term detrimental impacts and possible conflicts.

Objective

EIA is herein emphasised as a legal instrument for energy planning, as well as a tool to assess the real importance of its environmental impacts. In addition, there is the questionable EIA effectiveness of the methodological approaches regarding utility-scale solar photovoltaic in Brazil. In this scenario, this dissertation examines the environmental impacts of large-scale solar photovoltaic in the three spheres: legal aspects, likely environmental impacts and their significance, and current impact assessment approaches.

Each aspect is subdivided into specific objectives:

- Examine the current environmental regulations for licensing of utility-scale photovoltaic in Brazil and connect its role to the country’s energy planning;

- Outline potential environmental impacts caused by large-scale photovoltaic comparing ground-mounted to floating systems;
- Analyse the impact assessment methods used in the Environmental Impact Assessment and determine their effectiveness.
- If the impact assessment approaches are considered ineffective, propose a new method to improve the current assessment process.

Structure

The Energy Planning Program committee and the Graduate Teaching Council (CPGP) allowed me to write this work in a paper-based dissertation format. Thus, each chapter (paper) covers an aspect of this research. The papers are published/accepted in the Impact Assessment and Project Appraisal Journal (*IAPA*), official journal of the International Association for Impact Assessment (*IAIA*). The first paper (Chapter II) addresses environmental licensing applied to energy policy and current solar PV expansion. Chapter III reviews the negative and positive environmental impacts of large-scale solar PV. The analysis is conducted through a detailed review of impacts occurring at each project phase. Due to the lack of Brazilian experience with solar PV, the overview covers worldwide studies and synthesises the results for tropical regions. Chapter IV tackles the current approaches to assessment and proposes a new method to evaluate all the complex impacts (socio, environmental, and economic). The first part of the latter paper covers a detailed research on EIA worldwide; several national and international reports were taken into consideration because there are not many EIA reports (for utility-scale solar photovoltaic- USSPV) available in Brazil. The second part of the paper proposes a multicriteria approach to better integrate socio-environmental impacts of USSPV.

Chapter II

Is floating photovoltaic better than conventional photovoltaic? Assessing environmental impacts

Gardenio Diogo Pimentel da Silva & David Alves Castelo Branco

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Is floating photovoltaic better than conventional photovoltaic? Assessing environmental impacts

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ABSTRACT
Photovoltaic (PV) solar energy installations are growing all over the world as a promising renewable alternative to generate electricity. However, many studies have highlighted some drawbacks associated with the installation and operation of conventional solar energy power plants. Thus, floating photovoltaic (FPV) systems have been emerging as a new concept in solar energy to lessen negative environmental impacts caused by allocation of conventional PV facilities. This paper is an overview of the potential negative and positive environmental impacts caused by photovoltaic systems with particular interest on large-scale conventional and floating photovoltaic. This study addresses and compares the impacts at all phases of project implementation, which covers planning, construction, and operation and decommissioning, focusing on ambient located in the tropics. The overall impacts associated with project allocation such as deforestation (for the project implementation and site accessing), bird mortality, erosion, runoff, and change in microclimate are expected to have higher magnitudes for the implementation of conventional PV facilities. The results highlight advantages of FPV over conventional PV during the operational and decommissioning phases as well. Though, further studies are required to assess both qualitative and quantitative aspects of installations in similar areas.

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Introduction

Renewable energy sources have been increasingly researched during recent years, mainly due to the advances in technology, environmental issues, and necessity of more green and efficient power plants. The shift from fossil fuel energy generation to clean renewable energy is also a strategy to meet global goals such as reducing CO_2 emissions to the atmosphere and avoid extreme climate change conditions (Slootweg et al. 2001; Ellabban et al. 2014; Larsen 2014). In particular, solar energy harvested from photovoltaic and thermal systems is growing all over the world as a promising renewable alternative to generate electricity or heat because sunlight is freely available and its operation does not release greenhouse gases to the environment. Some other benefits from solar energy project are increasing the national/regional/local energy mix with renewable energy sources; more independence from fossil fuel utilities; new work opportunities for the region; and electrification of remote locales such as rural areas. Regarding the environment, solar energy projects can be used to reclaim degraded areas and as a strategy to minimise air pollution from conventional thermal facilities. Moreover, Turney and Fthenakis (Turney and Fthenakis 2011), analysing environmental impacts from solar technologies in comparison to traditional energy sources, claimed that 22 out of 32 impacts are classified as positive, 4 as neutral, and 6 demand additional studies. Solar energy projects are not, though, environmental-impact-free, the installation of renewable energy sources still causes environmental impacts and studies date back to the 1970s (Hernandez et al. 2014). Many studies have pointed out some drawbacks from solar energy technology during the manufacturing of the PV cells which requires intense energy and releases toxic chemical to the environment (Abbasi and Abbasi 2000; Tsoutsos et al. 2005; Gunerhan et al. 2009; Aman et al. 2015). Moreover, constraints associated with solar energy are the large land requirements such as productive land to install utility-scale solar energy (USSE) facilities, bird mortality, loss of wildlife habitat due to deforestation, visual pollution, use of chemicals to clean the panels, and water depletion (De Marco et al. 2014; Walston et al. 2016; Gasparatos et al. 2017). Most studies, though, tend to be site specific assessing impacts of solar utilities in particular regions (Hernandez et al. 2014) such as in the installation of a 100 MW solar power plant in Australia (Guerin 2017a).

To overcome some negative impacts such as deforestation and land requirements, floating photovoltaic

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(FPV) systems have been emerging as a new concept in electricity generation. The technology is the same applied in terrestrial solar projects; the main difference is that in FPV the photovoltaic panels are placed on the top of a floating structure made of polyethylene and other materials. The floating structure is then placed in lakes and reservoirs and it utilises unused areas. Costs with land allocation might be minimised along with problems related to deforestation and loss of habitat. Moreover, FPV can produce more energy than conventional land PV systems (Choi 2014a; Sahu et al. 2016; Singh et al. 2016) due to the evaporation on the back of the panels which helps to lower the PV cells temperature increasing its efficiency. This alternative might be used to prevent water loss in lakes and reservoirs (Lee et al. 2014; Santafé et al. 2014a; Singh et al. 2016; Wästhage 2017). There are floating systems being used in lakes for agriculture and pit lakes from open-cut mines all over the world. Successful experimental FPV plants were installed at lakes in countries such as Korea, United Kingdom, United States of America (USA), Italy, Japan, and Spain (Choi 2014a; Trapani and Santafé 2015; Hartzell 2016). These FPV facilities vary from 1 kW capacity to several MW of capacity (Sahu et al. 2016) (see list of some current and future projects by Ciel et Terre (2017)). FPV systems are being studied for application in other countries like Brazil which has a great potential due its location near the equator and its elevated irradiation levels, greater than many European countries that are currently leaders in solar energy generation (Abreu et al. 2008; Martins et al. 2008; Pereira et al. 2017). The same potential might be assumed to other tropical countries.

Most recent studies address technical and economic aspects of FPV in comparison to terrestrial photovoltaic installation. For instance, a previous study in Brazil pointed out Bolonha Lake's potential to host a FPV system, nonetheless the study did not tackle what potential environmental impacts the FPV system could cause or minimise on the surrounding area only environmental conditions such as weather parameters (Silva and Souza 2017). Therefore, concerning the environment, the majority of works focus on evaporation control in FPV. Furthermore studies must still be conducted to assess impacts of FPV facilities on the environment (Grippo et al. 2015; Liu et al. 2017). In particular, there is need for studies which overview the main environmental impacts in terrestrial scale solar energy power and contrasts them with the likely environmental impacts caused by this new alternative, the FPV, in all phases of implementation (allocation, construction, operation, and decommissioning).

The primary objective of this paper is to overview the potential negative and positive environmental impacts caused by photovoltaic systems with particular interest in large-scale conventional and FPV, as part of the environmental impact assessment (EIA) and strategic environmental assessment (SEA) processes (Slootweg et al. 2001; Benson 2003; Vanclay 2003; Larsen 2014). This is relevant to the production of effective assessment of all aspects surrounding large-scale solar PV and decision-making (see (Marshall and Fischer 2006; Phylip-Jones and Fischer 2015) for studies assessing the effectiveness of SEA and implications for EIA in wind energy). This study addresses and compares the impacts at all phases of project implementation, which covers planning, construction, and operation and decommissioning, focusing on ambient location in the tropics (understood here as places without occurrence of snowfall). The results of this analysis will contribute to the better understanding of environmental impacts of terrestrial and FPV and the decision-making for implementation and/or expansion of the renewable energy matrix through solar power plants in these regions.

Environmental characteristics

This study tackled an overall review of environmental impacts caused by solar PV projects. All environmental impacts discussed in this paper were based on an extensive literature review covering terrestrial and FPV systems. The impacts were characterised into impacts associated with land usage and phases of the project. The main topics discussed covered themes such as deforestation, impact on fauna and flora, water resource usage and depletion, pollution and risk of contamination, and positive impacts. Figure 1 summarises all environmental characteristics covered in the results section. At the end of every section, a table is presented to synthesise the main findings and differences between the two technologies proposed.

Solar terrestrial and FPV concept

Terrestrial and FPV concept are not different in technology; the main objective is to convert sunlight energy into electricity using semiconductor devices, within the solar panels. The main difference is on the location where the system is placed and some specific structural designs in FPV. In general solar photovoltaic installations require (Cabrera-Tobar et al. 2016; Sahu et al. 2016; Guerin 2017b):

- **Solar panels**: convert solar energy into electricity. They can be made of different materials such as crystalline (c-Si), polycrystalline silicon (m-Si), amorphous silicon (a-Si), and thin films of cadmium tellurium (CdTe). The modules capacity might range from few kWp to 325 kWp (System Advisor Model database) with efficiency varying from 6% a-Si to 20% in polycrystalline panels.

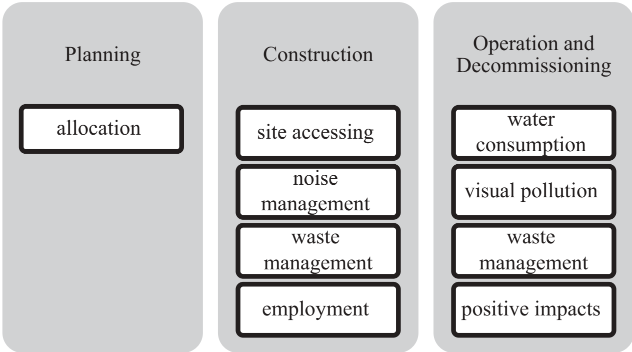

Figure 1. Environmental characteristics analysed at all phases of a PV project.

- **Inverters**: invert DC current produced in the solar modules to AC current used in residences or fed to the grid; they also control the flux of energy output fed into the grid (or battery bank) or consumed in the locale. Capacity varies from a few kW to several kW in utility scale solar facilities and efficiency of 'conversion' might reach 98%.
- **Voltage Transformer**: step up the voltage generated in the PV system to a higher voltage for transmission.
- **Mounting structures (terrestrial PV only)**: withstand the weight of the structure and used to combine solar modules in different arrangements (string and parallel) and distinguish locations (rooftop, ground, top-of-pole with or without tracking). They might be composed of aluminium frames, stainless steel, plastic or iron-made racks. Concrete foundation might often be necessary to support weight of the structure as well.
- **Foundation (terrestrial PV only)**: concrete foundation is often required to withstand the weight of the structure in the soil and the surrounding forces of storms and winds.
- **Screws and Cabling**: used to fix and connect the mounting structure and transmit the energy produced in the system.
- **Trenches**: pathway opened in the ground used to communicate cables and electrical components.
- **Trackers (not mandatory)**: orients solar module structure towards incoming sunlight. They are often used to maximise energy generation, though their usage implies in higher initial investment.

The most common technology applied is silicon-based panels (Ellabban et al. 2014). FPV will require the same area per MWp; nevertheless, the system covers the surface of freshwater lakes, reservoirs, ponds or water canals (not floating panels). There are also on-going experiments studying the potential of off-shore floating solar (Diendorfer et al. 2014). In addition to the common components in terrestrial photovoltaic systems, FPV will require (Santafé et al. 2014a, 2014b; Choi 2014b; Sahu et al. 2016):

- **Pontoons (floating structure)**: buoyant structure to support mounting structure and photovoltaic modules. They are made of different floating materials, i.e. plastic or high-density polyethylene.
- **Flexible coupling (mooring system)**: allow the system to adjust to different water level and maintain its position towards one another and in the lake through ropes stretched in the bottom of the reservoirs.

Anchoring (mooring): anchors the floating system, prevents the system from moving and resists surrounding forces such as wind that can rotate the PV modules.

Land use and allocation

Solar projects usually require large land area for construction varying from 2.2 to 12.2 acres/MW and produce less energy compared to fossil fuels' land requirement per MW (De Marco et al. 2014; Aman et al. 2015); the change in the surrounding area can lead to a variety of environmental impacts in the soil, air, water, fauna, and flora (Tsoutsos et al. 2005; Hernandez et al. 2014; Walston et al. 2016; Gasparatos et al. 2017). Consequently, the construction phase of a conventional utility-scale PV plant is considered the most impactful phase of the project due to deforestation and loss of habitat. Deforestation is linked to many other impacts in the environment such as loss of habitat and biodiversity and other impacts on the landscape. The lack of vegetation results in increased runoff and soil erosion. Therefore, intense landscape infrastructure to avoid stormwater runoff and loading sediments from the area is required in the installation of terrestrial solar plants as well as use of heavy machinery, concrete, and other materials, which negatively affects the local geomorphology. Usually, there is also need to open trenches to allocate cabling and connect the infrastructure. The implementation of such structures causes more disturbances (i.e. noise and soil degraded) during construction of the project (Lovich and Ennen 2011; Hernandez et al. 2014) and increase detrimental impacts on the soil and the geohydrological resources (sediment load, soil erosion, groundwater resources, flooding risks) (Turney and Fthenakis 2011). Additionally, in forested locations, i.e. conservation areas and many areas of tropical countries, the installation of solar power plants cause more impact compared to desert areas emitting 2–4 times more CO_2 to the atmosphere due to deforestation and cleaning of vegetation; these emissions might range from 16 to 86 g CO_2 kWh^{-1} (Turney and Fthenakis 2011). Changes in local microclimates and soil temperatures are reported as another negative impact associated with deforestation to install large solar energy facilities (Wu et al. 2014; Gasparatos et al. 2017). Due to these negative impacts of deforestation, many new USSE projects are being placed in desert areas in the USA and Australia (Tsoutsos et al. 2005; Gunerhan et al. 2009; Fthenakis et al. 2011). Though, recent studies have point out other environmental impacts on desert areas such as bird mortality because of either direct collision to photovoltaic panels or contact with solar flux in CSP facilities (Visser 2016; Walston et al. 2016). Insects may also be attracted to PV facilities which can increase the probability of bird collision with the PV infrastructure (Fthenakis et al. 2011; Jenkins et al. 2015). In aquatic systems, water birds can be attracted to panels causing mortality of birds in the area (Grippo et al. 2015). The glare caused by optical reflection of sunlight on the surface of the panels may also be a source of discomfort to the fauna or residents near the solar facility (Rose and Wollert 2015). Contaminant spills such as lubricants and oils are from vehicle and heavy machinery often a concern during the site preparation because of the risk of accidental spillage on soil and contamination of soil and water resources.

FPV system has emerged as an alternative to mitigate some of those negative impacts associated with deforestation and land allocation (Lee et al. 2014; Choi 2014a), loss of habitat, fauna and flora, necessity of runoff infrastructure, and other land-cover requirements. However, lakes with legal restrictions for water protection, fishing prohibition activity, marine leisure, and other similar areas should be avoided (Choi 2014b). FPV systems are suitable to install in abandoned mining lakes, making use of an unused degraded area (Song and Choi 2016). Installation of FPV in lakes used in agriculture is also reported to prevent water evaporation in remote locations (Dupraz et al. 2011; Dinesh and Pearce 2016). Regarding the impact on the local geomorphology and geohydrology, although FPV does not suppress vegetation, there may be detrimental impacts on the bottom of the lake due to the anchoring, cabling structure, and trenching on soil (on land) used to connect the floating structure to the substation. Some impacts might include the change in water quality and increase of water turbidity caused by the turnover of sediments in bottom of the lake during anchoring. Accidental oil and lubricants spillage and exhaustion emission from machinery can contaminate fauna and flora living on the water reservoir. Soil compacting, soil erosion, and dust generation can occur on the accessing area to the lake due to heavy machinery to transport the buoyant structure to the lake, though this will depend on the type of technology installed for the floating structure. The overall environmental impact, however, might not be significant in comparison to terrestrial large-scale solar PV (Costa 2017).

There might be temporary detrimental impact on benthonic and other aquatic communities living on the bottom of the lake due to the anchoring and mooring by increment of suspended solids or direct contact to the structure (Costa 2017). Thus, natural lakes might be more affected than artificial lakes, ponds or reservoirs. Nevertheless, little research has been done on the environmental impacts of FPV on flora and fauna in aquatic ecosystems (Grippo et al. 2015). Direct collision with PV panels might be minimised through FPV since the project is mounted far away from the lakeshore, trees, bird nests, and their flying area. The construction of nest boxes may be used to minimise loss of habitat by creating habitat to impacted birds (Guerin 2017b). Further studies must be conducted to better assess local birds' flying and migratory routes as well as their nest locations.

Blocking sunlight penetration in the lake is another impact of FPV systems. This parameter is essential to the growth of algae, responsible for photosynthesis; therefore at some lakes the shading provided by the FPV system can be used to prevent excessive algae growth and to guarantee water quality (Sharma et al. 2015; Sahu et al. 2016). FPV projects covering the entire or partial water surface of the lake lessen water evaporation (Ferrer-Gisbert et al. 2013; Santafé et al. 2014a; Gaikwad and Deshpande 2017). Nonetheless, when USSE facilities are planned in the reservoirs of lakes or other water surface with great biodiversity of organisms, spacing the PV rows to allow sunlight penetration is suggested to reduce possible detrimental impacts such as oxygen depletion in the water.

During this initial phase, new job opportunities are created in business, design, and pre-construction. Solar PV had the highest rate of employment in comparison to other renewable energies in 2016, there were more than 3 million people employed worldwide (Ferroukhi et al. 2017). Projects ranging from 1 to 5 MW in capacity generate more job opportunities than large-scale projects due to the greater demand in construction for these small capacity systems (the majority of them range from 1 to 10 MW). Business might employ 3–5 skilled people during 75–150 days in projects terrestrial PV projects ranging from 1 to 5 MW. Allocation (understood here as design and pre-construction) might employ 7–12 skilled people with more opportunities available in projects of less than 10 MW in conventional PV (Ghosh et al. 2014). There have not been reported studies on employment rates during FPV installation, though a metric of 1 kWh/hour/person is usually adopted and depends on the characteristics such as wind velocity and project's capacity. In some designs as the system is simple for installation and does not require heavy machinery, the number of personnel employed in the installation will be inferior to conventional PV (Ciel et Terre Brazil, personal communication). There are different types of buoyant structures to be used that might require heavy machinery to place the photovoltaic panels in the lake, but the overall ratio of employment during installation is inferior to conventional PV because of the no necessity to prepare the area for placement, i.e. suppress vegetation and foundation to the structures. Future studies should also address and compare environmental licensing time in floating and conventional PV, though one should expect less complexity in FPV as the system does not suppress local vegetation. Table 1 summarises the main environmental impacts and attributes considered during allocation and planning phase.

Construction phase of the project

Site access

Accessing the site where the system will be constructed is another concern associated with the implementation of any energy project (Tsoutsos et al. 2005). The project must be sited in locations with easy access by road to avoid deforestation and other impacts associated opening of new access routes. Geographic Information System (GIS) software can be used to assist the choice of the best location for a solar project by mapping and identifying degraded areas or other suitable locations for the project implementation (Stoms et al. 2013). During construction, the number of trips to access the local is expected to increase from both heavy and light vehicles. Its impacts on the environment must be accounted, though there might be cases when they are not significant. For example, in Australia the construction of a 100 MW USSE did not have significant impacts on traffic flows during its construction (Guerin 2017a). There is also potential air pollution sources in both terrestrial and FPV caused by the heavy machinery, increase in local traffic, and dust generation in the site (terrestrial PV) and accessing site (terrestrial and FPV). FPV will require more trips to transport the buoyant structure, though no heavy machinery such as crane lift and tractor crane are required (Ciel et Terre Brazil, personal communication). However, the project's capacity and the type of floating technology will determine whether heavy machinery will be used or not. Impacts are, therefore, site specific depending on the project capacity and the natural conditions (Gunerhan et al. 2009). In both cases, installation process will require construction of new routes or expansion of the existent ones causing problems of loss of habitat. FPV on lakes (natural or artificial) will reduce fishing and other recreation uses in lake impacting the public access to that resources (if existed) and therefore might suffer conflict of interest in allocation. A detailed local assessment of the access to the lake area (using GIS tools for instance) should be tackled in future works to better compare the impact of deforestation of both alternatives.

Noise and waste management during construction

Noise and waste generation during construction is claimed to be a temporary negative impact on the environment. During the one year construction period of a 100 MW USSE in Australia, no noise complaints were reported by travellers passing on the roadway near the project (Guerin 2017b). A noise monitoring programme should be carried out during construction to assess the impact of noise on wildlife and visitors if the area is a

Table 1. List of environmental impacts and attributes comparing conventional and floating PV during allocation and planning.

Aspect	Impact	Floating PV	Conventional PV	Comments
Deforestation	Multiples	Might occur for site accessing	Site accessing and installation	Higher impact in conventional PV
Foundation and support structure	Soil compacting, erosion, disturbance on water resources and impact on fauna and flora	Might occur due to anchoring and soil trenches, machinery and traffic	Foundation, trenches, heavy machinery, traffic, and site preparation for installation	Higher impact in conventional PV
Stormwater infrastructure	Runoff and soil erosion	-	Required	Higher impact in conventional PV
Deforestation	Change in microclimate	-	Existent	Higher impact in conventional PV
Bird collision with panels	Bird mortality	Might occur	Might occur	Higher in conventional PV
Attraction of insects	Bird mortality	Need further investigation	Might occur	
Sunlight blocking	Water quality depletion	Occur on the lake	-	It helps to prevent evaporation. Though, need planning not to cause oxygen depletion
Employment	Positive	Occur	Occur	Higher in conventional PV

Table 2. Comparison of environmental impacts and attributes for conventional and floating PV during construction.

Aspect	Impact	Floating PV	Conventional PV	Comments
Site access	Deforestation	Might occur	Might occur	The magnitude depends on the local characteristics.
Site access	Traffic in the area	Might increase	Might increase	Higher in floating PV
Noise	Disturb wildlife and visitors	Might occur	Might occur	Needs noise management plan
Waste generation	Pollution and contamination	Might occur	Might occur	Needs waste management plan. There might be different waste generated in conventional and floating PV.
Employment	Positive	Occur	Occur	Depends on the technology adopted

Park. Noise will only exist during construction and it is a common parameter in both terrestrial and FPV; PV technology does not produce noise during operation. The time required for floating system installation is not clear because it does not require site preparation (supress vegetation and civil infrastructure); however, the floating might be complex to be mounted on top of the buoyant structure and the local site accessibility to install the system. Usually terrestrial projects varying from 1 to 5 MW capacity take up to 100 days to be implemented while projects above 25 MW take more than 210 days to be constructed (Ghosh et al. 2014). Utility-scale solar photovoltaic power plants might take more than 12–14 months to complete installation process. No studies on time require to install/mount large-scale FPV have been reported, the duration might be the same but conditioned to environmental conditions such as wind velocity in the local. Noise on FPV depends on the technology and usage of heavy machinery and traffic to transport and place the buoyant structure on the reservoir.

In this phase, many materials are generated as well, including: cardboard boxes, diverse plastic materials, wooden pallets, metal wastes and cables, concrete, office material, and human sewage waste from toilets (Abbasi and Abbasi 2000; Guerin 2017a). Therefore, a waste management plan is required to minimise impacts caused by incorrect waste disposal during construction. FPV plants are considered more sustainable in terms of waste management too because these power plants do not require concrete structures and some electrical machinery used in conventional systems (Sharma et al. 2015). The amount of waste, though, might be superior in floating system due to the disposal of plastic used to wrap the buoyant structure.

Employment

Finally, employment generated during construction can be a positive impact of the project. The number of employees, however, is difficult to predict depending on the project capacity and occurs generally during this phase only. Ghosh et al. (2014) summarises the number of jobs created during all phases of a solar energy project. According to the authors, there is demand for both skilled and unskilled workers during the construction and commissioning phases. Full-time permanent positions vary from 12 to 30 persons according to the project's capacity; unskilled workers are also required, to complete the construction in short-time employment term, the median number increase with the power capacity of the project and vary from 50 to 450 persons (Ghosh et al. 2014). Conventional PV will probably generate more jobs due to the additional machinery to mount the system, FPV might only require screw drives to place the PV panels depending on the technology adopted. Additional studies must tackle employment rates in different FPV designs (see (Cazzaniga et al. 2017) for a review on FPV designs). The analysis with main environmental impacts is summarised in Table 2.

Operational phase and decommissioning

Cleaning, water consumption, dust suppressants, and impact on fauna

In the operation phase, conventional PV plants usually need to apply a large quantity of dust suppressants and water to clean the panels and prevent dust generation in the area (Lovich and Ennen 2011). The lack of vegetation increases dust generation through windy weather conditions in desert areas, intensifying the necessity of chemical to prevent dust on the system. Guerin (2017b) cited the use of weed suppressants in the power plant area of conventional PV. These chemicals are extremely toxic to the environmental and might cause many negative impacts to fauna and flora in the long term (Abbasi and Abbasi 2000; Lovich and Ennen 2011; Hernandez et al. 2014). Manual vegetation trimming is preferable in forested areas of the tropics because weed control through chemicals might contaminate the soil and groundwater. An alternative to manual grass trimming is to use animals (such as sheep) to eat and control weed growth beneath and around panels. The issue with dust cleaning is linked to water consumption in PV facilities, for instance, in desert areas in the USA where PV system are installed water consumption to clean and operate large-scale solar projects (thermal in particular) is the most noteworthy social barrier negatively affecting the development of USSE (Simon 2009). There are also concerns of water pollution from the suppressants used to clean the panels. These suppressants can be made of salts, fibre mixtures, lignin, clay additives, petroleum, organic nonpetroleum products, mulch, brines, synthetic polymers, and sulfonate. Contamination with these chemicals can lead to mortality of fish and other animals in the short term or water quality depletion due to growth of algae and loss of oxygen in the water body (Ettinger 1987; Lovich and Ennen 2011; Grippo et al. 2015). From a logistic point of view, the floating system is assumed to require less water for cleaning (Cazzaniga et al. 2017) since the system is placed far from the land and influence of dust carried by wind. No chemicals must also be used for cleaning of FPV due to the high risk of water body contamination and pollution. However, some contaminants might be released to the water body and atmosphere due to boat traffic to access the panels for maintenance, oil and lubricant spills, components natural degradation (i.e. anti-corrosion painting) (Costa 2017).

The literature reports that FPV systems can be used to save water due to the blockage of sunlight in the reservoir caused by the panels that prevents evaporation. In arid climates, such as Australia, a rough estimate that 5,000–20,000 m^3 of water can be saved per year for each MWp installed as FPV (Rosa-Clot et al. 2017). The system is a good strategy for irrigation lakes (Santafé et al. 2014a) and reservoirs designated to supply water for human consumption. Though, covering the entire lake surface should be avoided, in particular in lakes with organisms such as fish and algae, to guarantee sunlight penetration and production of oxygen through photosynthetic organisms. It is worth mentioning that although water evaporation control might be a positive aspect for irrigation lakes and water reservoirs, however, some natural lakes might suffer detrimental impacts due to shading and changes in the microclimate. Even when the system is spaced a few meters away for sunlight penetration, fauna and flora underneath the photovoltaic structure might likely change their interaction environment as their microclimate is under change. As result from FPV in natural lakes could cause some more substantial impacts in comparison to artificial water surfaces and suffer from public concerns for installation. However, further investigation must be done to assess the magnitude of this impact and its long-term importance depending on local characteristics and project's size. Other implications of FPV on lakes on the aquatic environment can include (Costa 2017) the electromagnetic field caused by the cabling on the bottom or lake surface; creation of habitat for aquatic alien species (algae and exotic encrusting species for instance); and habitat for bird roosting. The disturbances generated in the decommissioning are similar to the ones occurred on the installation process such as increase in suspended solids, changes in geomorphology of the bottom of the lake, temporary impact on water quality and lake fauna, noise and impacts on the surrounding area due to machinery traffic (Costa 2017).

Waste management

Another concern associated with the operation and decommissioning phases of PV projects is the waste management during operation and after the project lifetime. During the operation of the PV plant and decommissioning, waste management consists mostly of following the waste management plan and guidelines for replacement and disposal of batteries (when applicable), panels, and other malfunctioning equipment (Tsoutsos et al. 2005; Aman et al. 2015). Humidity and elevated temperatures can increase batteries (when applicable) and cell degradation, shortening its lifetime (Pingel et al. 2010); degradation of PV components in tropical areas must be addressed to estimate the quantity of material to be replaced during operation. These PV components are classified as E-waste so they must be sent to specialised facilities for segregation, recycling, and adequate disposal. Recycling of PV components is essential to lessen natural resource depletion in the future (Marwede and Reller 2012). Moreover, recycling of PV components recovers valuable materials such as copper, indium, gallium, diselenide, cadmium, telluride, and many silicon materials (McDonald and Pearce 2010). In case of the floating system, the waste management plan must also account for disposal of the floating structures. Plus the panels, inverters, cables and connectors common to the conventional system, the FPV system is composed of pontoon, floats, and mooring system (Choi 2014b; Santafé et al. 2014b; Sahu et al. 2016). The floating structure can contain galvanised iron, medium and high density polyethylene (the entire structure or just the pipes), aluminium and steel frames, metal rods, polyester and nautical ropes, and an anchor structure (weights) that can be made out of concrete (Santafé et al. 2014a, 2014b; Sahu et al. 2016; Cazzaniga et al. 2017). Lee et al. (2014) present the design, construction, and installation of floating structure for PV system using pultruded fibre reinforced polyethylene (PFRP) members as an alternative to minimise costs with the floating structure. A life cycle assessment might be used to quantify the impacts of structures during all phases of its lifetime (construction-operation-decommissioning) (Aman et al. 2015) and support the environmental assessment. More studies are needed addressing the producer and consumer responsibility and legal aspects on the disposal of waste from PV installation

Visual pollution

Visual pollution is often reported as a negative impact of large-scale photovoltaic projects. Mounting the system on the rooftop of houses and building facades is a suggestion used to minimise this negative impact. Allocating USSE facilities in desert areas is another alternative to alleviate visual pollution. When PV systems are placed in areas away from residences, visual pollution might not be a concern in both terrestrial and FPV system. Whenever this detrimental impact is an important affair for the public opinion, architecture and design might be applied in the mounting phase to improve the public acceptance of the project. If this strategy is applied to FPV system in lakes or parks and some protected areas with tourism, both lake and the solar system might be considered as local sightseeing, generating clean energy and minimising many negative impacts on the environment. The floating structure can be used to design new shapes to allow better appearance of the project, though the electrical engineering of the whole project has to be well designed to match the different architecture with generation of energy.

Positive impacts

Finally, there are positive environmental impacts encountered during all phases of the solar energy project. The first positive aspect is the generation of electricity without emissions of CO_2 or noise generation during its operation. The FPV is expected to generate about 11% more electricity than over land PV system due to the cooling effect on the panels caused by water evaporation on the lake (Choi 2014a). Employment of new personnel also occurs during operation and decommissioning; operation and maintenance (O&M) hires new personnel in permanent and short-term positions in proportions ranging from 3 to 12 permanent skilled workers per year to 7–30 unskilled workers per year in conventional PV plants (Ghosh et al. 2014). A study in Europe stated that 47% of jobs are created during O&M and decommissioning in solar photovoltaic (EY, Solar Power Europe 2017). However, due to inferior necessity to clean the panels and lower risks to overheat the system in FPV (Sahu et al. 2016), a decrease of 50% in employment rate is assumed for the FPV during O&M (Ciet el Terre Brazil, personal communication), decommissioning will follow the same ratio as installation phase of 1 kWp/hour/worker. There is still need for data on the number of employees during decommissioning phase; moreover, the estimates for job generation will vary according to each country and its solar industry, and not always will employ local community workers (Ribeiro et al. 2014).

Carbon dioxide and other toxic gas emission savings must be accounted as a positive impact of PV installation in comparison to others sources of energy (Turney and Fthenakis 2011). CO_2 savings through USSE reported in the literature vary from 0.53 kg CO_2/kWh (De Marco et al. 2014) to 0.6–1.0 kg/kWh (Tsoutsos et al. 2005). The 1 MW floating system simulated in Korea can save up to 471.21 tCO_2/year generating 971.57 MWh (Song and Choi 2016). A life cycle assessment should be carried out in future works to better estimate the quantity of CO_2 saved discounting the amount of CO_2 emission during all components fabrication, in particular the floating structure. Table 3 expresses the main environmental impacts assessed during operation and decommissioning.

Conclusion

This paper addressed and compared the environmental impacts caused during all phases of terrestrial and FPV projects focusing on countries with tropical climate. The analysis of the environmental impacts also pointed out promising results towards the installation of a FPV in artificial lakes and reservoirs with multiple purposes such agriculture, water storage, and hydro dams. The overall impacts associated with project allocation such as deforestation (for the project implementation and site accessing), bird mortality, erosion, runoff, and change in microclimate are expected to have higher magnitudes on the implementation of conventional PV facilities. Thus, concerning the environment, FPV is more suitable because it minimises these problems associated with conventional terrestrial utility-scale solar facilities. The FPV might minimise water evaporation from the lake and prevent algae growth, though more studies are still required in this area and need to be assessed locally considering all environmental conditions. The impact on water evaporation needs to be better assessed on natural lakes because it might change the local microclimate and cause disturbances to the local fauna and flora.

Table 3. Environmental impacts and attributes during operation and decommissioning phases.

Aspect	Impact	Floating PV	Conventional PV	Comments
Water consumption	Depletion of water resources	Occur	Occur	Higher consumption in conventional PV
Application of chemicals	Contamination and pollution	Not recommended	Might occur	Floating PV might not need dust suppressant or application of herbicides to control weeds
Visual pollution	Discomfort	Might occur	Might occur	Allocating the project far from population might minimise this impact
Waste	Pollution and contamination	Needed	Needed	Waste management plan is required during operation and at decommissioning
Employment	Positive	Occur	Occur	Needs further studies
Energy	Positive	Occur	Occur	Higher energy generation in floating PV
CO_2 savings	Positive	Occur	Occur	Needs further studies to access CO_2 savings during operation to CO_2 emitted to produce all components

Another benefit pointed out in the literature is that FPV will generate more electricity than conventional PV installations due to the cooling effect provided by the vapour of water that interacts with the back of the PV panels in the reservoir/lake.

Under the construction and operation phases, traffic of light and heavy vehicles may increase in the area. Thus, specific measures must be taken to lessen disturbances caused by noise and pollution on wildlife, residences, and visitors if the area is a park. Furthermore, studies must be done to compare disturbances due to required number of trips and total time to install floating and terrestrial PV. Another important aspect to reduce environmental impacts is the implementation of a waste management plan during construction. There will be similar topics in both terrestrial and FPV under the waste management plan such as toilet cabins for workers. However, some specificities of each project have to be addressed because floating and conventional PV have different components hence there will be different types of waste during construction phase.

Both projects will generate job opportunities for the community, though when there aren't skilled workers in the local community, external workers will be needed which might cause conflict in public acceptance in the local community (see a case study in Portugal and Spain (Ribeiro et al. 2014)). The construction/installation will generate more jobs than the operation phase. It is noteworthy that FPV may generate fewer opportunities than conventional PV due to higher complexity machinery and installation in conventional ground-mounted photovoltaic; this aspect might be very relevant for decision-making prior allocating a large-scale solar photovoltaic.

The results highlight advantages of FPV over conventional PV during operation and decommissioning phases. First of all, water consumption for cleaning the panels is expected to be higher for conventional PV due to the deforestation and soil exposition in the area. Moreover, the FPV is not expected to utilise chemicals such as dust suppressants and herbicides. Visual pollution might not be a concern for implementation, though specific studies are required to access the public acceptance of both terrestrial and FPV in the chosen area; natural lakes with great biodiversity and recreational purposes can experience public drawback for allocation. Future surveys concerning FPV might point out the same perspective as terrestrial PV: local population are mostly concerned with benefits of the project, i.e. job creation, increase in gross added value, and infrastructure, rather than ecological parameters (Ribeiro et al. 2014; Carlisle et al. 2015, 2016; Delicado et al. 2016). Waste management plan and reserve logistic plan must also be accounted for; and these procedures are mandatory for both systems.

Finally, CO_2 capture is expected to be greater in the FPV systems. Additional studies better addressing CO_2 savings in floating and conventional must be done, in particular, studies including a life cycle assessment discounting the CO_2 emitted during manufacturing of the structure and components. Further studies including SEA through qualitative and quantitative methods should be done, analysing critical aspects of the alternatives proposed as well as suggesting mitigation tactics for possible environmental impacts (Finnveden et al. 2003). Moreover, existent SEA and EIA reports around the world should go under analysis to assess their effectiveness for assessing environmental impacts and aid decision-making as SEA and EIA went for wind offshore energy in Europe (Marshall and Fischer 2006; Phylip-Jones and Fischer 2015) (see a guideline for SEA in (Fischer and Nadeem 2013)). Particularly, SEA and EIA for large-scale FPV must be latter addressed as it is a quite new locational alternative without long-term case-study investigation.

- For bulleted lists

(1) FPV reduce many impacts during allocation
(2) More mitigation measures might be required during installation of floating projects
(3) Advantages are observed during operation of FPV plants
(4) Impacts in artificial lakes might differ from natural lakes due to microclimate.

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Chapter III

Environmental licensing and energy policy regulating utility-scale solar photovoltaic installations in Brazil: status and future perspectives

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Environmental licensing and energy policy regulating utility-scale solar photovoltaic installations in Brazil: status and future perspectives

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ABSTRACT
Procurement auctions have been the main mechanism to ensure the deployment of utility-scale solar photovoltaic installations (USSPVI) in Brazil. To participate in the auction, investors must comply with all established requirements. In the solar case, the criteria incorporate State environmental licensing regulations (EL). The procurement auctions are a nationwide competition whereas the environmental licensing for those projects are under state jurisdiction. The lack of national guidance to licensing USSPVI might cause significant movement of projects to States whose EL procedures require fewer studies. This work examines the role of environmental licensing in the energy planning for USSPVI in Brazil. Analysing the 27 state regulations establishing the screening requirements that subject EIA to USSPVI, there are uneven threshold criteria to determine whether the plant will go through simplified licensing or regular process. There is also a need for studies tackling strategic environmental assessment for wind and solar expansion in Brazil. Specifically, incorporation of community concerns, public participation, and environmental constraints into the early stages of decision-making to prevent impacts and conflicts.

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Introduction

Utility scale solar photovoltaic installations (USSPVI) date back to the 1980s in the United States of America and Europe totaling about 11 MW in capacity by 1990 (Schaefer 1990). Thirty years later, the photovoltaic installed capacity has grown significantly around the world due to technological improvements, concerns about climate change, pollution from traditional energy sources, economies of scale, and a decrease in prices of panels and inverters. The worldwide estimated total capacity in 2015 was 227 GW (World Energy Council 2016) and one year later the new world' solar capacity increased to 303 GW due to the installation of at least 75 new solar farms (IEA-PVS Reporting Countries 2017). Table 1 summarizes the largest solar photovoltaic installations around the world indicating their location, capacity, and operator (the most significant in each region).

Brazil has a great solar energy generation potential due to its tropical location near the equator with a global horizontal radiation of 4.53–5.49 kWh/m^2.day (Pereira et al. 2017). Studies point out that Brazil's capacity to use solar PV is superior to European countries leading the expansion of this technology (mostly distributed PV) such as Germany, Spain, and Italy (Pereira et al. 2017). However, centralized solar photovoltaic installed capacity did not even count in the country's power mix in 2014. Electricity generation from USSPVI accounted for less than 1%. Most of the electricity currently generated, 64%, comes from hydropower plants (ANEEL 2018a). Nevertheless, due to difficulties of constructing new hydropower plants and the goal of maintaining high share of renewables, the country is expanding renewable energy sources other than hydro (e.g. biomass, wind, and solar energies) to at least 23% of the power mix by 2030 (UNFCCC 2015; EPE, MME 2017). The Paris Agreement, COP21, is another driver to increase utility-scale solar PV installations in the country. Brazil's Nationally Determined Contribution (NDC) aims to reduce GHG (greenhouse gases) emissions by 37% and 47% below 2005 levels by 2025 and 2030, respectively. This goal involves intense investment in renewable energy in the country's energy mix (UNFCCC 2015). In this context, solar energy auctions have played an important role in expanding centralized solar PV in the country. USSPVI in Brazil already represents 2% of the national installed capacity and the government national target predicts further development of this technology.

Previous studies have tackled conventional fossil fuels, nuclear, and hydro electricity generation and their environmental impacts. Indeed, there are abundant regulations and standards to mitigate their

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Table 1. Utility-scale solar photovoltaic plants in the world.

Operator/nameplate	Capacity	Location
Tengger Desert Solar Park	1547 MW	Zhongwei, China
Kurnool Ultra Mega Solar Park	1000 MW	Kurnool, India
Pavagada Solar Park	600 MW	Pavagada, India[a]
Solar Stars	579 MW	California, USA
Topaz Solar Farm	550 MW	California, USA
EDF Energies Nouvelles	400 MW	Pirapora, Brazil[b]
Cestas Solar Park	300 MW	Gironde, France
Nova Olinda Solar Park	290 MW	Piauí, Brazil
Ituverava Solar Park	252 MW	Bahia, Brazil
Mohammed Bin Rashid Al Maktoum Solar Park	213 MW	Dubai, United Arab Emirates[c]
De Aar Solar Farm	175 MW	De Aar, South Africa
Nacaome and Valle Solar Plant	146 MW	Honduras
El Salvador Solar Park	101 MW	Rosario, EL Salvador
USSE New South Wales	100 MW	Central NWS, Australia

[a]commissioned, the solar plant will have 2000 MW at its full capacity. [b]Under construction. [c]final capacity of 5000 MW by 2050.

impacts. Electricity generation through solar PV and wind are new and seen as environmental-friendly technologies, generally preferred by the public. Some wind farms in Brazil, however, are experiencing drawbacks because of impacts on local communities, that is, displacement of inhabitants, alterations in community subsistence, and nonenvironmental compensation. These communities claim that wind farms might not be as 'sustainable' as the media state [see (Gorayeb and Brannstrom 2016; Brannstrom et al. 2017; Paiva and Lima 2017)]. This led to demands for federal regulations to guide the growth of wind energy and to secure public acceptance towards this technology. The federal regulation usually addresses general criteria to include in the screening process for environmental permits approval.

Unlike wind farms and hydropower, utility-scale solar PV is somewhat new in Brazil and has been claimed to be an 'eco-friendly' alternative with low potential to damage the environment or pose threats to communities. Stakeholders and interested parties might question the need for environmental licensing and prior detailed studies because this technology has little impact on the environment. The international literature addressing the environmental impact of solar farms and their sustainability shows that USSPVI is not free from environmental or socioeconomic impacts, which should not, therefore, be neglected for decision-making [see (Turney and Fthenakis 2011; Hernandez et al. 2014; Da Silva and Branco 2018)]. However, little work has been done towards the federal and state environmental regulation surrounding environmental impact assessment (EIA), environmental licensing (EL) regulations, and integration of these instruments in the energy planning for USSPVI.

Regarding USSPVI in Brazil, there have been some studies analyzing Brazilian auction systems to procure electricity from solar farms and diversify the energy matrix (Dobrotkova et al. 2018; Viana and Ramos 2018). The procurement auctions are a nationwide competition whereas the environmental licensing for those projects are under state jurisdiction. The lack of national guidance for licensing large-scale PV installations might result in new projects moving to States whose environmental licensing process requires fewer studies. Other state governments might then be tempted to loosen their environmental licensing requirements in order to attract investments from the energy sector and lead to a cycle of impacts on sensitive areas and socioeconomic conflicts.

This work examines the current environmental regulations for licensing of utility-scale photovoltaic installations in Brazil. This paper also addresses energy policy toward utility-scale PV plants and connects the roles of environmental licensing in the energy planning for the country. At the end, the paper presents general advices aiming to guide future environmental regulations towards USSPVI.

The paper is divided as follows. The first part of this paper addresses energy governance and points out the growth in large-scale solar PV installations using national predictions. It also describes the auction systems used to procure new solar farms in the country, which is a component of the energy policy and planning for USSPVI in Brazil. This section also introduces the role of environmental aspects in the energy auctions. The second part focuses on the environmental framework at State and Federal levels to license large-scale PV power plants. At this stage, the environmental licensing procedures required for the allocation of these plants are introduced and discussed. The main Federal and State parameters required to license solar PV farms are also examined. This analysis shows the current status of the screening and scoping process for impact assessment studies used for solar energy planning in Brazil. The third part of this work deals with barriers and future perspectives for utility-scale PV in Brazil. Much of the analysis in this section is based on several issues raised by the expansion of large-scale onshore wind installed capacity. This may be the first paper addressing large-scale photovoltaic and environmental regulatory framework in Brazil and might lead to baseline studies in other countries as well.

Methodology

The methodology consisted of a bibliographic review of papers, focusing on utility-scale solar photovoltaic power plants, Brazilian laws, and regulations for the sector, and procedures for environmental licensing in the country. First, the topic of energy regulation and laws was based on the many resolutions set by the Brazilian Electricity Regulatory Agency (ANEEL) and the official guidelines and reports published by the Energy Research Office (EPE). The review focused on actual data of the installation of solar farms, the procedures considered for energy planning, and projections for the expansion of the technology. The second part tackled environmental regulation, especially environmental licensing, and how it interacts with energy regulation for planning and decision-making. At the national level, the National Environmental Council's (CONAMA) resolutions related to environmental licensing were consulted. Intensive research was also carried out on all 27 State Environmental Protection Agencies' (SEPA) websites to acquire data and analyze the current procedures for environmental licensing of solar farms at state level. The analysis first identified whether SEPA had regulated environmental licensing of USSPVI or not. Secondly, when specific regulations existed, a study was made of the criteria used for screening procedures of impact assessments for USSPVI, which determine whether regular detailed studies or simplified versions are needed. In the final section, a literature review of environmental impacts was conducted to point out current social and environmental constraints and conflicts of multimegawatt solar farms. The data are used to verify whether Brazilian state regulations are considered preventive and to propose improvements to environmental regulation for licensing. As utility-scale solar PV is quite new in Brazil, there has not previously been a Brazilian study on large photovoltaics installations. Thus, previous literature addressing conflicts and constraints for wind farms in northeast Brazil was consulted to suggest recommendations to avoid conflicts in future projects.

Brazilian energy policy for utility-scale solar PV

Electricity governance in Brazil and solar PV status

The energy governance in Brazil is executed by many federal agencies. Each is responsible for managing different aspects of the electricity sector. The electricity governance structure is summarized as follows (De Melo et al. 2016; Förster and Amazo 2016; Hochberg and Poudineh 2018; Viana and Ramos 2018):

- **CNPE – National Council for Energy Policy**: Proposes energy policies to the President of the Republic and supports the formulation of policies for national and regional energy planning.
- **MME – Ministry of Mines and Energy**: Formulates and implements policies for the energy sector in Brazil following directives given by CNPE. MME defines auctions guidelines, that is, techno-economic parameters and auction design, and fixes the initial price ceiling in electricity auctions.
- **EPE – Energy Research Office**: Supports the MME with studies on energy generation, transmission, and distribution aimed at energy planning in both short and long terms. The EPE also counsels MME on general aspects of energy auctions such as initial price ceiling and techno-economic aspects.
- **ANEEL – Brazilian Electricity Regulatory Agency**: Regulates and supervises electricity generation, transmission, distribution, and commercialization. The agency leads auctions, manages documents in the initial phase, and provides guidance to market players.
- **CCEE – Electric Energy Trading Chamber**: Functions as the wholesale electricity market operator. CCEE manages also long-term contracts between electricity distributors and generators.

The energy plans elaborated by EPE and approved by MME indicate long-term and medium-term sectoral expansion through the Energy National Plan (ENP) and the Decadal Plan for Energy Expansion (PDE), respectively. Then the auction ensures an efficient procurement of the solar energy projects. It is noteworthy that following the ANEEL resolutions 482/2012 and 687/2015, which classified PV systems below 5 MW capacity as microdistributed generation,[1] only projects above 5 MW are eligible to register on procurement auctions (ANEEL 2012). The EPE decadal plan estimates that USSPVI will grow from 1.3 GW to 7 GW in the horizon 2017–2026 reaching 55 GW by 2050 (EPE & MME 2017; Tolmasquim 2018). Currently, there is 0.8 GW of utility-scale solar PV under construction in the country plus another 0.9 GW authorized to initiate construction (ANEEL 2018a).

Energy regulation for microscale distribution PV systems placed on rooftops, parking lots, and solar condominiums for commercial and industrial electricity generation are important and discussed in the literature. Utility-scale PV plants, nevertheless, are still leading the market share and will continue on this trend for at least the next 5 years according to the Global Market Outlook for 2018–2022 (SolarPower Europe 2018). China has been placing policies to promote a shift from large-scale PV to distributed PV system; however, such policies have been judged unsuccessful (Zhang 2016). For instance, from the new 130 GW installed capacity in China, 106 GW accounts to utility-scale PV whereas rest are distributed PV system below 30 MW (which might be large

[1] Some countries might adopt different scales and count this capacity as medium to large scale. For instance, (Lai et al. 2017) classifies large-scale PV projects ranging from 10 to several MWs. Other authors and countries may otherwise target all projects above 1 MW as a large-scale generating system.

scale in some countries) (SolarPower Europe 2018). Germany has also stood out on promoting regulation to deploy distributed PV [see (Wirth 2018)] rather than utility-scale plants. In the Brazilian context, the authors (Vazquez and Hallack 2018) claimed that except for the environmental aspect, for which small-scale plants do not require analysis, energy regulation favors the installation of large-scale projects for commercial purposes. The authors also stress that it is necessary to establish clear incentives and regulations to make distributed PV feasible. Other studies specifically addressing Brazilian energy policy for distributed solar PV can be found in (De Melo et al. 2016; Aquila et al. 2017; Bradshaw 2017). However, as the present work focuses on utility-scale PV, the energy policy for distributed solar PV modality will not be further considered.

Procurement auctions for solar PV

Procurement auctions have been adopted in Brazil since 2004 as the main mechanism to promote the deployment of new energy power plants, guarantee supply adequacy to the national grid, reduce dependence on hydro plants, and achieve goals to decrease CO_2 emissions. At the beginning of the process the MME edict a regulation giving the main guidelines for auctions and indicating the deadline for investors to submit their projects for EPE analysis. At this initial screening stage, 4–5 months before the auction, only projects meeting the minimum requirements established by MME and EPE are allowed to participate in the auction, which includes environmental licensing [see (IRENA & CEM 2015; Förster and Amazo 2016; Bradshaw 2017; Dobrotkova et al. 2018; Hochberg and Poudineh 2018; Viana and Ramos 2018)]. Most of the auction procedure is executed in a hybrid scheme of descending clock auction (iterative auction) followed by a pay-as-bid (sealed-bid auction) phase. In the iterative auction phase, an initial ceiling price is announced so bidders must indicate the amount of electricity they are willing to supply at this given price. After each round, auctioneers continue to decrease price and receive new bids until the supply meets the demand plus an adjustment factor. In the second phase, all continuing bidders must propose a final blind sealed-bid lower or equal to the previous price. Final selected bidders to sign the PPA contract are those which present the lowest prices below clearance point (IRENA 2013; IRENA, CEM 2015; Förster and Amazo 2016; Hochberg and Poudineh 2018). The investors that offer the lowest price in the auction sign a 20-year power purchase agreement (PPA) with distributors (regular auction) or CCEE (reserve auction).

As wind energy has experienced a successful expansion through the procurement auctions, the Brazilian government aims to follow a similar path for centralized solar PV plants, and the MME has held five auctions since 2014 intended to procure centralized solar PV. The 2014 Reserve auction added the criterion 'specific technology competition' that made possible for solar PV to avoid competition with wind and other energy sources. Solar PV plants now compete only with other PV projects based on the demand for solar PV in the Brazilian electricity grid (EPE 2017; Viana and Ramos 2018). The following auctions in which solar PV competed (second and third auctions of 2015, second auction of 2016, and the first auction of 2018) adopted the same criterion of technology specific competition. The second auction for reserve energy of 2016 was cancelled due to the economic crisis and an electricity surplus.

The requirements for participation in the solar energy auction incorporate state environmental licensing and others technical-economic parameters such as solar certificate, water grant use, and land use rights (IRENA 2013; IRENA, CEM 2015; Dobrotkova et al. 2018; Hochberg and Poudineh 2018). In Brazil, project developers are responsible for selecting sites for solar plants, carrying out the preliminary environmental studies, and obtaining a preliminary license (LP – acronym for licença prévia in Portuguese) during the initial planning stage. LP is issued to approve the project's location. Environmental permits are, therefore, a critical issue to be analyzed to guarantee the project's success in the auction. For instance, in the 2014 reserve energy auction, 73% of the projects did not qualify due to problems related to environmental licensing (EPE 2014). In the following auctions, 8 projects did not qualify due to problems with the LP in the 1st auction of 2015, whereas this increased to 46 projects in the second auction of 2015. Disqualification due to environmental noncompliances amounted to 16 projects in the cancelled auction of 2016 (EPE 2015a, 2015b, 2016).

Considering all four valid auctions, 2047 solar PV projects were registered, 1166 were qualified to bid in the auctions, while 123 projects earned the PPA contract. This accounts to approximately 30 projects per

Table 2. Solar PV auctions history and distribution of projects. *combined results from the two auctions of the same year. N: number of projects registered. W: number of winners. IC: installed capacity.

	2014		2015*		2018		
State	N	W	N	W	N	W	IC (MW)
Bahia	161	**14**	332	**18**	177	-	833.94
Ceará	21	**2**	49	**4**	50	**14**	570.00
Goiás	4	**1**	6	-	-	-	10.00
Mato Grosso do Sul	-	-	2	-	20	-	-
Mato Grosso	1	-	-	-	-	-	-
Minas Gerais	17	**3**	97	**14**	40	**6**	679.80
Paraíba	26	**1**	47	**4**	26	-	144.00
Pernambuco	43	-	78	**4**	38	**3**	171.90
Piauí	45	-	150	**9**	114	**6**	449.8
Rio Grande do Norte	25	**1**	136	**5**	98	-	170.00
São Paulo	42	**9**	90	**1**	40	-	275.00
Tocantins	15	-	44	**4**	13	-	95.00
Totals	400	**31**	1,031	**63**	616	**29**	3,399.44

auction (ANEEL 2018b), see Table 2 for a summary with auction history in Brazil. All solar plants varied in capacity from 10 to 30 MW. It is noteworthy that although some projects are registered as 30 MW to benefit from governmental incentives, some belong to the same company and will be part of a multimegawatt solar farm.

Cumulative impacts of utility-scale PV must be reviewed in environmental studies from a strategic point of view for allocating new activities in the area, as their environmental impact can be significant (Grippo et al. 2015). Unfortunately, recent research demonstrated that the cumulative impact assessment is not satisfactory among EIA in Brazil (Lucia et al. 2011; Duarte et al. 2017) and might not be considered in the registration process for the project's participation in the auction.

The environmental framework

Environmental regulation and licensing

The Environment National Council (CONAMA) resolution 01/1986 determined that the environmental governance in Brazil would be executed in three spheres: federal, state, and local. This resolution also provided the framework for the elaboration of the EIA, whilst the resolution 237/1997 regulated the EL process in the country. According to the resolution 237/1997, modified by the complementary law 140/2011 and federal degree 8.437/2015, the project's environmental license will be assessed by one single institution depending on the location of the installation of the activity, except for special cases which are licensed by the federal environmental agency only, as listed in the decree 8.437/2015. The IBAMA (Brazilian Institute of Environment and Renewable Natural Resources) is responsible for licensing at the federal level, which usually occurs for projects falling in two state territories, offshore projects, federally protected areas, military sites, and nuclear plants. State Environmental Protection Agency (SEPA) licenses follow similar criteria, licensing projects located within two or more municipalities, state protected areas and forests, or when the IBAMA gives them power to act. Local Environmental Agencies (LEA) can license activities that solely affect their areas. First, the Environmental Agency (EA) will carry out the screening process to determine whether the project requires EIA or another simplified study. The following step is to establish the general scoping for the study, in other words, the key parameters to be assessed and methods to be used in the impact assessment (Morris and Therivel 2001; UNEP 2002; Glasson et al. 2012).

Environmental licensing follows a three-stage process. First, the proponent is required to obtain an LP (planning and design stage). This license attests the project's environmental viability, approves its location and design, and establishes general guidance for the following phases. At this initial planning stage, the proponent must also present the Environmental Impact Assessment which has to be approved by the Environmental Agency. For the national energy planning, LP is the main environmental requirement because its approval means the fulfilment of all scoping parameters determined by the EA. Nationwide, EIA is the main environmental study to support decision-making. Regarding simplified version of EIA, there are several state-wide nomenclatures providing the screening requirements (sometimes slightly modified). Table 3 shows different environmental studies requested for environmental licensing of USSPVI in the country. Most of the approaches are only shortened forms of environmental assessment to substitute the EIA and provide a simplified environmental license. The different nomenclatures for simplified studies were introduced by other CONAMA resolutions to fill gaps in the EIA and licensing of specific activities such as seismic exploration for petroleum research or mining activities. States adopted the nomenclature and created their own standards for producing of the studies to support licensing

Table 3. Types of environmental studies to support preliminary licensing. Based on (CONAMA 1997, 2001; CETESB 2014).

EIA- Environmental Impact Assessment RIMA – Environmental Impact Report	Regulated by the CONAMA 237/1997. It is necessary to assess impacts resulted from projects of significant potential to modify and degrade humans' health and natural environment. It must contain a fully assessment of biotic, abiotic, and socioeconomic environments. Moreover, the study must tackle all technological and locational alternatives, assess impacts from all phases of implementation, define zones of direct and indirect impact, and verify the project's compatibility to local policies and programs. Rima is the short version of the impact assessment and has to address the main conclusions of full report in accessible language with graphics so the public can understand the whole study.
RAP – Preliminary Environmental Assessment RAA – Environmental Assessment Report	Substitute EIA and RIMA to license projects of potential impact to the environment (but not necessarily significant). All parameters listed in EIA might be addressed at less complex assessment. Mitigation measures must also be contemplated in the study. RAA is often used when there is a pre-existent similar project in the same area.
RCA – Environmental Controlling Assessment	May be requested for approving the LP in cases EIA and RIMA is not necessary due to low impact on the environment or humans. The focus of RCA is given to mitigation measures, however, the report also addresses insights about the location, environmental aspects, construction, operation, potential impacts at all phases.
RAS or EAS – Simplified Environmental Assessment	Created through CONAMA 279/2001 to subsidy simplified energy sources EL and provide LP for projects of low impact on the environment. RAS must contain insights about the location, installation, operation, environmental aspects, potential impacts, and mitigation measures (similar to RCA).

procedures. Although other countries might also have a similar approach, the uneven nomenclature is noteworthy in Brazil. The different nomenclature might confuse stakeholders examining environmental criteria for project installation in more than one state.

The second stage is the Installation/Construction License (Licença de Instalação – LI), which authorizes the construction of the project according to the approved specifications in the plans, programs, and mitigating measures. The final stage is the Operating License (Licença de Operação – LO) permitting the project to fully start operating [see some studies addressing the environmental licensing in (Glasson et al. 2000; Lima and Magrini 2010; Bragagnolo et al. 2017; Fonseca et al. 2017)]. Each license type has a specific expiration date depending on the issuing EA and should be renewed before the expiry date. Moreover, a single environmental license process might be issued for small projects in the same area and under the same legal responsibility (CONAMA 1997), which occurs for solar farms composed of multiple 10–30 MW commercial scale plants. If projects are within the same area and proposed by different proponents, an individual license will be issued for each one.

Legal framework applied to the renewable energy sector

Environmental Licensing procedures have been claimed to be the main issue for delaying delivery of projects (World Bank 2008; IRENA, CEM 2015; Förster and Amazo 2016); especially those concerning energy (Lima and Magrini 2010). In the case of renewable energy onshore utility scale projects in Brazil, the EL screening and scoping falls into responsibility of SEPAs. These agencies follow guidelines from federal resolutions (CONAMAs) and adopt also their own criteria considering local socio-economic and environmental characteristics.

For energy generation, the CONAMA 01/86 pointed out the need to assess impacts of any electricity generation source above 10 MW, which was the first parameter for EIA and licensing of energy sources for many years. A new regulation for the sector was therefore needed. In 2001 the CONAMA 279/2001 was published as the main legal framework for environmental regulation of renewable energy. In order to give more celerity to the process, CONAMA issued this simplified fast track environmental license process (60 days) for electricity generation projects, **of any capacity**, that cause low environmental degradation, including: transmission lines, hydro and thermoelectricity, and other alternative sources of electricity (i.e. solar, wind, and biomass) (CONAMA 2001).

As large-scale wind energy grew exponentially during this period, a new environmental legal framework for renewable energy was created, the CONAMA 462/2014. The latter resolution addressed specific screening procedures for onshore wind energy and established simplified licensing (LP and LI) and studies for wind farms. With this resolution screening process, a full EIA is required only if the project impacts protected areas, endangered species, heritage sites, or replaces local inhabitants (CONAMA 2014). The project proponent hires a consulting company to conduct a prior assessment of the area. The initial results are sent to the SEPA which will scope the appropriate study to support the project's implementation. Hochstetler (2016) argues that CONAMA 462/2014 is positive and might be considered conflict preventive as the resolution maintains the regular EIA for special locations, such as dunes and coastlines. The practice, nonetheless, has shown that this regulation has not extinguished conflicts (socio or economic) with communities affected by wind energy farms. The impacted groups usually seek support from the Brazilian Prosecutor's Office (MP) to stop a project's deployment or receive economic compensation. This process, which is often called the 'judicialization of EIA', causes delays on the project's development. Therefore, even if renewable energy is not installed on a special area described in the CONAMA resolution, utility-wind demonstrated that they may not always be seen as 'low impact' (Gorayeb and Brannstrom 2016; Brannstrom et al. 2017; Gorayeb et al. 2018). USSPVI share similar characteristics to wind farms such as the land requirement, status of low impacting technology, and inexperience with impact assessment in comparison to hydro. The latter aspect is extremely relevant for decision-making because a lack of knowledge of potential impacts could be a weakness (Glasson et al. 2012) recognized in the environmental licensing. In this sense, utility solar PV plants could be subject to similar conflicts as the technology grows in number of installations.

Regarding utility-scale PV installations, it is noteworthy that procurement auctions are nationwide competitions and investors seek locations of high resource availability (irradiation), good logistics, grid connection, land acquisition at low costs, and flexible environmental licensing. As previously mentioned, environmental licensing is a crucial aspect to compete in the energy auctions. The research conducted found out that, currently, 15 out of the 27 states have screened a state-wide resolution with parameters that subject solar or wind energy to simplified licensing. Pernambuco, Paraíba, and Piauí are among the states without a specific screened resolution; this region has high irradiation levels and current investments attracting new USSPVI, see Figure 1.

The SEPA uses criteria such as the installed capacity (in MW) or the total area occupied to select a starting point for consideration. Based the project's likely environmental degradation and the mentioned criteria, the SEPA determines the environmental study

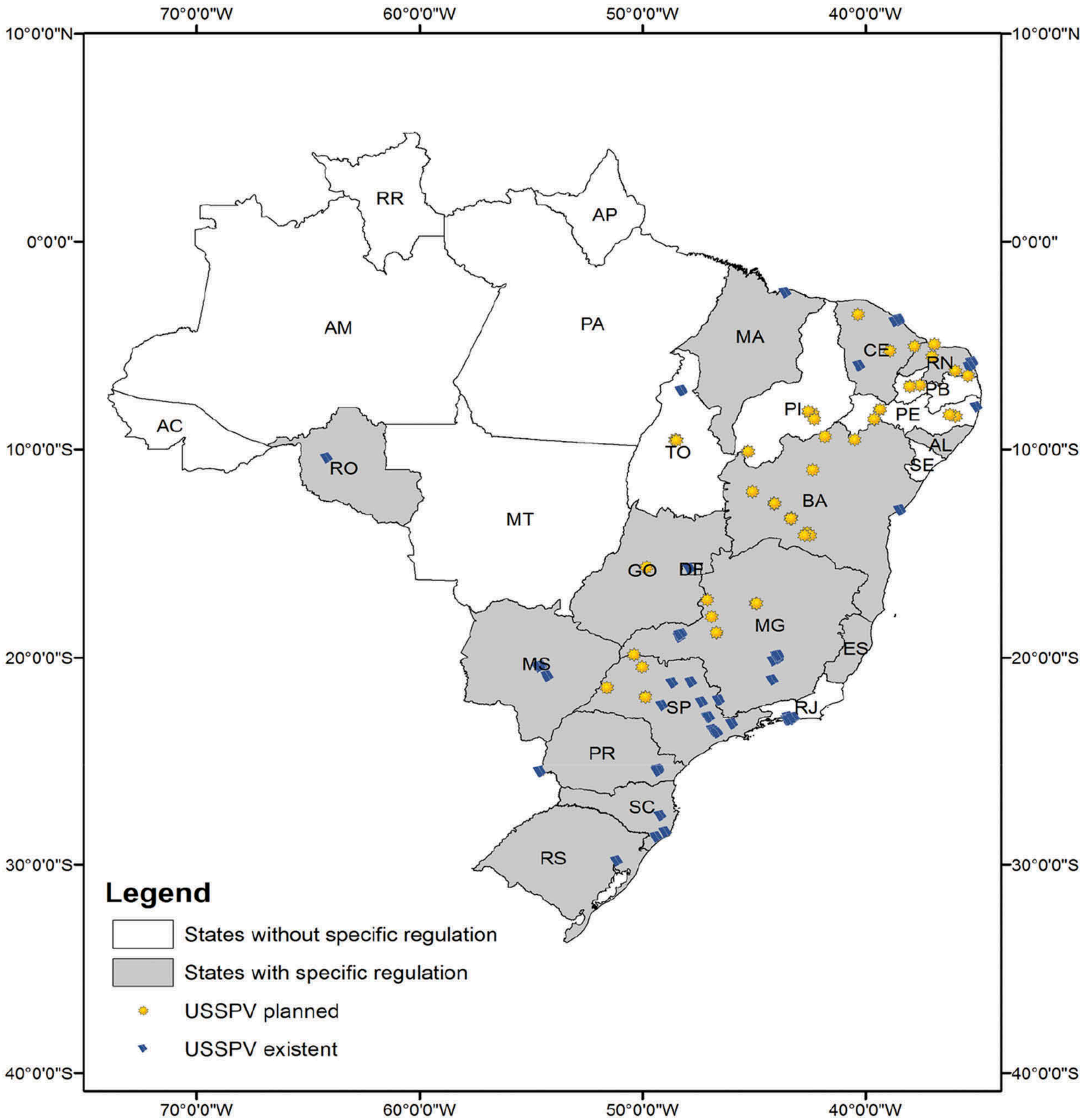

Figure 1. States with and without specific regulation for solar PV licensing plus current and future hired contracted projects. Source: elaborated by authors with data from states and (EPE & MME 2019).

(EIA or simplified version) to support the project's licensing. For instance, Glasson et al. (2012) reports that in the United Kingdom, wind farms above 5 MW (or with more than 5 turbines) are likely to undergo regular EIA procedure. The present work highlights that most Brazilian states have regulated criteria for licensing of wind or solar PV farm. Nevertheless, there is no national threshold established for EL of renewable energy. In the state regulations, there are great differences in the starting point criteria used to screen out regular EIA as mandatory requirement in the licensing process.

For solar farms, many Brazilian states use land occupation criterion to identify the significance of impacts according to four scales: micro, small, moderate, and large-scale, Table 4. Despite the differences in the project scales, SEPAs in those states classify all solar/wind farms as posing low potential to alter the environment. Moreover, the study necessary for licensing is not mentioned in the regulation, inferring that even large-scale solar PV farms could be approved with simplified licensing. This is a highly contradictory criterion to be used because moderate to large multimegawatt scale projects can disturb fauna, remove flora, resettle inhabitants, and modify the landscape, among other impacts. There is, therefore, a need to improve environmental screening and scoping criteria for environmental licensing of renewable energy projects in those states. However, there are states which clearly specify threshold intervals (in

Table 4. Criteria to license utility-scale solar PV without assigning the environmental impact assessment study. Remarks: EIA and RIMA may be requisite if project's location impacts protected area prescribed in CONAMA 237/2011 and 462/2014.

State	Scale definition (MW or ha)		Legal framework
Bahia	Small: below 50 ha; moderate: from 50 to 200 ha; large: above 200 ha. **Potential**: low potential to degrade the environment.		CEPRAM n°4420/2015
Espírito Santo	Small: below 50 ha; moderate: from 50 to 200 ha; large: above 200 ha. **Potential**: low potential to degrade the environment.		Norm n° 14/2016.
Federal District	License nonrequired for solar of any scale if project does not suppress vegetation		CONAM n° 10/2017
Rio Grande do Norte	Micro: below 5 MW; small: from 5 to 15 MW; moderate: from 15 to 45 MW; large: from 45 to 135 MW; exceptional: above 135 MW. **Potential**: low potential to degrade the environment.		CONEMA n° 4/2011; 2/2014;
Rio Grande do Sul	Small: below 10 MW; moderate: from 10 MW to 30 MW; large: from 30 to 50 MW; exceptional: above 50 MW. **Potential**: low potential to degrade the environment. Micro: below 40 ha; small: from 40.01 to 300 ha; moderate: from 300.01 to 600 ha; large: from 600.01 to 1000 ha; exceptional: above 1000 ha.		FEPAM N.º 004/2011; CONSEMA 372/2018
Rondônia	Moderate: from 5 to 10 MW; large: from 10 to 20 MW; exceptional: above 20 MW. **Potential**: low potential to degrade the environment.	Licensing nonrequired for micro- and small-scale projects (**below 5 MW**).	State law n° 3,686/2015

Table 5. States criteria to license utility-scale solar PV assigning the environmental impact assessment study. Remarks: EIA and RIMA may be requisite if project's location impacts protected area prescribed in CONAMA 237/2011 and 462/2014.

	Criteria: area (ha) or installed capacity (MW)				
State	Regular EIA for licensing	Simplified studies for licensing	Descriptive report required	License nonrequired	Legal framework
Alagoas	-	Above 30 MW (RAA); 1 to 30 MW (EAS)	-	-	CEPRAM n°170/2015
Ceará	Unmentioned	3–5 MW	2–3 MW	Below 2 MW	COEMA Nº 3/2016
Goiás	Above 100 ha	30–100 ha (RAS)	Below 30 ha (register, no study)	Micro/mini generation	SECIMA/GAB n° 36/2017
Maranhão	Nonapplicable	From 15 to 50 MW (descriptive report or RAS) Above 50 MW (RAS)	Below 15 MW (descriptive report for unique LP/LI license)		Norm SEMA n° 74/2013
Mato Grosso do Sul	-	Above 10 ha (RAS)	Below 10 ha (unique LP/LI)		SEMADE Nº 9/2015
Minas Gerais	Above 80 MW	10–80 MW (RCA)	-	-	Document n°1 GEMUC/DPED/FEAM/2013 COPAM n°217/2017
Paraná	Above 10 MW	5–10 MW	1–5 MW	Below 1 MW	Document IAP Nº 19/2017
Santa Catarina		1–30 MW (RAP) Above 30 MW (EAS)	-	Below 1 MW (register)	FATMA Norm 65/2017 CONSEMA n°14/2012
São Paulo	Above 90 MW	5–90 MW (EAS)	-	Below 5 MW	SMA Nº 74/2017

EIA: Environmental Impact Assessment. RAS or EAS: Simplified Environmental Assessment. RCA: Environmental Controlling Assessment. RAA: Environmental Assessment Report. RAP: Preliminary Environmental Assessment.

MW or area (ha)) and the required environmental study for environmental licensing based on project's potential to degrade the environment, Table 5. This classification seems to be a more acceptable approach to support the licensing and give a clear parameter for stakeholders at the planning stage. The intervals established for environmental licensing, nevertheless, should be uniform. Offsetting criteria requirements for EIA and licensing have been previously discussed in proposals to reform the system in Brazil [see (Fonseca et al. 2017)].

Conflicts and recommendations

USSPVI may in some cases modify the local environment during its installation, operation, and decommissioning, causing mortality in birds' and other animals', change local microclimates, enhance erosion, and sediment loads in water bodies. Other concerns include the use of chemical suppressants that pollute water resources and soil, suppress of vegetation, change the landscape, and visual pollution. There is also noise pollution during installation and decommissioning and the creation of conditions for the development and spreading of invasive grasses [see studies in (Torres-Sibille et al. 2009; Fthenakis et al. 2011; Lovich and Ennen 2011; Grippo et al. 2015; Rose and Wollert 2015; Delfanti et al. 2016; Suuronen et al. 2017)]. In addition, there may be concerns about water consumption for panel cleaning, displacement of local inhabitants, conflicts for land cover, restriction of access to recreational areas, and risks related to fire and flooding resulting from changes in the geomorphology (Tsoutsos et al. 2005; Turney and Fthenakis 2011; Da Silva and Branco 2018).

[2] That is, the Brazilian savannahs, and Caatinga biome in the Brazilian northeast (high irradiation levels) or Atlantic Forest across all coastlines (populated area).

In the context of Brazil, a country with large biodiversity and extensive vegetated areas, the overconcentration of utility-scale PV plants in some states where there are sensitive natural areas[2] might lead to conflicts with environmentalists. Moreover, a general concern is land requirement for several large-scale PV installations in a specific area. The spreading of multiple USSPV plants can occupy hundreds of hectares and possibly interfere in the resettlement of small communities living nearby, see a case in the Zongoro 100 MW solar PV, Nigeria (EnvironQuest 2017). As USSPVI are new in Brazil, there have not been any cases reported, though the impacts of wind farms on communities in northeastern Brazil is described in (Hochstetler and Tranjan 2016; Brannstrom et al. 2017; Gorayeb et al. 2018). The aspects addressed are common for various types of projects; nevertheless as wind and solar share similarities during installation, the planning stage should pay closer attention to potential conflicts on solar PV expansion. A list of common areas of conflict for wind and solar farms include (Araújo 2016; Gorayeb and Brannstrom 2016; Brannstrom et al. 2017; Paiva and Lima 2017):

- Obstruction of access roads to nearby communities/cities during construction phase;
- Lack of public participation in the process of decision-making in the planning stages;
- Privatization of areas used for subsistence by local communities;
- Land rights fraud;
- Resettlement of inhabitants;
- Exaggerated promise of economic benefits, for example, employment, electricity at low tariff, improvement in quality of life; and
- Noncompensation of impacts and lack of monitoring during operating phase.

Social conflicts could potentially reduce the perceived sustainability of solar PV. USSPVI may suffer from the same problems if clear and rigorous criteria are not defined to better assess the environmental and cumulative impacts of several ground-mounted PV plants. The nonstandard requirement for licensing and the criteria requiring less complex environmental studies might also be the target of critiques and legal conflicts with the Public Prosecutor's Office. Poor quality content can be observed even in the scoping of regular detailed EIA (Ministério Público Federal 2004; World Bank 2008; Chang et al. 2013; Borioni et al. 2017; Bragagnolo et al. 2017; Fonseca et al. 2017; Hochstetler 2018). Hence, in the attempt to propose improvements for policy making and environmental licensing under federal and state jurisdiction, the present study suggests that there should be a federal norm regulating licensing of USSPV installations. The norm should clearly set project sizes (installed capacity or area occupied) for which EIA would be mandatory. State agencies would have to consult this new federal regulation and scope similar rules for licensing of renewable energy sources for electricity generation under state jurisdiction.

Concerning Regulation of environmental licensing based on environmental impacts, an important note is the emerging application of utility-scale floating PV, first launched in China with 40 MW. Da Silva and Branco (2018), comparing terrestrial to floating PV, point out many benefits and lower negative impacts of floating PV over conventional terrestrial-based PV. Brazil has a great potential to exploit floating PV in hydro dams (Sacramento et al. 2015; Da Silva and Souza 2017). One exists already (10 MW floating PV pilot plant split between the Sobradinho and Balbina dams), and the government plans to expand its installed capacity to 300 MW (Ministério de Minas e Energia 2017). Therefore, future studies and regulation might well focus on licensing of floating PV once this modality increases in the country. Nonetheless, the environment licensing criteria for large-scale floating PV might be less stringent on artificial lakes such as reservoirs and rigid in natural lakes.

It is important to highlight that the examination of environmental studies and judgment on issuing the environmental license might take several months 'delaying the development of the country', especially for complex large-scale projects. In 2013, three proposals by state-level EIA agencies and industries were published. Fonseca et al. (2017) argues that although the proposals are intended to make EIA and EL simpler, faster, and less bureaucratic, they would, nevertheless, require less detailed studies to support decision-making. Furthermore, there is uncertainty regarding the real impacts of the proposed changes on licensing and EIA process. The probable future scenario with these suggested changes might be of partial implementation and creation of other problems. Several authors in (Bragagnolo et al. 2017; Duarte et al. 2017; Hochstetler 2018) explore the proposed law amendments (PL 3729/2004, PEC 65/2012, PEC 654/2015, and law 13,334/2016), discussed over the years in the Brazilian Chamber of Deputies, to reform EIA process and environmental licensing. The authors claim that the alterations would withdraw environmental licensing for infrastructure projects of significant importance for the country's development and make the environmental licensing more flexible and possibly less effective. The MP made a public statement opposing any similar proposal stating that they are unconstitutional. Therefore, the latter statement in addition to the current political instability suppressed the discussion for now according to (Hochstetler 2018). If environmental licensing were more flexible, new large-scale PV installation and wind farms would be constructed without further concerns about the likely negative impacts. However, as shown in the previous section, it is noteworthy that renewable energy plants such as photovoltaic and wind already have few rules regarding licensing requirements for the preliminary license and project's location approval.

In order to improve the role of EIA in the Brazilian environmental governance towards utility-scale solar PV, this work recommends the following steps for environmental planning of utility-scale PV.

- Formulate a national regulation for licensing of utility-scale solar PV;
- Improve EIA screening by regulating a national threshold, by installed capacity or area occupied, for which EIA should be mandatory in the licensing of terrestrial and floating PV;
- Enforce the necessity of methods that integrate different areas (economic, social, and environmental) and cumulative impacts even in simplified studies (Benson 2003);
- List sensitive areas where solar energy is off limits to any deployment;
- Standardization of nomenclature used for environmental studies; and
- Integrate Strategic Environmental Assessment (SEA)[3] in the process of energy planning, see a case study in UK concerning offshore wind and SEA (Glasson et al. 2012).

Conclusions

This study addresses environmental licensing and energy policy regarding utility-scale photovoltaic expansion in Brazil. The key objective was to examine the EIA current status for utility-scale solar PV and its role in the nationwide energy planning.

Regarding energy planning, energy regulation for USSPV plants follows the same criteria used for wind and other conventional electricity sources. There is a national plan which directs future demand and supply for electricity-specific generation. Procurement auctions are then implemented to guarantee that the targets proposed will be met. Environmental licensing is a mandatory component for projects to compete in the auction process. Projects lacking the preliminary environmental permit are not considered in the screening stage. Official data from EPE also affirms that environmental licensing is one of main reasons for disqualification in the screening process.

Major concerns arise in environmental regulation; currently, there is no specific CONAMA resolution and legislation addressing licensing criteria for USSPVI. Although there is a CONAMA resolution for wind farms, conflicts still exist as the resolution gives states authority to propose criteria for licensing based on the technology's 'low potential' to harm the environment. In addition, drawbacks have been observed in the lack of public participation during the planning process.

Analyzing the 27 state regulations regarding the screening requirements that subject EIA to USSPV installations, there are uneven threshold criteria to determine whether the plant will go through simplified licensing or regular process. Many EAs do not assign the environmental study-type necessary to support decision-making; this can bring insecurity to investors on choosing locations for future projects. Furthermore, it is discussed that criteria to issue environmental permits to renewable energy other than hydro is quite flexible. The process is enforced by resolutions guaranteeing studies that might easily overlook potential conflicts and the cumulative effects of multimegawatts power plants. Therefore, a national regulation scoping in EIA for solar and wind farms should be created to offset the criterion for simplified studies. The starting criterion to mandate EIA must be defined based on several studies and the realistic USSPVI potential to degrade the environment.

Finally, the Brazilian experience with large-scale renewable energy plants might also be very different from international cases in developed countries due to socioeconomic and regulatory parameters. Based on the wind experience in Brazil, unless proper environmental planning is conducted, USSPV plants will likely be prone to interventions from the MP regarding impacts on traditional communities or sensitive. This calls for new federal regulatory benchmarks setting principles and standards criteria for licensing of centralized solar PV. Recommendations are made is proposed to improve the environmental governance of renewable energy solar PV. The last recommendation stresses the importance of SEA in the energy planning, especially in the formulation of environmental and energy policies (Ahmed and Sánchez-Triana 2008). SEA is not project specific as EIA and can be used with Geographical Information Systems to screen suitable territories with minimal environmental and socio constraints, see (Glasson et al. 2012). These areas would be the preferred sites for utility-scale PV expansion and subject to fast track licensing. In fact, many European countries have been addressing SEA for energy planning (Fischer

[3] SEA can be used to select strategic areas, prescreened by studies, at which the environmental and social constrains are minimal. For instance, the inexistence of protected areas, communities, endangered fauna, or any element of concern in the defined area suitable for USSPV deployment. Investor would use these predefined areas to propose new projects.

and Onyango 2012) such as Belgium (Jay 2010), the United Kingdom, Germany (Phylip-Jones and Fischer 2015), and Portugal (Partidário 2012). There is, therefore, a need for studies tackling SEA for wind and solar expansion in Brazil. Specifically, incorporation of community concerns, public participation, and environmental constraints into the early stages of decision-making to prevent impacts ad conflicts.

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Chapter IV

A multicriteria proposal for large-scale solar photovoltaic impact assessment

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A multicriteria proposal for large-scale solar photovoltaic impact assessment

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ABSTRACT

Large-scale photovoltaic (LSPV) may cause significant changes in the environment and lead to detrimental impacts on the natural and anthropic environments. First, this paper reviews the scholarly literature to collect data regarding the different environmental impacts occurring during LSPV installation and operation. Secondly, methods used in the Environmental Impact Assessment (EIA) for LSPV are evaluated through a sample of 20 EIAs. This shows that there are flaws in the methodology used in the EIAs that support environmental licensing of LSPV. In this context, this work proposes a multicriteria approach that aims to convey the main environmental and socio-economic aspects of LSPV and assess impact magnitude and importance. The method is built on the needs to improve EIA for the licensing of solar projects in Brazil. The model offers a structured approach that incorporates detailed criteria that reflect direct and indirect impacts of both terrestrial and floating PV and is designed to provide the assessment magnitude and estimate scenarios according to different stakeholder's views.

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Introduction

Many countries are adopting the installation of large-scale solar photovoltaic (LSPV) plants to power energy and reduce fossil fuels dependency as well as GHG emissions. The worldwide Solar PV total installed capacity amounted to 227 GW in 2015, year of the Paris agreement. Due to the installation of 75 new solar farms, especially driven by China, the 2016–2017 new world's solar PV installed capacity amounted to 303 GW (World Energy Council 2016; IEA-PVS Reporting Countries 2017).

Brazil, which is mainly a hydropower electricity production country, has a huge solar energy potential and large available lands for implementation. Due to recent droughts and international policies driving to mix the energy matrix, the country is investing to diversify its energy generation with large-scale wind and solar PV farms. The first multi-megawatt wind farm (5 MW – 10 turbines of 500 kW each) was installed in 1999; the deployment of centralised PV came more recently, in 2011, with the 1 MWp Tauá solar plant (ANEEL 2002). In the context of expansion, the decadal plan produced by the Energy Research Office (EPE) predicts that by 2026 the current 0.75% of solar energy PV participation in the matrix will be expanded to 10% (7 GW) behind only to hydropower and wind (EPE, MME 2017; ANEEL 2018). Despite being a renewable alternative to generate energy without releasing GHG to the atmosphere on its operation, LSPV projects are susceptible to cause environmental impacts and potentially degrade the area, particularly related to the intense land requirement for installation and changing the landscape (Turney and Fthenakis 2011; Wu et al. 2014). Da Silva and Branco (2018) provides a comprehensive review on impacts contrasting terrestrial and floating solar plants.

In Brazil, centralised solar PV installations are mandated to go through environmental licensing supported by Environmental Impact Assessment (EIA). The International Association for Impact Assessment (IAIA) describes EIA as 'the process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken' (IAIA 1999). Social aspects of EIA are usually addressed as socio-economic impacts due to trade-offs between biophysical impacts and social gains (Morrison-Saunders and Fischer 2006). In terms of the current EIA process, Hochstetler (2018) carried out a survey in Latin America and argued that, theoretically, Brazil is a regional leader on procedures of impact assessment (IA) and EIA scoping. The practice, however, reveals that some approved EIA overlooked potential direct and indirect impacts (Neri et al. 2016; Hochstetler 2018). For example, Brannstrom et al. (2017) and Gorayeb et al. (2018) discuss the poor impact assessment performed in the installation and licensing of wind farms in the Brazilian Northeast which resulted in community unacceptability towards the new developments in the site. Moreover, Duarte et al. (2017) conducted a survey with EIA practitioners in Brazil to discover their opinions about the quality of process

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and EIA studies in the country. The authors claim that there is a negative view regarding the poor quality of the EIA method, which does not estimate cumulative impacts or present impact magnitudes (Duarte et al. 2017). Another comprehensive worldwide review of impact assessment in EIA provided by the South Africa Department of Environmental Affairs and Tourism (DEAT) suggested that environmental impact significance is poorly assessed and represents only technical perspectives; the judgment method to explain the scientific background behind the evaluation criteria is often missing in the reports; and the scoping is highly influenced by EIA team members (DEAT 2002). Lack of cumulative and indirect impacts in EIA is also acknowledged in the international literature (Morris and Therivel 2001). Indirect impacts and cumulative effects are difficult to measure and depend on the solar PV scale and the environmental characteristics (Tsoutsos et al. 2005). The method of impact prediction can be qualitative or quantitative (Morris and Therivel 2001). However, many EIA studies are merely descriptive and deficient in quantitative analysis (Nadeem and Hameed 2006). As result, the methods of impact assessment fail to integrate complex environment-socio-legal aspects (Canter and Sadler 1997). Yet, full integration of parameters is seen with some scepticism (Fischer and Nadeem 2013) and subject to prevailing economic aspects (Morrison-Saunders and Fischer 2006). Moreover, EIA has been evaluated in different ways due to governance mechanisms adopted by each country (Arts et al. 2012).

For Brazil, Magrini (1992) detected a similar issue when large hydropower plants were being expanded in the 1980s. The author proposes a multicriteria method to incorporate distinguish aspects such as environmental, social, and legal issues in the impact assessment to improve EIA's quality. Although the primary goal was to apply the methodology for hydroelectric plants, the approach seemed to be adaptable to application for different technologies and situations. For example, later adaptations of the method include risk assessment in a landfill (Magrini et al. 2011) and a consulting project to assess the magnitude of the impacts of Mariana mining accidental dam collapse (Magrini and La Rovere 2016). LSPV is new in the country hence EIA screening criteria for impact assessment of LSPV are unclear and depend on State agencies' guides for licensing, which might not have enough experience with the technology (Da Silva et al. 2019). Thus, it is expected that EIA for LSPV plants suffers similar problems in the quality of impact assessment methods as those described in the literature.

The purpose of this work is to propose a multicriteria approach that aims to convey the main environmental and socio-economic aspects of LSPV plants and assess impact magnitude and importance. The method is built on the needs to improve impact assessment practised in EIA for the licensing of solar projects in Brazil. The approach will be based on the SAMAMBAIA method (Portuguese acronym for 'Sistema de Análise Multicritério Aplicado como Método Base à Avaliação de Impacto Ambiental'- Multicriteria Analysis System applied as a Baseline Method to Environmental Impact Assessment) and its version for hydropower impact assessment (SAMAMBAIA-H)[1] (Magrini 1992). Furthermore, the objective of this work also includes a survey of how EIA and their IA methodological aspects are being treated towards LSPV in Brazil and around the world. This analysis aims to build up an understanding of multicriteria necessity to impact assessment of LSPV. Therefore, a section of this paper is dedicated to present the analysis of selected EIAs and their impact assessment methods.

The first uncertainty is the classification of LSPV and the second is the definition of project size required to present a detailed EIA for environmental licensing. For the former problem, the Brazilian Electricity Regulatory Agency (ANEEL) resolution 482/2012 classifies centralised PV commercial-scale projects above 5 MW (ANEEL 2012). This is the indicator of size significance for photovoltaic projects in the country. For the latter uncertainty that regards to environmental concerns and licensing, each Brazilian state can have its own criteria to require EIA before installing solar PV plants. The screening criterion varies from projects covering a minimum area of 100 hectares (ha) to all above 10 MWp PV plants according to (Da Silva et al. 2019), which will be the benchmark for LSPV plants in this study.

Therefore, in order to fulfil the analysis and its relevance for application in Brazil, and possibly worldwide, the second part of this paper covers the main environmental impacts caused by installation, operation, and decommissioning of LSPV (considering both terrestrial and floating PV). The purpose of this section is to highlight that although LSPV is a renewable source and often less impactful than conventional alternatives, there are many effects on the environment that must be accounted for. The following section (third part) analyses the main approaches used to assess impacts in real EIA for LSPV worldwide. This is a key section showing the importance to come up with a new and practicable approach to improve the quality of the studies. The method is then described in detail and continuously compared to other multicriteria approaches in the fourth part of this work and its implications for EIA in Brazil in the final fifth part.

Solar energy environmental impacts

Impacts on the physical-ecosystem environments

The most impactful phase for LSPV is the site preparation and installation. At this stage, there might be significant changes in the local natural landscape.

The land required for the installation of LSPV is usually very high of the order of 1 km^2 (or 100 ha) for each 20–30 MW (Wu et al. 2014). If the area has not been previously degraded, there will be a necessity to remove the local vegetation plus other activities such as opening trenches for cablings (Guerin 2017a, 2017b). These environmental aspects leave the soil fragile to erosion processes. The latter might also enhance sediment load in the surrounding lakes causing siltation and depletion of water resources (i.e. turbidity and eutrophication). Flood risks and increase in fire risks are cited in the literature and EIA studies as too other features for LSPV. Concerning fire risks, there are studies pointing out changes in the microclimate temperature due to the removal vegetation and increase in the local albedo. This in turn may also cause intensify local water evapotranspiration, except in floating PV, drying bush vegetation raising fire occurrence risks, see (Abbasi and Abbasi 2000; Turney and Fthenakis 2011; Marrou et al. 2013; Wu et al. 2014; Grippo et al. 2015; Guerin 2017a; Da Silva and Branco 2018). The aesthetic change in the landscape may be a key impact (Rodrigues et al. 2010) since the environment might suffer significant alterations in the landscape concerning the removal of vegetation and alteration in the local geomorphology (Torres-Sibille et al. 2009) which affects both terrestrial and aquatic ecosystems. During this phase, there will likely be intensive use of heavy machinery for foundation and transportation of equipment as well as an increase in vehicle traffic in the area (Guerin 2017a, 2017b). Some impacts are soil compaction, intermittent noise pollution (construction phase only), low to moderate emission of air pollutants such as SO_2, NO_2, particular matter (PM), O_3, and CO (Turney and Fthenakis 2011), waste generation (solid and effluent), accidental spillage of vehicle lubricants and oils (Rudman and Esler 2017), and stress on local roads and infrastructure (Guerin 2017a). Loss of habitat and consequently endogenous/endemic species (fauna and flora) is, perhaps, the most impactful issue concerning site preparation, vegetation suppression, and land occupation (Da Silva and Branco 2018). It is noteworthy to identify possible bird migration routes (Jenkins et al. 2015) as there might be impacts of LSPV on their nesting and breeding habitats. During the operational phase, the literature reports avian mortality caused by either direct impact with panels or other structures in the area (Walston et al. 2016). Although the site is enclosed by fencing limiting animals' entrance, there are cases when animals can access the facility and use it as hiding spots and for preying strategies (Fthenakis et al. 2011). Birds and bats can easily fly over fences and interact with the facility structure as well. Surprisingly some insects might be attracted to panels due to the glare effect emitted which, in turn, might attract avian fauna and cause mortality (Grippo et al. 2015; Gasparatos et al. 2017). Another concern is the propitious environment for exotic species installation in the area, some foreign bush vegetation may find perfect environmental conditions to spread across the area. In floating PV the cabling and floating structure can also host encrusted species (Costa 2017; Da Silva and Branco 2018). Animals, such as sheep, are frequently used to control vegetation growth; however, herbicides are as well applied to stop the spreading of undesired plants on the site [see a case study in (Guerin 2017a)]. Chemicals in the herbicides, dust suppressants (used to control dust generation in the site and optimise panels performance) or lubricants and oil spillage can potentially be a threat to fauna and flora due to its toxic components (Ettinger 1987; Abbasi and Abbasi 2000).

Impacts on the socio-economic environment

Without doubt, public acceptance is a key feature for permitting any type of project in a region, thus conflict of interest among communities, developers, and other stakeholders will cause a drawback in the project implementation (Vanclay et al. 2015). The installation of LSPV might require resettlement of local inhabitants to other areas, e.g. the 100 MW Solar Independent Power Plant and transmission line in Zongoro Village, Ganjuwa–Nigeria (EnvironQuest 2017). Resettlement of population can be a major source of conflict since it alters not only the environment but the way people live and interact with the land. In rural areas, land subsistence is highly noted for PV installations (Hanger et al. 2016; EnvironQuest 2017). Some projects are then placed in deserts to avoid such conflicts and take advantage of high irradiation levels (Hanger et al. 2016). There is a displacement of viable land that could be used for agriculture or housing, to energy generation. Large water consumption for panel cleaning is also pointed out as a key concern in water-stressed areas (Hernandez et al. 2014); this is particularly water-stressed regions such as the semiarid. The installation of large projects occupying great area might also directly or indirectly impact recreational uses in the area (Carlisle et al. 2016; Hoffacker et al. 2016), for instance, fishing activities or access to a specific site near the project's area. Positive impacts are often pointed out in the literature and EIA hearings. Some of the benefits include the increase in local job opportunities for both skilled and unskilled people in the project or in related areas (i.e. construction, recycling, maintenance). Increase in local domestic product and tourism with incoming of new inhabitants to work on the project. Improvements of local services infrastructure, i.e. roads, as a conditional parameter. Supply energy for the region/country and reduce greenhouse gases emissions (Ribeiro et al. 2014; EY, Solar Power Europe 2017; Ferroukhi et al. 2017; Da Silva and Branco 2018).

Impact assessment approaches for large-scale solar photovoltaic: Brazil and worldwide

This section turns its attention to methods in EIA for solar energy. As an emerging technology, there has been little energy and environmental regulation for licensing of renewable sources. There is no consolidated legislation for EIA of solar energy, nor is there a consolidated methodology for assessing these technologies impacts; in principle, any method can be used. Hence, the present study conducted detailed research to find real EIA reports for LSPV projects above 10 MW or occupying more than 100 ha. This investigation focused on the likely magnitudes and the integration of information appraised in the EIA. The local diagnosis and specific legal requirement are not addressed. Table 1 summarises the main findings for the analysis of 20 selected large-scale PV EIAs available worldwide. Other countries were analysed due to the shortage of online available EIA impact assessment for LSPV in Brazil. It is worth pointing out that many EIA reports below 10 MW were also analysed to check if any applied a multicriteria analysis, though none was found.

This research with selected EIAs for solar energy reveals that checklists and matrices are the main methods used in current EIAs to assess impacts of LSPV. The same trend is observed in past EIAs for other activities (Lemons and Porter 1992; Canter and Sadler 1997). This study also observed that all studies tend to include GIS (Geographic Information System) mapping to identify areas of direct and indirect impacts as well as possible environmental sources of interaction with the project, i.e. roads, protected area, and waterbodies.

Unsurprisingly, the studies lacked the integration of social-economic aspects into EIA. Assessment is mostly done in a descriptive manner focusing on each category alone and divided into several chapters (environment, social, economic, policies) throughout the report. Moreover, the analysis is based on a very subjective approach and there is a deficiency of criteria to judge the impacts, their interaction, temporality, and spatial distribution. None of the EIAs assigned a final score to the overall environmental impact in order to compare the different project alternatives (technological or spatial). Thereof, EIA may likely be ineffective to predict and prevent indirect impacts from conflicting issues concerning LSPV. The findings of this analysis are in agreement with the literature.

Checklists and matrices are good methodologies for a preliminary analysis to identify and organise data regarding the many aspects of one large project. However, the impact assessment should not be a linear process, it must otherwise incorporate diverse interactions and results at different scales. Therefore, a multicriteria approach proposed seems to be appropriate method to meet the growing necessity of predicting environmental impacts and incorporate all conflicting issues concerning the natural and anthropic environment through a single analysis.

Multicriteria approach applied to EIA

There are many types of multicriteria decision-making analysis (MCDA) that incorporate both, qualitative and quantitative criteria. Generally, the main goal is to select or rank the best alternative based on several criteria and interests. One example provided in the literature includes a web-designed multicriteria integrated with GIS to select the best sites to deploy solar energy projects in Spain. The criteria cover only technical and economic aspects of the energy, but the authors claim that future studies can address EIA (Wanderer and Herle 2015). Another MCDA applied to EIA of biomass energy in Slovakia compares the different alternatives and select the best option for

Table 1. Large-scale solar PV and main methods to assess their environmental impacts.

Name of project	Location	Size (MW)	Area (hectare)	Method	Type
Frv Massapê	Brazil	30	100	Checklist	Descriptive
Usina Fotovoltaica Francisco Sá	Brazil	90	220	Checklist	Descriptive
Pirapoca	Brazil	240	800	Checklist	Descriptive
Taua	Brazil	50	203	Checklist	Descriptive-quantitative
João Pinheiro	Brazil	90	260	Checklist	Descriptive
Metz Solar Farm	Australia	100	507	Checklist	Descriptive-quantitative
Nevertire	Australia	105	255	Checklist	Descriptive-quantitative
Solar Power Station Moree	Australia	150	300	Checklist	Descriptive
Nyngan Solar Plant	Australia	106	300	Checklist	Descriptive
Del Sur Solar Project	USA	100	293	Checklist	Descriptive
Rosamond Solar Array	USA	155	476	Checklist	Descriptive
Fotovoltaico Nacaome II	Honduras	50	90	Checklist	Descriptive-quantitative
Three phase PV power plant on the farm 267	South Africa	225	450	Checklist	Descriptive-quantitative
Sand Draai	South Africa	125	500	Checklist	Descriptive-quantitative
Alcoutim	Portugal	200	594	Matrices	Descriptive-quantitative
Ganjuwa Solar Plant	Nigeria	100	200	Matrices	Descriptive-quantitative
Malindi Solar Power Plant	Kenya	40	N/A	Checklist	Descriptive
Pavagada Solar PV Park	India	2000	4856	Checklist	Descriptive
Dahanur	India	40	140	Checklist	Descriptive
Benghan Solar PV Park	Egypt	1800	3720	Checklist	Descriptive

N/A: not available or not stated in the EIA. The analysis covered the EIA and its methodology to assess environmental impacts, the status of the project (construction or operation) is not given at this point.

installation in the area based on current legislation of the country (Ondrejka Harbulakova et al. 2018). An MCDA matrix is proposed (Kuitunen et al. 2008) to organise and compare different social and environmental aspects in different activities; the method, though, brings MCDA discussion to a strategic level broader than EIA itself. There is also work focusing on the hybridisation of least-cost analysis and MCDA to evaluate environmental impacts and select the best transmission line in Italy (Bagli et al. 2011). Despite the abundance of emerging methods in the international literature, it is the Analytic Hierarchy Process (AHP) developed by (Saaty 1987) which is usually cited when looking at the assessment of alternatives of energy projects and environmental impacts (Cheng et al. 2006; Huang et al. 2011; Wang and Poh 2014). AHP is a descriptive approach which uses pair-wise comparisons between alternative and criterion to estimate ratio-scaled importance (weights) (Løken 2007; Wang et al. 2009; Wang and Poh 2014). In fact, many of these models were adapted from previous MCDA. A review of all multicriteria methods is beyond the scope of this paper; however, some literature addressing the subject can be found in (Cheng et al. 2006; Wang et al. 2009; Mardani et al. 2017).

With regards to multicriteria decision-making as a method for impact assessment, we agree with Balasubramaniam and Voulvoulis (2005) who suggest that specialists should first judge the appropriateness of the methodology to achieve the objectives required in EIA; validity for the method and the easiness to apply the approach are also important to take into consideration (Hobbs 1985). With regards to EIA, Noble (2000) states that the report is undertaken when the decision to install the project has been made thus this environmental instrument has little power to influence decision-making. More specifically for decision-making in Brazil, the National Environmental Council resolution 01/1986 establishes that the Environmental Impact Statement (Estudo de Impacto Ambiental in Portuguese) should contain technical and locational alternatives to recommend the most viable solution. Borioni et al. (2017) conducted a survey of EIA scoping practised in 10 projects in Brazil. They claim that technical and locational alternatives are currently not the focus of the statements. Rather, EIAs appears to be applied to identify the outcomes of a determined project in order to allocate mitigation measures and prevent detrimental effects (Magrini 1992). We, therefore, suggest that the appropriate multicriteria proposal for impact assessment of LSPV should evidence the diverse project's effects on the environment and aid the selection of mitigation alternatives. The above-mentioned methods focused on the selection of areas or project, not on the integration of complex features of a specific project and its impact magnitudes and adverse effects on the environment.

The SAMAMBAIA method (Magrini 1992) was designed to reflect the requirements of EIA in Brazil and determine the most impacted areas and temporal occurrence of the significant impacts. The methodology has been validated in consulting and academic research. This method is subsequently adapted for large-scale PV impact assessment in Brazil and referred to as SAMAMBAIA-Solar.

Methodology approach proposed

SAMAMBAIA: the concept

The SAMAMBAIA method developed by Magrini in the early 1990s (Magrini 1992) is a multi-attribute analysis method, more specifically a multi-attribute value theory (MAVT) method, based on the Analytic Hierarchy Process (AHP) approach of Saaty (Saaty 1987). The general structure is as follows (Magrini 1992; Magrini and Viana 2012):

- **Definition of actions**: the first step is to identify temporal and spatial actions. Temporal actions are related to the impacts caused by the project during its lifetime (i.e. construction, operation and maintenance). Furthermore, the spatial distribution of impacts caused on a given geographical area is described and assessed in the spatial actions.
- **Definition of objectives and hierarchy tree construction**: this step is based on the Saaty AHP (Saaty 1987). The root objective is to 'reduce the environmental impacts' of the project. As a typical procedure of AHP, the main objective placed at the top of the hierarchy is decomposed into various sub-objectives, and sub-levels, typical of any MCDA (Løken 2007; San Cristóbal 2011; Wang and Poh 2014). As all objectives are subordinated to one another from top to bottom, the satisfaction of the lower sub-objective will automatically fulfil the higher objective in the same tree branch. In the model, the objectives placed at the top of the AHP are generally more strategic, whilst the sub-criteria at the bottom of the hierarchy are technical and specific.
- **Selection of evaluation criteria, rating scale, and value function**: the last sub-objective of each branch is named leaf-level objective. At each leaf-level objective, a composition of various evaluation criteria is used to assess the impact significance. The creation of evaluation criteria should follow a scale of impacts (from lower to higher impact). Experts in the respective field of expertise are invited to pair-wise the criteria chosen and assign magnitudes according to the rating scale varying from 1 to 100. The Saaty eigenvector technique is used to normalise the magnitudes and construct the function value for each evaluation

criteria. This function reflects the trade-off relationship between the two sub-criteria.

- **Assessment matrix**: this step consists of building a matrix of *i* columns by *j* lines, standing for spatial and temporal actions and the leaf-level objectives, respectively. A magnitude value should be assigned to each interaction 'objective x action'. Specialists in the field assign each magnitude, which is inserted in the function value that gives the normalised magnitude.
- **Weight definition**: first, the initial weights are assigned to the interaction of terminal criteria (pair-wise comparison) belonging to the same dimension (hierarchy level). Secondly, the total value score for each dimension is calculated by the eigenvector method of Saaty and the weighted sum approach. The pair-wise comparison, weight aggregation, and normalisation method are repeated on all dimensions above which the sub-level is directly or indirectly subordinated. A general suggestion is that specialists weight technical aspects (lower level of the hierarchy), whereas political stakeholders assign weights to political strategic aspects (top of the hierarchy). Many scenarios considering different weighting criteria can, therefore, be built to aid decision-making.
- **Final aggregation**: for each terminal criterion, the environmental impact is given by multiplying the final weight and the values from utility (value) function as $V = \sum P_i * V_i$. Where P_i are the final magnitudes and V_i are the values from the normalised value function for which the criteria is subordinated.

The proposed adaptation for large-scale solar photovoltaic

In the light of the above-mentioned steps, the following sections describe the adaptions conducted to apply the method on the impact assessment large-scale solar photovoltaic plants as a mean to improve the quality of the current assessment that assists environmental licensing of LSPV plants in Brazil.

Step 1: spatial and temporal actions

The proposed temporal actions adopted are construction (including land preparation and installation), operation and maintenance (O&M), and decommissioning; this classification is standard in impact assessment. The construction of spatial actions for LSPV plants is based on the study of (Carlisle et al. 2016) which showed that public acceptance towards LSPV varies according to distances from the project to distinguish land use types and socio-demographic areas such as protected areas, roads, residences, wildlife, agricultural land, and visual impact. Herein, instead of the traditional approach to characterise a 'direct and indirect zone of impact', this work suggests that it is reasonable to use a different approach to defining the impact boundaries based on socio-demographic impacts of solar facilities on land cover change. Four spatial boundaries are classified based on local technical, environmental, and socio-economic characteristics. The first area is the 'project area' which is the area designed for all project's infrastructure including the fencing (similar to the direct zone of impact), its buffer depends on the project's size. The second area, 'area of direct and near interaction', is a suggested buffer from the fencing area which incorporates roads, visual impact, recreational areas, and proximity to wildlife, and protected areas. The third buffer from the fencing and broader than the second area is the 'area of moderate interaction' which includes breeding sites, migration routes, and residential sites. The final buffer, which covers a broader distance is the 'area of economic interaction' where many people benefit (directly or indirectly) from the large-scale PV in the area, i.e. nearby cities or communities. The temporal-spatial actions are summarised in Table 2. Other approaches can be used even the 'direct and indirect impact zone' spatial division.

Step 2: definition of objectives and hierarchy tree construction

The originality of this section lies in selecting the key criteria for impact assessment of LSPV and constructing its AHP tree based on the typical technologies (terrestrial and floating) and likely impacts. For the proposed approach the main objective is to reduce the environmental impacts of LSPV plants. Following the AHP tree approach, each sub-objective is broken down into other criteria until the leaf-level objective is set. As a method to support impact assessment, the hierarchy branches (sub-objectives) followed the guidance provided by IAIA that stresses the identification of parameters that represent 'biophysical relevant effects' (IAIA 1999) and 'social issues

Table 2. Spatial and temporal actions in SAMAMBAIA-solar.

Action	Action	Description	Type
Construction			Temporal
Construction	Project area	Buffer	Spatial
Construction	Area of direct and near interaction	Buffer	Spatial
Construction	Area of moderate interaction	Buffer	Spatial
Construction	Area of economic interaction	Buffer	Spatial
O&M			Temporal
O&M	Operational area	Buffer	Spatial
O&M	Area of direct and near interaction	Buffer	Spatial
O&M	Area of moderate interaction	Buffer	Spatial
O&M	Area of economic interaction	Buffer	Spatial
Decommissioning			Temporal
Decommissioning	Operational area	Buffer	Spatial
Decommissioning	Area of direct and near interaction	Buffer	Spatial
Decommissioning	Area of moderate interaction	Buffer	Spatial
Decommissioning	Area of economic interaction	Buffer	Spatial

of project development' (Vanclay et al. 2015). Therefore, the proposed goal is subdivided into two sub-objectives: 'reduce the impacts on the natural environment – RNE' and 'reduce the impacts on the anthropic environment – RAE'. RNE is broken down into parameters reflecting the impacts on aesthetical characteristics, biotic factors (habitat, fauna, and flora), and abiotic factors (climate and atmosphere, soil and hydrology) further divided into more technical and specific sub-objective (leaf-level objective). RAE is also separated into three categories of impact: populations (i.e. displacement of inhabitants, migratory fluxes into the area, and people's subsistence), socio-economic (i.e. economic growth, employment, local infrastructure), and territory (i.e. recreational areas and land use). It is evident that the previous works with SAMAMBAIA-H and the adapted version for the mining accident in Brazil (Magrini 1992; Magrini and La Rovere 2016) also aided in the SAMAMBAIA-Solar tree and evaluation criteria construction (following section) by pointing out significant parameters common to all impact assessment.

In total, 64 leaf-level objectives are inserted into the model. Figure 1 shows the reduced AHP diagram for assessing environmental impacts of large-scale PV, all objective at level 2 are broken down until the leaf-level objective, see figure 4 and table 5 in the supplementary material. The AHP tree in the supplementary material is very comprehensive tackling the main aspects to be assessed on terrestrial and floating PV aspects. Its application can require adaptations such as suppression of parameters that might not be relevant to the specific project development (trimming the tree shorter).

Step 3: selection of evaluation criteria, rating scale, and value function

Evaluation criteria are assigned to every leaf-level objective at the bottom of the hierarchy. All evaluation criteria were based on several EIA reports (Table 1) and international literature on solar energy (terrestrial and floating), i.e. the bibliography presented in the second section. The evaluation criteria followed five basic principles (Wang et al. 2009):

- Independence: no relationship is observed between criteria of the same level. This requisite is important to satisfy the latter MAVT application.
- Systemic: indicates the main features of that type of project and its overall performance (i.e. environmental, social, and economic).
- Consistency: proposed objectives and criteria must be consistent and relevant to one another.
- Measurability: criteria can be either quantitative values (scales) or qualitative description.
- Comparability: criteria must be normalised and comparable.

As described in the 'SAMAMBAIA concept' section, the evaluation criteria should follow an increasing scale of degradation addressing the project's possible alterations on the environment. There is not a 'right' number of evaluation criteria at the leaf-objective, though the general recommendation is not to have too many (varying from 3 to 6) to facilitate the comparison. The process is applied to all leaf-level objective criteria to reduce environmental impacts of LSPV and should be standard for impact assessment of PV plants (table 4 in the supplementary material for all suggested evaluation criteria).

The following procedure is standard for the method. The consulting firm in charge of the EIA surveys for experts (biologists, engineers, socio scientists, etc.) to implement the scoring in their respective field; the final magnitude reflects the group decision for each evaluation criteria and should be used as a standard for PV project. The Saaty eigenvector is also applied to

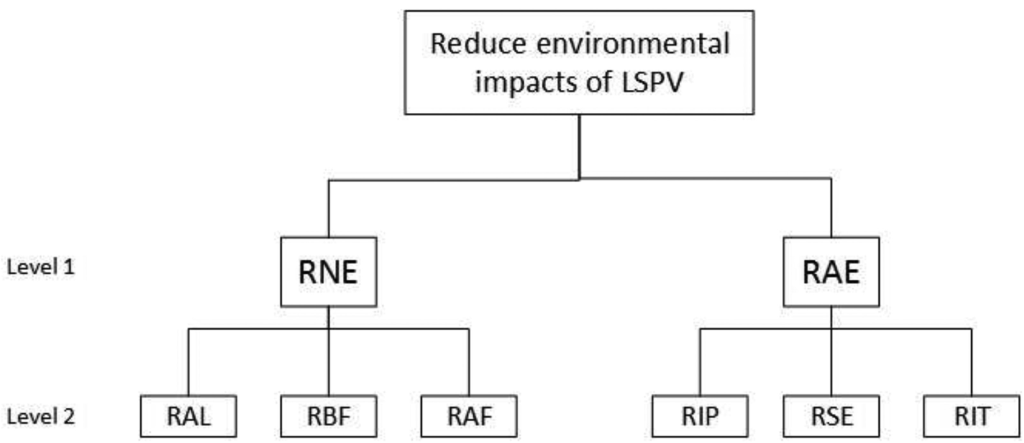

Figure 1. Reduced AHP diagram for multicriteria decision-making on the environmental impact assessment of large-scale photovoltaic projects.

Abbreviations: RNE: reduce the impact on the natural environment. RAE: reduce the impact on the anthropic environment. RAL: reduce the aesthetic impact on natural landscape. RBF: reduce the impact on biotic factors. RAF: reduce impact on abiotic factors. RIP: reduce the impact on populations. RSE: reduce the impact on local socio-economic. RIT: reduce the impact on the territory.

construct the preference value function and provide the consistency ratio (CR) of the previous score. This method aids stakeholders to judge the pair-wise scores to minimise subjectivity in the analysis (Al Garni et al. 2016). The linear aggregation sum approach is used to estimate the cumulative total value magnitude crosswise criteria, similar to (Løken 2007; Huang et al. 2011; Klein 2013). Figure 2 visually expresses the steps by providing an example created to pair-wise the leaf-level objective 'reduce the impact on the physical terrestrial habitat (PTH)' and the subordinated preference value function. Different MCDA might adopt other scaling score, such as Saaty scale (Haurant et al. 2011; Rahman et al. 2016).

Step 4: assessment matrix

A matrix of 12 columns (temporal actions) by 64 lines (leaf-level objective), is resulting from the previous steps, as is shown in Table 3. The magnitude value will change according to the project and should be assigned by specialists. The proposed matrix is a general approach for SAMAMBAIA-Solar, specialists can shorten spatial boundaries and leaf-level objectives according to the project' specificities. Larger projects should follow the standard criteria closely, as the model aims to reduce significant impacts of such projects. The goal of the matrix is to assign a magnitude value for the impacts at every phase of the project.

Step 5: weight definition

Different from typical AHP studies that assign weights to the objectives on the bottom of the hierarchy, our model structure does not have a distinguished bottom line with the project alternatives. All ranking criteria used to minimise the detrimental impacts are addressed during the AHP tree and in the leaf-level objective criteria.

Several features concerning the project play a role in evaluating the social, economic, environmental, and other impacts. This results in different perceptions to weight the importance of each feature for the project (Bazmi and Zahedi 2011). Therefore, communities and stakeholders express their opinion in this part of the method by signing provisory weights to the model for pair-wise comparison across the same hierarchy level

Table 3. Assessment matrix and assignment of magnitudes.

	Construction					O&M					Decommissioning				
Obj	PA	DNI	AMI	ECI	Σ	PA	DNI	AMI	ECI	Σ	PA	DNI	AMI	ECI	Σ
NTA	6	5	3	1	-	2	1	1	1	-	4	3	1	1	-
NAA	8	5	4	2	-	5	3	2	1	-	4	3	2	1	-
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
FAC	5	4	3	2	-	1	1	1	1	-	1	1	1	1	-
ARA	7	5	3	1	-	5	4	3	1	-	5	4	3	1	-
Σ NM	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Key legend: PA: project area. DNI: area of direct and near interaction. AMI: area of moderate interaction. ECI: area of economic interaction. NM: Normalised magnitude. Values are merely for description.

	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6	W	
Criterion 1	50	40	30	15	5	5	0.023	λmax
Criterion 2	***60***	50	40	20	10	10	0.039	6.021
Criterion 3	***70***	***60***	50	30	20	15	0.065	
Criterion 4	***85***	***80***	***70***	50	30	25	0.142	IC
Criterion 5	***95***	***90***	***80***	***70***	50	45	0.336	0.004
Criterion 6	***95***	***90***	***85***	***75***	***55***	50	0.395	

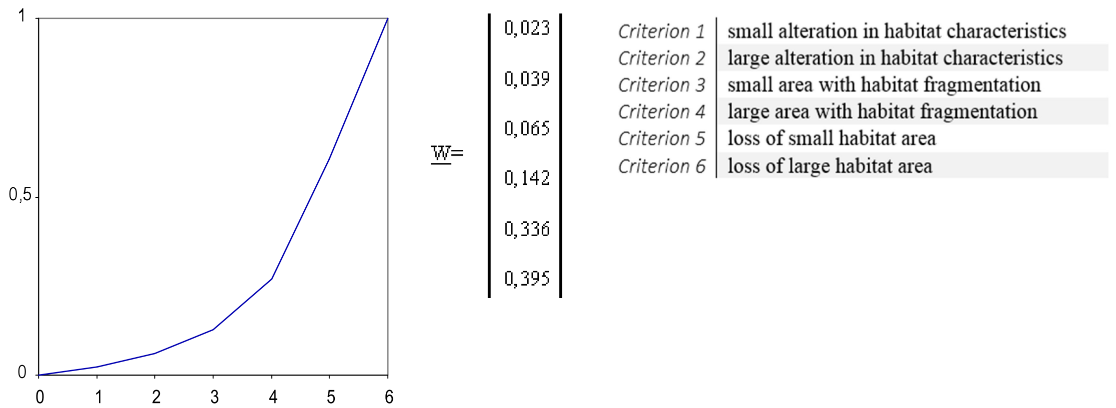

Figure 2. Specialist assignment of magnitudes in the evaluation criteria PTH and respective preference value function estimated through matrix of judgement and eigenvector method.

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(from bottom to top). The experts propose weights for technical aspects (lower level of the hierarchy – levels 3 and 4, for instance), whilst political stakeholders (communities, ONGs, and local authorities) assign weights to strategic aspects (top of the hierarchy – levels 1 and 2). A survey is carried with stakeholders and the weights reflect the group's decision.

The analysis is conducted similarly to step 4. The combination (multiplication) of normalised weights from different dimensions produces the final magnitude score for the impact, similar to the mathematical approach used in other MCDA [as in (Huang et al. 2011)]. The goal is to measure its trade-off across criteria and dimensions. Different stakeholders (or groups) can disagree on the weights assigned based on their interests. For example, a local stakeholder might consider the socio-economic impacts (jobs, local economy, etc.) more relevant than impacts on the natural environment. The community can consider the opposite analysis due to unique characteristics and a relationship of subsistence with the local. Scenarios considering different weighting criteria can, therefore, be constructed to assist decision-making when required. See Figure 3 uses criteria PTH and PAH (see the supplementary material for the full tree), a single scenario is presented for exemplification only.

Step 6: final aggregation

The additive value function MAVT (Multi-attribute value theory) is a common synthesising criteria method used to estimate the final score of the desired analysis (Løken et al. 2009), the overall environmental impact, in this case. In light of the adapted model to solar PV, the final aggregation and final magnitude can estimate the impacts of a specific solar project on the temporal and spatial actions analysed. Higher scores (closer to 1) mean greater potential to degrade the environment and cause conflicts (Malczewski 1999).

LEVEL 1

	RNE	RAE	Weight	λmax= 2 CR= 0
RNE	50	40	0.4	
RAE	**60**	50	0.6	

RNE: reduce the impact on the natural environment
RAE: reduce the impact on the anthropic environment

LEVEL 2

	RAL	RBF	RAF	Weight	λmax= 2.998 CR= 0.001
RAL	50	20	25	0.56	
RBF	**80**	50	55	0.60	
RAF	**75**	**45**	50	0.39	

RAL: reduce the impact on the natural landscape
RBF: reduce the impact on biotic factors
RAF: reduce the impact on abiotic factors

LEVEL 3

	HBT	RBF	RAF	Weight	λmax= 2.997 CR= 0.001
HBT	50	70	75	0.56	
RFN	**30**	50	60	0.26	
RFL	**25**	**40**	50	0.18	

HBT: reduce the impact on habitat
RFN: reduce the impact on fauna
RFL: reduce the impact on flora

LEVEL 4

	PTH	PAH	Weight	λmax= 2 CR= 0
PTH	50	70	0.7	
PAH	**30**	50	0.3	

PTH: reduce the impact on physical terrestrial habitat
PAH: reduce the impact on physical aquatic habitat

FINAL WEIGHT OF PTH: 0.7*0.56 *0.6*0.4 = 0.09408
FINAL WEIGHT OF PAH: 0.3*0.56 *0.6*0.4 = 0.04032

Figure 3. Weight aggregation for PTH and PAH.

Discussion

Analysis and implications for environmental assessment: focus on the Brazilian case

EIA practised for large-solar PV in Brazil (and other countries) does not integrate political, economic, and social impacts in the methodology and lack a quantitative assessment to provide environmental impact magnitudes and significance. The analysis of selected EIA confirmed the need to propose a multicriteria method to improve impact assessment of LSPV and include views from different stakeholders.

In this context, the above-mentioned method was adapted here for application on large-scale solar photovoltaic projects and intends to serve as a tool to improve the impact assessment methodology part of EIA for licensing in Brazil. The model offers a structured approach that incorporates detailed criteria that reflect the direct and indirect impacts of both, terrestrial and floating PV. The multicriteria aspect of SAMAMBAIA-Solar allows planners to integrate many conflicting issues and interests, so impact assessment is carried out based on a diagram considering both, qualitative and quantitative analysis. Furthermore, the model aims to discretise the project's temporal and spatial actions evaluating their impact on the environment, in order words, it calculates the LSPV impacts magnitudes and importance throughout time and area. The method is not applied to select or rank alternatives as usual AHP-based approaches. The analysis to compare two or more projects can be conducted when the proponent gives more than one possibility for installation (different sizes, sites or technologies). For instance, for the comparison between a terrestrial PV and floating PV plant in the area; the model estimates the 'environmental performance' of each project over time on each spatial action and considering the weights assigned differently for each project. Technical weights are standard, however, the magnitude of impact changes for both projects giving a different quantitative assessment for each project. Based on the overall impact of each alternative project, decision-makers can choose the least impactful option. Otherwise, the method will only estimate and highlight the significant impacts of a specific project; the results are still valid because they will be used to identify areas and temporal actions requiring mitigation measures. In summary, modelling outcomes produce graphics and estimated scores for the main overall environmental impact (placed in the top of the hierarchy) and other subordinated aspects at each level of the hierarchy; present matrices pair-wising all relevant aspects considered in the impact assessment of LSPV; and aids the construction of scenario that can be made when considering the weighting scoring by different stakeholders.

EIA practitioners and governmental agents do not have to master the complex calculation behind MCDA. The experts will be required to adapt the AHP tree for the local characteristics, and the solar project's specifics and provide the weights and magnitudes for pairwise comparison. The judgment of weights and magnitudes is aided by the Saaty IC scale. In this sense, the proposed SAMAMBAIA-solar method aims to improve the lack of synergy amongst different interested part and cumulative impacts in EIA.

With regards to improvements, the present proposal is not coupled with a GIS tool such as other current methods (Wanderer and Herle 2015; Aly et al. 2017), however, this adaption and improvement is the focus of later work. Moreover, despite a tendency to include a fuzzy logic approach to translate qualitative perceptions into quantitative values such as in Liu et al. (2009) and Rikhtegar et al. (2014), this adaption would increase the complexity of the model, which can turn it less attractive for application.

The model has also limitations. The complexity associated with any multicriteria analysis can be pointed out as a limitation for the pair-wise comparisons, especially for practitioners who have never used any similar method. The magnitude aggregation and weighting might take a long time to be completed and confronted to be consistent. Other AHP-based methods cross-wise the many criteria belonging to different hierarchy level or structure, whereas the proposed method can only cross-wise sub-criteria and criteria in the same hierarchy.

Conclusions

The installation of large-scale renewable energy plants presents great complexity for decision-making regarding environmental, political-strategic, economic, and social issues and interests, which may frequently be conflicting. The majority single-criterion methods applied to assess environmental impacts (checklists and matrices) give a preliminary overview of the multiple problems concerning large-scale projects. These methods, however, lack the possibility of integrating several conflicting issues faced by planners. Even though some EIAs apply a quantitative approach, the weighting aggregation is usually not clear, neither does it necessarily reflect all community and stakeholders' interest. Multicriteria approaches have been proposed in the literature to improve EIA impact assessment and aggregate the distinguishing aspects. The usual focus of multicriteria methods lies in selecting the best alternative for implementation; EIA in Brazil, however, is conducted when the project has already been chosen. With regards to large-scale solar photovoltaic impact assessment in Brazil, this work identified the necessity to apply a multicriteria approach that integrates the intricate environment of project installation and operation into the measurement of impact magnitudes and significance required by EIA.

This research then proposes a method named SAMAMBAIA-Solar which is adapted from a previous work of Magrini (1992) who also acknowledged a similar issue in impact assessment conducted during the expansion of hydropower plants in Brazil in the 1990s. The SAMAMBAIA-Solar is equipped with a detailed hierarchal tree and evaluation criteria that reflect the main parameters assessed in EIAs for LSPV around the world. The approach is also designed to provide the assessment magnitudes for impacts of different projects (floating or land-based PV) and estimate scenarios according to different stakeholders' views (expressed as the weights input in the model). Indirect impacts and social impacts are considered in the analysis as well as cumulative impacts. Additionally, scores, histograms, and matrices for each level are shown in the modelling so decision-makers can determine the most significant areas of impact and allocate mitigation measures. Although the method is created to complement the environmental impact assessment techniques used in Brazil, the tree and criteria might be adapted to project's characteristics in other countries.

A validation of the SAMAMBAIA-Solar through a study case will be attained in a future paper contrasting the results obtained in the model with a real impact assessment undertaken on an EIA for solar photovoltaic project.

Some of the future works with SAMAMBAIA-Solar are pointed out as follows:

- Update the current software created to run the programme, upgrade the graphical interface and make further improvements in the graphical display. A general thought is to complement SAMAMBAIA-Solar with GIS in order to better assess spatial actions [see (Wanderer and Herle 2015; Aly et al. 2017) for study cases using GIS and MDCA].
- Application of method on SEA and Life-cycle analysis to support decision-making (Magrini and Viana 2012). For SEA, the application of Strategic Choice Approach is thought as a future approach to manage uncertainties until linked to the multi-criteria analysis and weight aggregation by different interested parts.

Note

1. SAMAMBAIA is the general methodology (the steps and structure) for assessing environmental impacts. Thus, every time we refer to the structure followed, we will make reference to SAMAMBAIA. The SAMAMBAIA-H was a specific application to exemplify the model.

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Chapter V

Conclusion

This work discussed utility-scale solar photovoltaics' Environmental Impact Assessment in Brazilian national energy planning. The aim here was to build an understanding of the different standpoints from which EIA is being used to support the expansion of renewable solar energy. Three peer-reviewed papers compose the main body of this work and this conclusion combines the main findings of each section.

In the national planning context, energy auctions (responsible to recruiting energy developments and supplying the specific demand) request that the project's proponent acquire the provisory environmental permit to compete in the bidding process. This is the main role of EIA in terms of national energy planning for solar energy. The Agency which analyses and issues the permits is not the same one that organises the energy auctions. The energy regulatory agency does not dictate criteria for licensing nor will it interfere with the permitting process. Furthermore, the Brazilian Environmental Council has not published a national guidance norm for the licensing of utility-scale solar energy either. Thus, State Environmental Protection Agencies (SEPA) solely stablish criteria for the impact assessment screening (whether a full detailed EIA or a simplified version is needed) and scoping (methods, environmental aspects, measures) applied to solar energy licensing.

As a result, environmental permitting evaluation criteria significantly vary from one state agency to another. The estimated threshold in the screening process for simplified EIA remains unclear in many state regulations. For those states with a fixed criterion limit (in MW capacity or area occupied) to determine whether simplified or full EIA is required to support the environmental license, the difference in the threshold is notable, ranging from 10-90 MW or 30-100 hectares. This scenario creates a non-strategic environment for planning in which investors might over concentrate the PV deployment in regions of flexible permitting thresholds and high irradiation levels. It is noteworthy that some of the north-eastern states without regulated EIA screening criteria have great resources available [27], [28], as well as environments sensitive to degradation, and endemic species [29]–[31]. In addition to this lack of planning, this research did not encounter a governmental plan issuing a special area, programmes, or plans that merge sustainability, nature preservation, and energy generation. EIA, which should be an instrument to aid decision-making and prevent impacts [15], seems to be only a light requirement to issue a permit to compete in the auction. There is, therefore, a clear deficiency in environmental planning in the energy sector.

Regarding the analysis of the different impacts from solar PV installation, operation, and decommissioning, there are typical impacts resulting from any project deployment such as deforestation, changing in the local landscaping, visual pollution, and temporary impacts. Specific impacts include the likely link between bird mortality through direct impact with solar panels [32] (see [33] for a contradictory study on this allegation), attraction of insects to the panels' surfaces, and changes in the microclimate from the panels albedo. I agrees with [10], that utility PV are better than traditional energy; however, I debate that the potential impacts should be taken seriously because of the long-term effects associated with landscaping changes and operating characteristics. This research brings attention to realistic USSPV impacts and their importance in degradation of the environment, and thus this work serves as a starting reference in the creation of new environmental regulations for solar licensing that consider the new floating modality.

Mapping special areas with the least detrimental potential to avoid environmental and social conflicts is highly recommended for integrated environmental and energy planning; see a case-study involving offshore wind in the United Kingdom [34]. The utilisation of large-scale floating photovoltaic in Brazilian reservoirs can play a dual strategic goal: generate electricity and prevent water evaporation. Hydropower dams could be seen as potential candidates to host FPV due to the fact that these lakes are artificial environments and have an installed transmission infrastructure, causing less environmental stress.

Finally, the absence of a standardised regulation in addition to low experience with large-scale ground-mounted photovoltaic is reflected in the impact assessment approach to measure degradation significance and importance. The findings reveal that checklists and matrices are the predominant techniques used, though there are also purely descriptive reports. The objective here is not to completely invalidate these methods for impact assessment; rather this analysis explains that the impacts magnitudes and importance have been addressed separately without further integration of social, environmental, and economic aspects. Regarding the values for magnitude and importance (when available), the methods used do not explain the origin of the weights used nor do they calculate a final weighted likely "impact" comparing different alternatives.

The method presented in Chapter III, and adapted from [35], is a tool to increase stakeholders participation in the process, explain and judge the weights assigned, calculate a final "impact", and estimate the trade-offs (benefits/constraints) among the distinguished environments of concern. The objective is to identify significant areas of impact and propose alternatives to prevent or minimise their effects. It is important to highlight that no method is capable of finishing subjectivity; a multicriteria analysis such as SAMAMBAIA-Solar might decrease it by explaining weighting criteria and using a consistency index to judge the results.

This detailed analysis on regulation, impacts of LSPV, and approaches to integrate impacts suggests that that EIA might not be the best instrument for decision-making because the decision to construct the project has already been taken. This statement is in agreement with [36], [37]. EIA is based on a decision-made approach without the proposition of significant alternatives for the region. As many conflicts result from lack of planning, the key solution to prevent conflicts is not to predict impacts resulting from a specific energy project; instead, good environmental management that introduces all complex issues in the early stages (before any decision has been made) will lead to reduced detrimental impacts and legal conflicts. EIA currently practiced does not include important strategic features that will support nationwide or state-wide policymaking around selecting the preferred energy options by proposing scenarios that consider programmes, policies, and plans (PPP) for a region/sector [38]. Another conclusion is that the EIA process must not be targeted as the problem itself. The shortcomings result from the lack of proper environmental management towards PPP for energy projects.

What should future research focus on?

All three works recommend further research towards Strategic Environmental Assessment (SEA) for energy and environmental planning. Sánchez [39] reports several adverse impacts caused by improper environmental strategic management in Brazil, including in the energy sector. SEA was introduced to aid the preparation of environmental (and energy) policies as well as insert sustainability aspects in the early stages of the decision-making process [40]. Fischer [41] summarises "SEA helps to ensure that many of the environmental issues of global importance are considered in policies, plans and programmes at different administrative levels (i.e. national, regional, local)" (p. 162). SEA is based on a proactive approach (non-project specific) that follows goals in a broader context [36]. This instrument reflects long-term strategies driving a specific development in the region or country [42]. In the Brazilian context, SEA is a voluntary instrument as there is not a legal requirement for implementation in the country. Sánchez reviews many efforts to implement the SEA as an instrument to simplify environmental licensing and diminish conflicts [39]. Well-structured PPP driving renewable energy expansion can integrate complex and distinguished interests.

Technical and economic studies as well as EIA are limited to a predetermined power project and fail to support decision-making on a long-term framework and broader perspective. The attributes of SEA allows decision-makers to act through strategic plans that involve: setting enduring visions (goal), the ability to process and understand uncertainties and make the system flexible to changes, capacity to adapt the strategies to achieve desired goals, and the establishment of a focused and broader perspective [43]. Application of SEA to energy at local level planning can minimize economic costs, environmental risks, and present competitive advantages [44]. Therefore, SEA can contribute to the formulation of policies (such as regulations), programmes, and plans for a sustainable and less impactful renewable energy expansion in Brazil. The importance of SEA for the energy sector is irrefutable.

The methodologies and guidelines to implement SEA are vast [45]. For example, countries such as Belgium [38], United Kingdom, Germany [46], Portugal [43] and others have used SEA for energy planning and different purposes [47]. SEA for large-scale renewable energy plants presents great complexity for decision-making regarding environmental aspects, political-strategical issues, economic interests, social concerns, and stakeholders' interests. Practitioners and decision-makers find it difficult to manage the approaches to integrate all intricate and separate information to achieve the right choice [45]. The problem seems to require a multi-objective, non-project specific, and holistic approach. Multicriteria decision-making analysis (MCDA) may offer integrating tools to execute the analysis; Geographical Information Systems (GIS) can be coupled with SEA to screen territories and site select areas of fewest restrictions as well; see [34]. In conclusion, future studies should focus on understanding SEA for wind and solar and proposing a multicriteria GIS-SEA application to aid renewable energy expansion in Brazil.

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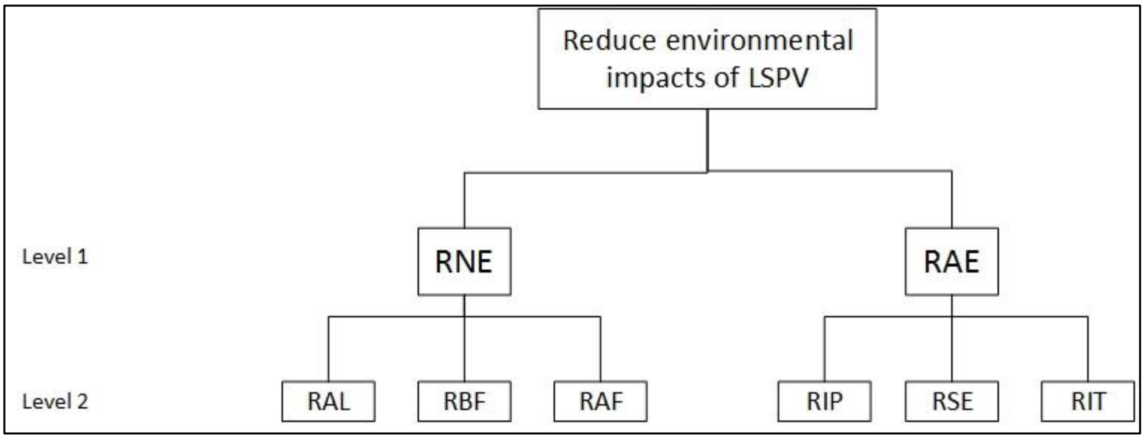
Supplementary material

Table 12. AHP objective levels description.

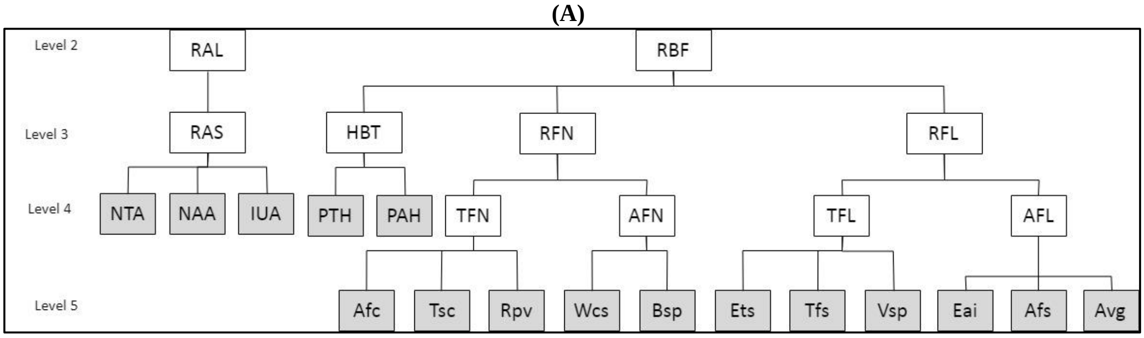
Level 1 RNE- reduce the impact on the natural environment RAE- reduce the impact on the anthropic environment	**Level 2** RAL- reduce the aesthetic impact on natural landscape RBF- reduce the impact on biotic factors RAF- reduce the impact on abiotic factors RIP- reduce the impact on populations RSE- reduce the impact on local socioeconomic RIT- reduce the impact on the territory
Level 3 RAS- reduce the impact on areas of aesthetic sensitivity HBT- reduce the impact on habitat RFN- reduce the impact on fauna RFL- reduce the impact on flora ICA- reduce the impact on the climate and atmosphere SOI- reduce the impact on the soil LHD- reduce the impact on the hydrology ILL- reduce the impact on the local logistic IPH- reduce the impact on population health ILD- reduce loss in income and local development LIF- reduce the impact on local infrastructure LUS- reduce the impact on land cover use WBU- reduce the impact on water body use	**Level 4** NTA- reduce the impact on natural terrestrial areas NAA- reduce the impact on natural aquatic areas IUA- reduce the impact on urban areas PTH- reduce the impact on physical terrestrial habitat PAH- reduce the impact on physical aquatic habitat TFN- reduce the impact on terrestrial fauna AFN- reduce the impact on aquatic fauna TFL- reduce the impact on terrestrial flora AFL- reduce the impact on aquatic flora MCT- reduce the impact on microclimate and atmosphere GEA- reduce gas emissions to the atmosphere SQT- reduce the impact on soil quality SAV- reduce the impact on soil availability WQT- reduce the impact on water quality WAT- reduce the impact on water quantity IID- reduce the impact on inhabitants displacement PMF- reduce the impact on the population migratory flux IPS- reduce the impact on population subsistence PAI- reduce the impact of non-access to information IDP- impact of diseases on the population LPV- reduce the impact on property value GDP- reduce loss on gross domestic product RUP- reduce the local unemployment RLS- reduce loss on local services LEP- reduce the impact on energy prices RAW- reduce the impact on local roads and access ways LBD- reduce the impact on local bridges TRA- reduce the impact on terrestrial recreational areas AGR- reduce conflicts with agriculture land cover use EXT- reduce conflicts related to extractivism FAC- reduce the impact on fishing activities ARA- reduce the impact on aquatic recreational areas
Level 5 Afc- reduce the impact on avian fauna contingent Tsc- reduce the impact on terrestrial species contingent (exclude avian fauna) Rpv- reduce the proliferation of vectors Wcs- reduce the impact on water column species Bsp- reduce the impact on benthic species Ets- reduce exotic terrestrial species Tfs- reduce the impact on terrestrial flora contingent Vsp- reduce loss of vegetation quantity Eai- reduce exotic aquatic species Afs- reduce the impact on aquatic flora contingent Avg- reduce aquatic vegetation growth Rpl- reduce noise pollution Ltp- reduce the impact on local temperature Gla- reduce the impact of glare effect PM- reduce emission of particulate matter SOx- reduce emission of sulphur oxides	**Level 6** Ds- Reduce the impact of dust suppressants Hb- reduce the impact of herbicides Wg- reduce the impact of waste disposal Sp- reduce accidental spillage of toxic products Cu- reduce the concentration of copper Cd- reduce the concentration of cadmium Te- reduce the concentration of tellurium Ga- reduce the concentration of gallium In- reduce the concentration of Indium

NOx- reduce emission of nitrogen oxides CO- reduce emission of carbon monoxide O_3- reduce emission of ozone Hdc- reduce emission of hydrocarbon Ser- reduce the impact of soil erosion Scp- reduce the impact of soil compaction Sct- reduce soil contamination Loc- reduce the impact of land occupation Geo- reduce the impact on local geomorphology BOD- reduce the impact of biological oxygen demand OD- reduce the impact of oxygen demand Tur- reduce the impact of water turbidity Ph- reduce the impact of water PH TSS- reduce concentration of totals suspended solids Chm- reduce concentration of heavy metals Wtp- reduce the impact on water temperature Wac- reduce the impact on water consumption Wav- reduce the impact on water availability Wev- reduce the impact on water evaporation	

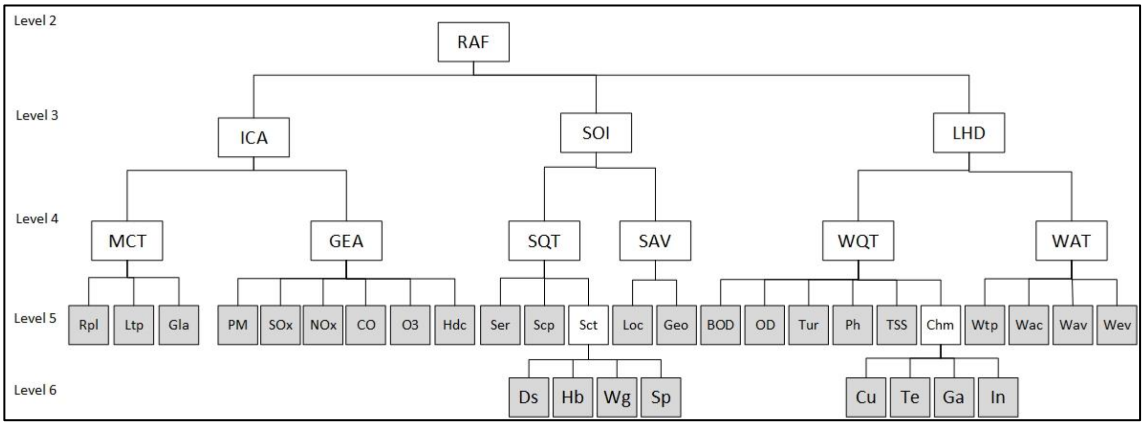
Figure 1. Proposed broken down objective of the AHP MCDA diagram for the environmental impact assessment of large-scale photovoltaic projects. (A) level 0 to 2. (B) RAL and RBF. (C) RAF. (D) RIP, RSE, and RIT.



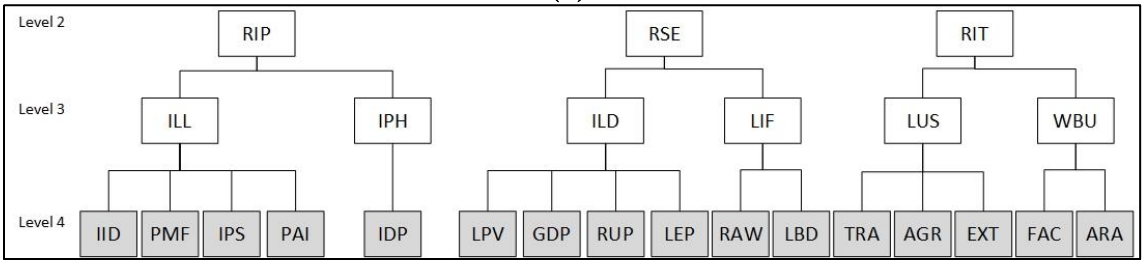
(A)



(B)



(C)



(D)

Remarks: there isn't a "right" number of evaluation criteria at the leaf-objective, though we recommend not to have too many (from 3 to 6) to facilitate the pair-wise comparison. Concentrations and other parameters must follow specific legal standard and might contain other subdivisions, i.e. CONAMA and State standards for the Brazilian case or EPA for USA.

Table 13. Evaluation criteria at the leaf-objective level.

Leaf-objective	Level 1	Level 2	Level 3	Level 4	Level 5	level 6
1-NTA: reduce the impact on natural terrestrial areas	alteration of aesthetic characteristics in a small area	alteration of aesthetic characteristics in a large terrestrial area	alteration of aesthetic characteristics in a small area with interference in a protected area	alteration of aesthetic characteristics in a large area with interference in a protected area	alteration of aesthetic characteristic in protected area	
2- NAA: reduce the impact on natural aquatic areas	alteration of aesthetic characteristics in a small area	alteration of aesthetic characteristics in a large terrestrial area	alteration of aesthetic characteristics in a small area with interference in a protected area	alteration of aesthetic characteristics in a large area with interference in a protected area	alteration of aesthetic characteristic in protected area	
3- IUA: reduce the impact on urban areas	alteration of aesthetic characteristics in a small area	alteration of aesthetic characteristics in a large area	alteration of aesthetic characteristics in a small area with interference in historical area	alteration of aesthetic characteristics in a large area with interference in historical area	alteration of aesthetic characteristic in urban historical protected area	
4- PTH- reduce the impact on physical terrestrial habitat	small alteration in habitat characteristics	large alteration in habitat characteristics	small area with habitat fragmentation	large area with habitat fragmentation	loss of small habitat area	loss of large habitat area
5- PAH- reduce the impact on physical aquatic habitat	small alteration in habitat characteristics	large alteration in habitat characteristics	small area with habitat fragmentation	large area with habitat fragmentation	loss of small habitat area	loss of large habitat area

6- Afc: reduce the impact on avian fauna contingent	small alteration of avian species	loss of non-endangered avian species	loss of endemic or migratory avian species	loss of endangered avian species		
7- Tsc- reduce the impact on terrestrial species contingent (exclude avian fauna)	small alteration of terrestrial species	loss of non-endangered terrestrial species	loss of endemic or migratory terrestrial species	loss of endangered terrestrial species		
8- Rpv: reduce the proliferation of vectors	small alteration in vectors population	increase vectors population in up to 25%	increase vectors population in up to 50%	increase vectors population in up to 75%	increase vectors population in up to 100%	increase vectors population above 100%
9-Wcs: reduce the impact on aquatic water column species	small alteration in the species community	large alteration in the species community	loss of endemic or migratory species	loss of endangered species		
10- Bsp: reduce the impact on benthic species	small alteration in the species community	large alteration in the species community	loss of endemic species	loss of endangered species		
11- Ets: reduce the exotic terrestrial species	small presence of invasive species	large presence of invasive species	invasive species spread to other areas			
12- Tfs: reduce the impact on terrestrial flora contingent	small alteration in terrestrial flora	loss of non-endangered terrestrial flora	loss of endemic terrestrial flora	loss of endangered terrestrial flora		
13- Vsp: reduce loss of vegetation quantity	loss of area with planted terrestrial vegetation	loss of area with non-native shrub vegetation	loss of area with non-native climax vegetation	loss of area with native terrestrial vegetation	loss of area with native shrub vegetation	loss of area with climax vegetation
14- Eai: reduce exotic aquatic species	small presence of invasive species	large presence of invasive species	invasive species spread to other areas			
15- Afs: reduce the impact on aquatic flora contingent	small alteration in aquatic flora	loss of non-endangered aquatic flora	loss of endemic aquatic flora	loss of endangered aquatic flora		
16- Avg: reduce the aquatic vegetation growth	significant retardation in algae growth	insignificant interference in algae growth	algae growth increases			
17- Rnp: reduce the noise pollution	noise pollution is low according to legal framework	noise pollution is moderate according to legal framework	noise pollution is high, but still within limit to legal framework	noise pollution is above legal framework		
18- Ltp: reduce the impact on local temperature	local temperature increases below 0.5°C	local temperature increases up to 1.0°C	local temperature increases up to 1.5°C	local temperature increases up to 2.0°C	local temperature increases above 2.0°C	
19- Gla: reduce the	glare effect is low	glare effect is moderate	glare effect is intense			

impact of glare effect						
20- PM: reduce the emission of particulate matter	registered particulate matter is below permitted level	registered particulate matter is within permitted level	registered particulate matter is above permitted level	registered particulate matter is at critical levels		
21- SOx: reduce the emission of sulphur oxides	registered SOx is below permitted level	registered SOx is within permitted level	registered SOx is above permitted level	registered SOx is at critical levels		
22- NOx: reduce the emission of nitrogen oxides	registered NOx is below permitted level	registered NOx is within permitted level	registered NOx is above permitted level	registered NOx matter is at critical levels		
23- CO: reduce the emission of carbon oxides	registered COx is below permitted level	registered COx is within permitted level	registered COx is above permitted level	registered COx is at critical levels		
24- O_3: reduce emission of ozone	registered O_3 is below permitted level	registered O_3 is within permitted level	registered O_3 is above permitted level	registered O_3 is at critical levels		
25- Hdc: reduce emission of hydrocarbon	registered hydrocarbon is below permitted level	registered hydrocarbon is within permitted level	registered hydrocarbon is above permitted level	registered hydrocarbon is at critical levels		
26- Ser: reduce the impact of soil erosion	small area with low erosion	large area with increasing erosion	disruption of fertile soil layer	soil is completely degraded creating gullies		
27- Scp: reduce the impact of soil compaction	small area decreasing infiltration	large area decreasing infiltration	first layers of soil suffering significant compaction	soil compaction reaches deep layers		
28- Ds: reduce the use of dust suppressant	low use of dust suppressant in small area	low use of dust suppressant in large area	high use of dust suppressant in small area	high use of dust suppressant in large area		
29- Hb: - reduce the use of herbicides	low use of herbicides in small area	low use of herbicide in large area	high use of herbicide in small area	high use of herbicide in large area		
30- Wg: reduce the impact of waste disposal	100% of waste is correctly disposed	75% of waste is correctly disposed	50% of waste is correctly disposed	25% of waste is correctly disposed	incorrect waste disposal	
31- Sp: reduce spillage of toxic products	insignificant spill volume of toxic products	low spill volume of toxic products	moderate spill volume of toxic products	high spill volume of toxic products		
32- Loc: reduce the impact of land occupation	land cover below 75 ha	land cover between than 75 and 150 ha	land cover between 150 and 250 ha	land cover between 250 and 500 ha	land cover between 500 and 1000 ha	land cover above 1000 ha
33- Geo: reduce the impact on local geomorphology	insignificant interference in local geomorphology	small alteration in local Geomorphology	moderate (50%) alteration in local Geomorphology	Complete geomorphology alteration in large area of the project		
34- BOD: reduce the impact of	concentration below legal framework	concentration within legal framework	concentration above legal framework			

biological oxygen demand						
35- OD: reduce the impact of oxygen demand	concentration below legal framework	concentration within legal framework	concentration above legal framework			
36- Tur: reduce the impact of turbidity	concentration below legal framework	concentration within legal framework	concentration above legal framework			
37- Ph: reduce the impact of water ph	water Ph change below legal framework	water Ph change within legal framework	water Ph change above legal framework			
38- TSS: reduce the concentration of total suspended solids	concentration below legal framework	concentration within legal framework	concentration above legal framework			
39- Cu: reduce the concentration of copper	concentration below legal framework	concentration within legal framework	concentration above legal framework			
40- Cd: reduce the concentration of cadmium	concentration below legal framework	concentration within legal framework	concentration above legal framework			
41- Te: reduce the concentration of tellurium	concentration below legal framework	concentration within legal framework	concentration above legal framework			
42- Ga: reduce the concentration of gallium	concentration below legal framework	concentration within legal framework	concentration above legal framework			
43- In: reduce the concentration of indium	concentration below legal framework	concentration within legal framework	concentration above legal framework			
44- Wtp: reduce the impact on water temperature	water temperature below 0.5°C	water temperature rises up to 1.0°C	water temperature rises up to 1.5°C	water temperature rises up to 2.0°C	water temperature above 2.0°C	
45- Wac: reduce the impact on water consumption	consumption rate below 5 litres/MW	consumption rate up to 15 litres/MW	consumption rate up to 30 litres/MW	consumption rate above 30 litres/MW		
46- Wav: reduce the impact on water availability	water resource is highly available	water resource is available	water resource is scarce			
47- Wev: reduce the impact on water evaporation	water evaporation decreases more than 50%	water evaporation decreases up to 25%	water evaporation decreases up to 10%	insignificant alteration in water evaporation	water evaporation increases	
48- IID: reduce the impact on	no inhabitants displacement	displacement of few inhabitants	displacement of villages' inhabitants	displacement of inhabitants in traditional communities		

inhabitants displacement						
49- PMF: reduce the impact on the population migratory flux	short-term interference in population density	small permanent interference in population density	significant short-term alteration in population density	significant permanent alteration in population density		
50- IPS- reduce the impact on population subsistence	partial and short-term loss of way of living	partial and long-term loss of way of living	complete loss of way of living			
51- PAI: reduce the impact of non-access to information	up to 90% public informed of project's impacts	up to 75% public informed of project's impacts	up to 60% public informed of project's impacts	up to 45% public informed of project's impacts	up to 30% public informed of project's impacts	up to 15% public informed of project's impacts
52- IDP: reduce the impact of diseases on the population	occurrence of short-term diseases	occurrence of communicable diseases	registration of epidemic	registration of death		
53- LPV: reduce the impact on property value	property value increases	property value maintains the same level	property value decreases			
54- GDP: reduce loss on gross domestic product	increase in goods and services through economic activity	more goods and services due to other activities	Maintenance of some goods and services	reduction of economic activity, goods, and services	loss of goods and services	
55- RUP: reduce the local unemploymen t	employment of personnel through economic activity	more employment of personnel in other activities	Maintenance of employment of skilled personnel	reduction of economic activity and employment of personnel	loss of employment due to end of activities	
56- RLS: reduce the impact on local services	High services required	Moderate services required	Low services required to supply	insignificant alteration observed in services		
57- LEP: reduce the impact on local energy prices	energy prices decreases	maintenance in energy prices	energy prices increase			
58- RAW: reduce the impact on local roads and access ways	maintenance of traffic volume	traffic volume increases up to 25%	traffic volume increases up to 50%	traffic volume increases up to 75%	traffic volume increases up to 100%	traffic volume increases above 100%
59- LBD: reduce the impact on local bridges	maintenance of traffic volume	traffic volume increases up to 25%	traffic volume increases up to 50%	traffic volume increases up to 75%	traffic volume increases up to 100%	traffic volume increases above 100%
60- TRA: reduce the impact on terrestrial recreational areas	small interference in terrestrial recreational areas	alteration in small terrestrial recreational area	alteration in large terrestrial recreational area	loss of important feature in terrestrial recreational area	complete loss of terrestrial recreational area	
61- AGR: reduce the conflicts with	agricultural area not affected	loss of small agricultural area with possible	loss of large agricultural area with possible	loss of small agricultural area without possible	loss of large agricultural area without	

agriculture land cover use		future coexistence (agrivoltaic)	future coexistence (agrivoltaic)	future coexistence	possible future coexistence	
62- EXT: reduce the conflicts related to extractivism	extractivism not affected	loss of small area of extractivism with possible future coexistence	loss of large area of extractivism with possible future coexistence	loss of small area of extractivism without possible future coexistence	loss of large areas of extractivism without possible future coexistence	
63- FAC: reduce the impact on fishing activities	fishing not affected	loss of small fishing area with possible future coexistence (floatovoltaic)	loss of large fishing area with possible future coexistence (floatovoltaic)	loss of small fishing area without possible future coexistence	loss of large fishing area without possible future coexistence	
64- ARA: reduce the impact on aquatic recreational areas	small interference in aquatic recreational areas	alteration in small aquatic recreational area	alteration in large aquatic recreational area	loss of important feature in aquatic recreational area	complete loss of aquatic recreational area	

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