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

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Dissertação de Mestrado apresentada ao Programa de Pós-graduação em Planejamento Energético, COPPE, da Universidade Federal do Rio de Janeiro, como parte dos requisitos necessários à obtenção do título de Mestre em Planejamento Energético.

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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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Orientadores: David Alves Castelo Branco
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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.)

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Advisors: David Alves Castelo Branco
Alessandra Magrini.

Department: Energy Planning

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 acronym

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 co-Authorship/previous publications

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I certify that, with the above qualification, this dissertation, and the research to which it refers, is the product of my own work.

This thesis includes four original papers that have been previously published/submitted for publication in peer reviewed journals, as follows:

THESIS CHAPTER	PUBLICATION	PUBLICATION STATUS
CHAPTER I AND V	Letter to the editor: Large-scale solar photovoltaic impact assessment in the context of the Brazilian environmental and energy planning	Waiting for submission
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.	Under Revision
CHAPTER III	Da Silva, GDP & Branco, DAC. Is floating photovoltaic better than conventional photovoltaic? Assessing environmental impacts. Impact Assessment & Project Appraisal, vol. 36, n. 5, 390-400, 2018. DOI: 10.1080/14615517.2018.1477498	Published
CHAPTER IV	Da Silva, GDP, Magrini, A, Branco, DAC. A multicriteria proposal for large-scale solar photovoltaic impact assessment. Impact Assessment & Project Appraisal	Under Revision

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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 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 (social, natural, and economic aspects) 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 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 and socio 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 a specific objective:

- 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.

Division

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 (submitted or 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

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

Gardenio Diogo Pimentel da Silva, Alessandra Magrini, Maurício Tiomno Tolmasquim, and David Alves Castelo Branco

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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.

Keywords: Environmental licensing; Regulatory framework; Solar PV; Energy Auction.

Introduction

Utility scale solar photovoltaic installations (USSPVI) date back to the 1980s in the United States of America and Europe totalling 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 summarises the largest solar photovoltaic installations around the world indicating their location, capacity, and operator (the most significant in each region).

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[1]
Solar Stars	579 MW	California, USA
Topaz Solar Farm	550 MW	California, USA
EDF Energies Nouvelles	400 MW	Pirapora, Brazil[2]
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[3]
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

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

[1] commissioned, the solar plant will have 2000 MW at its full capacity. [2] Under construction. [3] final capacity of 5000 MW by 2050.

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, centralised 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 centralised 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 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 i.e. displacement of inhabitants, alterations in community subsistence, and non-environmental compensation. These communities claim that wind farms might not be as "sustainable" as the media state [see (Gorayeb & Brannstrom 2016; Brannstrom et al. 2017; Paiva & 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 & Fthenakis 2011; Hernandez et al. 2014; Da Silva & 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 analysing Brazilian auction systems to procure electricity from solar farms and diversify the energy matrix (Dobrotkova et al. 2018; Viana & 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 analyse 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 multi-megawatt 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 summarised as follows (Förster & Amazo 2016; De Melo et al. 2016; Hochberg & Poudineh 2018; Viana & 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, i.e. 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-term. 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 commercialisation. 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 micro-distributed 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 authorised to initiate construction (ANEEL 2018a).

Energy regulation for micro-scale 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-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 & Hallack 2018) claimed that except for the

[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.

environmental aspect, for which small-scale plants do not require analysis, energy regulation favours 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 to 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 & Amazo 2016; Bradshaw 2017; Dobrotkova et al. 2018; Hochberg & Poudineh 2018; Viana & 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 & Amazo 2016; Hochberg & 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 centralised solar PV plants, and the MME has held five auctions since 2014 intended to procure centralised 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 & Ramos 2018). The following auctions in which solar PV competed (2nd and 3rd auctions of 2015, 2nd auction of 2016, and the 1st auction of 2018) adopted the same criterion of technology specific competition. The 2nd 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 & 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 analysed 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 2nd auction of 2015. Disqualification due to environmental non-compliances amounted to 16 projects in the cancelled auction of 2016 (EPE 2015a; EPE 2015b; EPE 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 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 multi-megawatt 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.

	2014		**2015***		**2018**		**IC (MW)**
State	N	W	N	W	N	W	
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

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

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 & 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 nomenclature 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 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 authorises the construction of the project according to the approved specifications in the plans, programmes, 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 & 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 to 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.

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 programmes. 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).

Table 3. Types of environmental studies to support Preliminary Licensing. Based on (CONAMA 1997; CONAMA 2001; CETESB 2014).

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 & Amazo 2016); especially those concerning energy (Lima & 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 licence 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, 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 "judicialisation 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 & 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) recognised 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; the region has high irradiation levels and current investments attracting new USSPVI, **see figure 2**.

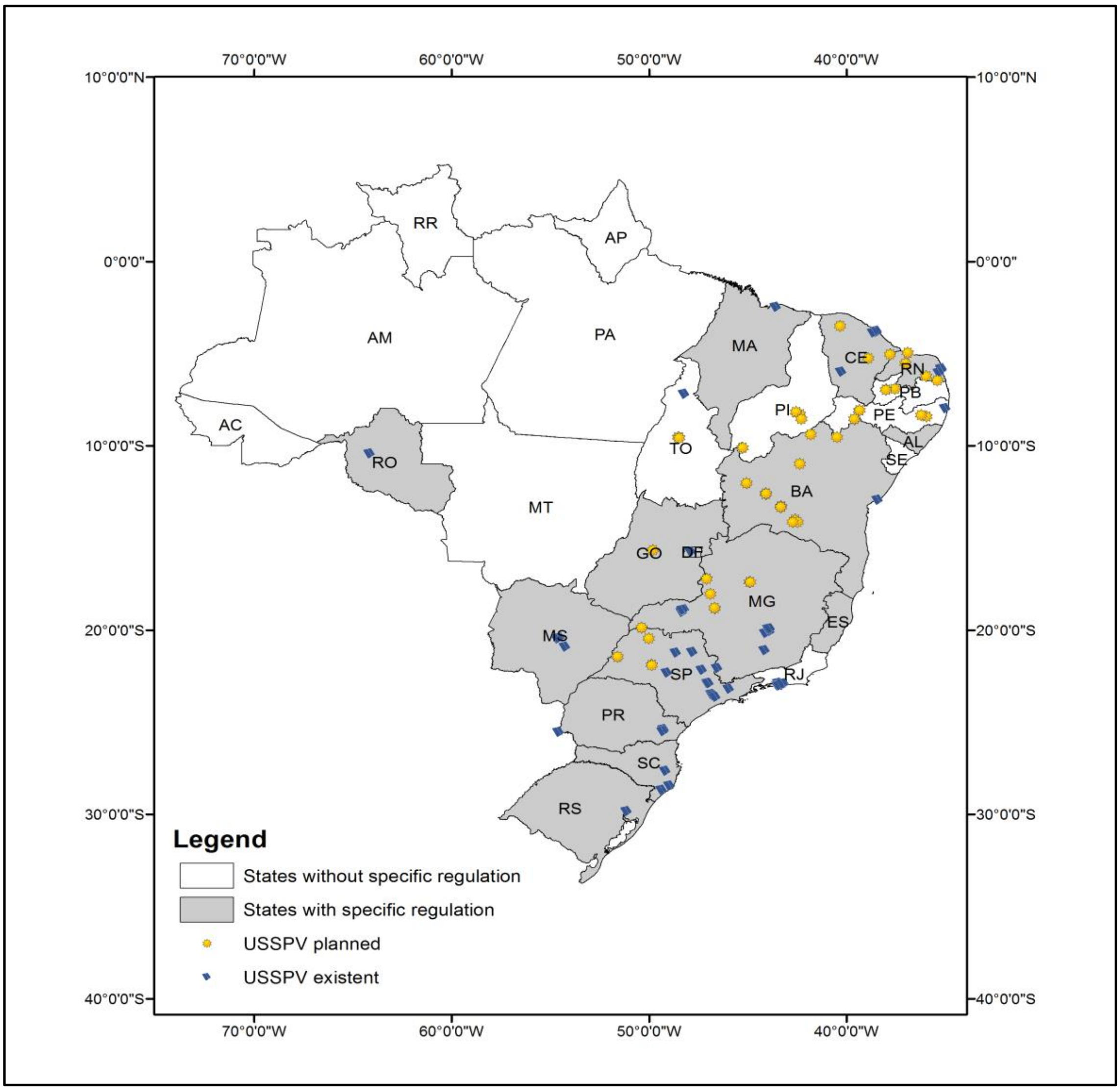

Figure 2. States with and without specific regulation for solar PV licensing plus current and future hired contracted projects. Source: elaborated by authors with data from states and (EPE & MME 2019).

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 (EIA or simplified version) to support the project's licensing. For instance, Glasson *et al*. (2012) reports that in the UK, 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 multi-megawatt 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 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)].

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 non-required 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 non-required for micro and small scale projects (**below 5 MW**).	State law n° 3,686/2015

Table 4. 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.

Criteria: area (ha) or installed capacity (MW)					
State	**Regular EIA for licensing**	**Simplified studies for licensing**	**descriptive report required**	**license non-required**	**legal framework**
Alagoas	-	above 30 MW (RAA); 1 to 30 MW (EAS)	-	-	CEPRAM n°170/2015
Ceará	unmentioned	3 to 5 MW	2 to 3 MW	below 2 MW	COEMA Nº 3/2016
Goiás	above 100 ha	30 to 100 ha (RAS)	below 30 ha (register, no study)	micro/mini generation	SECIMA/GAB n° 36/2017
Maranhão	non-applicable	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 to 80 MW (RCA)	-	-	Document n°1 GEMUC/DPED/FEAM/2013 COPAM n°217/2017
Paraná	above 10 MW	5 to 10 MW	1 to 5 MW	below 1 MW	Document IAP Nº 19/2017
Santa Catarina		1 to 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 to 90 MW (EAS)	-	below 5 MW	SMA Nº 74/2017

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.

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

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 & Ennen 2011; Grippo et al. 2015; Rose & 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 & Fthenakis 2011; Da Silva & Branco 2018).

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 north-eastern Brazil is described in (Hochstetler & 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 & Brannstrom 2016; Brannstrom et al. 2017; Paiva & 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;
- Privatisation of areas used for subsistence by local communities;
- Land rights fraud;
- Resettlement of inhabitants;
- Exaggerated promise of economic benefits, e.g. employment, electricity at low tariff, improvement in quality of life;
- Non-compensation 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 non-standard 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

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

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 & 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 & 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;
- Standardisation of nomenclature used for environmental studies;
- 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.

Analysing 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

[3] SEA can be used to select strategic areas, pre-screened 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 pre-defined areas to propose new projects.

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 multi-megawatts 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, areas 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 centralised 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 & 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 & Onyango 2012) such as Belgium (Jay 2010), United Kingdom, Germany (Phylip-Jones & 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.

References

Ahmed K, Sánchez-Triana E. 2008. Strategic Environmental Assessment for Policies: an instrument for good Governance. Washington, DC: The World Bank.

ANEEL. 2012. Resolução normativa n° 482 de 17 de Abril de 2012 [Internet]. [cited 2018 Jan 1]. Brasília: Aneel. Available from: http://www2.aneel.gov.br/cedoc/ren2012482.pdf

ANEEL. 2018a. Capacidade de Geração do Brasil. BIG- banco informação geração [Internet]. [cited 2018 Jan 1]. Available from: http://www2.aneel.gov.br/aplicacoes/capacidadebrasil/capacidadebrasil.cfm

ANEEL. 2018b. Resultados de Leilões [Internet]. [cited 2018 Jan 1].. Available from: http://www.aneel.gov.br/resultados-de-leiloes

Aquila G, Pamplona E de O, Queiroz AR de, Rotela Junior P, Fonseca MN. 2017. An overview of incentive policies for the expansion of renewable energy generation in electricity power systems and the Brazilian experience. Renew Sustain Energy Rev. 70:1090–1098. DOI:10.1016/j.rser.2016.12.013

Araújo JCH. 2016. Entre expropriações e resistências: a Implementação de Parques Eólicos na Zona Costeira do Ceará, Brasil. Cad do CEAS.:327–346.

Benson JF. 2003. What is the alternative? Impact assessment tools and sustainable planning. Impact Assess Proj Apprais. 21:261–280.

Borioni R, Gallardo ALCF, Sánchez LE. 2017. Advancing scoping practice in environmental impact assessment: an examination of the Brazilian federal system. Impact Assess Proj Apprais. 35:200–213. DOI:10.1080/14615517.2016.1271535

Bradshaw A. 2017. Regulatory change and innovation in Latin America: The case of renewable energy in Brazil. Util Policy. 49:156–164. DOI:10.1016/j.jup.2017.01.006

Bragagnolo C, Lemos CC, Ladle RJ, Pellin A. 2017. Streamlining or sidestepping? Political pressure to revise environmental licensing and EIA in Brazil. Environ Impact Assess Rev. 65:86–90. DOI:10.1016/j.eiar.2017.04.010

Brannstrom C, Gorayeb A, de Sousa Mendes J, Loureiro C, Meireles AJ de A, Silva EV da, Freitas ALR de, Oliveira RF de. 2017. Is Brazilian wind power development sustainable? Insights from a review of conflicts in Ceará state. Renew Sustain Energy Rev. 67:62–71. DOI::10.1016/j.rser.2016.08.047

CETESB. 2014. Manual para Elaboração de Estudos para o Licenciamento Ambiental com Avaliação de Impacto Ambiental no âmbito da CETESB. São José dos Campos.

Chang T, Nielsen E, Auberle W, Solop FI. 2013. A quantitative method to analyze the quality of EIA information in wind energy development and avian/bat assessments. Environ Impact Assess Rev. 38:142–150. DOI:10.1016/j.eiar.2012.07.005

CONAMA. 1997. Resolução CONAMA 237/1997. Brasília, Brazil: National Council of the Environment.

CONAMA. 2001. Resolução do CONAMA nº 279. Brasília, Brazil: National Council of the Environment.

CONAMA. 2014. Resolução do CONAMA nº 462. Brasília, Brazil: National Council of the Environment.

Da Silva GDP, Branco DAC. 2018. Is floating photovoltaic better than conventional photovoltaic? Assessing environmental impacts environmental impacts. Impact Assess Proj Apprais. 36:390–400.

Da Silva GDP, Souza MJR. 2017. Estimativa de geração de energia através de um sistema fotovoltaico: implicações para um sistema flutuante no lago Bolonha, Belém-Pará. Rev Bras Energias Renov. 6:149–164.

Delfanti L, Colantoni A, Recanatesi F, Bencardino M, Sateriano A, Zambon I, Salvati L. 2016. Solar plants, environmental degradation and local socioeconomic contexts: A case study in a Mediterranean country. Environ Impact Assess Rev. 61:88–93. DOI:10.1016/j.eiar.2016.07.003

Dobrotkova Z, Surana K, Audinet P. 2018. The price of solar energy: Comparing competitive auctions for utility-scale solar PV in developing countries. Energy Policy. 118:133–148. DOI:10.1016/j.enpol.2018.03.036

Duarte CG, Dibo APA, Siqueira-Gay J, Sánchez LE. 2017. Practitioners' perceptions of the Brazilian environmental impact assessment system: results from a survey. Impact Assess Proj Apprais. 35:293–309. DOI:10.1080/14615517.2017.1322813

EnvironQuest. 2017. Final Environmental and Social Impact Assessment Report for the Proposed 100MW Solar Independent Power Plant and 18 KM Transmission Line Project , Ganjuwa Local Government Area , Bauchi State by Nigerian Solar Capital Partners / Globeleq / ARM- Harith Jun [Internet]. [cited 2018 Jan 1].. Nigeria. Available from: https://www3.opic.gov/Environment/EIA/bauchisolar/Nigeria_ESIA_June2017.pdf

EPE. 2014. Leilão de Energia de Reserva 2014 [Internet]. [cited 2018 Jan 1].. Rio de Janeiro. Available from: http://www.epe.gov.br/leiloes/Paginas/default.aspx?CategoriaID=6845

EPE. 2015a. 2º Leilão de Energia de Reserva de 2015. Rio de Janeiro.

EPE. 2015b. Expansão da geração. 1 Leilão de Energia de Reserva de 2015. Participação dos Empreendimentos Solares Fotovoltaicos: Visão Geral. 26.

EPE. 2016. Retrato dos Novos Projetos Solares Fotovoltaicos no Brasil [Internet]. [cited 2018 Jan 1].. Rio de Janeiro. Available from: http://epe.gov.br/leiloes/Documents/NT_EPE-DEE-NT-030_2017-r0.pdf

EPE. 2017. Brazilian Electricity Auctions in 2017. Rio de Janeiro.

EPE, MME. 2017. Plano decenal de expansão de energia 2026 [Internet]. [cited 2018 Jan 1].. Rio de Janeiro. Available from: http://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/Plano-Decenal-de-Expansao-de-Energia-2026

EPE, MME. 2019. Webmap EPE [Internet]. [cited 2019 Jan 11]. Available from: https://gisepeprd.epe.gov.br/webmapepe/

Fischer TB, Onyango V. 2012. Strategic environmental assessment-related research projects and journal articles: An overview of the past 20 years. Impact Assess Proj Apprais. 30:253–263.

Fonseca A, Sánchez LE, Ribeiro JCJ. 2017. Reforming EIA systems: A critical review of proposals in Brazil. Environ Impact Assess Rev. 62:90–97. DOI:10.1016/j.eiar.2016.10.002

Förster S, Amazo A. 2016. Auctions for Renewable Energy Support in Brazil: Instruments and lessons learnt.

Fthenakis V, Blunden J, Green T, Krueger L, Turney D. 2011. Large photovoltaic power plants: wildlife impacts and benefits. In: Photovolt Spec Conf. Seatle, WA, USA: IEEE; p. 2011–2016.

Glasson J, Neves N, Salvador B. 2000. EIA in Brazil: a procedures – practice gap. A comparative study with reference to the European Union, and especially the UK. Environ Impact Assess Rev. 20:191–225.

Glasson J, Therivel R, Chadwick A. 2012. Introduction to environmental impact assessment. 4nd ed. London and New York: Routledge Taylor & Francis Group. DOI:10.1080/07293682.2012.747551

Gorayeb A, Brannstrom C. 2016. Caminhos para uma gestão participativa dos recursos energéticos de matriz renovável (parques eólicos) no nordeste do Brasil. Rev Mercat.

15:101–115.

Gorayeb A, Brannstrom C, de Andrade Meireles AJ, de Sousa Mendes J. 2018. Wind power gone bad: Critiquing wind power planning processes in northeastern Brazil. Energy Res Soc Sci. 40:82–88. DOI:10.1016/j.erss.2017.11.027

Grippo M, Hayse JW, O'Connor BL. 2015. Solar Energy Development and Aquatic Ecosystems in the Southwestern United States: Potential Impacts, Mitigation, and Research Needs. Environ Assess. 55:244–256.

Hernandez RR, Easter SB, Murphy-mariscal ML, Maestre FT, Tavassoli M, Allen EB, Barrows CW, Belnap J, Ochoa-hueso R, Ravi S, Allen MF. 2014. Environmental impacts of utility-scale solar energy. Renew Sustain Energy Rev. 29:766–779. DOI:10.1016/j.rser.2013.08.041

Hochberg M, Poudineh R. 2018. Renewable Auction Design in Theory and Practice : Lessons from the Experiences of Brazil and Mexico. Oxford: The Oxford Institute for Energy Studies.

Hochstetler K. 2018. Environmental impact assessment: evidence-based policymaking in Brazil. Contemp Soc Sci. 13:100–111. DOI:10.1080/21582041.2017.1393556

Hochstetler K, Tranjan RJ. 2016. Environment and Consultation in the Brazilian Democratic Developmental State. Comp Polit. 48:497–516.

Hochstetler KA. 2016. Conflicts between state and civil society related to infrastructure projects. Brasília: Institute for Applied Economic Research.

IEA-PVS Reporting Countries. 2017. Snapshot of Global Photovoltaic Markets - IEA PVPS.

IRENA. 2013. Renewable Energy Auctions in Developing Countries. [place unknown].

IRENA, CEM. 2015. Renewable Energy Auctions: a Guide To Design [Internet]. [cited 2018 Jan 1].. [place unknown]. Available from: http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/Jun/IRENA_Renewable_Energy_Auctions_A_Guide_to_Design_2015.pdf

Jay S. 2010. Strategic environmental assessment for energy production. Energy Policy. 38:3489–3497. DOI:10.1016/j.enpol.2010.02.022

Lai CS, Jia Y, Lai LL, Xu Z, McCulloch MD, Wong KP. 2017. A comprehensive review on large-scale photovoltaic system with applications of electrical energy storage. Renew Sustain Energy Rev. 78:439–451. DOI:10.1016/j.rser.2017.04.078

Lima LH, Magrini A. 2010. The Brazilian Audit Tribunal's role in improving the federal environmental licensing process. Environ Impact Assess Rev. 30:108–115. DOI:10.1016/j.eiar.2009.08.005

Lovich JE, Ennen JR. 2011. Wildlife Conservation and Solar Energy Development in the Desert Southwest, United States. Bioscience. 61:982–992. DOI:10.1525/bio.2011.61.12.8

Lucia A, Figueiredo C, Bond A. 2011. Capturing the implications of land use change in Brazil through environmental assessment : Time for a strategic approach ? Environ Impact Assess Rev. 31:261–270. DOI:10.1016/j.eiar.2010.06.002

De Melo CA, Jannuzzi GDM, Bajay SV. 2016. Nonconventional renewable energy governance in Brazil: Lessons to learn from the German experience. Renew Sustain Energy Rev. 61:222–234. DOI:10.1016/j.rser.2016.03.054

Ministério de Minas e Energia. 2017. Hidrelétrica Balbina inicia projeto com flutuadores para gerar energia solar [Internet]. [cited 2018 Oct 1]. Available from: http://www.mme.gov.br/web/guest/pagina-inicial/outras-noticas/-/asset_publisher/32hLrOzMKwWb/content/hidreletrica-balbina-inicia-projeto-com-flutuadores-para-gerar-energia-solar

Ministério Público Federal. 2004. Deficiências em Estudos de Impacto Ambiental. Brasília, DF: Escola Superior do Ministério Público da União.

Morris P, Therivel R. 2001. Methods of Environmental Impact Assessment. 2nd ed. London and New York: Spon Press (Taylor & Francis).

Paiva ITP, Lima EC. 2017. Conflitos ambientais: energia eólica e seus impactos socioambientais no interior Ceará. Geogr Opportuno Tempore. 3:306–318.

Partidário MR. 2012. Guia de melhores práticas para Avaliação Ambiental Estratégica - orientações metodológicas para um pensamento estratégico em AAE.

Pereira EB, Martins FR, Gonçalves AR, Costa RS, Lima FJL de, Rüther R, Abreu SL de, Tiepolo GM, Pereira SV, Souza JG. 2017. Atlas Brasileiro de Energia Solar. 2nd ed. São José dos Campos: INPE.

Phylip-Jones J, Fischer TB. 2015. Strategic environmental assessment (SEA) for wind energy planning: Lessons from the United Kingdom and Germany. Environ Impact Assess Rev. 50:203–212. DOI:10.1016/j.eiar.2014.09.013

Rose T, Wollert A. 2015. The dark side of photovoltaic - 3D simulation of glare assessing risk and discomfort. Environ Impact Assess Rev. 52:24–30. DOI:10.1016/j.eiar.2014.08.005

Sacramento EM, Carvalho PCM, Araújo JC De, Riffel DB, Corrêa MR da C, Pinheiro Neto JS. 2015. Scenarios for use of floating photovoltaic plants in Brazilian reservoirs. IET Renew Power Gener. 9:1019–1024.

Schaefer JC. 1990. Review of photovoltaic power plant performance and economics. IEEE Trans Energy Convers. 5:232–238.

SolarPower Europe. 2018. Global Market Outlook for Solar Power/2018-2022. Brussels, Belgium.

Suuronen A, Muñoz-Escobar C, Lensu A, Kuitunen M, Guajardo Celis N, Espinoza Astudillo P, Ferrú M, Taucare-Ríos A, Miranda M, Kukkonen JVK. 2017. The Influence of Solar Power Plants on Microclimatic Conditions and the Biotic Community in Chilean Desert Environments. Environ Manage. 60:630–642. DOI:10.1007/s00267-017-0906-4

Tolmasquim MT. 2018. Fontes renováveis e alternativas energéticas. Rio de Janeiro: UFRJ; COPPE.

Torres-Sibille A del C, Cloquell-Ballester VA, Cloquell-Ballester VA, Artacho Ramírez MÁ. 2009. Aesthetic impact assessment of solar power plants: An objective and a subjective approach. Renew Sustain Energy Rev. 13:986–999.

Tsoutsos T, Frantzeskaki N, Gekas V. 2005. Environmental impacts from the solar energy technologies. Energy Policy. 33:289–296.

Turney D, Fthenakis V. 2011. Environmental impacts from the installation and operation of large-scale solar power plants. Renew Sustain Energy Rev. 15:3261–3270. DOI:10.1016/j.rser.2011.04.023

UNEP UNEP. 2002. United Nations Environment Programme Environmental Impact Assessment Training Resource Manual. Environ Impact Assess Train Resour Man. 600.

UNFCCC. 2015. Intended Nationally Determined Contribution. Brasília. Available from: http://www4.unfccc.int/submissions/INDC/Published Documents/Brazil/1/BRAZIL iNDC english FINAL.pdf%0Ahttp://www4.unfccc.int/Submissions/INDC/Published Documents/Brazil/1/BRAZIL iNDC english FINAL.pdf

Vazquez M, Hallack M. 2018. The role of regulatory learning in energy transition: The case of solar PV in Brazil. Energy Policy. 114:465–481. DOI:10.1016/j.enpol.2017.11.066

Viana AG, Ramos DS. 2018. Outcomes from the first large-scale solar PV auction in Brazil. Renew Sustain Energy Rev. 91:219–228.

Wirth H. 2018. Recent Facts about Photovoltaics in Germany. Freiburg. Available from: https://www.ise.fraunhofer.de/content/dam/ise/en/documents/publications/studies/recent-facts-about-photovoltaics-in-germany.pdf

World Bank. 2008. Environmental Licensing for Hydroeletric Projects in Brazil A Contribution to the Debate. volume I. Work Bank.

World Energy Council. 2016. World Energy Resources: Solar 2016.

Zhang S. 2016. Analysis of DSPV (distributed solar PV) power policy in China. Energy. 98:92–100. DOI:10.1016/j.energy.2016.01.026

Chapter III

Is floating photovoltaic better than conventional photovoltaic? Assessing environmental impacts

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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 floating PV 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.

Keywords: floating photovoltaic; terrestrial photovoltaic; solar energy; environmental impacts; EIA

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 & 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 & 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 (Marco et al. 2014; Walston Jr 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 (T. Guerin 2017).

To overcome some negative impacts such as deforestation and land requirements, floating photovoltaic (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 floating PV 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; M.R. Santafé et al. 2014;

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 & Santafé 2015; Hartzell 2016). These floating PV facilities vary from 1 kW capacity to several MW of capacity (Sahu et al. 2016) (see list some current and future projects by Ciel et Terre (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 floating PV in comparison to terrestrial photovoltaic installation. For instance, a previous study in Brazil pointed out Bolonha Lake's potential to host a floating PV system, nonetheless the study did not tackle what potential environmental impacts the FPV system could cause or minimize on the surrounding area only environmental conditions such as weather parameters (Silva & Souza 2017). Therefore, concerning the environment the majority of works focus on evaporation control in floating PV. Furthermore studies must still be conducted to assess impacts of floating PV 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 floating photovoltaic, 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 floating photovoltaic, as part of the EIA (Environmental Impact Assessment) and SEA (Strategic Environmental Assessment) 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 & Fischer 2006; Phylip-Jones & 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 floating photovoltaic 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 floating PV systems. The impacts were characterized 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 3** summarises all environmental characteristics covered in the results section. At the end of every section a table is presented to synthesize the main findings and differences between the two technologies proposed.

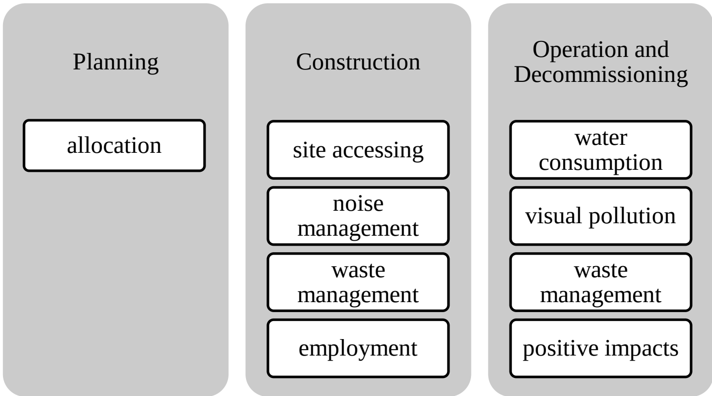

Figure 3. Environmental characteristics analysed at all phases of a PV project.

Solar terrestrial and floating photovoltaic concept

Terrestrial and floating photovoltaic 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 floating PV. In general solar photovoltaic installations require (Cabrera-Tobar et al. 2016; Sahu et al. 2016; T.F. Guerin 2017):

- **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.
- **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). Floating photovoltaic 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, floating photovoltaic will require (Choi 2014b; R.M. Santafé et al. 2014; M.R. Santafé et al. 2014; 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 (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 Jr 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 & 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 & 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 & 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 Jr 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 & 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.

Floating PV system has emerged as an alternative to mitigate some of those negative impacts associated with deforestation and land allocation (Choi 2014a; Lee et al. 2014), 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). Floating PV systems are suitable to install in abandoned mining lakes, making use of an unused degraded area (Song & Choi 2016). Installation of floating PV in lakes used in agriculture is also reported to prevent water evaporation in remote locations (Dupraz et al. 2011; Dinesh & Pearce 2016). Regarding the impact on the local geomorphology and geohydrology, although floating PV 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 that 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 (T.F. Guerin 2017). 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 floating PV 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; M.R. Santafé et al. 2014; Gaikwad & 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 to 5 skilled people during 75 to 150 days in projects terrestrial PV projects ranging from 1 to 5 MW. Allocation (understood here as design and pre-construction) might employ 7 to 12 skilled people with more opportunities available in projects of less than 10 MW in conventional PV (Ghosh, Arunabha Palakshappa et al. 2014). There have not been reported studies on employment rates during floating PV 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 floating PV as the system does not suppress local vegetation. Table 6 summarises the main environmental impacts and attributes considered during allocation and planning phase.

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

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 (T. Guerin 2017). There is also potential air pollution sources in both terrestrial and floating PV caused by the heavy machinery, increase in local traffic, and dust generation in the site (terrestrial PV) and accessing site (terrestrial and floating PV). Floating PV 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. Floating photovoltaic 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 (T.F. Guerin 2017). 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 Park. Noise will only exist during construction and it is a common parameter in both terrestrial and floating photovoltaic; 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, Arunabha Palakshappa et al. 2014). Utility-scale solar photovoltaic power plants might take more than 12 to 14 months to complete installation process. No studies on time require to install/mount large scale floating photovoltaic have been reported, the duration might be the same but conditioned to environmental conditions such as wind velocity in the local. Noise on floating photovoltaic 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 & Abbasi 2000; T. Guerin 2017). Therefore, a waste management plan is required to minimise impacts caused by incorrect waste disposal during construction. Floating PV 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. (Ghosh, Arunabha Palakshappa 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, Arunabha Palakshappa et al. 2014). Conventional PV will probably generate more jobs due to the additional machinery to mount the system, floating photovoltaic might only require screw drives to place the PV panels depending on the technology adopted. Additional studies must tackle employment rates in different floating PV designs (see (Cazzaniga et al. 2017) for a review on floating PV designs). The analysis with main environmental impacts is summarised in table 7.

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

Table 7. Comparison of environmental impacts and attributes for conventional and floating PV during construction.

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 & 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 (T.F. Guerin 2017) 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 & Abbasi 2000; Lovich & 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 & 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 floating PV due to the high risk of water body contamination and pollution. However, some contaminants might be release 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 floating PV 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 floating PV(Rosa-Clot et al. 2017). The system is a good strategy for irrigation lakes (M.R. Santafé et al. 2014) 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 floating PV 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 & Reller 2012). Moreover, recycling of PV components recovers valuable materials such as copper, indium, gallium, diselenide, cadmium, telluride, and many silicon materials (McDonald & 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 floating PV system is composed of pontoon, floats, and mooring system (Choi 2014b; R.M. Santafé et al. 2014; 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 (R.M. Santafé et al. 2014; M.R. Santafé et al. 2014; Sahu et al. 2016; Cazzaniga et al. 2017). Lee, Joo, and Yoon (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 floating PV 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 floating PV 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 floating PV 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 3-12 permanent skilled workers per year to 7-30 unskilled workers per year in conventional PV plants (Ghosh, Arunabha Palakshappa 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 floating photovoltaic (Sahu et al. 2016), a decrease of 50% in employment rate is assumed for the floating PV 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 & Fthenakis 2011). CO_2 savings through USSE reported in the literature vary from 0.53 kg CO_2/kWh (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 & 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 8 expresses the main environmental impacts assessed during operation and decommissioning.

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

Table 8. Environmental impacts and attributes during operation and decommissioning phases.

Conclusion

This paper addressed and compared the environmental impacts caused during all phases of terrestrial and floating photovoltaic projects focusing on countries with tropical climate. The analysis of the environmental impacts also pointed out promising results toward the installation of a floating PV 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, floating photovoltaic is more suitable because it minimises these problems associated with conventional terrestrial utility scale solar facilities. The floating PV 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. Another benefit pointed out in the literature is that floating PV 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 floating PV 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 floating PV 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 floating PV 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 floating PV 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 floating PV in the chosen area; natural lakes with great biodiversity and recreational purposes can experience public drawback for allocation. Future surveys concerning floating photovoltaic 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; Carlisle et al. 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 floating PV 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 strategic environmental assessment (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 & Fischer 2006; Phylip-Jones & Fischer 2015) (see a guideline for SEA in (Fischer & Nadeem 2013)). Particularly, SEA and EIA for large-scale floating PV must be latter addressed as it is a quite new locational alternative without long-term case-study investigation.

- For bulleted lists

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

References

Abbasi SA, Abbasi N. 2000. The likely adverse environmental impacts of renewable energy sources. Appl Energy [Internet]. [cited 2017 Nov 12]; 65:121–144.

Abreu SL, Rüther R, Colle S, Martins FR, Pereira EB. 2008. Brazilian Atlas for solar energy resource: SWERA results. In: Proc ISES World Congr 2007. Berlin, Heidelberg:

Springer; p. 2–5.

Aman MM, Solangi KH, Hossain MS, Badarudin A, Jasmon GB, Mokhlis H, Bakar AHA, Kazi SN. 2015. A review of Safety , Health and Environmental (SHE) issues of solar energy system. Renew Sustain Energy Rev [Internet]. 41:1190–1204. Available from: http://dx.doi.org/10.1016/j.rser.2014.08.086

Benson JF. 2003. What is the alternative? Impact assessment tools and sustainable planning. Impact Assess Proj Apprais. 21:261–280.

Cabrera-Tobar A, Bullich-Massagué E, Aragüés-Peñalba M, Gomis-Bellmunt O. 2016. Topologies for large scale photovoltaic power plants. Renew Sustain Energy Rev [Internet]. 59:309–319. Available from: http://dx.doi.org/10.1016/j.rser.2015.12.362

Carlisle JE, Kane SL, Solan D, Bowman M, Joe JC. 2015. Public attitudes regarding large-scale solar energy development in the U.S. Renew Sustain Energy Rev [Internet]. 48:835–847. Available from: http://dx.doi.org/10.1016/j.rser.2015.04.047

Carlisle JE, Solan D, Kane SL, Joe J. 2016. Utility-scale solar and public attitudes toward siting: A critical examination of proximity. Land use policy [Internet]. 58:491–501. Available from: http://dx.doi.org/10.1016/j.landusepol.2016.08.006

Cazzaniga R, Cicu M, Rosa-clot M, Rosa-clot P, Tina GM, Ventura C. 2017. Floating photovoltaic plants : Performance analysis and design solutions. Renew Sustain Energy Rev [Internet].:1–12. Available from: http://dx.doi.org/10.1016/j.rser.2017.05.269

Choi Y. 2014a. A study on power generation analysis of floating PV system considering environmental impact. Int J Softw Eng its Appl. 8:75–84.

Choi Y. 2014b. A Case Study on Suitable Area and Resource for Development of Floating Photovoltaic System. Int J Electr Comput Energ Electron Commun Eng. 8:828–832.

Ciel et Terre. 2017. Our references: the floating solar expert with hydrelio technology [Internet]. [cited 2018 Jan 1]:1–40. Available from: http://www.ciel-et-terre.net/wp-content/uploads/2017/12/CT-References-December-2017.pdf

Costa SG e. 2017. Impactes ambientais de sistemas fotovoltaicos flutuantes. Lisboa: Universidade de Lisboa.

Delicado A, Figueiredo E, Silva L. 2016. Community perceptions of renewable energies in Portugal: Impacts on environment, landscape and local development. Energy Res Soc Sci [Internet]. 13:84–93. Available from: http://dx.doi.org/10.1016/j.erss.2015.12.007

Diendorfer C, Haider M, Lauermann M. 2014. Performance Analysis of Offshore Solar Power Plants. Energy Procedia [Internet]. 49:2462–2471. Available from: http://www.sciencedirect.com/science/article/pii/S1876610214007152

Dinesh H, Pearce JM. 2016. The potential of agrivoltaic systems. Renew Sustain Energy Rev [Internet]. 54:299–308. Available from: http://dx.doi.org/10.1016/j.rser.2015.10.024

Dupraz C, Marrou H, Talbot G, Dufour L, Nogier A, Ferard Y. 2011. Combining solar photovoltaic panels and food crops for optimising land use: Towards new agrivoltaic schemes. Renew Energy [Internet]. 36:2725–2732. Available from: http://dx.doi.org/10.1016/j.renene.2011.03.005

Ellabban O, Abu-Rub H, Blaabjerg F. 2014. Renewable energy resources : Current status, future prospects and their enabling technology. Renew Sustain Energy Rev [Internet]. 39:748–764. Available from: http://dx.doi.org/10.1016/j.rser.2014.07.113

Ettinger WS. 1987. Impacts of a chemical dust suppressant/soil stabilizer on the physical and biological characteristics of a stream. Soil Water Conserv Soc. 42:111–114.

EY, Solar Power Europe. 2017. Solar PV Jobs & Value Added in Europe.

Ferrer-gisbert C, Ferrán-gozálvez JJ, Redón-santafé M, Ferrer-gisbert P, Sánchez-romero FJ, Torregrosa-soler JB. 2013. A new photovoltaic floating cover system for water reservoirs. Renew Energy [Internet]. 60:63–70. Available from: http://dx.doi.org/10.1016/j.renene.2013.04.007

Ferroukhi R, Khalid A, García-Baños C, Renner M. 2017. Renewable Energy and Jobs: Annual Review 2017. [place unknown]. Available from: https://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Jobs_Annual_Review_2017.pdf

Finnveden G, Nilsson M, Johansson J, Persson A, Morberg A, Carlsson T. 2003. Strategic environmental assessment methodologies — applications within the energy sector. Environ Impact Assess Rev [Internet]. 23:91–123. Available from: http://muse.jhu.edu/content/crossref/journals/comparative_technology_transfer_and_society/v007/7.3.simon.html

Fischer TB, Nadeem O. 2013. Environmental impact assessment (EIA) course curriculum for tertiary level institutions in Pakistan: national impact assessment Programme (NIAP) Pakistan [Internet]. [place unknown]. Available from: http://www.iaia.org/publications-resources/pdf/FullEIAcurriculumFischerNadeemSeptember2013-with corrections.pdf

Fthenakis V, Blunden J, Green T, Krueger L, Turney D. 2011. Large photovoltaic power plants: wildlife impacts and benefits. In: Photovolt Spec Conf. Seatle, WA, USA: IEEE; p. 2011–2016.

Gaikwad OD, Deshpande UL. 2017. Evaporation control using floating pv system and canal roof top solar system. Int Res J Eng Technol. 4:214–216.

Gasparatos A, Doll CNH, Esteban M, Ahmed A, Olang TA. 2017. Renewable energy and biodiversity : Implications for transitioning to a Green Economy. Renew Sustain Energy Rev [Internet]. 70:161–184. Available from: http://dx.doi.org/10.1016/j.rser.2016.08.030

Ghosh, Arunabha Palakshappa R, Jain R, Aggarwal S, Choudhury P, Jaiswal A, Connolly M, Deol B, Kaun N, Holden M. 2014. Solar Power Jobs : Exploring the Employment Potential in India ' s Grid-Connected Solar Market. India.

Grippo M, Hayse JW, O'Connor BL. 2015. Solar Energy Development and Aquatic Ecosystems in the Southwestern United States : Potential Impacts , Mitigation , and Research Needs. Environ Assess. 55:244–256.

Guerin T. 2017. A case study identifying and mitigating the environmental and community impacts from construction of a utility-scale solar photovoltaic power plant in eastern Australia. Sol Energy [Internet]. 146:94–104. Available from: http://dx.doi.org/10.1016/j.solener.2017.02.020

Guerin TF. 2017. Evaluating expected and comparing with observed risks on a large-scale solar photovoltaic construction project : A case for reducing the regulatory burden.

Renew Sustain Energy Rev [Internet]. 74:333–348. Available from: http://dx.doi.org/10.1016/j.rser.2017.02.040

Gunerhan H, Hepbasli A, Giresunlu U. 2009. Environmental Impacts from the Solar Energy Systems. Energy Sources. 31:131–138.

Hartzell TS. 2016. Evaluating potential for floating solar installations on Arizona water management text [Internet]. [place unknown]: University of Arizona. Available from: http://hdl.handle.net/10150/608582

Hernandez RR, Easter SB, Murphy-mariscal ML, Maestre FT, Tavassoli M, Allen EB, Barrows CW, Belnap J, Ochoa-hueso R, Ravi S, Allen MF. 2014. Environmental impacts of utility-scale solar energy. Renew Sustain Energy Rev [Internet]. 29:766–779. Available from: http://dx.doi.org/10.1016/j.rser.2013.08.041

Jenkins AR, Ralston S, Smit-Robinson HA. 2015. Birds and solar energy best practice guidelines. South Africa.

Larsen SV. 2014. Is environmental impact assessment fulfilling its potential? The case of climate change in renewable energy projects. Impact Assess Proj Apprais [Internet]. 32:234–240. Available from: http://dx.doi.org/10.1080/14615517.2014.898386

Lee Y, Joo H, Yoon S. 2014. Design and installation of floating type photovoltaic energy generation system using FRP members. Sol Energy [Internet]. 108:13–27. Available from: http://dx.doi.org/10.1016/j.solener.2014.06.033

Liu L, Wang Q, Lin H, Li H, Sun Q, Wennersten R. 2017. Power Generation Efficiency and Prospects of Floating Photovoltaic Systems. Energy Procedia [Internet]. 105:1136–1142. Available from: http://dx.doi.org/10.1016/j.egypro.2017.03.483

Lovich JE, Ennen JR. 2011. Wildlife Conservation and Solar Energy Development in the Desert Southwest, United States. Bioscience [Internet]. 61:982–992. Available from: https://academic.oup.com/bioscience/article-lookup/doi/10.1525/bio.2011.61.12.8

Marco A De, Petrosillo I, Semeraro T, Pasimeni MR, Aretano R, Zurlini G. 2014. The contribution of Utility-Scale Solar Energy to the global climate regulation and its effects on local ecosystem services. Glob Ecol Conserv [Internet]. 2:324–337. Available from: http://dx.doi.org/10.1016/j.gecco.2014.10.010

Marshall R, Fischer TB. 2006. Regional electricity transmission planning and SEA: The case of the electricity company ScottishPower. J Environ Plan Manag. 49:279–299.

Martins FR, Ruther R, Pereira EB, Abreu SL. 2008. Solar energy scenarios in Brazil Part two : Photovoltaics. Energy Policy. 36:2865–2877.

Marwede M, Reller A. 2012. Future recycling flows of tellurium from cadmium telluride photovoltaic waste. Resour Conserv Recycl [Internet]. 69:35–49. Available from: http://dx.doi.org/10.1016/j.resconrec.2012.09.003

McDonald NC, Pearce JM. 2010. Producer responsibility and recycling solar photovoltaic modules. Energy Policy [Internet]. 38:7041–7047. Available from: http://dx.doi.org/10.1016/j.enpol.2010.07.023

Pereira EB, Martins FR, Gonçalves AR, Costa RS, Lima FJL de, Rüther R, Abreu SL de, Tiepolo GM, Pereira SV, Souza JG. 2017. Atlas Brasileiro de Energia Solar. 2nd ed. São José dos Campos: INPE.

Phylip-Jones J, Fischer TB. 2015. Strategic environmental assessment (SEA) for wind energy planning: Lessons from the United Kingdom and Germany. Environ Impact Assess Rev [Internet]. 50:203–212. Available from: http://dx.doi.org/10.1016/j.eiar.2014.09.013

Pingel S, Frank O, Winkler M, Daryan S, Geipel T, Hoehne H, Berghold J. 2010. Potential induced degradation of solar cells and panels. In: Photovolt Spec Conf (PVSC), 2010 35th IEEE. Honolulu, HI, USA: IEEE; p. 2817–2822.

Ribeiro F, Ferreira P, Araújo M, Braga AC. 2014. Public opinion on renewable energy technologies in Portugal. Energy [Internet]. 69:39–50. Available from: http://dx.doi.org/10.1016/j.energy.2013.10.074

Rosa-Clot M, Tina GM, Nizetic S. 2017. Floating photovoltaic plants and wastewater basins: An Australian project. Energy Procedia [Internet]. 134:664–674. Available from: https://doi.org/10.1016/j.egypro.2017.09.585

Rose T, Wollert A. 2015. The dark side of photovoltaic - 3D simulation of glare assessing risk and discomfort. Environ Impact Assess Rev [Internet]. 52:24–30. Available from: http://dx.doi.org/10.1016/j.eiar.2014.08.005

Sahu A, Yadav N, Sudhakar K. 2016. Floating photovoltaic power plant : A review. Renew Sustain Energy Rev. 66:815–824.

Santafé MR, Gisbert PSF, Romero FJ, Sánchez, Soler JBT, Gozálvez JJF, Gisbert CMF. 2014. Implementation of a photovoltaic floating cover for irrigation reservoirs. J Clean Prod [Internet]. 66:568–570. Available from: http://dx.doi.org/10.1016/j.jclepro.2013.11.006

Santafé RM, Soler JBT, Romero FJS, Gisbert PSF, Gozálvez JJF, Gisbert CMF. 2014. Theoretical and experimental analysis of a floating photovoltaic cover for water irrigation reservoirs. Energy [Internet]. 67:246–255. Available from: http://dx.doi.org/10.1016/j.energy.2014.01.083

Sharma P, Muni B, Sen D. 2015. Design parameters of 10kw floating solar power plant. Int Adv Res J Sci Eng Technol. 2:85–89.

Silva GDP, Souza MJR. 2017. Estimativa de geração de energia através de um sistema fotovoltaico: implicações para um sistema flutuante no lago Bolonha, Belém-Pará. Rev Bras Energias Renov [Internet]. 6:149–164. Available from: http://revistas.ufpr.br/rber/article/view/46194/pdf

Simon CA. 2009. Cultural Constraints on Wind and Solar Energy in the U.S. Context. Comp Technol Transf Soc [Internet]. 7:251–269. Available from: http://muse.jhu.edu/content/crossref/journals/comparative_technology_transfer_and_society/v007/7.3.simon.html

Singh AK, Boruah D, Sehgal L, Prasath RA. 2016. Feasibility study of a grid-tied 2MW floating solar PV power station and e-transportation facility using ‘SketchUp Pro’ for the proposed smart city of Pondicherry in India. J Smart Cities. 2:49–59.

Slootweg R, Vanclay F, van Schooten M. 2001. Function evaluation as a framework for the integration of social and environmental impact assessment. Impact Assess Proj Apprais. 19:19–28.

Song J, Choi Y. 2016. Analysis of the Potential for Use of Floating Photovoltaic Systems on Mine Pit Lakes : Case Study at the Ssangyong Open-Pit Limestone Mine in Korea. Energies. 9:1–13.

Stoms DM, Dashiell SL, Davis FW. 2013. Siting solar energy development to minimize biological impacts. Renew Energy [Internet]. 57:289–298. Available from: http://dx.doi.org/10.1016/j.renene.2013.01.055

Trapani K, Santafé MR. 2015. A review of floating photovoltaic installations: 2007–2013. Prog Photovolt Res Appl [Internet]. 23:524–532. Available from: http://dx.doi.org/10.1002/pip.1160

Tsoutsos T, Frantzeskaki N, Gekas V. 2005. Environmental impacts from the solar energy technologies. Energy Policy. 33:289–296.

Turney D, Fthenakis V. 2011. Environmental impacts from the installation and operation of large-scale solar power plants. Renew Sustain Energy Rev [Internet]. 15:3261–3270. Available from: http://dx.doi.org/10.1016/j.rser.2011.04.023

Vanclay F. 2003. International Principles for Social Impact Assessment. Impact Assess Proj Apprais. 21:5–11.

Visser E. 2016. The impact of South Africa's largest photovoltaic solar energy facility on birds in the Northern Cape, South Africa. [place unknown]: University of Cape Town.

Walston Jr LJ, Rollins KE, Lagory KE, Smith KP, Meyers SA. 2016. A preliminary assessment of avian mortality at utility-scale solar energy facilities in the United States. Renew Energy [Internet]. 92:405–414. Available from: http://dx.doi.org/10.1016/j.renene.2016.02.041

Wästhage L. 2017. Optimizatin of Floating PV Systems. [place unknown]: Mälardalen University.

Wu Z, Hou A, Chang C, Huang X, Shi D, Wang Z. 2014. Environmental impacts of large-scale CSP plants in northwestern China. Environ Sci Process Impacts [Internet]. 16:2432–2441. Available from: http://xlink.rsc.org/?DOI=C4EM00235K

Chapter IV

A multicriteria proposal for large-scale solar photovoltaic impact assessment

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Large-scale photovoltaic (LSPV) may cause significant changes in the environment and lead to detrimental impacts on the natural and anthropic environments. A sample analysis of several EIA's worldwide demonstrated that checklists and matrices are the main methods used to assess impacts of LSPV. These methods tend to focus on a descriptive analysis of the natural environment alone and fail to incorporate and interact key conflicting features. Moreover, the analysis is very subjective and there is a lack of criteria to judge the impacts, their interaction, temporality, and spatial distribution. The purpose of this work is thus to propose a multicriteria methodology that assesses and conveys the main environmental and socioeconomic aspects of LSPV and support decision-making on the project licensing in Brazil. The proposed method aims to improve the current poor quality and ineffective EIA presented for LSPV. The method might be applied to any solar photovoltaic project in different climate regions and is designed to provide the assessment score for impacts of different alternatives and estimate scenarios according to the interests of the parts.

Keywords: EIA quality; Analytic Hierarchy Process (AHP); Multicriteria method; Large-scale Solar PV; Terrestrial and floating PV

Introduction

The continuous discussion about climate change, its global threats and impacts, global mitigation alternatives and agreements (i.e. Kyoto Agreement), and sustainable development goals lead to years of research and adaptation of technologies to propose ways to achieve development without exhausting natural resources or overwarming the planet. Energy generation sector, mainly powered by fossil fuels since the Industrial revolution, has experienced great development in renewable and sustainable alternatives that do not release greenhouse gases (GHG) to the atmosphere during operation and exploit naturally infinite resources (renewable over time, i.e. solar irradiance and wind). The 2015 Paris Agreement calls nations (Parties and non-Parties) to adopt a long-term framework and reduce their GHG emissions by 2020 in order to keep the global temperature rise below 2°C pre-industrial levels and limit the increase up to 1.5°C pre-industrial levels (UNFCCC 2015). In this context, many countries are adopting the installation of large-scale solar photovoltaic (LSPV) 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 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 & Fthenakis 2011; Wu et al. 2014) (see (Da Silva & Branco 2018) for a comprehensive review on impacts of terrestrial and floating solar plants). For this reason, the expansion of the current solar PV capacity through centralised LSPV has to go through environmental licensing and present a detailed study, the Environmental Impact Assessment (EIA), containing the impacts of power plant on the environment (natural and socioeconomic).

EIA practitioners and the international literature, though, have been claiming several problems regarding the poor quality of the EIA and its lack of effectiveness to prevent detrimental impacts (Duarte et al. 2017a; Kolhoff et al. 2018). As there isn't any specific federal regulation regarding the installation of LSPV in Brazil plus the fact that solar PV is a quite new emerging technology for utility-scale in Brazil, the criteria used for assessing impacts are unclear and depend on State agencies' guides for licensing (Da

Silva et al. Under revision)[4]. As result, many EIA studies (or simplified version of EIA) for LSPV are merely descriptive, not reflecting the complex interaction faced in energy planning; the quality and methods used may be very susceptible to critique and subjectivity. Magrini (Magrini 1992) detected a similar issue when large hydropower plants were being expanded in the 1980s in Brazil. Most studies back then lacked quantitative and qualitative analysis nor did they look at the integration of environment-socio-legal aspects present in the allocation of large hydro dams. Moreover, the studies did not estimate an overall impact score neither did they compare different alternatives. The author proposed a multicriteria methodology named SAMAMBAIA (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 Assess Environmental Impacts) to better assess impacts at different perspectives and improve the poor quality of studies presented to aid decision-making. The author then exemplifies its potential application by adapting the method for hydroelectric plants (SAMAMBAIA-H)[5].

The installation of large-scale renewable energy plants presents great complexity for decision-making regarding environmental, political-strategical, 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 fully integrating several conflicting issues faced by planners. Even though some EIA applies a quantitative approach, the weighting aggregation is not clear, neither does it necessarily reflect all community and stakeholders' interest. Therefore, there is a clear need to propose new and feasible methodological approaches to assess and analyse all complex conflicting issues and environmental impacts in EIA (Loomis & Dziedzic 2018), particularly involving the emerging expansion of large-scale solar photovoltaic.

The purpose of this work is to propose a multicriteria model, named SAMAMBAIA-Solar, following the structure given by the original SAMAMBAIA method, which assesses and conveys the main environmental and socioeconomic aspects of LSPV to support decision-making on the project licensing focusing on Brazil. 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

[4] The reference will be added after acceptance.

[5] 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.

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 hectares) 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 (T. Guerin 2017; T.F. Guerin 2017). 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 & Abbasi 2000; Turney & Fthenakis 2011; Marrou et al. 2013; Wu et al. 2014; Grippo et al. 2015; T. Guerin 2017; Da Silva & 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 (T. Guerin 2017; T.F. Guerin 2017). 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 & Fthenakis 2011), waste generation (solid and effluent), accidental spillage of vehicle lubricants and oils (Rudman; & Esler 2017), and stress on local roads and infrastructure (T. Guerin 2017). 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 & Branco 2018). It is noteworthy to identify possible bird migration routes (Jenkins et al. 2015) as there is allegation of 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 Jr 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 & 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 in the site [see a case study in (T. Guerin 2017)]. 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 & 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 hearing. 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 & Branco 2018).

Approaches to assess environmental impacts of large-scale solar photovoltaic: Brazil and worldwide.

The International Association for Impact Assessment (IAIA) defines 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 (some countries might use the nomenclature Social Impact Assessment- SIA) have been addressed as socio-economic impacts due to trade-offs between biophysical impacts and social gains (Morrison-Saunders & Fischer 2006).

It is noteworthy that non-compensated economic impacts are usually the sources of conflicts. EIA is thus a tool used to support decision-making in choosing the best alternative to be implemented.

A list of the main techniques (not exhaustive) created to aid EIA is expressed as follows (Pendse Rao, RV, Sharma, PK 1989; Magrini 1990; Canter & Sadler 1997; Morris & Therivel 2001; Glasson et al. 2005):

- **Experts' judgment**: method used to address the specific impacts on the environment caused by components of the project. The actual impacts on specific environmental components are not outlined. This approach is highly subjective and fragile to critiques.
- **Checklists**: standard list that identifies several environmental attributes and key impacts caused by the project. The method includes questions that need to be answered to assess the project's potential to degrade the environment. Magnitude and importance might or might not be included in the analysis along with a quantitative approach. However, the method is mainly descriptive rather than quantitative (Põder & Lukki 2011), and it does not allow planers to predict secondary environmental impacts nor does it link impacts to consequences.
- **Matrices**: evolution of checklists. This method consists of pairwise impact sources or project actions (plotted in one axis) to impacts caused (plotted on another axis) showing the cause-effect relationship between the environmental factors and project actions. Magnitude, importance, extension of the project (local or extensive), durability (short or long-term) are common features included in this analysis. The lack of interaction between different components and impossibility to predict secondary impacts are disadvantages of this approach. Moreover, some methods add a quantitative approach to estimate the overall score for the environmental impact. The definition of weights, however, is very subjective and fragile to critiques.
- **Flowcharts and networks**: construction of network diagram that enables the identification of inter-relationship among different impact sources, sources and impacts, cumulative impacts, primary and secondary impacts resulting from particular actions. This method might be complex to apply; visualisation of interactions might be also hard to perceive. The most known method is the Sorensen Network [see (Mason & Moore 1998)].
- **Multicriteria**: this method addresses complex relationships of different environmental and socio-economic characteristics, policies, conflicting objectives, information, and multi-interest aspects to aid decision-making. The main goal is to choose the best alternative based on several criteria and interests. There are many types of multicriteria decision making analysis (MCDA) which incorporate both qualitative and quantitative criteria. Differently from checklists and matrices, the quantitative approach is based on mathematical tools that help decision-makers to judge the consistency of the weights used thus adjusting the weights when they do not represent someone's interest. Moreover, many MCDA methods cover network diagrams and matrices to

compare and conflict the multi-objective problems concerning environmental impact assessment (Finnveden et al. 2003; Pohekar & Ramachandran 2004; Kowalski et al. 2009; Huang et al. 2011). The complexity of the method might be pointed out as the main disadvantage.

- **GIS (Geographic Information System) and creation of maps**: production of maps indicating locations, important environmental features, impact area, and sources of interaction with the project. Overlay map combine different components (layers) and display the possible changes caused by the interaction of the proposed action. Many methods now incorporate GIS tools and other criteria to assess visual impacts of renewable energy plants [see (Rodrigues et al. 2010; Minelli et al. 2014; Aly et al. 2017)]

Currently, all studies tend to include GIS 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 water bodies, although it can potentially be used for impact prediction (Rodriguez-Bachiller & Wood 2001).

In the light of EIA for renewable energy (other than hydro) in Brazil, the expansion is relatively new in the country. The first multi-megawatt wind farm (5 MW-10 turbines of 500 kW each) was installed in 1999 (ANEEL 2002); the deployment of centralised PV came more recently, in 2011, with the 1 MWp Tauá solar plant. Thus, there has been energy and environmental regulation for these sources of electricity. There is no consolidated legislation on legal requirements for impact assessment and licensing, nor is there a consolidated methodology for elaborating the EIA of these technologies (in principle, any method abovementioned can be used).

The necessity of this work (propose a multicriteria method to integrate conflicts impacts) began with a survey of how EIA and their methodological aspects have been conducted towards LSPV in Brazil and around the world. EIA in other countries may reflect a similar reality as solar farms are new electricity sources in many parts of the world as well. Firstly, there is not a general understanding to classify large-scale PV plants and the necessity to undergo through a detailed EIA; i.e. all PV projects above 10 MW (Lai et al. 2017), or 1 MW (Moore-O'Leary et al. 2017), whilst the Brazilian Electricity Regulatory Agency (ANEEL) resolution 482/2012 classifies centralised PV commercial-scale projects above 5 MW (ANEEL 2012). Secondly, each Brazilian state can have its own criteria to require EIA before installing solar PV plants, which varies from projects covering at least 100 hectares (ha) in area to all above 10 MWp PV plants (Da Silva et al. Under revision). Hence the present study conducted a deep research to find EIA reports for LSPV projects above 10 MW or occupying more than 100 ha. The investigation focused on the impacts reported in the EIA and their methodological approach to assess magnitudes of impacts and integrate the aspects appraised. The local diagnosis and specific legal requirement are not addressed.

The method of impact prediction can be qualitative or quantitative (Morris & Therivel 2001). In the present study, descriptive assessment is understood as a qualitative analysis without assigning weights or scores to measure the impacts. Quantitative assessment involves the assignment of scores for each impact magnitude and the application of a technique to express the overall project’s impact on the environment. The techniques (checklist, matrices, flowchart and network, etc) are also accounted for during the integration of impacts. Therefore, **table 9** summarises the main findings for the analysis of 20 selected large-scale PV EIAs available worldwide. 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.

Name	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[1]	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

Table 9. Large-scale Solar PV and main methods to assess their environmental impacts[6].

The research demonstrates that checklists and matrices (with GIS to identify the areas) are the main methods used in EIAs to assess impacts of LSPV. The EIA studies tend to focus on a descriptive analysis of the impacts on the natural environment alone and fail to incorporate and interact key conflicting features (i.e. public acceptance, socioeconomic characteristics, and stakeholder interests). Moreover, the analysis is based on a very subjective approach and there is a lack of criteria to judge the impacts, their interaction, temporality, and spatial distribution.

[6] 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.

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. None of the EIA have assigned a final score to the overall environmental impact in order to compare the different alternatives (technological or spatial). It is noteworthy that despite being a renewable energy source, there might be several conflicts in the area for installation large-scale projects. In the Brazilian context, despite some improvements in technological tools to predict environmental impacts (such area covered by a hydropower reservoir), the methodologies do not tend to be preventive. On its conception, EIA should be based on prevention of impacts (Morris & Therivel 2001; Glasson et al. 2005). The studies still lack the integration of social-economic aspects into the EIA. In fact, the major assessment is done under a descriptive analysis focusing on each category alone divided into several chapters (environment, social, economic, policies) throughout the report. Thereof, EIA may likely be ineffective to predict and prevent impacts from conflicting issues concerning LSPV.

From a strategic point of view, possible local planning and programmes can also suffer the same problem allocating large-scale projects (poor quality of studies and lack to predict environmental impacts) which was a problem reported in the wind off-shore expansion in UK and Germany [see (Marshall & Fischer 2006; Phylip-Jones & Fischer 2015)]. The multicriteria model SAMAMBAIA-Solar is, therefore, a proposal to meet the growing necessity to predict environmental impacts and incorporate all conflicting issues concerning the natural and anthropic environment through a multicriteria analysis. The approach is mainly discussed for EIA, but it can be adapted and applied to SEA as well.

Methodology approach proposed

SAMAMBAIA: the conception

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), Giangrande and rating scale. It will therefore follow common steps required in multicriteria analysis application such as: selection of spatial and temporal actions, definition of objectives, selection of attributes, construction of AHP tree to break attributes down into levels and sub-levels, construction of evaluation matrix to pair-wise criteria (i.e. environmental aspects) to alternatives (i.e. environmental policy); assessment of weights, and calculation of the overall score to the each alternative (MAVT method), and the assessment of consistency index. The general structure is given as follows (Magrini 1992; Magrini & Viana 2012):

- Definition of actions: the first step is to identify temporal and spatial actions. The former action is related to the impacts caused by the project during its lifetime (i.e. construction, operation and maintenance). The latter action is used to classify or describe the spatial distribution of impacts caused on a given geographical area. Magrini suggests to create a buffer for a possible area affected by the project and divide it into smaller territorial units (TU) of equal sizes, however, this approach is very subjective and should consider the project's scale and specificities. Moreover, the TU units should not be too small and non-representative, nor should it be too large at risk of making the analysis unfeasible. The other alternative is to identify spatial actions based on the typical characteristics and impacts caused by technology; this option requires prior knowledge of the technology's likely impacts and the environment.

- Definition of objectives and hierarchy tree construction: the step is based on the AHP developed by (Saaty 1987). The overall 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 criteria, sub-criteria, and sub-levels, respectively (Løken 2007; San Cristóbal 2011; Wang & Poh 2014). As all criteria are subordinated to one another from bottom to the top, the satisfaction of the lower sub-criteria will automatically fulfill the higher criteria 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-criterion of each branch is named leaf-level objective. At each leaf-level objective, a composition of various sub-levels (evaluation criteria) of detrimental impacts is assigned to assess the environmental impact (level zero means no impact). The creation of evaluation criteria should follow a scale of impacts (from the lower to the higher impact) and avoid inclusion of temporal or spatial actions (i.e. description of the current status of the area). The evaluation criteria might be either quantitative or qualitative according to the specialists' judgment, though it is suggested to use a qualitative descriptive approach. Experts in the respective field of expertise are invited to pair-wise the criteria chosen and assign weights according to the rating scale varying from 1 to 100. The final procedure is to convert the ordinal scale of leaf-level objectives to a numerical scale ranging from 0 to 1 (minimum to maximum impact). The normalisation of the rationale scale is implemented through the eigenvector method of Saaty.
- 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 score. Using the Saaty eigenvector all values are normalised again.
- Weight aggregation: 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 so $\sum_i \underline{W_i} = 1$. 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 weight 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 weights and V_i from the value function.

Previous works with the SAMAMBAIA adapted to assess impacts and risks of contaminated areas by landfill (Magrini et al. 2011) and the accidental Mariana mining dam collapse in Brazil (Magrini & La Rovere 2016) have validated the methodology's flexibility and feasibility to interact quantitative and qualitative information with specialist judgment. In both cases, the method is applied to assess the impacts of existing projects, which already degraded the environment. The former application sought to validate the methodology and assess the current state of degradation and risks in the area. The latter aimed to measure the environmental impacts of the mining accident and estimate environmental improvements (mitigation of the impacts) over time (temporal actions) in the affected area (spatial action). The adaptions occur in the selection of actions (spatial actions depend on the impacted area and project) and objectives, the construction of the AHP tree, and the creation of the evaluation criteria. The scoring and weighting depend on each project and its calculation follows the Saaty eigenvector method. Although the original proposal exemplified the structure for hydropower plants, the author did not apply the method for the hydropower impact assessment. Ultimately, Magrini, Viana and Araujo (Magrini et al. 2011) claim that the method is easily adapted to diagnosing and identifying the more impactful areas thus helping managers to better allocate mitigation resources and minimise risks and impacts.

The proposed adaptation for large-scale solar photovoltaic

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.

For spatial actions, many studies classify direct and indirect impacted zones and cumulative impacts of those to describe spatial boundaries. The direct zone of impact is defined as the area where the project is implemented including the areas of photovoltaic panels, substation, transmission line, and fencing. Indirect impacts are more difficult to measure and depend on the solar PV scale and the environmental characteristics (Tsoutsos et al. 2005), i.e. roads or protected areas nearby. The studies developed by (Carlisle et al. 2016) tackle public acceptance towards LSPV according to distances from the project to distinguish land use types and socio-demographic characteristics such as protected areas, roads, residences, wildlife, agricultural land, and visual impact. The results show that public acceptance of LSPV varies with the proximity of sites. Herein, instead of the traditional approach to characterise an "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 socioeconomic characteristics. The first area is the "operational 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 summarized in **table 10**. Other approaches can be used even the "direct and indirect impact zone" spatial division. However, this work focuses on possible areas currently considered in the impact assessment of LSPV.

Action	*Action*	*description*	*type*
construction			temporal
construction	operational 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

Table 10. Spatial and temporal actions in SAMAMBAIA

Step 2: definition of objectives and hierarchy tree construction

AHP is a descriptive approach that uses pair-wise comparisons between alternative and criterion to estimate ratio-scaled importance (weights) (Løken 2007; Wang et al. 2009; Wang & Poh 2014) to be applied on the environmental impact assessment.

The originality of this section lies into 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. Following the AHP 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 of project development” (Vanclay et al. 2015). Therefore, the proposed goal is subdivided into 2 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-criteria (leaf-level objective). RAE is also separated into 3 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). The previous works with SAMAMBAIA-H and the adapted version for the mining accident in Brazil (Magrini 1992; Magrini & La Rovere 2016) also aided in the SAMAMBAIA-Solar tree and evaluation criteria (following section) construction by pointing out significant parameters common to all impact assessment.

At total, 64 leaf-level objectives are inserted into the model. **Figure 4** expresses the reduced AHP diagram for assessing environmental impacts of large-scale PV, all criteria at level 2 are broken down until the leaf-level objective, **see figure 7 and table 13 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).

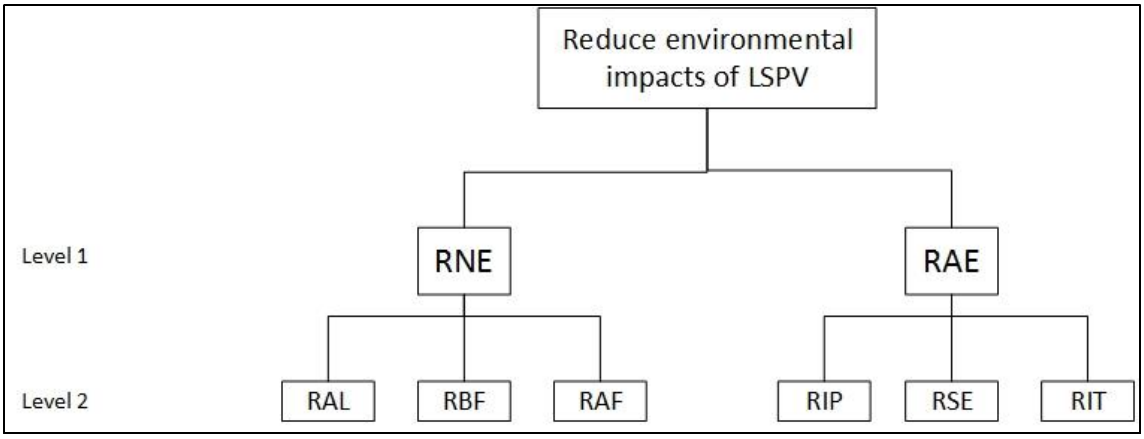


Figure 4. Reduced AHP diagram for multicriteria decision-making on the environmental impact assessment of large-scale photovoltaic projects.

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 socioeconomic. RIT: reduce the impact on the territory.

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 must obey five basic principles to be selected for use in decision-making (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 conception" section, the evaluation criteria should follow an increasing scale of degradation addressing the project's possible alterations on the environment. The criteria cover technical, economic, environmental, and social parameters, which are the main four categories applied to MCDA and energy according to (Wang et al. 2009). See T**able 11** for an example created to pair-wise the leaf-level objective "reduce the impact on the physical terrestrial habitat (PTH)"**.** 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 same process is applied to all relevant leaf-level objective criteria to reduce environmental impacts of LSPV and should be standard for EIA of PV plants (see table 14 in the supplementary material for all suggested evaluation criteria). Some evaluation criteria such as "Rnp- reduce noise pollution" in the supplementary material- must follow specific legal standards, which for Brazil may be CONAMA (National Environmental Council) resolutions and State regulations.

Criterion 1	small alteration in habitat characteristics
Criterion 2	large alteration in habitat characteristics
Criterion 3	small area with habitat fragmentation
Criterion 4	large area with habitat fragmentation
Criterion 5	loss of small habitat area
Criterion 6	loss of large habitat area

Table 11. Leaf-objective criteria for reduce impact on the physical terrestrial habitat.

The following procedure is standard for the method, translation of the descriptive evaluation criteria into a numerical scale (0 to 1). 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 scores reflect the group decision for each evaluation criteria and should be used as a standard for PV project. **Table 12** illustrates the pair-wise comparison and the specialists scoring in the leaf-level objective "reduce the impact on the physical terrestrial habitat”. Different MCDA might adopt other scaling score, see (Haurant et al. 2011; Rahman et al. 2016). The Saaty eigenvector is also applied to construct the preference function and provide the consistency ratio (CR) of the previous score (see **figure 5**). This method aids stakeholders to judge the pair-wise scores since it might suffer from subjectivity (Al Garni et al. 2016). The linear weighted sum approach is used to estimate the cumulative total value score crosswise criteria, similar to (Løken 2007; Huang et al. 2011; Klein 2013).

	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	

Table 12. Rating score applied to leaf-level objective evaluation criteria PTH. Weights are assigned below the main diagonal, the number above the diagonal are symmetric for pair-wise comparison.

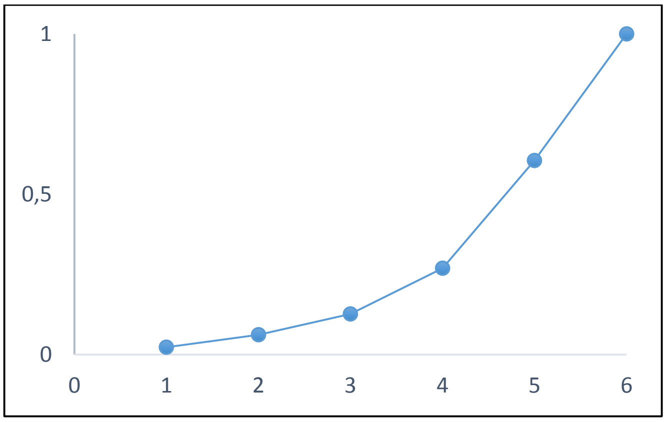


Figure 5. Preference value function estimated through matrix of judgement and eigenvector method.

Step 4: Assessment matrix

A matrix of 13 columns (temporal actions) by 64 lines (leaf-level objective), is resulted from the previous steps. The magnitude value will change according to the project and should be assigned by specialists [See table 15 in the **supplementary material]**. The proposed matrix is a general approach for SAMAMBAIA-Solar, a real application 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 aggregation

Different from typical AHP studies which assign weights to the alternatives on the bottom of the hierarchy, 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 & 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 (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 values are then normalised by the eigenvector method of Saaty. The combination (multiplication) of normalised weights from different dimensions produces the final score for the impact**,** similar to the mathematical approach used in other MCDA [see (Huang et al. 2011)]. The goal is to measure its trade-off across criteria and dimensions. A fuzzy logic approach can be integrated into this phase to translate qualitative perceptions into quantitative values, see some studies using fuzzy logic with EIA in (Liu et al. 2009; Rikhtegar et al. 2014). 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 economic, 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. See **figure 6** using criteria PHT and PAH (see the **supplementary material** for the full tree), a single scenario is presented for exemplification only.

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

RAL	50	20	25	0.56	CR= 0.001
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
HBT	50	70	75	0.56	CR= 0.001
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=
PTH	50	70	0.7	2
PAH	**30**	50	0.3	CR= 0

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 6. Weight Aggregation for PTH and PAH

Step 6: final weighting aggregation

The additive value function MAVT (Multi-attribute value theory) is a common synthesizing criteria method used to estimate the final overall 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 weighting aggregation and final score can estimate the impact of different technological and locational alternatives: the comparison between a terrestrial and floating PV in the area; two terrestrial PV plants of different sizes or using distinguish panels; and the "environmental performance" of each alternative over time on each spatial action. Higher scores (closer to 1) mean greater potential to degrade the environment and cause conflicts.

Discussion

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

In the light of the Brazilian Environmental Policy Act and the CONAMA resolutions, EIA is a mandatory instrument for environmental licensing of large-scale projects that may potentially harm the environment. Thus, the reports must present locational and technological alternatives for the project and address, in detail, all impacts in the three spheres: economic, natural, and social environments. The environmental licensing for large-scale projects is often issued by the Federal Environmental Agency, however for renewable energy plants the State Environmental Agencies are designed to the process of analysing EIA and issuing the licensing based on federal regulation[7] and their own State criteria (Da Silva et al. Under revision). The practice demonstrates that some approved EIA overlooked potential impacts and cumulative effects (C.G. Duarte et al. 2017b) being unsuccessful in preventing conflicts, i.e. the cases for wind farms in the coastal communities on Brazilian Northeast (Brannstrom et al. 2017; Gorayeb et al. 2018).

Moreover, due to energy crisis supply in the early 2000s, the energy sector pressured the government to edict the CONAMA resolution 279/2001 establishing simplified environmental permit for energy plants to incentivise generation of energy by technologies of “low environmental impact” (such as centralised PV and wind plants). Few years later, a new resolution, CONAMA 462/2014, regulated the general guidelines for simplified licensing of terrestrial wind energy power plants. Large-scale PV does not have any specific regulation at the moment, States have been licensing LSPV following dissimilar criteria to classify the potential risks for the environment and to issue simplified licensing (with simplified qualitative studies) (Da Silva et al. Under revision). As the conventional EIA is susceptible to flaws in predicting and preventing conflicts, simplified environmental studies may be even less effective due to the poor methodology to integrate the contradictory interests for the implementation of multi-megawatts PV plants.

EIA practiced for large-solar PV in Brazil (and other countries) does not integrate political, economic, and social impacts in the methodology to assess the overall environmental impacts. In practice, full integration of parameters is seen as sceptical (Fischer & Nadeem 2013) and subject to prevailing economic aspects (Morrison-Saunders & Fischer 2006). There is, therefore, the need to propose the SAMAMBAIA-Solar method to assess impacts of LSPV and evaluate locational and technological alternatives based on many views from different stakeholders. The multicriteria aspect of SAMAMBAIA-Solar also allows planners to integrate many conflicting issues and interests so decision-making is carried out based on a diagram considering both qualitative and quantitative analysis.

The modelling results in many outcomes to analyse environmental impacts of the project of interest. At global and each temporal scale, the method outputs (Magrini 1992):

- Production of graphics and estimated score for the main overall environmental impact (placed in the top of the hierarchy).
- Histogram for the impacts occurring the sub-level 1 of the hierarchy.
- Matrices showing the most significant impacts according to the scenarios adopted.

[7] Law 6938/1986, CONAMA 01/1986 and 237/1997 and complementary law 140/2011.

The weights assigned in the model aid the environmental impact estimative for the locational and technological PV alternatives[8], a feature that has not been present in the EIA in Brazil. Based on the overall impact of each alternative, decision-makers can choose the least impactful option. It is assumed that the project proponent gives more than one possibility for installation (different sizes, sites, technologies) otherwise the method will only estimate and highlight the significant impacts of the specific project. 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. Therefore, the proposed SAMAMBAIA-solar method aims to improve the lack of synergy amongst different interested part and cumulative impacts in EIA, which are pointed out as very unsatisfactory according to a current survey with practitioners in Brazil (Duarte et al. 2017a).

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 scoring 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. In 2008, Magrini et al. (Magrini et al. 2011) developed a software based on Excel 2008 to structure the proposal (any SAMAMBAIA adaption) and perform the estimates. The software is out-of-date generating diagrams of poor quality to be presented in reports.

Conclusion

Large-scale solar photovoltaic installations are growing all over the world, and the methodologies used to assess the environmental impacts from such plants have demonstrated a lack proper measures to predict and prevent environmental impacts from the interaction of conflicting interests among stakeholders and community. Thus, the current analysis EIA reports for LSPV may be very subjective in nature, of poor quality and be unfeasible to fully support decision-making. The focus of this paper was to analyse this growing issue and propose a multicriteria model able to confront different features concerning large-scale photovoltaic power plants and its impacts (environmental, social and economic). The proposed method, SAMAMBAIA-Solar, is adapted from a previous work (named SAMAMBAIA) done by Magrini (Magrini 1992) who identified a similar issue during the expansion of hydropower plants in Brazil in the 1990s.

The SAMAMBAIA-Solar is able to perform the environmental impact assessment of utility-scale solar energy project and support decision-making based on a multicriteria

[8] The AHP must be adapted to receive other parameters, but it must be the same for each problem. When a component is significant to one alternative but not to another, the rating score is assigned as 1; zero values cannot be assigned because the comparison would not be possible among different alternatives.

analysis involving many complex features of energy planning. All criteria addressed in the AHP tree and evaluation criteria reflect the main parameters assessed in EIAs around the world. Thus, although the method is created to subsidize the environmental impact assessment techniques used in Brazil, tree and criteria might be adapted to project's characteristics in other countries. The approach is also designed to provide the assessment score for impacts of different alternatives (floating or land-based PV) and estimate scenarios according to the different interests of the parts (expressed as the weights input in the model). An overall impact score is also displayed to compare the different alternatives proposed/studied. Additionally, score, histogram, and matrices for each level are showed in the modelling so decision-makers can determine the most significant areas of impact and allocate mitigation measures.

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 solar photovoltaic EIA.

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 (Aly et al. 2017) for a study case using GIS and MDCA].
- Application of method on SEA and Life-cycle analysis to support decision-making (Magrini & Viana 2012). For SEA, the application of Strategic Choice Approach is thought as a future approach to manage uncertainties until linked to the multicriteria analysis and weight aggregation by different interested parts.

References

Abbasi SA, Abbasi N. 2000. The likely adverse environmental impacts of renewable energy sources. Appl Energy. 65:121–144.

Aly A, Jensen SS, Pedersen AB. 2017. Solar power potential of Tanzania: Identifying CSP and PV hot spots through a GIS multicriteria decision making analysis. Renew Energy. 113:159–175. DOI: 10.1016/j.renene.2017.05.077

ANEEL. 2002. Atlas de Energia Elétrica no Brasil. Brasília, DF: Brazilian Electricity Regulatory Agency.

ANEEL. 2012. Resolução normativa n° 482 de 17 de Abril de 2012 [Internet] [cited 2018 Jan 1]. Brasília: Aneel. Available from: http://www2.aneel.gov.br/cedoc/ren2012482.pdf

ANEEL. 2018. Capacidade de Geração do Brasil. BIG- banco informação geração [Internet]. [cited 2018 Jan 1]. Available from: http://www2.aneel.gov.br/aplicacoes/capacidadebrasil/capacidadebrasil.cfm

Bazmi AA, Zahedi G. 2011. Sustainable energy systems: Role of optimization modeling techniques in power generation and supply - A review. Renew Sustain Energy Rev . 15:3480–3500. DOI:10.1016/j.rser.2011.05.003

Brannstrom C, Gorayeb A, de Sousa Mendes J, Loureiro C, Meireles AJ de A, Silva EV da, Freitas ALR de, Oliveira RF de. 2017. Is Brazilian wind power development sustainable? Insights from a review of conflicts in Ceará state. Renew Sustain Energy Rev . 67:62–71. DOI: 10.1016/j.rser.2016.08.047

Canter L, Sadler B. 1997. A Tool Kit For Effective EIA Practice. Rewie of Methods and Perpectives on their Application. :157.

Carlisle JE, Solan D, Kane SL, Joe J. 2016. Utility-scale solar and public attitudes toward siting: A critical examination of proximity. Land use policy. 58:491–501. DOI: 10.1016/j.landusepol.2016.08.006

Costa SG e. 2017. Impactes ambientais de sistemas fotovoltaicos flutuantes. Lisboa: Universidade de Lisboa.

Duarte CG, Dibo APA, Sánchez LE. 2017. What does the academic research say about impact assessment and environmental licensing in Brazil? Ambient e Soc. 20:1–20.

Duarte CG, Dibo APA, Siqueira-Gay J, Sánchez LE. 2017. Practitioners' perceptions of the Brazilian environmental impact assessment system: results from a survey. Impact Assess Proj Apprais . 35:293–309. DOI: 10.1080/14615517.2017.1322813

EnvironQuest. 2017. Final Environmental and Social Impact Assessment Report for the Proposed 100MW Solar Independent Power Plant and 18 KM Transmission Line Project, Ganjuwa Local Government Area [Internet] [cited 2018 Nov 26]. Nigeria. Available from:
https://www3.opic.gov/Environment/EIA/bauchisolar/Nigeria_ESIA_June2017.pdf

EPE, MME. 2017. Plano decenal de expansão de energia 2026 [Internet]. Rio de Janeiro. Available from: http://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/Plano-Decenal-de-Expansao-de-Energia-2026

Ettinger WS. 1987. Impacts of a chemical dust suppressant/soil stabilizer on the physical and biological characteristics of a stream. Soil Water Conserv Soc. 42:111–114.

EY, Solar Power Europe. 2017. Solar PV Jobs & Value Added in Europe.

Ferroukhi R, Khalid A, García-Baños C, Renner M. 2017. Renewable Energy and Jobs: Annual Review 2017.

Finnveden G, Nilsson M, Johansson J, Persson A, Morberg A, Carlsson T. 2003. Strategic environmental assessment methodologies — applications within the energy sector. Environ Impact Assess Rev. 23:91–123.

Fischer TB, Nadeem O. 2013. Environmental impact assessment (EIA) course curriculum for tertiary level institutions in Pakistan: national impact assessment Programme (NIAP) Pakistan. Calgary, Alberta: IAIA.

Fthenakis V, Blunden J, Green T, Krueger L, Turney D. 2011. Large photovoltaic power plants: wildlife impacts and benefits. In: Photovolt Spec Conf. Seatle, WA, USA: IEEE; p. 2011–2016.

Al Garni H, Kassem A, Awasthi A, Komljenovic D, Al-Haddad K. 2016. A multicriteria decision making approach for evaluating renewable power generation sources in Saudi Arabia. Sustain Energy Technol Assessments. 16:137–150. DOI: 10.1016/j.seta.2016.05.006

Gasparatos A, Doll CNH, Esteban M, Ahmed A, Olang TA. 2017. Renewable energy and biodiversity : Implications for transitioning to a Green Economy. Renew Sustain Energy Rev . 70:161–184. DOI: 10.1016/j.rser.2016.08.030

Glasson J, Therivel R, Chadwick A. 2005. Introduction to environmental impact assessment. 3nd ed. London and New York: Routledge Taylor & Francis Group.

Gorayeb A, Brannstrom C, de Andrade Meireles AJ, de Sousa Mendes J. 2018. Wind power gone bad: Critiquing wind power planning processes in northeastern Brazil. Energy Res Soc Sci . 40:82–88. Available from: DOI: 10.1016/j.erss.2017.11.027

Grippo M, Hayse JW, O'Connor BL. 2015. Solar Energy Development and Aquatic Ecosystems in the Southwestern United States: Potential Impacts, Mitigation, and Research Needs. Environ Assess. 55:244–256.

Guerin T. 2017. A case study identifying and mitigating the environmental and community impacts from construction of a utility-scale solar photovoltaic power plant in eastern Australia. Sol Energy . 146:94–104. DOI: 10.1016/j.solener.2017.02.020

Guerin TF. 2017. Evaluating expected and comparing with observed risks on a large-scale solar photovoltaic construction project : A case for reducing the regulatory burden. Renew Sustain Energy Rev. 74:333–348. DOI: 10.1016/j.rser.2017.02.040

Hanger S, Komendantova N, Schinke B, Zejli D, Ihlal A, Patt A. 2016. Community acceptance of large-scale solar energy installations in developing countries: Evidence from Morocco. Energy Res Soc Sci . 14:80–89. DOI: 10.1016/j.erss.2016.01.010

Haurant P, Oberti P, Muselli M. 2011. Multicriteria selection aiding related to photovoltaic plants on farming fields on Corsica island: A real case study using the ELECTRE outranking framework. Energy Policy . 39:676–688. DOI: 10.1016/j.enpol.2010.10.040

Hernandez RR, Easter SB, Murphy-mariscal ML, Maestre FT, Tavassoli M, Allen EB, Barrows CW, Belnap J, Ochoa-hueso R, Ravi S, Allen MF. 2014. Environmental impacts of utility-scale solar energy. Renew Sustain Energy Rev. 29:766–779. DOI: 10.1016/j.rser.2013.08.041

Hoffacker K, Murphy-mariscal ML, Wu GC, Hernandez RR, Hoffacker MK, Murphy-mariscal ML, Wu GC, Allen MF. 2016. Solar energy development impacts on land cover change and protected areas. Proc Natl Acad Sci. 113:E1768–E1768. Available from: DOI: 10.1073/pnas.1602975113

Huang IB, Keisler J, Linkov I. 2011. Multi-criteria decision analysis in environmental sciences: Ten years of applications and trends. Sci Total Environ . 409:3578–3594. DOI: 10.1016/j.scitotenv.2011.06.022

IAIA. 1999. Principles of environmental impact assessment best practice. [Fargo] [cited 2018 Nov 29]. Available from: https://www.iaia.org/uploads/pdf/principlesEA_1.pdf

IEA-PVS Reporting Countries. 2017. Snapshot of Global Photovoltaic Markets - IEA PVPS. available from: http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA-PVPS_-_A_Snapshot_of_Global_PV_-_1992-2017.pdf

Jenkins AR, Ralston S, Smit-Robinson HA. 2015. Birds and solar energy best practice guidelines. South Africa.

Klein SJW. 2013. Multi-Criteria Decision Analysis of Concentrated Solar Power with Thermal Energy Storage and Dry Cooling. Environ Sci Technol . 47:13925–13933. Available from: DOI: 10.1021/es403553u

Kolhoff AJ, Driessen PPJ, Runhaar HAC. 2018. Overcoming low EIA performance - A diagnostic tool for the deliberate development of EIA system capacities in low and middle income countries. Environ Impact Assess Rev. 68:98–108.

Kowalski K, Stagl S, Madlener R, Omann I. 2009. Sustainable energy futures: Methodological challenges in combining scenarios and participatory multi-criteria analysis. Eur J Oper Res . 197:1063–1074. DOI: 10.1016/j.ejor.2007.12.049

Lai CS, Jia Y, Lai LL, Xu Z, McCulloch MD, Wong KP. 2017. A comprehensive review on large-scale photovoltaic system with applications of electrical energy storage. Renew Sustain Energy Rev . 78:439–451. DOI: 10.1016/j.rser.2017.04.078

Liu KFR, Liang HH, Yeh K, Chen CW. 2009. A qualitative decision support for environmental impact assessment using fuzzy logic. J Environ Informatics. 13:93–103.

Løken E. 2007. Use of multicriteria decision analysis methods for energy planning problems. Renew Sustain Energy Rev. 11:1584–1595.

Løken E, Botterud A, Holen AT. 2009. Use of the equivalent attribute technique in multi-criteria planning of local energy systems. Eur J Oper Res . 197:1075–1083. DOI: 10.1016/j.ejor.2007.12.050

Loomis JJ, Dziedzic M. 2018. Evaluating EIA systems' effectiveness: A state of the art. Environ Impact Assess Rev. 68:29–37.

Magrini A. 1990. A avaliação de impactos ambientais. In: Mergulis S, editor. Meio Ambiente Aspectos técnicos e Econômicos. Rio de Janeiro: IPEA: Brasília; IPEA/PNUD; p. 246.

Magrini A. 1992. Metodologia de Avaliação de Impacto Ambiental: o caso das hidrelétricas. [Rio de Janeiro]: Federal University of Rio de Janeiro. Available from: http://teses2.ufrj.br/41/teses/Tese_Alessandra_Magrini.pdf

Magrini A, La Rovere EL. 2016. Avaliação dos impactos da ruptura da barragem de rejeitos de fundão em Mariana nove meses após o desastre. Rio de Janeiro.

Magrini A, Viana D de B. 2012. Uma ferramenta multicritério para a realização de avaliações ambientais: o modelo SAMAMBAIA. In: 1° Congr Bras Avaliação Impacto. São Paulo: Associação Brasileira de Avaliação de Impacto; p. 1–17.

Magrini A, Viana DB, Araujo MG. 2011. the " Samambaia " Model : a Multicriteria Tool for Management of Contaminated Areas. In: Sardinia 2011, Thirteen Int Waste Manag Landfill Symp. [Sardina, Italy]: International Waste Working Group; p. 1–9.

Marrou H, Guilioni L, Dufour L, Dupraz C, Wery J. 2013. Microclimate under agrivoltaic systems: Is crop growth rate affected in the partial shade of solar panels? Agric For Meteorol . 177:117–132. DOI: 10.1016/j.agrformet.2013.04.012

Marshall R, Fischer TB. 2006. Regional electricity transmission planning and SEA: The case of the electricity company ScottishPower. J Environ Plan Manag. 49:279–299.

Mason SA, Moore SA. 1998. Using the sorensen network to assess the potential effects of ecotourism on two australian marine environments. J Sustain Tour. 6:143–154.

Minelli A, Marchesini I, Taylor FE, Rosa P De, Casagrande L, Cenci M. 2014. An open source GIS tool to quantify the visual impact of wind turbines and photovoltaic panels. Environ Impact Assess Rev . 49:70–78. DOI: 10.1016/j.eiar.2014.07.002

Moore-O'Leary KA, Hernandez RR, Johnston DS, Abella SR, Tanner KE, Swanson AC, Kreitler J, Lovich JE. 2017. Sustainability of utility-scale solar energy – critical ecological concepts. Front Ecol Environ. 15:385–394.

Morris P, Therivel R. 2001. Methods of Environmental Impact Assessment. 2nd ed. London and New York: Spon Press (Taylor & Francis).

Morrison-Saunders A, Fischer TB. 2006. What Is Wrong With Eia and Sea Anyway? a Sceptic'S Perspective on Sustainability Assessment. J Environ Assess Policy Manag . 08:19–39. Available from: DOI: 10.1142/S1464333206002372

Pendse Rao, RV, Sharma, PK YD. 1989. Environmental impact assessment methodologies- shortcomings and appropriateness for water resources projects in developing countries. Water Resour Dev. 5:252–258.

Phylip-Jones J, Fischer TB. 2015. Strategic environmental assessment (SEA) for wind energy planning: Lessons from the United Kingdom and Germany. Environ Impact Assess Rev. 50:203–212. DOI: 10.1016/j.eiar.2014.09.013

Põder T, Lukki T. 2011. A critical review of checklist-based evaluation of environmental impact statements. Impact Assess Proj Apprais. 29:27–36.

Pohekar SD, Ramachandran M. 2004. Application of multi-criteria decision making to sustainable energy planning - A review. Renew Sustain Energy Rev. 8:365–381.

Rahman MM, Paatero J V., Lahdelma R, Wahid MA. 2016. Multicriteria-based decision aiding technique for assessing energy policy elements-demonstration to a case in Bangladesh. Appl Energy. 164:237–244. DOI: 10.1016/j.apenergy.2015.11.091

Ribeiro F, Ferreira P, Araújo M, Braga AC. 2014. Public opinion on renewable energy technologies in Portugal. Energy. 69:39–50. DOI: 10.1016/j.energy.2013.10.074

Rikhtegar N, Mansouri N, Oroumieh AA, Yazdani-Chamzini A, Zavadskas EK, Kildienė S. 2014. Environmental impact assessment based on group decision-making methods in mining projects. Econ Res Istraz . 27:378–392. DOI: 10.1080/1331677X.2014.966971

Rodrigues M, Montañés C, Fueyo N. 2010. A method for the assessment of the visual impact caused by the large-scale deployment of renewable-energy facilities. Environ Impact Assess Rev . 30:240–246. DOI: 10.1016/j.eiar.2009.10.004

Rodriguez-Bachiller A, Wood G. 2001. Geographical Information Systems (GIS) and EIA. In: Morris P, Therivel R, editors. Methods Environ Impact Assess. 2nd ed. London and New York: Spon Press (Taylor & Francis); p. 381–401.

Rudman; J, Esler PGKJ. 2017. Direct environmental impacts of solar power and shale gas developments in arid biomes of South Africa. S Afr J Sci . 113:1–13.

Saaty RW. 1987. The analytic hierarchy process—what it is and how it is used. Math Model. 9:161–176.

San Cristóbal JR. 2011. Multi-criteria decision-making in the selection of a renewable energy project in spain: The Vikor method. Renew Energy. 36:498–502. DOI: 10.1016/j.renene.2010.07.031

Da Silva GDP, Branco DAC. 2018. Is floating photovoltaic better than conventional photovoltaic? Assessing environmental impacts environmental impacts. Impact Assess Proj Apprais. 36:390–400.

Torres-Sibille A del C, Cloquell-Ballester VA, Cloquell-Ballester VA, Artacho Ramírez MÁ. 2009. Aesthetic impact assessment of solar power plants: An objective and a subjective approach. Renew Sustain Energy Rev. 13:986–999.

Tsoutsos T, Frantzeskaki N, Gekas V. 2005. Environmental impacts from the solar energy technologies. Energy Policy. 33:289–296.

Turney D, Fthenakis V. 2011. Environmental impacts from the installation and operation of large-scale solar power plants. Renew Sustain Energy Rev. 15:3261–3270. DOI: 10.1016/j.rser.2011.04.023

UNFCCC. Conference of the Parties (COP). 2015. Paris Climate Change Conference-November 2015, COP 21. Adopt Paris Agreement Propos by Pres . 21932:32. Available from: http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf

Vanclay F, Esteves AM, Franks DM. 2015. Social Impact Assessment: guidance for assessing and managing the social impacts of projects. Fargo ND: International Association for Impact Assessment.

Walston Jr LJ, Rollins KE, Lagory KE, Smith KP, Meyers SA. 2016. A preliminary assessment of avian mortality at utility-scale solar energy facilities in the United States. Renew Energy . 92:405–414. DOI: 10.1016/j.renene.2016.02.041

Wang JJ, Jing YY, Zhang CF, Zhao JH. 2009. Review on multi-criteria decision analysis aid in sustainable energy decision-making. Renew Sustain Energy Rev. 13:2263–2278.

Wang Q, Poh KL. 2014. A survey of integrated decision analysis in energy and environmental modeling. Energy . 77:691–702. DOI: 10.1016/j.energy.2014.09.060

World Energy Council. 2016. World Energy Resources: Solar 2016.

Wu Z, Hou A, Chang C, Huang X, Shi D, Wang Z. 2014. Environmental impacts of large-scale CSP plants in northwestern China. Environ Sci Process Impacts . 16:2432–2441.

Chapter V

Conclusion

This work discussed utility-scale solar photovoltaics' Environmental Impact Assessment in Brazilian national energy planning. The current analysis is conducted from the environmental governance perspective for decision-making. Thus, legal aspects, the environmental degradation and benefits, and methodological approaches to predict and integrate impacts are debated. 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.

Similar to any large-scale energy development project, the impact assessment report supports the environmental licensing that authorises the project's design and location. 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 in order 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 special areas, 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 in order 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. This study agrees with [10], claiming that utility PV are better than traditional coal and nuclear sources; however, 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. This research selected 20 EIA reports from Brazil and other countries (due to the lack of available specific solar energy EIA in Brazil). 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 the analysis explains that the impacts magnitudes and importance have been addressed separately without further integration of social, environmental, and economic aspects (the environment). 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.

In an attempt to improve the impact assessment approach in Brazil (and possibly contribute to other countries as well), a multicriteria method was designed based on the detailed information of floating and terrestrial photovoltaic (Chapter III) and the work of Magrini [35]. The method 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.

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 as they lack elements that let the studies strategically to prevent conflicts. 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. The current role of EIA for LSPV, as it seems, is as a final instrument to "measure" the likely impacts and set improvements for a determined project in a specific location. The reports presented might be flawed in content and absent in proper evaluation of long-term and cumulative impacts. 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. The approach 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. Sánchez [39] reports several adverse impacts caused by improper environmental management in Brazil, including in the energy sector.

What should future research focus on?

All three works recommend further research towards Strategic Environmental Assessment (SEA) for energy and environmental planning. 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]. For instance, SEA applied in the Netherlands in 1992 aided promoting the country's fuel mix policy and selecting locations for transport facilities [38]. 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 and aid in answering questions such as:

- Is it better to develop a large-scale wind/solar farm comprising several hectares or a number of small-middle scale projects in the area?
- From the environmental, technical, and economic perspective, should solar PV be driven as centralized or distributed projects?
- What is the preferred energy alternative for this area, solar, hydro, biofuel, or wind? And why?

The allegation that the answers lie on a technical and project-specific report (such as EIA) will lead to queries such as:

- How will this policy impact land occupation patterns, deforestation, and landscape changes in the short and long-terms for the region? And what is the national impact of these changes?
- Can the country meet climate change commitments through this programme?
- Could another project be preferred and be simpler for environmental licensing?
- Can the grid support distributed systems? (when choosing distributed PV over centralised)

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.

References for introduction and conclusion

[1] R. E. L. Tolbert and J. C. Arnett, “Design, installation and performance of ARCO solar photovoltaic power plants,” in *Conf. Rec. IEEE Photovoltaic Spec. Conf.*, 1984.

[2] SunPower, “Nellis Air Force Base Builds Largest Solar Photovoltaic Power Plant in North America with SunPower,” 2007.

[3] F. Dinçer, “The analysis on photovoltaic electricity generation status, potential and policies of the leading countries in solar energy,” *Renew. Sustain. Energy Rev.*, vol. 15, no. 1, pp. 713–720, 2011.

[4] A. Sharma, “A comprehensive study of solar power in India and World,” *Renew. Sustain. Energy Rev.*, vol. 15, no. 4, pp. 1767–1776, 2011.

[5] E. Romero-Cadaval, G. Spagnuolo, L. G. Franquelo, C. A. Ramos-Paja, T. Suntio, and W. M. Xiao, “Grid-Connected Photovoltaic Generation Plants: Components and Operation,” *IEEE Ind. Electron. Mag.*, vol. 7, no. 3, pp. 6–20, 2013.

[6] PVresources, “Large-Scale PV Power Plants - Top50,” 2018. [Online]. Available: http://www.pvresources.com/en/top50pv.php. [Accessed: 15-Dec-2018].

[7] SolarPower Europe, “Global Market Outlook for Solar Power/2018-2022,” Brussels, Belgium, 2018.

[8] L. M. Miller, D. W. Keith, E. Res, and L. M. Miller, “Observation-based solar and wind power capacity factors and power densities,” *Environ. Res. Lett.*, vol. 13, pp. 1–11, 2018.

[9] Z. Wu, A. Hou, C. Chang, X. Huang, D. Shi, and Z. Wang, “Environmental impacts of large-scale CSP plants in northwestern China,” *Environ. Sci. Process. Impacts*, vol. 16, no. 10, pp. 2432–2441, 2014.

[10] D. Turney and V. Fthenakis, “Environmental impacts from the installation and operation of large-scale solar power plants,” *Renew. Sustain. Energy Rev.*, vol. 15, no. 6, pp. 3261–3270, 2011.

[11] New Atlas, “Plant openings signal ‘birth of large-scale solar in Australia,’” 2016. [Online]. Available: https://newatlas.com/australia-nyngan-broken-hill-solar-photovoltaic-plants/41462/. [Accessed: 22-Dec-2018].

[12] SteelGuru, “Sri Lanka and China to build dendro power plant,” 2018. [Online]. Available: https://steelguru.com/power/sri-lanka-and-china-to-build-dendro-power-plant/500481. [Accessed: 22-Dec-2018].

[13] PwC, “Building the largest solar farm in the southern hemisphere,” 2018. [Online]. Available: https://www.pwc.com/gx/en/about/stories-from-across-the-world/building-the-largest-sola-farm-in-the-southern-hemisphere.html.

[Accessed: 22-Dec-2018].

[14] HowStuffWorks, “China Flips Switch on World’s Largest Floating Solar Farm,” 2017. [Online]. Available: https://science.howstuffworks.com/environmental/green-tech/energy-production/china-flips-switch-on-world-s-largest-floating-solar-farm.htm. [Accessed: 22-Dec-2018].

[15] IAIA, “Principles of environmental impact assessment best practice,” Fargo ND, 1999.

[16] T. Tsoutsos, N. Frantzeskaki, and V. Gekas, “Environmental impacts from the solar energy technologies,” *Energy Policy*, vol. 33, pp. 289–296, 2005.

[17] V. Fthenakis, J. Blunden, T. Green, L. Krueger, and D. Turney, “Large photovoltaic power plants: wildlife impacts and benefits,” in *Photovoltaic Specialists Conference*, 2011, pp. 2011–2016.

[18] G. D. P. Da Silva and D. A. C. Branco, “Is floating photovoltaic better than conventional photovoltaic? Assessing environmental impacts environmental impacts,” *Impact Assess. Proj. Apprais.*, vol. 36, no. 5, pp. 390–400, 2018.

[19] R. G. Sullivan, L. B. Kirchler, C. McCoy, J. McCarty, K. Beckman, and P. Richmond, “Visual impacts of utility-scale solar energy facilities on Southwestern desert landscapes.” Argonne National Laboratory, p. 31, 2013.

[20] L. Delfanti *et al.*, “Solar plants, environmental degradation and local socioeconomic contexts: A case study in a Mediterranean country,” *Environ. Impact Assess. Rev.*, vol. 61, pp. 88–93, 2016.

[21] M. Grippo, J. W. Hayse, and B. L. O’Connor, “Solar Energy Development and Aquatic Ecosystems in the Southwestern United States: Potential Impacts, Mitigation, and Research Needs,” *Environ. Assess.*, vol. 55, no. October 2014, pp. 244–256, 2015.

[22] C. G. Duarte, A. P. A. Dibo, J. Siqueira-Gay, and L. E. Sánchez, “Practitioners’ perceptions of the Brazilian environmental impact assessment system: results from a survey,” *Impact Assess. Proj. Apprais.*, vol. 35, no. 4, pp. 293–309, 2017.

[23] K. Hochstetler, “Environmental impact assessment: evidence-based policymaking in Brazil,” *Contemp. Soc. Sci.*, vol. 13, no. 1, pp. 100–111, 2018.

[24] T. Chang, E. Nielsen, W. Auberle, and F. I. Solop, “A quantitative method to analyze the quality of EIA information in wind energy development and avian/bat assessments,” *Environ. Impact Assess. Rev.*, vol. 38, pp. 142–150, 2013.

[25] M. T. Tolmasquim, “Fontes renováveis e alternativas energéticas,” UFRJ; COPPE, Rio de Janeiro, 2018.

[26] K. Hochstetler, “The Politics of Environmental Licensing: Energy Projects of the Past and Future in Brazil,” *Stud. Comp. Int. Dev.*, vol. 46, no. 4, pp. 349–371, 2011.

[27] E. B. Pereira *et al.*, *Atlas Brasileiro de Energia Solar*, 2nd ed. São José dos Campos: INPE, 2017.

[28] G. D. P. da Silva, “Utilisation of the System Advisor Model to Estimate Electricity Generation by Grid-Connected Photovoltaic Projects in all Regions of Regions of Brazil,” *Int. J. Softw. Eng. its Appl.*, vol. 11, no. 7, pp. 1–12, 2017.

[29] L. F. Silveira, F. Olmos, and A. J. Long, “Birds in Atlantic Forest fragments in north-east Brazil,” *Cotinga*, vol. 20, pp. 32–46, 2003.

[30] J. M. Barnett, C. J. Carlos, and S. A. Roda, “Renewed hope for the threatened avian endemics of northeastern Brazil,” *Biodivers. Conserv.*, vol. 14, no. 9, pp. 2265–2274, 2005.

[31] MME, “The Status of Brazilian Biological Diversity,” in *First National Report for the Convention on Biological Diversity - Brazil*, Brasília, DF: Ministry of the Environment, 1998, pp. 21–30.

[32] L. J. Walston Jr, K. E. Rollins, K. E. Lagory, K. P. Smith, and S. A. Meyers, “A preliminary assessment of avian mortality at utility-scale solar energy facilities in the United States,” *Renew. Energy*, vol. 92, pp. 405–414, 2016.

[33] C. Harrison, H. Lloyd, and C. Field, “Evidence review of the impact of solar farms on birds , bats and general ecology (NEER012),” Manchester, 2017.

[34] J. Glasson, R. Therivel, and A. Chadwick, *Introduction to environmental impact assessment*, 4nd ed. London and New York: Routledge Taylor & Francis Group, 2012.

[35] A. Magrini, “Metodologia de Avaliação de Impacto Ambiental: o caso das hidrelétricas,” Federal University of Rio de Janeiro, 1992.

[36] B. F. Noble, “Strategic environmental assessment: what is it ? & what makes it strategic ?,” *J. Environ. Assess. Policy Manag.*, vol. 2, no. 2, pp. 203–224, 2000.

[37] A. Morrison-Saunders and T. B. Fischer, “What Is Wrong With Eia and Sea Anyway? a Sceptic’S Perspective on Sustainability Assessment,” *J. Environ. Assess. Policy Manag.*, vol. 08, no. 01, pp. 19–39, 2006.

[38] S. Jay, “Strategic environmental assessment for energy production,” *Energy Policy*, vol. 38, no. 7, pp. 3489–3497, 2010.

[39] L. E. Sánchez, “Por que não avança a avaliação ambiental estratégica no Brasil?,” *Estud. Avançados*, vol. 31, no. 89, pp. 167–183, 2017.

[40] K. Ahmed and E. Sánchez-Triana, *Strategic Environmental Assessment for Policies: an instrument for good Governance*. Washington, DC: The World Bank, 2008.

[41] T. B. Fischer, “Strategic environmental assessment in post-modern times,” *Environ. Impact Assess. Rev.*, vol. 23, no. 2, pp. 155–170, 2003.

[42] M. D. R. Partidario, *Strategic Environmental Assessment Better Practice Guide - methodological guidance for strategic thinking in SEA Strategic Environmental Assessment*. Lisbon: Portuguese Environment Agency and Redes Energéticas Nacionais (REN), 2012.

[43] M. R. Partidário, *Guia de melhores práticas para Avaliação Ambiental Estratégica - orientações metodológicas para um pensamento estratégico em*

AAE. 2012.

[44] G. Finnveden, M. Nilsson, J. Johansson, A. Persson, A. Morberg, and T. Carlsson, “Strategic environmental assessment methodologies — applications within the energy sector,” *Environ. Impact Assess. Rev.*, vol. 23, pp. 91–123, 2003.

[45] B. F. Noble, J. Gunn, and J. Martin, “Survey of current methods and guidance for strategic environmental assessment,” *Impact Assess. Proj. Apprais.*, vol. 30, no. 3, pp. 139–147, 2017.

[46] J. Phylip-Jones and T. B. Fischer, “Strategic environmental assessment (SEA) for wind energy planning: Lessons from the United Kingdom and Germany,” *Environ. Impact Assess. Rev.*, vol. 50, no. October, pp. 203–212, 2015.

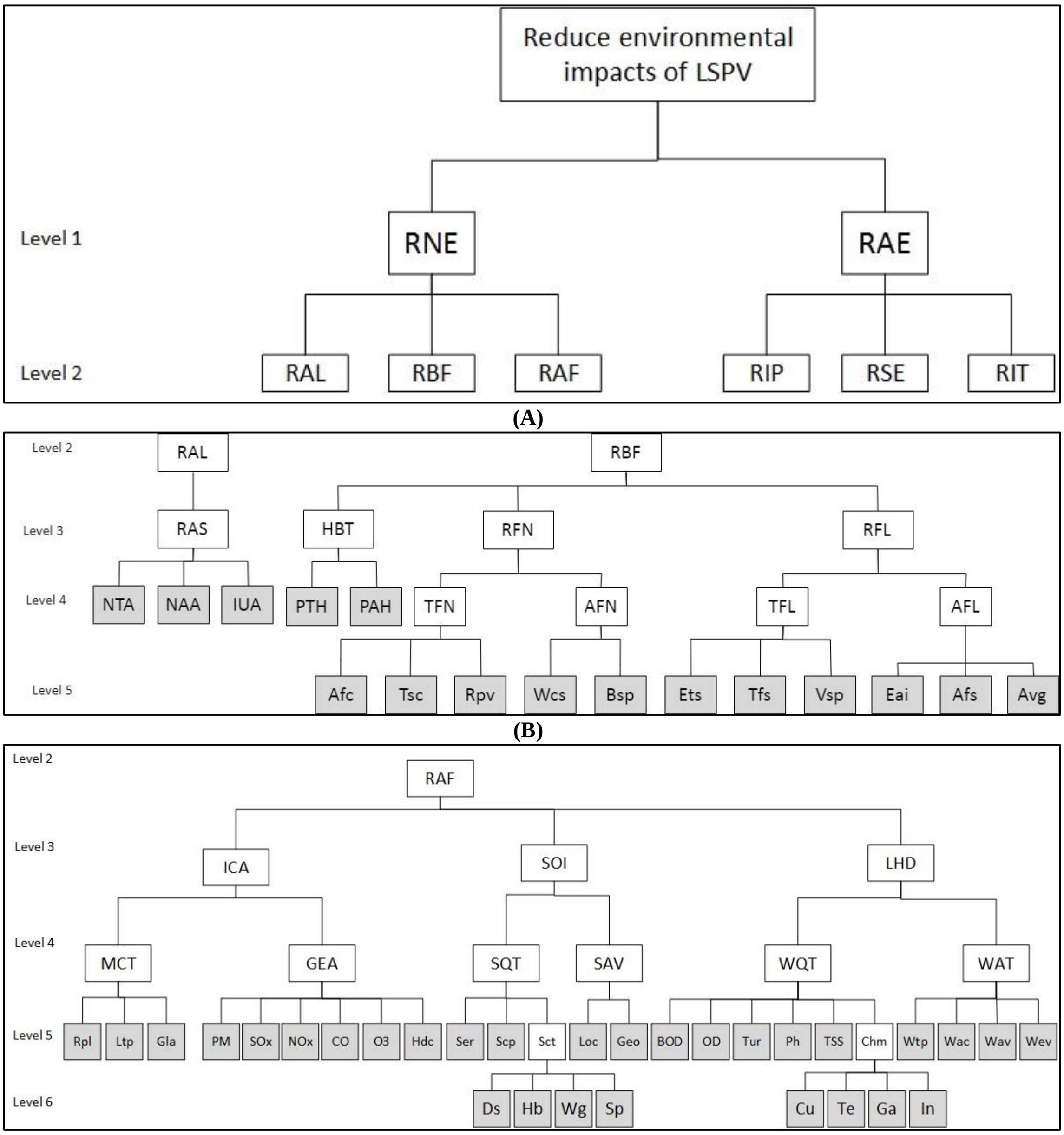
[47] T. B. Fischer and V. Onyango, “Strategic environmental assessment-related research projects and journal articles: An overview of the past 20 years,” *Impact Assess. Proj. Apprais.*, vol. 30, no. 4, pp. 253–263, 2012.

Supplementary material

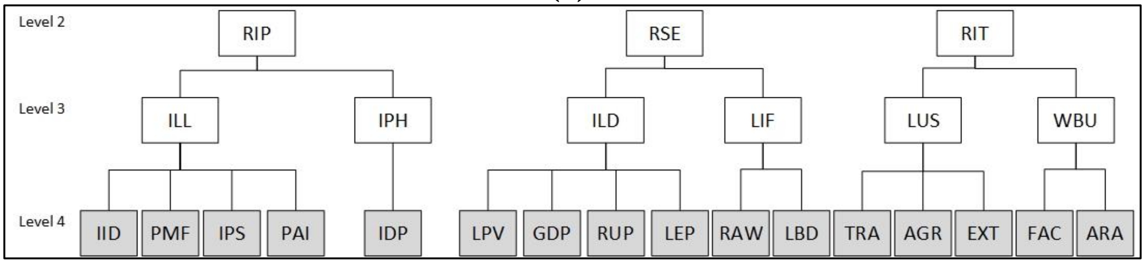
Level 1 RNE- reduce the impact on the natural environment RAE- reduce the impact on the anthropic environment	**Level 2** RAL- reduce the aesthetic impact on natural landscape RBF- reduce the impact on biotic factors RAF- reduce the impact on abiotic factors RIP- reduce the impact on populations RSE- 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 NOx- reduce emission of nitrogen 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

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	

Table 13. AHP criteria levels description.



(C)



(D)

Figure 7. Proposed broken down criteria 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.

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.

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 impact of glare effect	glare effect is low	glare effect is moderate	glare effect is intense			
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 biological oxygen demand	concentration below legal framework	concentration within legal framework	concentration above legal framework			
35- OD: reduce the impact of oxygen demand	concentration below legal framework	concentration within legal framework	concentration above legal framework			
36- Tur: reduce the	concentration below legal framework	concentration within legal framework	concentration above legal framework			

impact of turbidity						
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 inhabitants displacement	no inhabitants displacement	displacement of few inhabitants	displacement of villages' inhabitants	displacement of inhabitants in traditional communities		
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	partial and short-term loss of way of living	partial and long-term loss of way of living	complete loss of way of living			

population subsistence						
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 unemployment	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 agriculture land cover use	agricultural area not affected	loss of small agricultural area with possible future coexistence (agrivoltaic)	loss of large agricultural area with possible future coexistence (agrivoltaic)	loss of small agricultural area without possible future coexistence	loss of large agricultural area without 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	

Table 14. Evaluation criteria at the leaf-objective level.

Objective	OCA	Ct	O&M	Dcs	DNI	Ct	O&M	Dcs	AMI	ECI	Ct	O&M	Dcs
NTA	1	1	1	1	1	1	1	1	1	1	1	1	1
NAA	1	1	1	1	1	1	1	1	1	1	1	1	1
IUA	1	1	1	1	1	1	1	1	1	1	1	1	1
PTH	1	1	1	1	1	1	1	1	1	1	1	1	1
PAH	1	1	1	1	1	1	1	1	1	1	1	1	1
Afs	1	1	1	1	1	1	1	1	1	1	1	1	1
Tsc	1	1	1	1	1	1	1	1	1	1	1	1	1
Rpv	1	1	1	1	1	1	1	1	1	1	1	1	1
Wcs	1	1	1	1	1	1	1	1	1	1	1	1	1
Bsp	1	1	1	1	1	1	1	1	1	1	1	1	1
Ets	1	1	1	1	1	1	1	1	1	1	1	1	1
Tfs	1	1	1	1	1	1	1	1	1	1	1	1	1
Vsp	1	1	1	1	1	1	1	1	1	1	1	1	1
Eai	1	1	1	1	1	1	1	1	1	1	1	1	1
Afs	1	1	1	1	1	1	1	1	1	1	1	1	1
Avg	1	1	1	1	1	1	1	1	1	1	1	1	1
Rnp	1	1	1	1	1	1	1	1	1	1	1	1	1
Ltp	1	1	1	1	1	1	1	1	1	1	1	1	1
Gla	1	1	1	1	1	1	1	1	1	1	1	1	1
PM	1	1	1	1	1	1	1	1	1	1	1	1	1
SOx	1	1	1	1	1	1	1	1	1	1	1	1	1
NOx	1	1	1	1	1	1	1	1	1	1	1	1	1
CO	1	1	1	1	1	1	1	1	1	1	1	1	1
O_3	1	1	1	1	1	1	1	1	1	1	1	1	1
Hdc	1	1	1	1	1	1	1	1	1	1	1	1	1
Ser	1	1	1	1	1	1	1	1	1	1	1	1	1
Scp	1	1	1	1	1	1	1	1	1	1	1	1	1
Ds	1	1	1	1	1	1	1	1	1	1	1	1	1
Hb	1	1	1	1	1	1	1	1	1	1	1	1	1
Wg	1	1	1	1	1	1	1	1	1	1	1	1	1
Sp	1	1	1	1	1	1	1	1	1	1	1	1	1
Loc	1	1	1	1	1	1	1	1	1	1	1	1	1
Geo	1	1	1	1	1	1	1	1	1	1	1	1	1
BOD	1	1	1	1	1	1	1	1	1	1	1	1	1
OD	1	1	1	1	1	1	1	1	1	1	1	1	1
Tur	1	1	1	1	1	1	1	1	1	1	1	1	1
Ph	1	1	1	1	1	1	1	1	1	1	1	1	1
TSS	1	1	1	1	1	1	1	1	1	1	1	1	1
Cu	1	1	1	1	1	1	1	1	1	1	1	1	1
Cd	1	1	1	1	1	1	1	1	1	1	1	1	1
Te	1	1	1	1	1	1	1	1	1	1	1	1	1
Ga	1	1	1	1	1	1	1	1	1	1	1	1	1
In	1	1	1	1	1	1	1	1	1	1	1	1	1
Wtp	1	1	1	1	1	1	1	1	1	1	1	1	1
Wac	1	1	1	1	1	1	1	1	1	1	1	1	1
Wav	1	1	1	1	1	1	1	1	1	1	1	1	1
Wev	1	1	1	1	1	1	1	1	1	1	1	1	1
IID	1	1	1	1	1	1	1	1	1	1	1	1	1
PMF	1	1	1	1	1	1	1	1	1	1	1	1	1
IPS	1	1	1	1	1	1	1	1	1	1	1	1	1
LPV	1	1	1	1	1	1	1	1	1	1	1	1	1
PAI	1	1	1	1	1	1	1	1	1	1	1	1	1
IOP	1	1	1	1	1	1	1	1	1	1	1	1	1

LPV	1	1	1	1	1	1	1	1	1	1	1	1	1
GDP	1	1	1	1	1	1	1	1	1	1	1	1	1
RUP	1	1	1	1	1	1	1	1	1	1	1	1	1
RLS	1	1	1	1	1	1	1	1	1	1	1	1	1
LEP	1	1	1	1	1	1	1	1	1	1	1	1	1
RAW	1	1	1	1	1	1	1	1	1	1	1	1	1
LBD	1	1	1	1	1	1	1	1	1	1	1	1	1
TRA	1	1	1	1	1	1	1	1	1	1	1	1	1
AGR	1	1	1	1	1	1	1	1	1	1	1	1	1
EXT	1	1	1	1	1	1	1	1	1	1	1	1	1
FAC	1	1	1	1	1	1	1	1	1	1	1	1	1
ARA	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 15. Assessment matrix and assignment of magnitudes

Key legend: OCA: operational and contact area. Ct: construction: Dcs: decommissioning. O&M: operation and maintenance. DNI: area of direct and near interaction. AMI: area of moderate interaction. ECI: area of economic interaction. Magnitude 1 was assigned as example only.