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Is floating photovoltaic better than conventional photovoltaic? Assessing environmental impacts

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

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Introduction

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

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

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

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

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

Environmental characteristics

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

Solar terrestrial and FPV concept

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

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

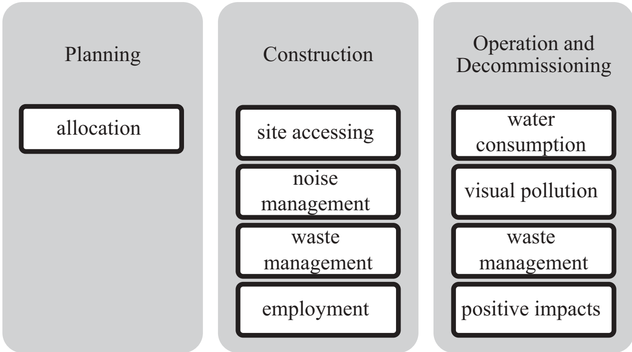

Figure 1. Environmental characteristics analysed at all phases of a PV project.

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

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

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

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

Land use and allocation

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

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

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

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

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

Construction phase of the project

Site access

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

Noise and waste management during construction

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

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

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

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

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

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

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

Employment

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

Operational phase and decommissioning

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

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

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

Waste management

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

Visual pollution

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

Positive impacts

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

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

Conclusion

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

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

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

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

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

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

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

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

- For bulleted lists

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

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