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► To cite this version:

Regina Nobre, Stéphanie Boulêtreau, Fanny Colas, Frédéric Azémar, Loïc Tudesque, et al.. Potential ecological impacts of floating photovoltaics on lake biodiversity and ecosystem functioning. *Renewable and Sustainable Energy Reviews*, 2023, 188, pp.113852. 10.1016/j.rser.2023.113852 . hal-04264272

HAL Id: hal-04264272

<https://hal.science/hal-04264272v1>

Submitted on 30 Oct 2023

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1 **Potential ecological impacts of floating photovoltaics on lake biodiversity and ecosystem**
2 **functioning**

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18 **Abstract**

19 The need to mitigate the effects of climate change is accelerating the development of novel
20 technologies such as floating photovoltaics (FPV). Despite FPV being identified as an emerging
21 issue of concern for biodiversity conservation, it is fast spreading globally and our understanding
22 of their potential ecological impacts is limited. We present an overview of the current knowledge
23 and provide an ecological perspective on FPV potential impacts on lake biodiversity and
24 ecosystem functioning. To date, published works have highlighted reductions in light arrival,
25 wind speed and water temperature with increased FPV cover but the subsequent cascading
26 effects on biological and ecological processes remain unknown. We suggest that modifications in
27 light and water temperature can alter individual regulatory processes affecting, primary
28 production and energy transfer within lake food webs. Additionally, FPV can modify the thermal
29 functioning and oxygenation of the water column while providing artificial habitats for
30 organisms. These modifications can affect individual behavior and life-story but also alter the
31 composition of plant and animal communities, trophic interactions and greenhouse gas balances.
32 We suggest that FPV can also modify socioecological activities related to lake use (e.g., angling,
33 leisure) and pressures at the meta-ecosystem level. Overall, we argue that FPV impacts will be
34 highly context-dependent, varying across ranges of environmental conditions and industrial
35 characteristics (e.g., FPV cover and location). Given the ecological and socio-economic
36 implications of FPV, empirical quantifications based on robust designs are urgently needed and
37 we provide here a unique guideline to help developing research programs to monitor these
38 potential impacts.

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42 **Highlights**

- 43 • High FPV cover can limit light arrival, wind speed and reduce water temperature
- 44 • FPV have effects ranging from individual metabolic rates to ecosystem functioning
- 45 • Water column thermal functioning and oxygenation may also be modified by FPV
- 46 • FPV can alter lake socioecological activities, modulating meta-ecosystems fluxes
- 47 • FPV impacts will be context-dependent and robust empirical studies are needed

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49 **Keywords:** renewable energy, ecosystem functioning, primary production, freshwater

50 biodiversity, lakes, sustainable development

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62 **Abbreviations**

63 FPV - Floating photovoltaics

64 GHG - Greenhouse gas

65 Chl-a - Chlorophyll – a

66 PV – photovoltaic

67 NCP - Nature’s contribution to people

68 DO – Dissolved oxygen

69 DOC - Dissolved organic carbon

70 MTE - Metabolic Theory of Ecology

71 GPP – Gross primary production

72 R – respiration

73 OC – Organic carbon

74 POC – Particulate organic carbon

75 Kl – Kilolitre

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78 **1. Introduction**

79 Climate change is driven by increasing greenhouse gas (GHG) emissions and is critically
80 impacting biodiversity and ecosystems across the globe, with critical implications for humans
81 [1,2]. The energy sector (electricity, heat, and transport) is responsible for 75% of GHG
82 emissions [3]. The increasing energy demand coupled with the urgent need to mitigate climate
83 change is accelerating the renewable energy industry [4,5]. Contradictory, climate mitigation
84 strategies such as renewable energies may have unexpected and counterproductive impacts on
85 biodiversity and ecosystem functioning [6,7], and therefore pose a key challenge in their
86 implementation. One such renewable energy strategy is the use of photovoltaic (PV) energy. The
87 PV industry is evolving fast due to technological advances and cost reductions [8], allowing the
88 exploration of innovative applications. A recent and promising advance of PV is the floating
89 photovoltaic systems (FPV or floatovoltaic), which refers to arrays of PV modules attached to a
90 floating structure and usually fixed on artificial water bodies (e.g., reservoirs, dams, gravel pit
91 lakes, ponds) using a mooring system [8–12]. The FPV market is spreading over the globe with
92 more than 545 FPV plants already in operation and many forthcoming projects [13], notably in
93 Asia, Australia, and Europe [14]. These new installations are motivated because FPV presents
94 several advantages compared to traditional terrestrial PV plants such as reduction in land use
95 pressures for food production, and increased performance due to the cooling effects of water
96 [15–17]. Yet, FPV might also induce negative impacts on freshwater ecosystems that might
97 counterbalance their ecological benefits [18,19].

98 FPV is likely to affect a wide range of ecological parameters in freshwater ecosystems,
99 acting across levels of biological organization. It is therefore extremely challenging to predict the
100 overall outputs of these interacting ecological effects, raising many questions about its potential

101 (negative or positive) ecological consequences [20]. These uncertainties lead to an unclear
102 regulation of FPV development [13], and stakeholders (industry, biodiversity managers or
103 governmental services) are requesting the production of robust scientific knowledge to ensure
104 knowledge-based management of this technology [13,21,22]. Freshwater systems support
105 countless nature's contribution to people (NCP) and, in addition to their utilitarian value (e.g.,
106 drinking water), NCP also includes invaluable intrinsic and cultural values, such as climate
107 regulation, biodiversity maintenance, and cultural aspects like well-being and scenic appreciation
108 [23,24]. However, freshwater ecosystems are amongst the most threatened and degraded
109 ecosystems due to multiple anthropogenic impacts such as habitat degradation and pollution
110 [25]. This is particularly true for lakes that integrate human-induced effects on watersheds,
111 airsheds and landscapes [26–28]. FPV has recently been recognized as one of the 15 emerging
112 important issues of concern for global biodiversity conservation [29]. The deployment of FPV in
113 water bodies can directly affect ecosystem functioning and associated services through abrupt
114 changes in environmental conditions but, because its development is still very recent,
115 assessments of their ecological impacts are still lacking [12,15,18,29].

116 In this study, we first provide a state-of-the-art of the current literature on the ecological
117 impacts of FPV on freshwater ecosystems. Given the overall lack of knowledge in the literature,
118 we then provide a novel ecological perspective exploring the potential impacts of FPV using
119 well-established ecological theory and analogous studies. Based on the potential impacts
120 identified with this approach, we finally provide a comprehensive guideline for monitoring FPV
121 impacts on freshwater ecosystems. The integration of ecological theory to develop this
122 monitoring guideline provides valuable insights into understanding the ecological consequences
123 of FPV plants in freshwater ecosystems.

124 **2. Current state-of-the art on the ecological effects of FPV**

125 We first performed a search for published literature using the Web of Science (all
126 databases and all years) on the ecological effects of FPV. The search terms included a
127 combination of terms that refer to floating photovoltaic technology and potential ecological
128 impacts on water quality, biodiversity and ecosystem functioning. Specifically, the search query
129 was set as follow: “floating PV” OR “floating photovoltaics” OR “floating solar” OR “FPV”
130 AND "impact" OR "water quality" OR "biodiversity" OR "primary production" OR "ecosystem
131 service". The research outputs were then refined to include only research areas of interest,
132 resulting in a first set of 58 studies. References cited in these studies were checked, and the list of
133 references was completed by performing a similar search using Google Scholar. After screening
134 the abstract of each study, a total of 25 studies that explicitly addressed the potential ecological
135 impacts of FPV were considered as relevant. For each study, year of publication, research area,
136 type of study, and main parameters considered were extracted.

137 We found that a large majority (68%) of the selected studies were published within the
138 last three years (2021-2023), highlighting the novelty of this topic. These studies were mainly
139 published in the field of solar energy and renewables journals (48%), and in the field of
140 environmental sciences and ecological research (36 %). In total, we identified 13 studies that
141 performed empirical measurements (experimental mesocosm, laboratory and field studies) of
142 potential ecological impacts (Table 1). Most of the empirical studies were conducted in Asia (n =
143 7), followed by Europe (n = 4) and focused nearly exclusively on the consequences on abiotic
144 parameters.

145 Overall, these empirical studies highlighted that FPV can lead to a reduction in light
146 penetration, with studies measuring irradiance reductions as high as 73% and up to 100% under

147 panels [30,31]. Also, FPV can induce temperature reductions on the water column [32–36] (but
148 see [37]), and the intensity of this effect is more pronounced during spring and summer. For
149 instance, by comparing an area with FPV with an adjacent area without FPV, a reduction of
150 water temperature of 0.2°C during spring and 0.8°C during summer under panels was observed,
151 while no differences were observed in winter [36]. Reductions in DO [33–35,37,38] have also
152 been reported, and can also vary accordingly to season. It was observed that DO in the water
153 column was, on average, 1.1 mg/L and 1.7 mg/L lower under FPV during winter and summer,
154 respectively[33]. Additionally, reductions of chlorophyll-a concentration [32,34,35,37,38] were
155 also been reported. For instance, a reduction of 60% of evaporation between a mesocosm with
156 FPV cover compared to an uncovered one was measured [32]. Quantitative empirical studies on
157 biotic parameters were particularly rare. In fact, only one recent study measured changes in
158 zooplankton communities between coal mining subsidence wetlands with and without FPV and
159 found that, while rotifers density was higher in wetlands without FPV, rotifer diversity and
160 evenness were higher under FPV sites [39]. These were associated with changes in the relative
161 distribution of dominant species due to modifications in light arrival affecting phytoplankton
162 production [39], although this was not directly measured.

163 The rest of the literature used modelling approaches, and a large majority of them, were
164 based on simulations in artificial reservoirs. Overall, these modelling studies have consistently
165 predicted a decrease in evaporation rates with increased FPV cover [15,18,40–45] . While some
166 models predicted that FPV covering 10% of the recipient water body can lead to a reduction in
167 evaporation ranging from 7% to 19%[41], other simulations predicted that 20% cover can lead to
168 a reduction of about 62% on water evaporation. DO was also expected to decrease under FPV
169 [34,37,46]. Additionally, FPV was predicted to induce changes in temperature and stratification

170 patterns with the intensity of these changes being dependent on FPV cover [18,31,34,37,46–48].
171 Modelling approaches have also provided some first predictions on the effects of FPV plants on
172 wind and solar radiation (and consequently water temperature), altering the air-water interface
173 and surface meteorology [18,47], likely having consequences for biodiversity and ecosystem
174 functioning. These predicted effects, however, are highly context-dependent, varying for instance
175 with FPV cover on the simulated lake [47]. A global consensus that emerged from these studies
176 indicates that the ecological impacts of FPV will be mainly driven by reductions of light and
177 wind intensity at the water surface , which will affect the thermal properties of the lakes.

178

179

180 **Table 1.** List of studies investigating the ecological impacts of FPV. References are grouped by study type (empirical,
 181 empirical/modelling and modelling).

182

Study type	Country	Approach	FPV ecological effects	References
Empirical	Jordan	Mesocosm	<ul style="list-style-type: none"> • Evaporation reduced by 60% in FPV experimental ponds • 61% reduction of chlorophyll-a for covered systems with groundwater source and 17.5% for surface water source • Nitrate concentrations were 14% lower with FPV 	Abdelal et al. 2021
	Indonesia	Mesocosm	<ul style="list-style-type: none"> • Mesocosms with 100% FPV cover had lower average temperature, lower DO, conductivity and Chlorophyll-a 	Andini et al. 2022
	Netherlands	Artificial reservoir	<ul style="list-style-type: none"> • Pronounced effects of FPV on light intensity, with light reduction between 73% and 100% compared to a reference measurement • Limited evidences for FPV effects on water temperature and DO due to limited size of the pilot system 	Bax et al. 2023
	Netherlands	Quarry/pit lake	<ul style="list-style-type: none"> • FPV lead to lower upper layer water temperature • DO in the water column was, on average, 1.1 mg/L and 1.7 mg/L lower with FPV during winter and summer, respectively • Floaters were covered by biofouling after 9 months 	De lima et al. 2021
	South Korea	Artificial reservoir	<ul style="list-style-type: none"> • Water quality parameters did not differ before and after a FPV installation (0.04% FPV cover) • Light intensity decreased by 50% under FPV 	Kim et al. 2019
	China	Mining subsidence wetlands	<ul style="list-style-type: none"> • Higher density of rotifers in wetlands without FPV • Higher diversity and evenness indices of rotifers in wetlands covered by FPV • Rotifers richness was not different between lakes with and without FPV 	Li et al. 2023

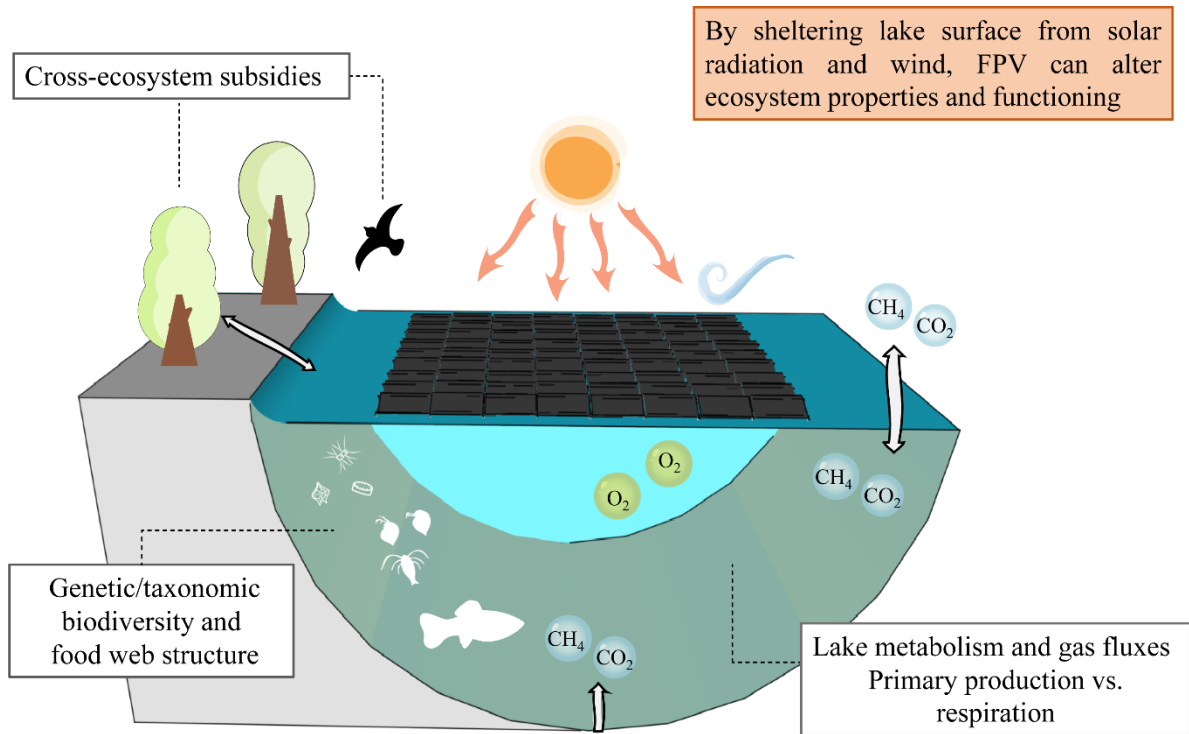
	Taiwan	Aquaculture ponds	<ul style="list-style-type: none"> • Lower temperature, lower DO concentration, lower BOD, lower plankton biomass with FPV • Higher production and survival rates of cultured species with FPV 	Wang et al. 2021
	Netherlands	Shallow pond	<ul style="list-style-type: none"> • water temperature was lower under FPV by 0.2°C in spring and 0.8°C in summer. No difference in winter • Frequency of hypoxia (DO < 6 mg/L) increased under FPV • There were no differences on other water quality parameters between FPV covered and uncovered areas • Plant growth was reduced under FPV areas 	Ziar et al. 2020
	<i>not applicable</i>	Laboratory set-up	<ul style="list-style-type: none"> • PV cables did not release microplastics 	Rebelo et al. 2021
	<i>not applicable</i>	Laboratory set-up	<ul style="list-style-type: none"> • FPV using semitransparent polymer solar cells can presented increased algal growth compared to opaque systems. 	Zhang et al. 2020
Empirical & Modelling	Taiwan	Aquaculture pond	<ul style="list-style-type: none"> • 40% FPV cover could reduce chlorophyll-a concentration from 1.61 to 1.06 mg/L in winter and from 1.06 to 0.86mg/L in summer • 40% FPV could reduce in water temperature from 20.99°C to 20.22°C in winter and from 31.03°C to 29.63°C in summer • Reduction in DO concentration of 0.80 mg/L with a 40% FPV cover 	Château et al. 2019
	Germany	Dredge lake	<ul style="list-style-type: none"> • 73% reduction in irradiance on the lake surface • Average reduction of 23% in near-surface wind speed • No effect on water temperature when FPV cover < 2% • Nonlinear relationship between water temperature and FPV cover 	Ilgen et al. 2023

Modelling	Singapore	Artificial reservoir	<ul style="list-style-type: none"> • FPV could increase water temperature by 0.3°C and water column stability • FPV could reduce chlorophyll-a, TOC and DO by 30%, 15% and 50%, respectively, and increase total nitrogen (10%) and total phosphorus (30%) • No effects on water temperature, water column stability or water quality in areas adjacent of the panels 	Yang et al. 2022
	Egypt	Artificial reservoir	<ul style="list-style-type: none"> • Decreased water evaporation can save up to 61.7% when FPV cover was 20% 	Abdelgaied et al. 2023
	United Kingdom	Artificial reservoir	<ul style="list-style-type: none"> • Increase in FPV cover can reduce water temperature, stratification period and mixing depths 	Exley et al. 2021
	United Kingdom	Artificial reservoir	<ul style="list-style-type: none"> • Water temperature decreases with increasing FPV cover • Chl-a usually decreases with increasing FPV cover • Variations in FPV cover and sitting position affect the dominance of different functional groups of phytoplankton • FPV impacts on phytoplankton were dependent of FPV cover and location 	Exley et al. 2022
	Chile	Artificial reservoir	<ul style="list-style-type: none"> • Lower FPV cover (< 40%) has little or no effect on algal growth. Higher FPV cover strongly reduce algal biomass 	Haas et al. 2020
	China	Artificial reservoir	<ul style="list-style-type: none"> • FPV can reduce water temperature, water age, and relative water column stability of the reservoir. • The influence range of FPV on water temperature is spatially limited 	Ji et al. 2022
	India	Artificial reservoir	<ul style="list-style-type: none"> • FPV covering 30% of the reservoir could save 42,731.56 m³ of water by reducing in evaporation loss 	Nagananthini et al. 2021
	Romania	Artificial reservoir	<ul style="list-style-type: none"> • No effects on water quality after FPV implementation 	Popa et al. 2021

		were predicted for a cover of 0.32 %	
South Africa	Irrigation pond	<ul style="list-style-type: none"> • FPV could lead to 2961 Kilolitres (Kl) of water preserved by avoiding evaporation 	Prinsloo et al. 2021
Italy	Artificial reservoir	<ul style="list-style-type: none"> • FPV covering 30% of a water body could lead to 49% reduction in water evaporation • Positive relationship between evaporation reduction and FPV cover 	Scavo et al. 2020
Italy	Artificial reservoir	<ul style="list-style-type: none"> • FPV cover of 10.0% could reduce evaporation (7 to 19%) 	Scavo et al. 2020
India	Artificial reservoir	<ul style="list-style-type: none"> • For a 10 MW plant covering an area of 120,000 m², the estimated evaporation loss reduction was 210,000 Kl/year 	Goswami et al. 2019
Egypt	Artificial reservoir	<ul style="list-style-type: none"> • FPV cover of 25%, 50%, 75%, and 100% could save about 2.1, 4.2, 6.3, 7.0, and 8.4 x 10⁹ m³/year 	Abd-elhamid et al. 2021

184 **3. An ecological perspective on the potential impacts of FPV**

185 Our state-of-the-art section confirms that current knowledge on the potential ecological
186 impacts of FPV is still at its infancy, have primarily focused on abiotic parameters, and the
187 subsequent effects on biological and ecological processes remain unknown. Therefore, we aim
188 here to provide a novel perspective on the ecological impacts of FPV on freshwater ecosystems
189 using current and reference knowledge. This approach will allow to broaden the scope of
190 previous studies and identify potential ecological implications that might have been overlooked
191 in previous research due to the oversimplification of the ecological functioning of freshwater
192 ecosystems. Based on ecological theory and analogue literature on effects of light, temperature,
193 and wind on freshwater ecosystems, we investigated the potential ecological outcomes that FPV
194 structures can trigger in lake ecosystems. Because freshwater ecosystems are extremely complex
195 [49], we do not seek to conduct an exhaustive list of all possible ecological impacts of FPV on
196 lake ecosystems, rather we aim to shed light on the main direct and indirect pathways through
197 which FPV plants may influence biodiversity and ecosystem functioning by modifying key
198 abiotic parameters, such as light, wind, and temperature (Fig. 1).



199

200 **Fig 1** – Potential effects of FPV on lake ecology. FPV will partially block sunlight and,
 201 altering lake temperature. These modifications will induce ecological changes across levels of
 202 biological organization, from genotypes and phenotypes to communities, food webs and
 203 ecosystem functioning, including the fluxes of energy and organisms across ecosystems.

204

205 3.1 FPV effects mediated by light

206 To maximize energy production, FPV can cover a high proportion of water surface (up to
 207 74%, [19]). The physical presence of FPV on the lake has the potential to strongly limit the
 208 arrival of light and photosynthetically active radiation [33,50,51]. Availability of light is amongst
 209 the main constraints for primary production, a crucial process driving the flow of energy within
 210 ecosystems [52,53]. Reduced light penetration will directly affect phytoplanktonic, macrophytic
 211 and benthic primary production, having the potential to modify biomass distribution in

212 autotrophic communities [54] and organic matter dynamics [55,56] and to influence consumers
213 diversity and nutrient cycling [57].

214 Previous studies have demonstrated that covering water surface (naturally and artificially)
215 decrease light availability and primary production [52,58–60]. Models predicted that increases in
216 FVP cover can result in lower algal growth and chlorophyll-*a* (chl-*a*) concentrations [20,34].
217 Château et al. [34] estimated that a 40% FPV cover in a fish pond, would reduce average chl-*a*
218 concentration from 1.61 to 1.06 mg/L during winter and from 1.06 to 0.86mg/L over summer.
219 However, the response of primary producers will depend on the percentage of surface covered
220 [20]. Simulations suggested that significant reductions in algal biomass might happen when
221 FPV cover is above 40% [20]. A recent modelling approach predicted exponential decline in
222 chlorophyll-*a* concentration as FPV cover increased. For instance, it was predicted that FPV
223 cover exceeding 60% or 70%, depending on the array's location, could lead to extremely low
224 chlorophyll-*a* concentrations ($< 1 \mu\text{g L}^{-1}$) [48]. In fact, reductions in algal growth is perceived as
225 a positive outcome of FPV because it could improve water quality in eutrophic lakes [15].
226 Paradoxically, low light can also lead to higher phytoplankton abundance due to interactions
227 among species [61]. Competitive interactions between pelagic and benthic producers are driven
228 by light (and nutrient context), and phytoplankton and periphyton are both better competitors for
229 light (compared to macrophytes). Therefore, shifts in ecosystem functioning can be expected if
230 drastic changes in light availability are made [61,62]. Light availability can also influence
231 species composition [48,63,64] by acting as an environmental filter, favoring species with
232 functional traits related to light utilization [65,66], as demonstrated for phytoplankton [59,67,68].
233 A compilation of growth-irradiance relationships of freshwater phytoplankton suggested that
234 cyanobacteria are more adapted to low light environments [69] as they present adaptive

235 strategies, such as the capacity of maintaining high rates of photosynthesis under low light
236 [70,71]. Furthermore, mixotrophic species can alter their nutrition pathway from autotrophy to
237 heterotrophy to compensate deficiency in light or nutrients [72]. Hence, the alterations induced
238 by FPV on fundamental resources availability can trigger changes in processes regulating
239 community assembly such as stabilizing mechanisms of coexistence regulated by intraspecific
240 and interspecific competition.

241 Light drives the outcome of predator-prey encounters in lakes as phytoplankton,
242 zooplankton and fish exhibit diel activity patterns associated with light intensity that will
243 influence prey risk [73–75]. Many fish are visual predators and reducing light can affect prey
244 detection and foraging success [76–78]. Low light conditions are known to affect visual
245 detection of prey by i) reducing the reactive distance of planktivorous fish [77,79], ii) decreasing
246 attack rates [80] and iii) decreasing the overall predation rate [78]. Ultimately, this can lead to
247 evolutionary changes such as changes in phenotypes as observed when deteriorated visual
248 conditions (high dissolved organic carbon, DOC) is associated to increased eye size in perch, a
249 predatory fish [81].

250 Shading caused by FPV is also expected to reduce consumer biomass via lower trophic
251 transfer efficiency [34,82]. Indeed, when light is a limiting resource (e.g., high DOC lakes),
252 reduced benthic primary production can induce a decreased production and biomass at higher
253 trophic levels such as benthic invertebrates and fish [52]. Light limitation can also have positive
254 effects on consumers biomass when nutrient availability is limiting [83,84]. Indeed, in low light
255 conditions, net photosynthetic rates are reduced, decreasing the Carbon to Nutrient ratio (better
256 food quality) within primary producers, and reducing the elemental mismatch between primary
257 producers and herbivores [84–86]. Consequently, the impacts of FPV on trophic transfer

258 efficiency will likely depend on the interaction between multiple factors such as light levels and
259 nutrient availability.

260 FPV will affect other environmental parameters such as dissolved oxygen (DO)
261 concentration, an essential water quality parameter [87]. DO can be directly affected by FPV
262 through reduced air-water contact and gas exchanges with the atmosphere and indirectly through
263 reduced light incidence. DO and primary productivity are strongly coupled, especially in bottom
264 waters [88], with reductions in light limiting phototrophic activity (DO production). In fact, DO
265 reductions under floating solar panels have been predicted by modelling studies [34] and *in-situ*
266 measurements [33]. Château et al. [34] estimated a significative reduction in DO concentration
267 of about 0.80 mg/L with a 40% FPV cover. By comparing DO concentrations under a FPV
268 structure and an open water reference point, de Lima et al. [33] found that DO concentrations
269 were lower under the FPV (4.6 mg/L compared to 6.0 mg/L at the reference point). Low DO
270 levels can alter organisms' distribution that will move from hypoxic to oxygenated water, or even
271 be lethal to a variety of aquatic organisms when migration is not possible or anoxia in the entire
272 ecosystem [89,90]. In fact, anoxia is recognized as one of the main possible negative outcomes
273 of FPV deployment [19] (see section 4.3).

274

275 **3.2 FPV effects mediated by temperature**

276 FPV will physically block the incidence of shortwave radiation, reducing surface heating
277 and likely leading to cooler surface water [18,31,34,47]. FPV can also alter diel variability in
278 water temperature[31,37]. This is because FPV structure will warm during the day and release
279 heat during the night potentially leading to lower diel variability in water surface. While, for a
280 very low FPV cover (2%), no effects on water temperature under a FPV plant and an adjacent

281 area were measured [31]. It was estimated that FPV covering large proportions of lake surface (>
282 ~50%) can result in significant water temperature reduction [47]. Château et al. [34] indicated
283 that 40% FPV cover can reduce, on average, water temperature from 20.99°C to 20.22°C in winter
284 and from 31.03°C to 29.63°C in summer. Temperature regulates a variety of physical and
285 chemical characteristics of water that have implications for ecological processes. For instance,
286 temperature regulates oxygen solubility, decreasing with higher temperatures [91]. Water
287 temperature also affect water viscosity and density that determine phytoplankton sinking rates
288 regulating phytoplankton suspension and survival [92,93]. Water temperature modulates
289 stratification patterns that can affect chemical and biological aspects within freshwater
290 ecosystems (see section 4.1).

291 The Metabolic Theory of Ecology (MTE, [94]) predicts that metabolic rate controls
292 ecological processes, with fundamental processes rates increasing exponentially with
293 temperature within the physiological range of organisms [94,95]. From plants to animals,
294 increased physiological and metabolic rates (photosynthesis, respiration, growth, nutrient uptake)
295 is commonly observed with increased temperature until a temperature optimum where rates start
296 declining due to enzymatic system break down [93,94,96]. In fact, all organisms are
297 characterized by a thermal niche and their species-specific thermal tolerances can thus define
298 organisms' distribution and community composition. For instance, high temperatures can be
299 lethal for some organisms, that under these circumstances may die or find a refugee in adjacent
300 cool waters [97–99]. Over the long term, water temperature also play an important role on life
301 history traits such as body size, life span, feeding mode and behavior [100]. Water temperature
302 is a key driver of organism phenology by regulating, for instance, fish reproduction [101,102]
303 and insect emergence [103,104]. A recent concern regarding climate change, is its effects on lake

304 water surface warming and its consequences to lake ecology (e.g., phenological effects, lake
305 biodiversity, biogeochemical processes). Globally, lake surface water temperature has increased
306 at a global average rate of 0.34°C per decade [105]. It has been suggested that FPV can thus be
307 used as a management tool to buffer the effects of climate change on water surface warming
308 [47].

309 From bacteria to fish, warmer temperatures promotes an increased proportion of small-
310 sized organisms, among and within species [93,106–108]. Body-size is a central biological and
311 ecological trait and a myriad of processes (from molecular to evolutionary dynamic) are linked to
312 body size [109]. Body size is not only correlated to individual fitness and population growth, but
313 it also affects size-dependent predation, having consequences to population and community
314 dynamics. In mesocosms, Chironomids, which are usually abundant and with fast generation
315 time, presented reduced body-size with increased temperature [110]. Because they represent an
316 important food source for fish, birds and other invertebrates, reductions in body size can alter
317 their nutritional value and modify attack rates and handling time of predators [110].

318 Temperature shapes the strength and stability of trophic relationships in aquatic food-
319 webs through a variety of indirect pathways [111]. For instance, temperature can stimulate
320 respiration in a greater extent than gross primary production because the temperature-
321 dependence of respiration is higher than the temperature-dependence of photosynthesis, affecting
322 the metabolic balance of the system [112,113]. Consumers will likely be more sensible to
323 temperature changes than producers, leading to reinforced top-down control in linear food webs
324 by increased grazing under higher temperatures [114,115]. In the scenario where FPV leads to
325 lower temperature, it can be expected the opposite trend, with weaken top-down control and
326 lower grazing pressure.

327 Furthermore, modifications in temperature leading to phenological alteration can also
328 cause trophic mismatch between prey and predators affecting energy flow in aquatic food webs
329 [114]. For example, it has been well documented that elevated temperatures cause earlier
330 phytoplankton blooms in spring [116,117]. These asynchronies across different trophic levels
331 can uncouple resource availability and consumer needs, and alter food webs [114,117].
332 Temperature changes can induce shifts in consumer diet, with increased herbivory observed in
333 warmer conditions [118] and a higher consumption pressure on primary producers [118,119]. If
334 FPV deployment cause a significant reduction in water temperature, it may favor ectothermic
335 omnivores to consume more animal resources and less plants as they are easier to digest in lower
336 temperatures and have higher nutrient content [120].

337 Water temperature strongly influences ecosystem-level processes which are mediated by
338 biological activity. Higher temperature can increase physiological rates, such as fish excretion
339 [121,122]. This is important because fish, via excretion, can significantly alter nutrient supply,
340 supporting a high proportion of primary production [123]. Water temperature also modulates the
341 decomposition rates of organic matter [76,124]. This is partially because C processing,
342 sequestration, and mineralization rates in the water column and sediments are dependent on
343 microbial activity that is directly associated to temperature [125]. Lower water temperature is
344 usually related to decreased decomposition rate and thus, lower mineralization rates, likely
345 because of reduced metabolic activity of decomposing bacteria and scavengers [76,126]. If FPV
346 reduce water temperature and the mineralization of organic C, this will lead to higher organic C
347 burial in sediments and alter C cycling [125].

348 Changes in water temperature induced by FPV have the potential to affect a variety of
349 physiological and biological processes related to individual metabolism and even small

350 temperature shifts could generate a cascade of impacts from the individual level to the whole
351 food web [111]. The response of ecosystems to changes in temperature will therefore depend on
352 the complexity of interaction networks and feedbacks between physical and biological processes
353 [111].

354

355 **3.3 FPV effects mediated by wind**

356 FPV create sheltered areas that decrease air-water contact and increase surface roughness,
357 likely reducing wind speed at lake surface [18]. A recent study measured that FPV can lead to an
358 average reduction of 23% of near-surface wind speed [31].The intensity of this effects is,
359 however, hard to predict as it will depend on a combination of factors such as FPV surface cover,
360 plant design, lake characteristics and surrounding landscape (e.g., morphometry and presence of
361 littoral vegetation;[18]). Nevertheless, even small changes in wind intensity can have significant
362 effects on lake ecology [18,47]. Wind has a pivotal role on freshwater ecosystem function [127]
363 as it directly influences water mixing, lake thermal dynamics [18,47], gas fluxes in the air-water
364 surface [128], sediment resuspension, and nutrient distribution in the water column [129,130].
365 Reduction in wind speed can, for instance, decrease DO concentration because the rate of gas
366 exchange at the air-water interface is a function of wind speed and gas concentration [131].

367 Decline in wind can also have indirect effects on eutrophication in shallow lakes due to
368 wind-induced internal nutrient release. Indeed, reduction in wind speed and longer low speed
369 duration can lead to longer stability periods and low DO in lake bottom (hypoxia), increasing
370 phosphorus release from the sediments and algal production [127]. On the other hand, high wind
371 is often related to nutrient release from the sediment due to resuspension, especially in shallow

372 lakes [132]. Thus, while the deployment of FPV can inhibit sediment resuspension due to lower
373 wind speed, it may also increase nutrient release from the sediments due to hypoxia in the water-
374 sediment interface.

375 Additionally, reduction of wind intensity can modulate vertical displacement and
376 horizontal drift passive dispersion processes, changing distribution patterns of aquatic organisms
377 [133]. For phytoplankton, under low wind-speed, wind-generated turbulence is not strong
378 enough to mix phytoplankton, neither to re-suspend planktonic species into the water column,
379 favoring smaller and buoyant phytoplankton species to remain at water surface [134,135]. It has
380 also been demonstrated that wind-induced water movements can affect zooplankton horizontal
381 distribution, leading to downwind accumulation of larger zooplankton species [133,136]. Such
382 effects on the fine-scale patterns of species distribution are likely to be induced by FPV.

383

384 **4. Interactive effects of wind, temperature and light**

385 **4.1 FPV effects on stratification patterns and its implications**

386 FPV shelters water surface from solar radiation and wind and alters water temperature,
387 leading to modifications in lake thermal stratification patterns [18,47]. While temperature and
388 wind are physical drivers of vertical mixing, they have different effects: reduction in wind tends
389 to suppress mixing and stratify while decreased water temperature can enhance mixing [137].
390 Using a model, Exley et al. [47] predicted that significant FPV cover (> ~50%) can result in
391 large temperature changes and extensive modification in stratification timing. The most common
392 responses found were reduction in water temperature, shorter stratification period and shallower
393 mixed depth, however, in low FPV cover scenarios, stratification was prolonged [47].

394 Understanding how FPV design will affect intensity and timing of lake stratification
395 (stratification phenology) is therefore of utmost importance. Stratification determines many
396 physical, chemical, and biological processes within lakes, including population dynamics and
397 species interactions and it also influences the exchange of oxygen, nutrients, and carbon between
398 lake surface and bottom [138]. Changes in the timing of stratification onset can cause shifts in
399 phytoplankton bloom, leading to trophic mismatches at the basis of food web [139]. In addition,
400 longer stratifications are usually related to hypolimnetic anoxia due to restrictions in the vertical
401 mixing of oxygen from the surface [91]. In turn, anoxic conditions at the lake bottom can lead to
402 nutrient remineralization (e.g., phosphorus release) and promote higher methane (CH₄) emission
403 through methanogenesis [138]. CH₄ is a highly potent greenhouse gas compared to CO₂ [140]
404 and, if FPV causes longer periods of stratification and lake bottom anoxia, it may generate
405 counterproductive results by increasing lake contribution to global warming through increased
406 CH₄ emission.

407

408 **4.2 FPV effects on evaporation and seasonal dynamics**

409 Water evaporation is an essential physical control of lakes, regulating for instance
410 surface water temperature, stratification, gas fluxes in the air-water interface and water levels
411 [105,141,142]. Evaporation rates are highly dependent on temperature. Climatic change is
412 expected to lead to an increase of 16% of global annual mean lake evaporation rates by 2100
413 [105]. Higher temperatures have been correlated with changes in water level seasonal cycles, due
414 to early summer evaporation rates, leading to lower lake water levels [143]. Changes in water
415 level can not only compromise water quantity [144] but also water quality by inducing regime
416 shifts in lake ecosystems [145].

417 FPV are predicted to reduce evaporative losses due to the combined effect of decreased
418 wind speed and water temperature [40,146,147]. A study using floating covers demonstrated that
419 water evaporation can be suppressed up to 96.8% with high FPV cover fractions as the floating
420 cover reduces solar radiation input, the ventilation at water–air interface and blocks water vapor
421 [144]. In a pilot scale test (2m x 2m x 1m tank), FPV lead to a 60% reduction in evaporation
422 [32]. Although empirical studies specifically with FPV as floating covers are limited, models
423 predicted an evaporation reduction potential of FPV ranging from 50% to 90% [15,41–45].
424 Because climate change will limit water availability and more prolonged and frequent droughts
425 are expected [148,149], FPV could provide water savings. However, this claimed benefit may be
426 highly context dependent, as it will depend on FPV cover and local meteorological conditions
427 such as relative humidity, wind speed and temperature [150].

428 By affecting fundamental properties of lakes such as temperature, light availability and
429 mixing, FPV can potentially impact lake spatial and seasonal dynamics (e.g., water level
430 seasonal dynamics). These dynamics defines the match-mismatch of food web interactions,
431 impacting food web structure and energetics at lake ecosystems, which can lead to severe
432 consequences such as regime shifts [151].

433

434 **4.3 FPV influence on lake metabolism and gas fluxes**

435 Lake metabolism is the balance between respiration (R) and gross primary production
436 (GPP), two of the most fundamental processes in ecosystems [152]. GPP is the assimilation of
437 inorganic carbon into organic plant material and O₂ release through photosynthesis (dependent
438 on light), while respiration is related to biochemical transformations of lake organic carbon (OC)
439 resulting in the uptake of O₂ and release of CO₂ and CH₄ [153]. On a global-scale the GPP:R rate

440 defines the role of the ecosystem as sources or sinks of C [153], with lake productivity also being
441 an important driver of lakes' emission rates [154]. GPP and R have a high sensitivity to light
442 availability and temperature and FPV can affect lake metabolism and gas emissions in multiple
443 and interactive ways (e.g., light and primary production, temperature and respiration rates, wind
444 and nutrient loading). For instance, if FPV reduce primary production due to reduced light, and
445 to lower metabolic rates caused by lower temperature, the ecosystem might increase its potential
446 as a CO₂ source. Following FPV installation, a high mortality of primary producers (e.g.,
447 phytoplankton and macrophytes) from light limitation is expected. This might induce an input of
448 organic matter to the sediment that has the potential to fuel methanogenesis, and hence the CH₄
449 emissions to the atmosphere [155,156].

450 The role of lake as a source of GHGs might also be enhanced by FPV if wind reductions
451 decrease DO concentration or induce longer stratifications to promote hypoxia. Generally, low
452 oxygen concentrations and anoxic conditions favor the use of alternative electron acceptors such
453 as carbon (for methanogenesis) and nitrate (denitrification), having N₂O and CH₄ as final
454 products which are gases with greater potential as GHG than CO₂ (IPCC, 2014). Over a longer
455 time period, lakes may undergo a process of oligotrophication caused by the reduced biomass of
456 primary producers. This will decrease OM availability and GHG production and emission are
457 expected to decrease. This dynamic will be dependent of temperature, oxygen conditions and
458 nutrients availability. While the effects of FPV on ecosystem metabolism are hard to predict
459 [18], their understanding is of utmost importance to ensure that FPV is not triggering
460 counterproductive impacts regarding GHG emissions.

461

462 **5. FPV acting from genes to the meta-socio-ecosystem scale**

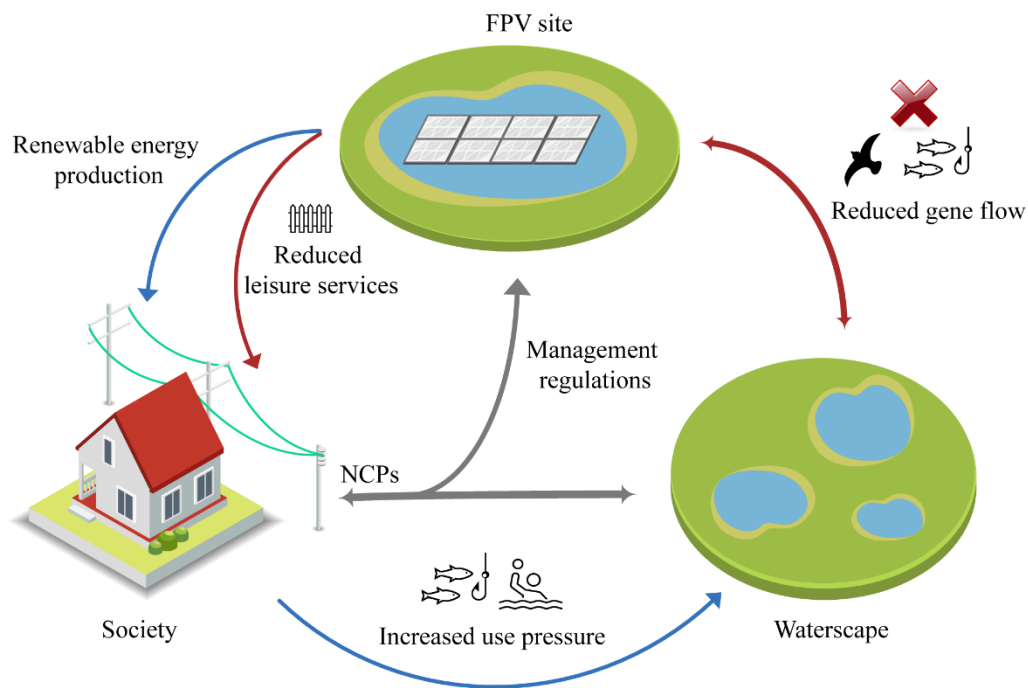
463 Regarding the individual and genetic level, organisms can respond to modifications in
464 their environment by genetic adaptation (e.g., selection of intraspecific variation in light
465 limitation), phenotypic plasticity (e.g., alteration of photosynthetic traits under low light) and
466 species sorting (e.g., sorting due to interspecific variation in light limitation) [157]. For instance,
467 phytoplankton species from different functional groups, when exposed to low light conditions,
468 increased their phenotypic variability to reduce interspecific competition and maximize
469 individual success [158]. Fish can also display rapid responses (within a few generations) to
470 environmental pressures such as changes in temperature [159]. Using models, Château et al. [34]
471 predicted that the cooling effect of 60% of FPV cover could reduce fish appetite and
472 subsequently fish production. Species generation time will affect the temporal dynamics of their
473 responses to FPV, with faster and more intense responses likely occurring for short-generation
474 time species [160]. This is especially true for phytoplankton, because they are abundant, have
475 fast generation time and high genotypic diversity, providing the ground for fast trait evolution
476 induced by strong selective pressures [157]. Rapid changes induced by FPV (e.g., temperature,
477 light) are therefore expected to induce rapid response for such organisms and time-lagged effects
478 at higher trophic levels, such as long-lived fish [160].

479 FPV can also interfere on processes happening at the land-water interface. Fluxes of
480 matter, organisms and energy across ecosystems is ubiquitous, with ecosystems being connected
481 by reciprocal subsidies [161–163]. Hence, perturbations in one habitat can cascade in unexpected
482 consequences in the adjacent ecosystem [164]. Terrestrial allochthonous organic matter is an
483 important resource for aquatic food webs and affects the lake C budget. Carbon budgets in
484 aquatic ecosystems can be highly dependent on inputs of dissolved and particulate organic
485 carbon from land (DOC and POC, respectively), with tree leaves being a major input of

486 terrestrial POC [165,166]. FPV can affect the arrival of terrestrially derived organic matter in
487 different ways: 1) by partial removal of the surrounding vegetation during the construction,
488 reducing terrestrial POC production (e.g., leaves); 2) FPV may impede leaves to enter the lake,
489 and finally 3) spatial disposition of FPV arrays will determine the fate of suspended leaf and its
490 sedimentation within lakes as FPV will limit their drifting. FPV will modulate the availability
491 and modify spatial distribution of POC, with potentially important consequences on biochemistry
492 and ecosystem functioning [166].

493 Emerging insects link freshwater and the adjacent terrestrial ecosystems [167] and, in
494 some areas adjacent to large lakes, insect emergence can exceed terrestrial secondary production
495 by a factor of 100 or more [168]. Therefore, aquatic insects represent a significant input of
496 resources supporting terrestrial consumers such as birds, reptiles, and spiders [169]. Light and
497 temperature trigger insect emergence, with earlier emergence in warmer water temperatures and
498 longer photoperiod [104,170]. Thus FPV may alter the timing of aquatic insect emergence and
499 nutrient subsidization across ecosystems, potentially inducing trophic mismatch with terrestrial
500 consumers.

501 Mobile organisms, such as birds, have an important role in driving the flow of nutrients
502 across ecosystems through the spatial interactions between nutrient recycling and feeding and
503 affect ecosystem functioning across spatial scales[171] (Fig.2). FPV may alter the habitat use
504 and behavior of piscivorous birds, changing the flux of nutrients across ecosystems. While FPV
505 may attract some birdlife [172], their presence, however, may be unwanted. While bird dropping
506 is a natural input of nutrients from adjacent ecosystems into lakes [173,174], when they are
507 accumulated above the panels and then flushed into the water during discrete cleaning or rainfall
508 events, they may represent a pulsed input of nutrients and affect water quality [33].



510

511 **Fig 2** – Potential changes in socio-meta-ecosystem dynamics induced by FPV. The schema also
 512 highlights the role of society to apply management regulations in FPV sites and at the waterscape
 513 level to guarantee the maintenance and provisioning of material and non-material Nature’s
 514 Contributions to people. Red arrows represent reduced fluxes and blue arrows increased fluxes.

515 FPV impacts are also anticipated at the waterscape level [175]. FPV deployment can
 516 affect the movements of organisms and matter in the network of lakes within the landscape
 517 [176], (Fig. 2). Wind blowing in the lake surface can release vegetative cells from water
 518 collecting and transporting phytoplankton by wind [177]. Anemochory has also been
 519 demonstrated to be a relevant route of dispersion between freshwater ecosystems for zooplankton
 520 [178–180]. Reduction of dispersal capacity, combined with the selective pressures induced by
 521 resource limitation (e.g., light reduction) caused by FPV deployment can lead to declines in
 522 interspecific and intraspecific diversity due to genetic bottleneck and inbreeding processes. In

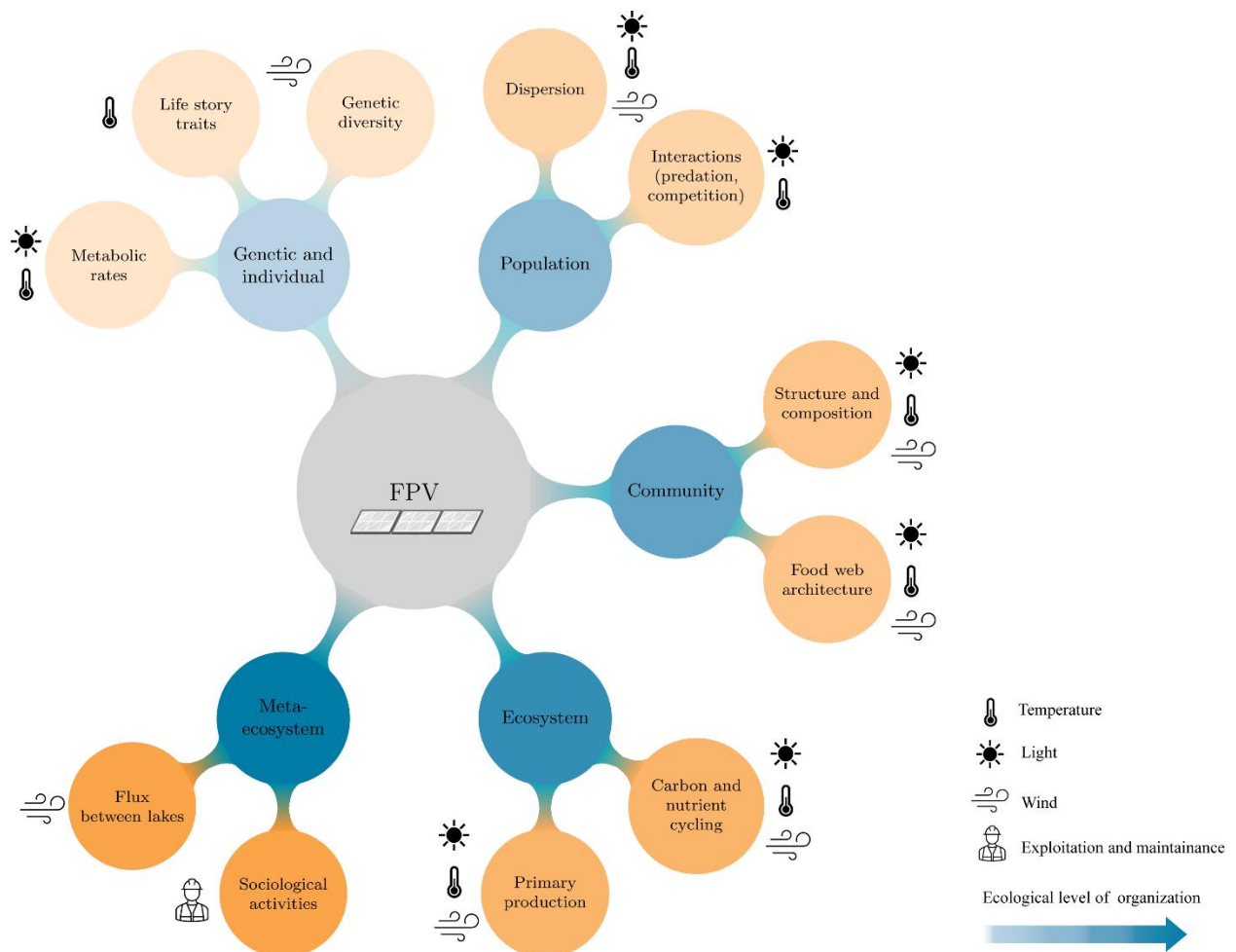
523 that sense, FPV deployment might interfere with patterns of local but also regional species
524 diversity.

525 The flux of matter and energy between ecosystems is also greatly affected by human
526 actions [181]. Lakes are ecosystems known for their multiple uses such as drinking water,
527 recreational and cultural activities (e.g., angling, lake shore running, dog walk, scenic
528 appreciation). When FPV are deployed, exploitation, maintenance or security reasons will
529 decrease or totally limit other activities. For instance, angling will be affected by FPV because
530 access to sites can be prohibited, or when co-use of site is allowed, angling area will be
531 diminished to guarantee the integrity of FPV structure. Recreational angling can also be affected
532 by change in fish behavior that may hide under FPV, in areas where angling may not be allowed.
533 These changes must therefore be modulated and associated with fishery management practices
534 such as stocking. If public access is prohibited, this will considerably limit the movement of
535 humans in the waterscape and reduce important vector of nonnative species introduction [175].
536 The reduction (or total disappearance) of angling will strongly alter fishing-induced selective
537 pressure and might lead to new evolutionary trajectories in unfished lakes.

538 FPV also cause a visual change in the landscape due to modifications on the water
539 bodies, but also on its adjacent terrestrial habitat (e.g., vegetation removal during construction or
540 to avoid shading on the panels). These changes have the potential to generate conflicts with the
541 local population [50,182] and compromising the non-material psychological benefits provided by
542 freshwaters such as aesthetic value[182]. In that sense, FPV deployment must be thought in the
543 meta-socio-ecosystem context [181] as it can impose changes also in human activities related to
544 freshwater ecosystems (Fig. 2 and 3).

545 Using theoretical ecology and current FPV studies, we argue that i) FPV plant can have
 546 the potential to trigger numerous ecological impacts in both aquatic and adjacent terrestrial
 547 ecosystems, affecting different levels of biological organizations (Fig.3), and that ii) these effects
 548 have been largely overlooked despite this representing a pre-requisite to limit the negative
 549 ecological impacts of FPV and ensure that the full environmental benefits of FPV are obtained
 550 without sacrificing freshwater biodiversity or the functioning of lake ecosystems.

551



552

553

554 **Fig.3** – Expected ecological effects of FPV across different levels of ecological organization.
555 These effects are caused by alterations in light, wind, temperature, and restrictions in lake access
556 caused by FPV exploitation and maintenance.

557

558 **6. The role of FPV physical structure**

559 FPV arrays will enhance the structural complexity of a lake by providing new habitat in
560 the pelagic zone. The floating pontoons that are the base structure of the floatovoltaic arrays
561 create a novel surface area located at the euphotic zone, providing conditions for the
562 development of biofouling [33] and habitat for sessile species in the pelagic zone of lakes. de
563 Lima et al. [183] found that, 9 months after FPV installation, a high proportion of the floating
564 structure was covered by small bivalves and biofouling. Although there is still a lack of empirical
565 evidence regarding the ecological effects of FPV physical structure, studies on habitat
566 complexity provided by artificial structures have shown that habitat heterogeneity provided by
567 the presence of artificial structures can be correlated with increased abundance and diversity of
568 macroinvertebrates [184]. Fish can also be attracted to artificial structures because the enhanced
569 habitat complexity can provide cover, increasing juvenile fish survival by creating refuges from
570 predation and also by providing spawning and nesting substrate [185–187]. Indeed, it has been
571 observed that the underneath portion of the FPV may be used as a resting and nesting area for
572 birds and fish [33,172]. Rosa-Clot (2020) observed that, in a lake where FPV plants were
573 installed, carps tended to spend time under the FPV platforms due to sun shading and to the
574 presence of attached algae. FPV structure can also reduce predation pressure by piscivorous birds
575 because i) water accessibility (or predation area) is reduced due to FPV cover; ii) FPV can serve
576 as a refuge for fish hiding from bird predation [188]; and due to iii) the use of repellent

577 technologies. Additionally, FPV structure can be a source of chemical pollution to water bodies
578 due to release of chemicals and microplastics originated from degradation of FPV components
579 over time[189].

580

581 **7. A guideline for monitoring the potential ecological impacts of FPV**

582 Recently, FPV has been identified as one of the main emerging issues of concern for
583 biodiversity conservation [29], and there is still an important knowledge gap regarding their
584 potential ecological impacts. Based on our investigations and existing knowledge, we provide
585 here a comprehensive set of parameters related to i) the physical and chemical characteristics of
586 the water, ii) the structure of biodiversity and iii) the functioning of ecosystems that we
587 recommend to monitor when aiming to assess the ecological impacts of FPV (Table 2). This set
588 of parameters is based on previous recommendations from existing literature [18,30], and from
589 our investigations. These guidelines offer a unified, multidisciplinary framework for assessing
590 the potential effects FPV on aquatic ecosystems and should provide knowledge that could help to
591 understand their context-dependency.

592 Ideally, we recommend to performed these monitoring surveys using a BACI (Before -
593 After - Control – Impact) design that allows to take into consideration potential confounding
594 factors and natural variability in ecosystems [190,191]. This means that water bodies that are
595 meant to receive FPV should be monitored several years before FPV installation to obtain a
596 robust reference. Control sites with similar geomorphological, physico-chemical and biological
597 characteristics should also be included in the monitoring program to provide a baseline of
598 biodiversity and ecosystem dynamics. Monitoring should be performed at least once per season

599 to take into account the main changes occurring in lake ecosystems. It is expected that the
600 complex ecological impacts of FPV will take several years – decades- to eventually reach an
601 equilibrium.

602

603 **Table 2.** List of suggested parameters to be monitored when assessing the ecological impacts of FPV on freshwater biodiversity
 604 and ecosystem functioning.

Properties	Parameters	Rationale
<i>Water physical and chemical properties</i>	Light intensity	Light intensity and photosynthetically active radiations in the water column will be modified due to FPV shading effect.
	Temperature	Solar radiation and wind mixing will be modified, likely altering water temperature profiles and stratification patterns.
	Nutrients	By reducing wind, FPV can inhibit sediment resuspension and affect the internal loading of nutrients (C, N and P). FPV can also increase nutrient release by sediments if it is associated to hypoxia at the water-sediment interface. Change in biodiversity will also modify nutrient cycling.
	Dissolved oxygen (DO)	Reduced wind and contact at the water-atmosphere interface can lead to lower water column oxygenation and change in (DO) profiles. Reduced light penetration can limit phototrophic activity and DO production by primary producers.
	Micropollutants	Leaching and UV degradation from FPV panels and flotation devices may induce the released of a variety of micropollutants (e.g. heavy metal and organic compounds).
<i>Biodiversity</i>	Phytoplankton, periphyton and macrophytes	Alterations in light arrival induced by FPV can lead to a reduction in algal growth, mainly in the area covered by FPV, and a shift in community structure favoring taxa adapted to low light conditions.
	Zooplankton and macroinvertebrates	Changes in light distribution and wind can influence patterns of zooplankton diel vertical migration and horizontal distribution. Additionally, biomass and community structure of zooplankton and macroinvertebrates may change following changes in the structure of primary producer and aquatic vertebrates consuming them. Emergence of macroinvertebrates will likely change.

	<p data-bbox="415 331 659 358">Fish and amphibians</p> <p data-bbox="879 233 1934 415">FPV will reduce predation pressure by providing refuge from piscivorous birds, will increase habitat complexity, provide shaded areas and reduce water temperature which can influence spatial distribution of fish, fish behavior, food availability as well as fish metabolism and consequently community biomass. Amphibians inhabiting littoral habitats are likely to be less affected by FPV than fish.</p> <p data-bbox="415 542 583 570">Birds and bats</p> <p data-bbox="879 467 1934 610">FPV can alter bird and bats behavior and habitat use as they can be attracted by FPV platforms for nesting but they may also avoid the area due to the use of repellent technologies or reduced availability of predation areas. Changes in fish habitat use and insect emergence will also change food availability.</p>
<p data-bbox="186 894 333 959"><i>Ecosystem Functioning</i></p>	<p data-bbox="415 716 852 781">Pelagic and benthic primary production</p> <p data-bbox="879 662 1934 805">Light is the main source of energy for primary producers and changes in primary production will energy flow within the ecosystem. Additionally, floaters can represent a novel growing area (i.e. biofouling) leading to a new source of organic matter for consumers and providing habitat for sessile organisms.</p> <p data-bbox="415 932 837 959">Greenhouse gases emission (GHGs)</p> <p data-bbox="879 854 1934 997">FPV may change the role of the water bodies as a source or sink of GHGs. If FPV leads to longer stratification periods or bottom anoxia due to lower oxygenation of the water column, it can favor process such as methanogenesis. On the other hand, water bodies can become a sink of CO₂ if FPV leads to lower organic matter production.</p> <p data-bbox="415 1105 617 1133">Lake metabolism</p> <p data-bbox="879 1049 1934 1192">Because FPV may affect oxygenation of water column through i) changes in gas exchanges at the air-water interface, ii) changes in oxygen solubility due to modification in water temperature and iii) changes in metabolic rates of primary producer and consumer, FPV can alter lake metabolism.</p>

605

606

607 **8. Conclusion**

608 FPV may induce a myriad of ecological impacts in aquatic and their adjacent terrestrial
609 ecosystems across levels of biological organization. While it is difficult to predict the general
610 outcome of these multiple, sometimes opposing, effects, some alterations can compromise the
611 conservation of multiple NCPs derived from freshwater ecosystems such as water provisioning
612 and climate regulation. Based on existing literature of the ecological effects of FPV as well as on
613 ecological theory regarding the ecological effects of the physical parameters most likely
614 impacted by FPV (light, temperature, wind), we expect that these ecological effects will be
615 highly context-dependent, varying across ranges of environmental (e.g., lake trophic status,
616 community assemblage, local climate) and industrial (e.g., FPV % cover, array design), resulting
617 in a large variability in responses between ecosystems. While water temperature, chlorophyll- a
618 and DO concentrations and evaporation rates have been the main parameters studied so far, the
619 development of the ecological perspective on the potential effects of FPV suggested in this
620 study should improve our ability to identify the potential ecological implications that have been
621 overlooked in previous research, such as species behavior and migration patterns, freshwater
622 communities structure (but see [39,48]), ecosystem functioning (e.g. nutrient cycling, lake
623 metabolism and GHGs emission). Quantifying the impacts (positive or negative) of such an
624 environmental change and how lake ecosystems will respond to it is extremely challenging. It
625 will require continuous and long-term monitoring before and after FPV installation and the use in
626 conjunction of methods to quantify aquatic biodiversity, food webs and ecosystem functions
627 (e.g., C Cycle and lake metabolism) within context-dependent scenarios. We hope that the
628 guideline for monitoring FPV plants provided in this study should serve as a practical tool for
629 researchers, policymakers, and industry stakeholders to assess and manage the potential

630 ecological impacts of FPV installations. Again, we argue that empirical studies such as *in situ*
631 monitoring and experiments based on robust and replicated designs are essential to quantify the
632 possible ecological impacts of FPV, assuring that it is reaching its goals as a sustainable
633 technology, but also providing fundamental knowledge on ecosystem responses to abrupt
634 environmental changes.

635

636 **Acknowledgements**

637 This work was supported by the Office Français de la Biodiversité (OFB) and the French Agency
638 for Ecological Transition (ADEME) as part of the SOLAKE projects and by the European
639 Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie
640 grant agreement n° 101065785. The authors are grateful to 4 reviewers for the comments that
641 have greatly improved our manuscript. The authors have no conflicts of interest to declare.

642

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