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Water Practice & Technology Vol 15 No 3
doi: 10.2166/wpt.2020.062

Potential impact of floating solar panels on water quality in reservoirs; pathogens and leaching

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Abstract

Application of floating solar panels is especially suited for the Netherlands, given the limited availability of land (surface area). Evides water company owns and operates several open storage reservoirs which can be used for installation of these panels, but the installations could affect the local environment, naturally occurring processes and water quality. In this research, we evaluate leaching of various substances and possible effects based on a theoretical approach following the Analysis of Microbiological Safety of Drinking water (AMSD method). Besides the water quality issues, the ongoing research at Evides will focus on the effect of the floating solar installation on algae, microbiological and chemical parameters, birds, aquatic flora and fauna, and also look into possibilities of applying alternative storage possibilities using hydrogen.

Key words: energy transition, environmental impacts, heavy metals, photovoltaics, water storage reservoir

Highlights

- Application of floating solar panels could make Evides energy neutral.
- Leaching of heavy metals from certain components is limited.
- Leaching of organic micropollutants was not detected.
- A theoretical analysis was made for the microbial safety of drinking water.
- Future measurements aim to assess many unknown effects.

INTRODUCTION

The Netherlands has limited space available for the transition towards renewable energy. The Solar Energy Application Centre (SEAC) expects that about 383 km^2 of floating solar panels will be needed in order to reach goals for renewable energy (SEAC 2017). The water storage reservoirs of Evides, a drinking water utility in the south west of the Netherlands, are in principle suitable for floating solar panels. With a total surface area of about 8 km^2 (Table 1), the reservoirs could potentially generate about 200 GWh of power on a yearly basis. Evides is aiming to become energy- and climate neutral by 2025 and the application of floating solar panels on water storage reservoirs has the potential to fully realize the goals of energy and climate neutrality, and to contribute significantly to the Dutch transition towards renewable energy. Although some information is available on the environmental effects of solar panels on land (Turney & Fthenakis 2011; Armstrong *et al.* 2016; Robinson &

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Table 1 | Planned projects for floating solar at Evides

Water storage reservoir	Nett. acreage reservoir (ha)	Max. acreage solar park (ha)	Max. expected power[a] (MW)	Max. expected energy production[b] (GWh)
Kralingen	3	1	1	1
Baanhoek	51	10	10	9.5
Berenplaat	96	26	26	24.7
Braakman	63	19	19	18.1
Petrusplaat	89	17	17	16.2
Honderd en Dertig	186	56	56	53.2
De Gijster	272	82	82	77.9
Total	**760**	**211**	**211**	**201**

[a]Assuming 100 Wp/m^2 of solar park.
[b]The solar irradiance varies slightly over the different locations; for simplicity a fixed power output of 950 kWh/kWp was used to calculate the maximum expected output. This output is typically used by RVO, the Dutch government organization that deals with the subsidy for solar parks.

Meindl 2019), there is currently little to no knowledge available on the effects of floating solar panels on the quality of the underlying water and local environment. These aspects of application of floating solar panels are relevant for Dutch drinking water companies, especially as potential negative effects need to be identified and quantified to be able to make an informed decision on whether to apply floating solar on a large scale. Here, we describe the setup of our research into the effects of floating solar panels on water quality and ecology and some preliminary results.

MATERIALS AND METHODS

The analysis of the effect on the decimal elimination capacity (DEC) for various microorganisms was done based on data gathered for the obligatory (by Dutch law) AMSD and following the standard method used by the Dutch drinking water companies (Smeets 2017). We used a worst-case approach, assuming the percentage of coverage is linearly related to a decrease in the DEC.

Leaching experiments were done at Aqualab Zuid. We evaluated which materials of the installation have the most contact with the water: the PE tubing, PE caps and sealant material of the caps used in the flotation mechanism. For other materials in direct contact with the water, the contact area is minimal, and these were therefore neglected in our analysis. The storage reservoir at Kralingen will be covered for about 30% by 8,000 m^2 of floating solar. The volume of the storage reservoir is about 72,000 m^3. Therefore, the contact area is about 1 cm^2/L. Based on this amount, leaching tests of 24 h and 2 weeks were performed with a blanc, 1 cm^2 of PE tubing, 1 g of PE caps and 1 cm^2 of sealant, at 20 °C. The water used for the tests was the same that is delivered to the reservoir at Kralingen: Meuse river water that has passed through a series of water storage reservoirs with a residence time of in total two to three months and has been softened to a hardness of about 1.5 mM. Circa 200 different compounds were analysed in the water phase at the end of the leaching test, by Aqualab Zuid with accredited methods. The list of tested-for compounds includes heavy metals, poly- and monocyclic aromatic hydrocarbons, volatile halogenated hydrocarbons, monocyclic (halogenated) nitrogen compounds, phenols and halogenated phenols.

RESULTS AND DISCUSSION

We analysed the potential effects of floating solar on the DEC of the reservoirs via Quantitative Microbial Risk Assessment (QMRA) in a worst-case scenario where the floating solar panels block

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all incoming light. It was found that the lower limits on the DEC for the application of floating solar panels on reservoirs at Evides for *Cryptosporidium* and *Giardia* are reached first, and not as was initially suspected for *Campylobacter* (Tables 2–4). Based on this analysis we conclude that from the point of view of the QMRA, depending on the transparency of the floating solar system for UV light (typically ranging between 0 and 67%), 10–30% of the surface area of the reservoirs can be covered at Evides.

Table 2 | DEC required and available for *Campylobacter*

Treatment plant (year)	Required DEC *Campylobacter* [1]		Total DEC treatment plant, incl. UV40 and ClO_2
	Mean	*Max*	
Berenplaat (2012)	7.9	9.0	>11.9
Kralingen (2012)	7.6	8.7	>15.5
Baanhoek (2014)	6.9	7.8	>14.7

Green background: DEC for treatment plant, including reservois, is sufficient.
[a]Calculated on the basis of pathogen concentration in the local storage reservoir.

Table 3 | Estimated DEC for the produced drinking water with water storage reservoirs with 10% coverage of 100% opaque floating solar panels for the reservoirs in the Biesbosch (BB)

Index pathogen	Required DEC <u>*90% DEC BB*</u>		Total DEC reached			
	Average	*Max*	*BERENPLAAT*	*KRALINGEN*	*BAANHOEK*	*BRAAKMAN*
Adenoviruses	≥4.6	≥5.4	6.0 – 8.2	>7.2 – 9.4	>6.6 – 8.8	QMRA unavailable
Enteroviruses	3.6	4.5	7.2 – 9.4	8.6 – 10.8	8.9 – 11.1	
Cryptosporidium	4.1	5.7	7.6	>5.8	>6.3	
Giardia	4.5	6.4	7.7	>6.7	>6.4	

DEC needed and DEC reached for locations Berenplaat, Kralingen, Baanhoek and Braakman (new situation reservoir, no current QMRA available).
Green background: DEC for treatment plant, including reservoirs, is sufficient.
Orange background: DEC for treatment plant, including reservoirs, is only just sufficient.

Table 4 | Estimated DEC for the produced drinking water with water storage reservoirs with 30% coverage of 100% opaque floating solar panels for the reservoirs in the Biesbosch (BB)

Index pathogen	Required DEC <u>*70% DEC BB*</u>		Total DEC reached			
	Average	*Max*	*BERENPLAAT*	*KRALINGEN*	*BAANHOEK*	*BRAAKMAN*
Adenoviruses	≥4.6	≥5.4	6.0 – 8.2	>7.2 – 9.4	>6.6 – 8.8	QMRA unavailable
Enteroviruses	4.2	5.0	7.2 – 9.4	8.6 – 10.8	8.9 – 11.1	
Cryptosporidium	4.4	6.0	7.6	>5.8	>6.3	
Giardia	4.8	6.7	7.7	>6.7	>6.4	

DEC needed and DEC reached for locations Berenplaat, Kralingen, Baanhoek and Braakman (new situation reservoir, no current QMRA available).
Green background: DEC for treatment plant, including reservoirs, is sufficient.
Orange background: DEC for treatment plant, including reservoirs, is only just sufficient.
Red background: DEC for treatment plant, including reservoirs, is insufficient.

Another concern, besides the DEC, is the effect of leaching of, for example, heavy metals from the solar panels and flotation devices. The leaching tests were performed at a relatively high water temperature of 20 °C, representing a worst-case scenario as leaching speed is expected to increase with temperature. Of the circa 200 compounds tested for (for the full list and results: see supplementary information), only some heavy metals were found in higher concentrations than in the blank (values with orange background, Table 5). The PE tubing and caps release some aluminium and zinc. Some aluminium, copper, manganese and zinc leach from the sealant, but leaching appeared to take longer as most of these (excluding aluminium) were only found leaching after 2 weeks and

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Table 5 | Results of the leaching experiments for the heavy metals, after 2 weeks and 24 h

			PE tubing		PE caps		Sealant		Blanc	
Heavy metal	Unit	IS	2 weeks	24 h	2 weeks	24 h	2 weeks	24 h	2 weeks	24 h
Aluminium	μg/l	10	3.43	2.21	2.77	8.0	3.91	3.05	0.88	1.09
Arsenic	μg/l	2	1.76	1.58	1.69	1.67	1.79	1.6	1.69	1.6
Boron	μg/l	250	52.5	47.5	50.1	45.2	44.9	45.0	45.8	46.8
Cadmium	μg/l	0.1	0.02	0.03	0.02	0.03	0.03	0.02	0.02	0.02
Chromium	μg/l	1	0.44	0.38	0.37	0.33	0.36	0.46	0.38	0.33
Copper	μg/l	40	2.77	1.51	1.51	1.52	10.9	2.88	2.24	1.58
Mercury	μg/l	0.05	0	0	0	0.03	0	0	0	0
Lead	μg/l	1	0.06	0.07	0.08	0.04	0.19	0.09	0.11	0.04
Manganese	μg/l	40	0.56	0.59	0.44	0.49	3.91	0.53	0.63	0.5
Nickel	μg/l	5	2.81	2.41	2.61	2.5	2.65	2.67	2.51	2.52
Selenium	μg/l	1	0.25	0.26	0.27	0.29	0.29	0.29	0.26	0.26
Zinc	μg/l	50	9.05	6.74	5.18	1.34	4.19	2.74	3.33	1.91

IS = Internal Standard for produced drinking water at Evides.
Orange background: higher then blank but below Internal Standard.
Green background: comparable to blanc.

not after 24 hrs. The concentrations are several times lower than the internal standard for produced drinking water. Considering that at Kralingen only at most 4% of the raw water is taken in from the reservoir and that the water will still be coagulated as a first treatment step, it is highly unlikely that these heavy metals will cause any detectable increase of heavy metal concentrations in the finished drinking water. Longer term prospects of leaching in practice are uncertain and will therefore be monitored at Kralingen. Seasonal effects may also occur and it is possible that longer term leaching may give rise to other compounds being released.

The presence of heavy metals in the vicinity of a solar panel installation on land has been investigated (Robinson & Meindl 2019). Although some elevated heavy metal concentrations were found near the solar panels, it was concluded that no elements were, on average, present in concentrations that would pose a risk to nearby ecosystems. The exact source (e.g. component of the installation) of the heavy metals was not determined. In our case not all materials were tested, but it seems likely that the main components that are responsible for leaching of heavy metals from the floating solar system to be installed at Kralingen have been identified, as the tested materials represent the main mode of contact with the reservoir.

Application of floating solar panels on water storage reservoirs should preferably have no or negligible negative effects, or a net beneficial effect. This is especially important for Evides as the largest storage reservoirs ('De Gijster' and 'Honderd en Dertig') are located in a Natura 2000 area. Possible effects of covering a reservoir with floating solar panels include, but are not limited to: reduced mixing (by wind) of the reservoirs, changes related to flora and fauna and related organisms (birds, fish, water plants, mussels, insects, algae, bacteria, viruses, etc., which are all present in or around the reservoir; note that these could also be beneficial), leaching of heavy metals (or other compounds), other changes in physico-chemical parameters and reduced evaporation.

The first application of floating solar panels at Evides will be located at Kralingen and is expected to be operational in Q1 2020. An extensive monitoring program including baseline measurements is already in place, running and aims to assess several of the issues mentioned in the previous paragraph. Monitoring includes: (1) microbiological parameters (*Escherichia coli*, coliform bacteria, *Clostridium perfringens*, *Campylobacter*), (2) algal composition, algal biovolume and chlorophyll a, (3) chemical parameters, including oxygen level profiles in the water column in the reservoir (a good indication for adequate mixing), total organic carbon, leaching of organic micropollutants and heavy metals, and (4) species and numbers of birds and aquatic flora and fauna. We expect that these parameters will give sufficient insight into the effects of floating solar panels on water quality and the local environment.

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Next to water quality aspects, transport of generated electrical energy requires considerable investment in infrastructure when done via the public electricity grid. Alternative methods of storage and conversion are being investigated; for example, the use of hydrogen as an energy storage medium.

CONCLUSIONS

For the application of floating solar panels on a water storage reservoir, used for the production of drinking water, it was concluded from a worst-case QMRA analysis that 10–30% of the Evides reservoirs can be covered. Although some leaching of heavy metals is observed in the leaching tests, these are expected to be (partially) removed by the subsequent drinking water treatment and the concentrations are expected to remain well within internal standards.

With a coverage of 30%, the current maximum output of floating solar panels at Evides is around 200 GWh, sufficient to cover the complete energy demand of Evides. An extensive measurement program including baseline measurement is already running at Kralingen. This program will gather valuable data to determine the effect of floating solar on water quality and several environmental aspects.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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