

## Supplementary Information

### Durable Superhydrophobic Coatings Enable Scalable Offshore Photovoltaics for Global Energy Decarbonization

Mengying Lu<sup>a</sup>, Wenhao Lv<sup>b</sup>, Mengwei Liu<sup>a</sup>, Haoliang Bai<sup>a</sup>, Song Lv<sup>a, b, \*</sup>

#### Environmental resistance tests

##### 1. Self-cleaning test

The self-cleaning performance of the superhydrophobic coating was evaluated using garden soil as organic contaminants, which were deposited on the coated surface positioned at a 30° tilt angle. Subsequently, water droplets stained with methyl orange were continuously dropped onto the surface to observe whether the droplets removed the contaminants.

##### 2. Mechanical durability test

Sandpaper abrasion resistance was assessed by translating the sample 20 cm along 600-grit sandpaper under controlled conditions. The sample was inverted to ensure direct coating-sandpaper contact, with abrasion forces applied through a 200 g calibrated mass. WCA and WSA measurements were recorded following each 20 cm abrasion cycle.

For hydraulic durability evaluation, sample was mounted at 45° inclination and exposed to standardized water jet impacts (50 cm fall height, 300 mL aliquots), with WCA and WSA characterization performed post-impact.

##### 3. Chemical Stability Testing

Chemical stability was evaluated through immersion testing in aggressive media: 3.5 wt% NaCl, HCl (pH = 5 ± 0.2), and NaOH (pH = 9 ± 0.2) solutions. Post-immersion characterization of WCA and WSA was conducted at 1-day intervals to monitor coating degradation.

##### 4. Outdoor Durability Test

Samples were mounted on rooftop exposure racks at Wuhan University of Technology's Yujiatou Campus (114.35659°E, 30.606353°N) for natural weathering assessment. The 365-day exposure period spanned from 24 February 2024 to 24 February 2025 (inclusive), encompassing seasonal variations in environmental conditions.

##### 5. Salt Spray Test

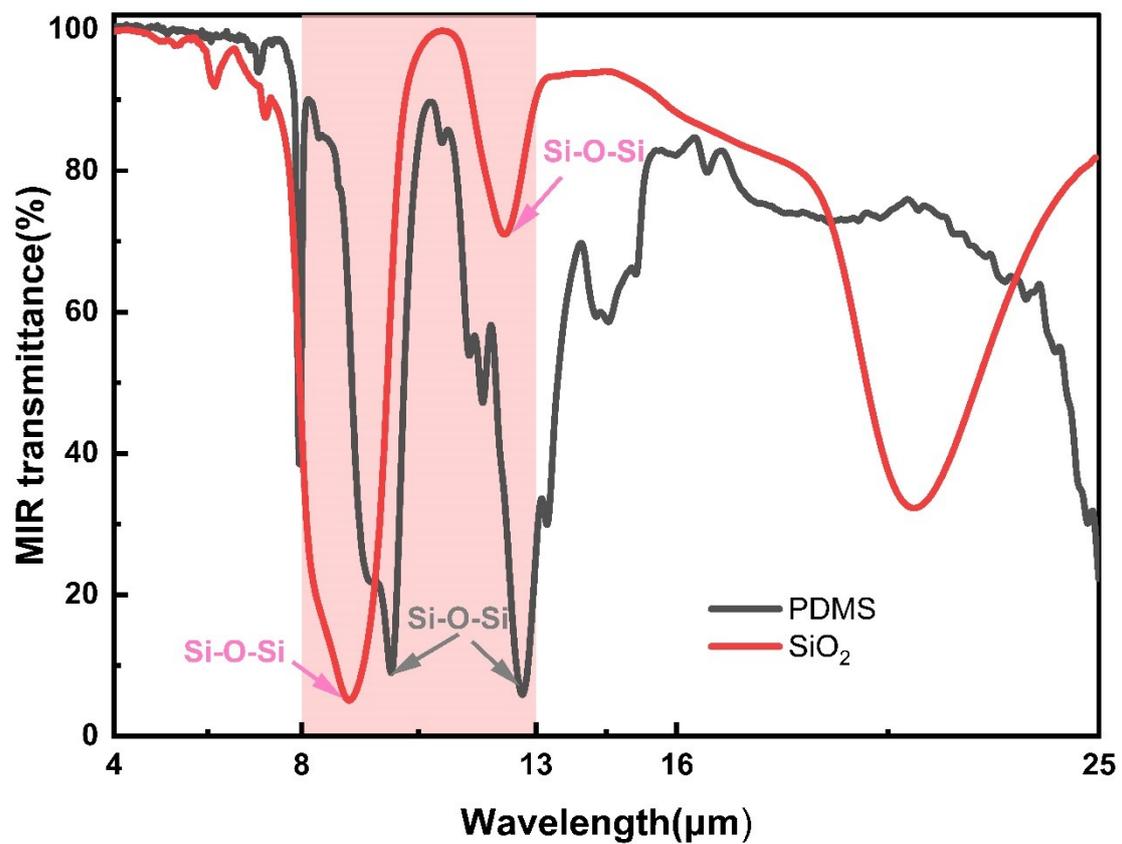
The corrosion resistance of coatings applied to Q235 steel substrates was evaluated through neutral salt spray testing and salt solution immersion. Long-term stability under neutral salt spray conditions was assessed in accordance with ASTM B117. During testing, samples were mounted at a 70° inclination within a salt spray chamber maintained at 35°C, with a 5 wt% NaCl solution atomized to simulate marine conditions. The WCA and WSA were monitored at 24-hour intervals throughout the salt spray exposure to quantify corrosion protection efficacy.

**Supplementary Table 1 Comparison with previous studies**

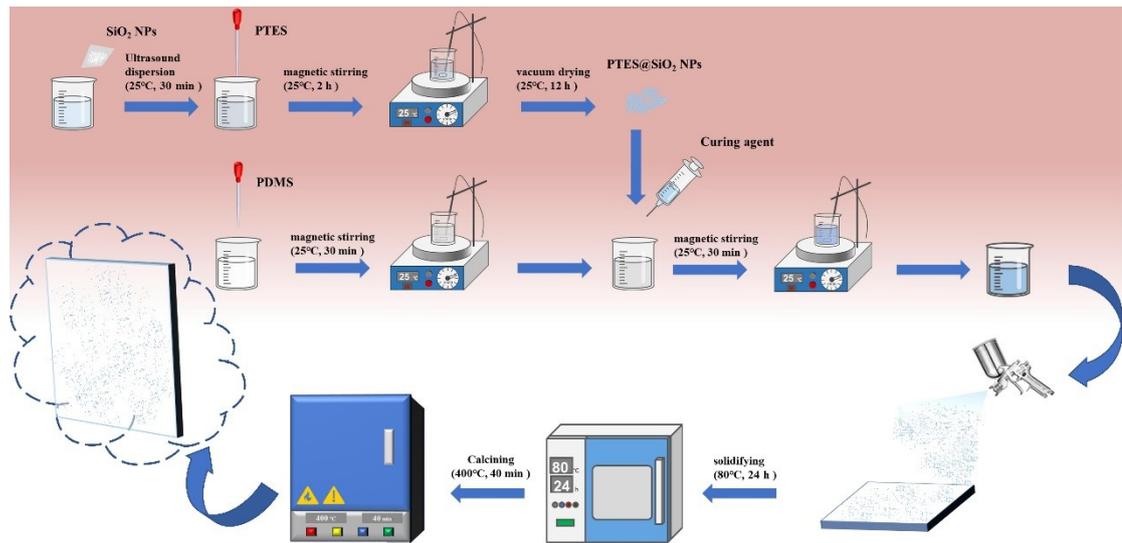
Ref.	Relative transmittance	WCA/W SA	Emissivity/ $\Delta t$	Salt spray durability/ Outdoor durability	Application to PV	Applicati on region
This work	$T_{max}$ : 96.4%	164°/3.6°	0.95 (8-13 $\mu$ m) /13.3°C	After 720 hours, WCA > 150°, WSA < 10° After 365 days: $\Delta T = 1.95\%$ , $\Delta E = 0.29\%$ , $\Delta WCA = 8^\circ$ .	8.67 % increase in PCE compared to uncoated coatings PV after one-month outdoor exposure	Ocean
1			-		Salt spray causes 6% reduction in maximum power of PV modules	
2			-		PCE drops 9.48% after three days of salt immersion PV	
3			-		Salt deposition causes 14.52% reduction in maximum power of PV modules	
4			-		Salt causes 7% reduction in maximum power of PV modules	
5	$T_{max}$ : 102.6%	151.4°/-	-	-	17.6% increase in power output compared to uncoated coatings PV	
6	$T_{max}$ : 101.4%	121.2°/20°	-	WCA and WSA almost unchanged after 50 days of seawater immersion	PCE restored to initial state after self-cleaning	
7	$T_{max}$ : 97%	-	-	-	No change in PCE compared to uncoated PV	
8	$T_{max}$ : 104.9%	155.1°/0.1°	-	-	PCE+3.5%	Land
9	$T_{max}$ : 105.6%	170°/ < 10°	-	-	PCE+6.1%	
10	$T_{max}$ : 102.7 %	165°/ -	-	-	PCE+1.3%	
11	$T_{max}$ : > 100%	89°/ -	-	-	PCE+4.5%	
12	$T_{avg}$ : 89.6%	101°/ < 7°	-	-	$P_e$ -11.3%	
13	$T_{avg}$ : 103.8%	114°/ -	-	-	PCE+0.05%	
14	$T_{max}$ : ~100%	165°/1°	-	After 800 hours: $\Delta CA$	PCE+ 0.12%	

				(dodecane) = 8°	
15	T <sub>avg</sub> : 90%	168°/-	0.85 (~2.5 - 13μm) /5°C	After 128 days: ΔWCA=8°	The external quantum efficiency (EQE) decreased by 2.0% ± 0.3%.
16	T <sub>avg</sub> : 79.2%	166°/-	-	-	PCE+9.4 %
17 (simulation)	T <sub>max</sub> :93.4% (0.3-1.1 μm)	-	0.94 (8- 13μm) / 9.5°C	-	4.28% increase in operational efficiency

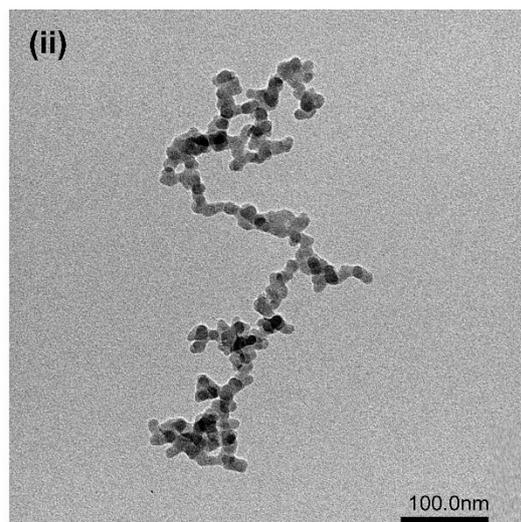
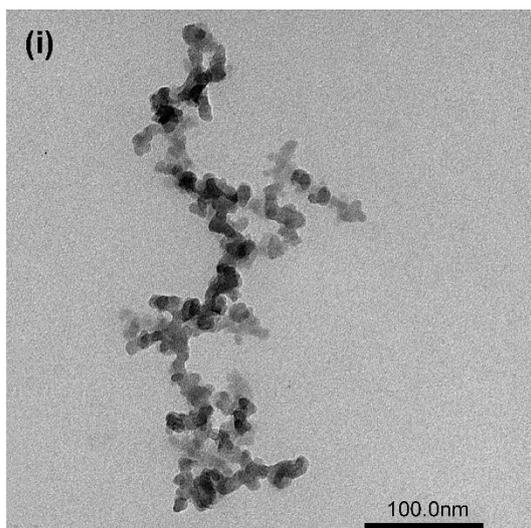
Supplementary Figures



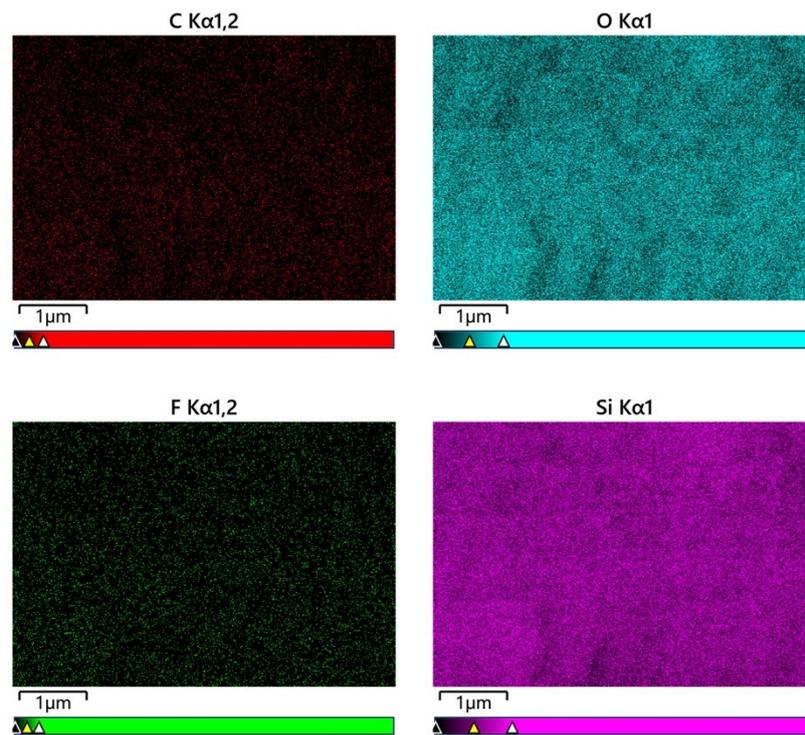
Supplementary Fig. 1 Fourier infrared spectra of PDMS and SiO<sub>2</sub>(Exhibits strong phonon vibrations in 8-13 μm)



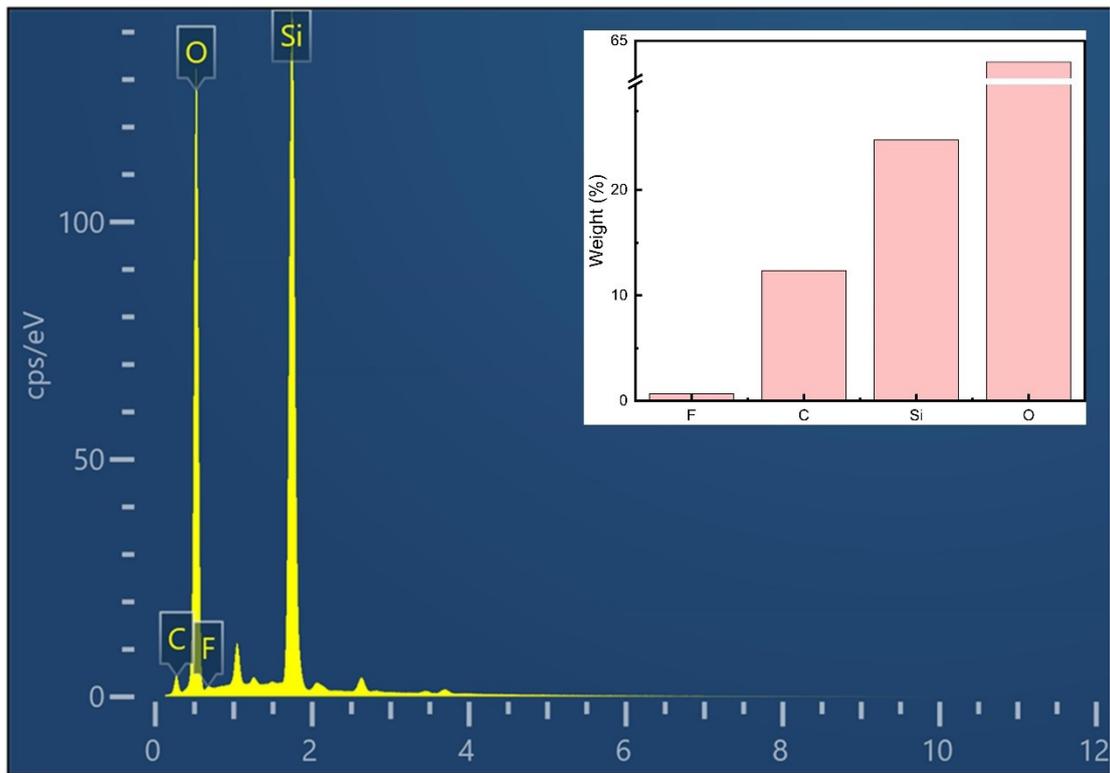
**Supplementary Fig. 2** Schematic diagram of the preparation process.



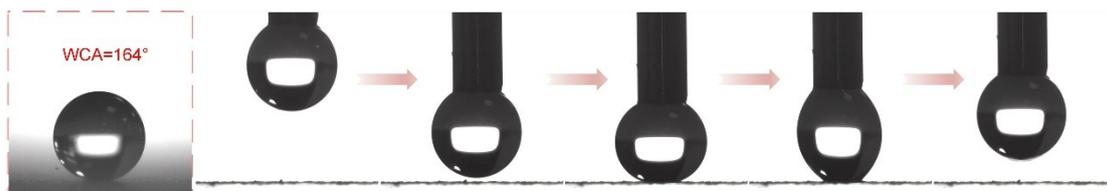
**Supplementary Fig. 3** Transmission Electron Microscopy (TEM) images of (i) SiO<sub>2</sub>NPs and (ii) PTES@SiO<sub>2</sub>NPs.



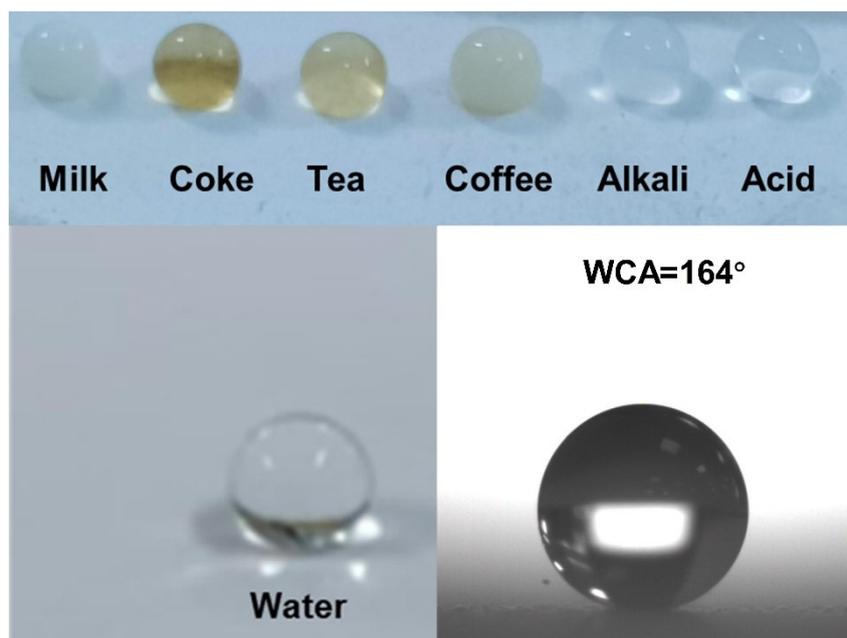
**Supplementary Fig. 4** EDS spectrum of the superhydrophobic surface, showing the presence of C, O, F, and Si elements.



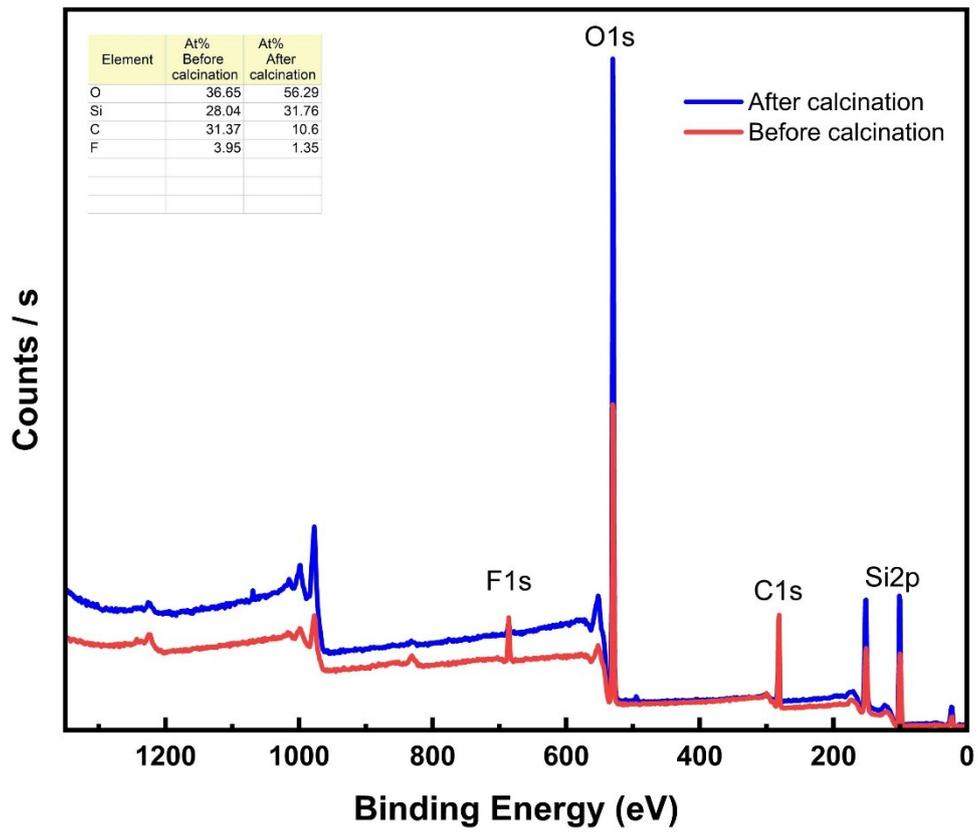
**Supplementary Fig. 5** Uniform distribution of C, O, F and Si elements on CPSP coatings



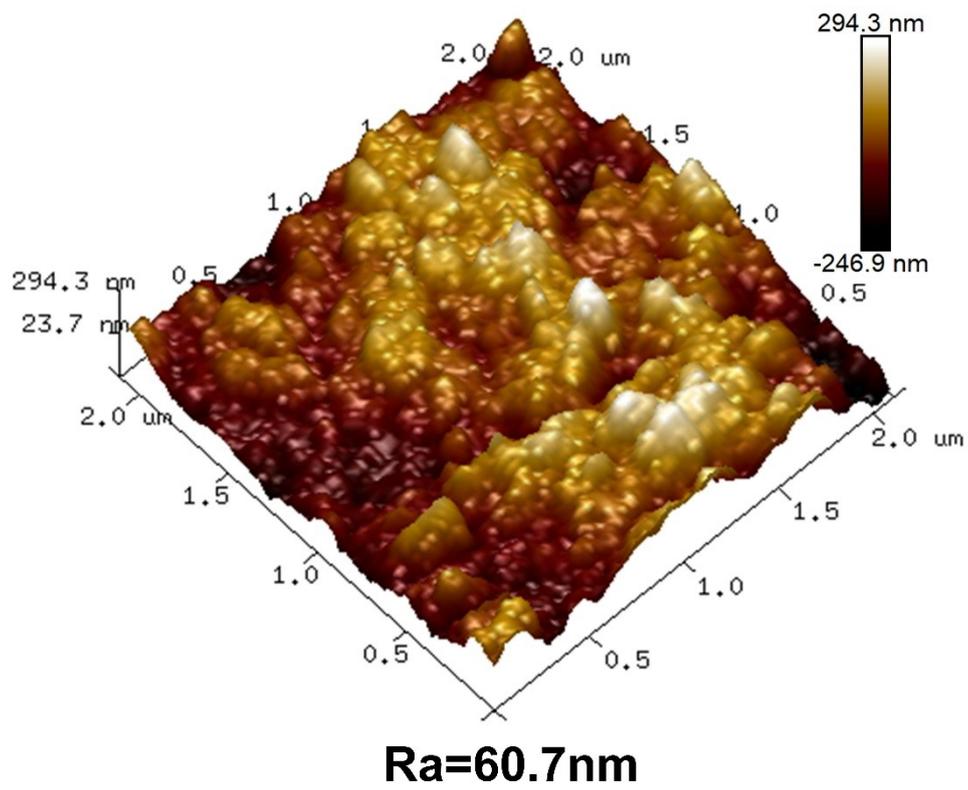
**Supplementary Fig.6 Contact angle measurement of CPSP coatings.** The WCA of a droplet on the surface of CPSP coating was  $164^\circ$  and dynamic non-adhesion process of the coating.



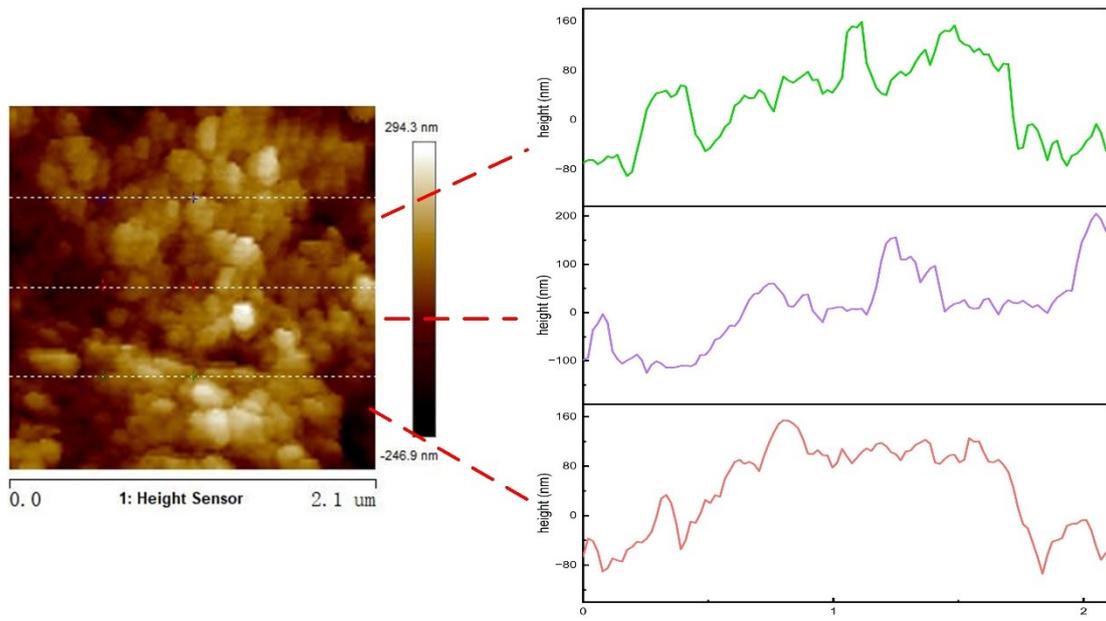
**Supplementary Fig. 7** Liquid rejection capability of CPSP coatings.



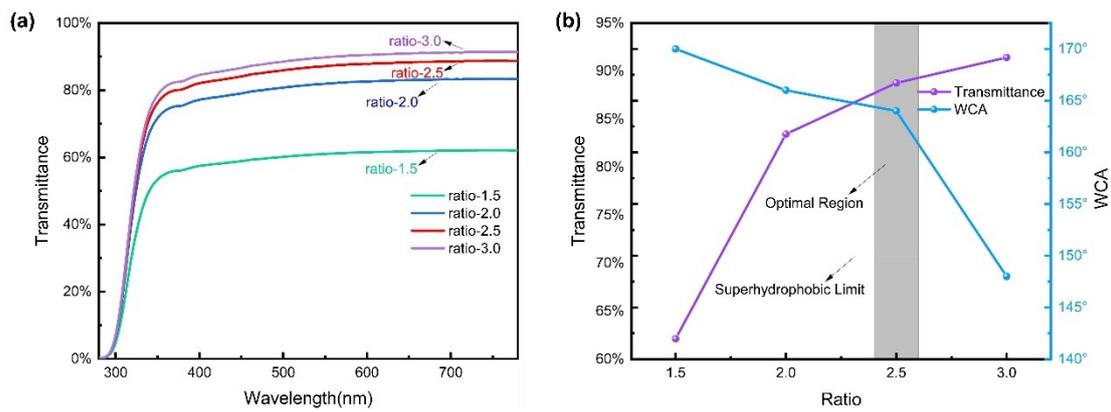
Supplementary Fig. 8 The XPS analysis of coatings before and after calcination.



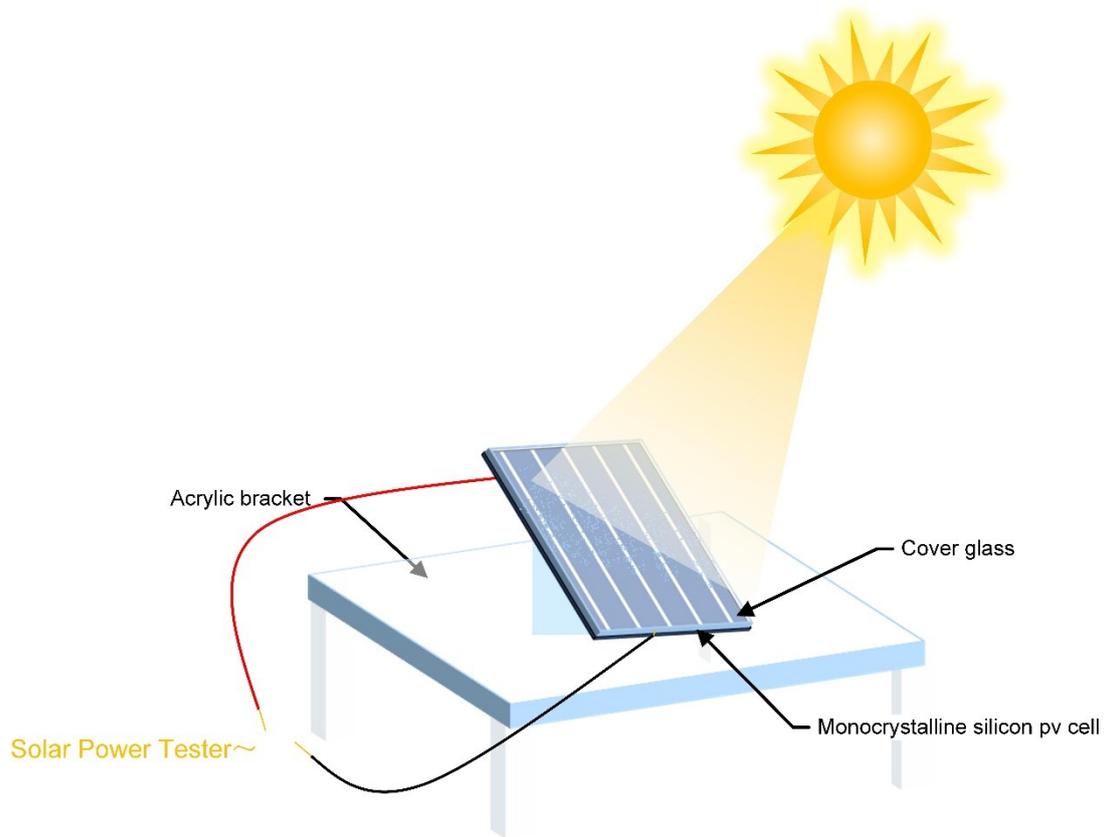
**Supplementary Fig. 9** The Atomic Force Microscope (AFM) images of CPSP coatings.



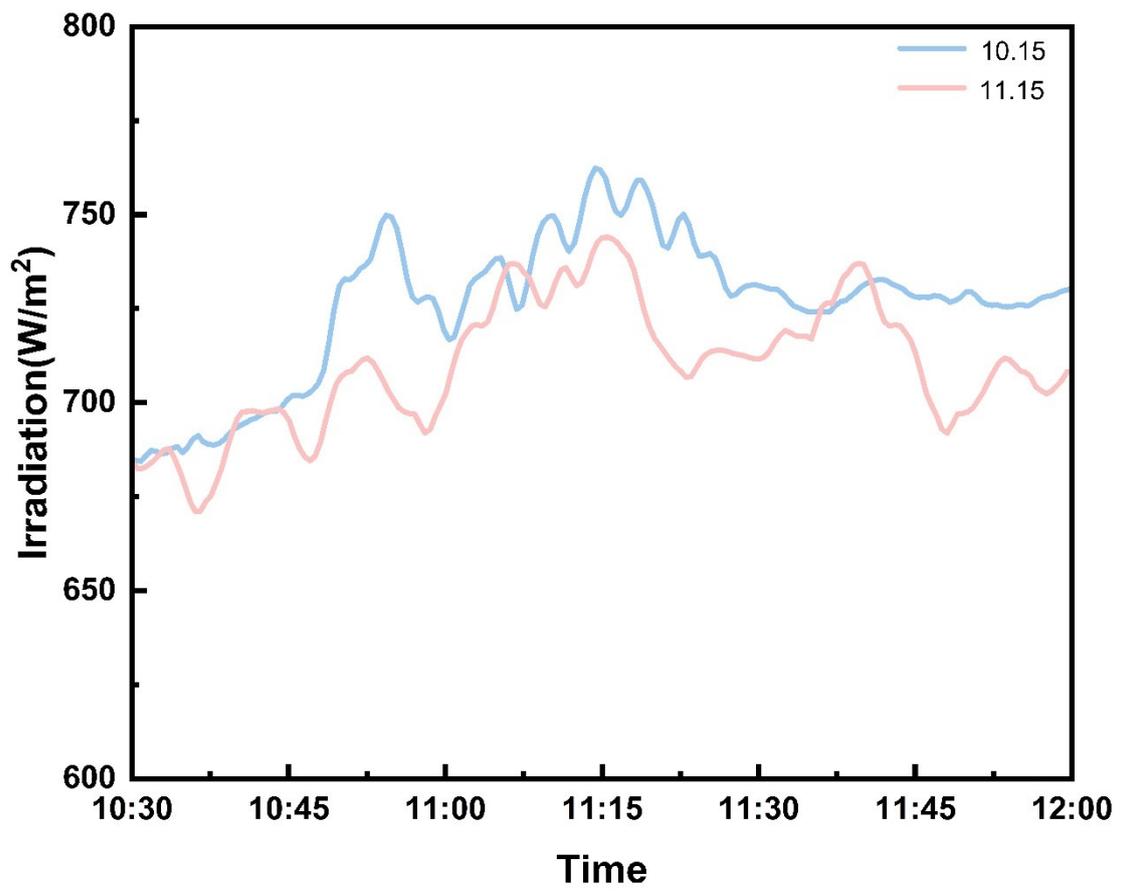
**Supplementary Fig. 10** The profile of the CPSP coating.



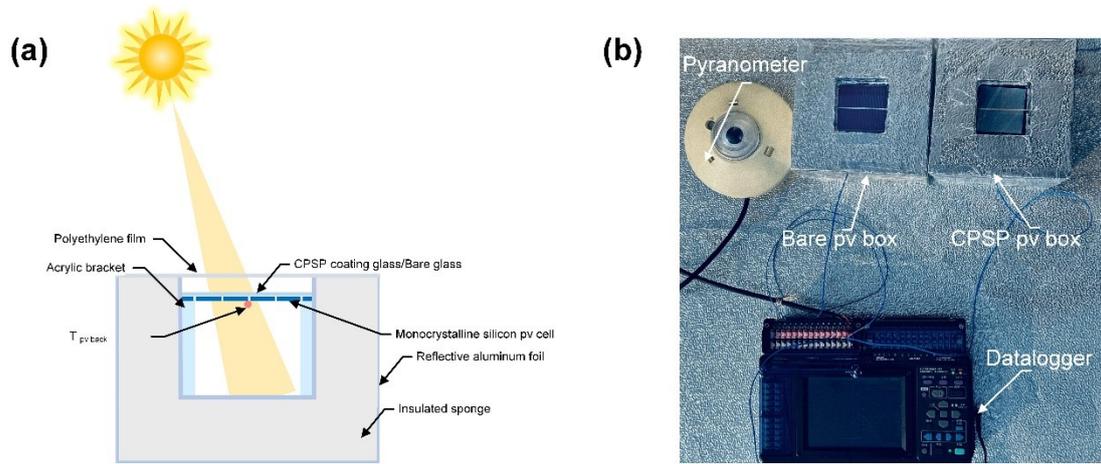
**Supplementary Fig. 11** (a) Optical transmittance spectra (200–800 nm) of coatings prepared with varying PDMS-to-SiO<sub>2</sub> mass ratios. (b) The critical trade-off relationship between optical transmittance and water contact angle.



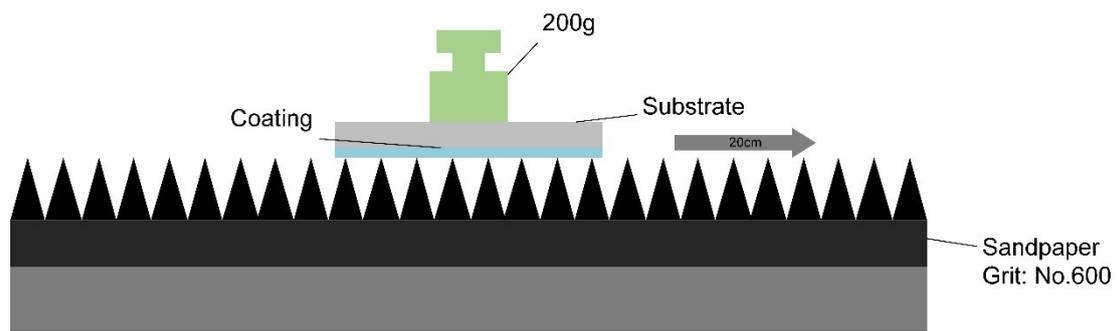
**Supplementary Fig. 12** Schematic diagram of coated glass photovoltaic power test.



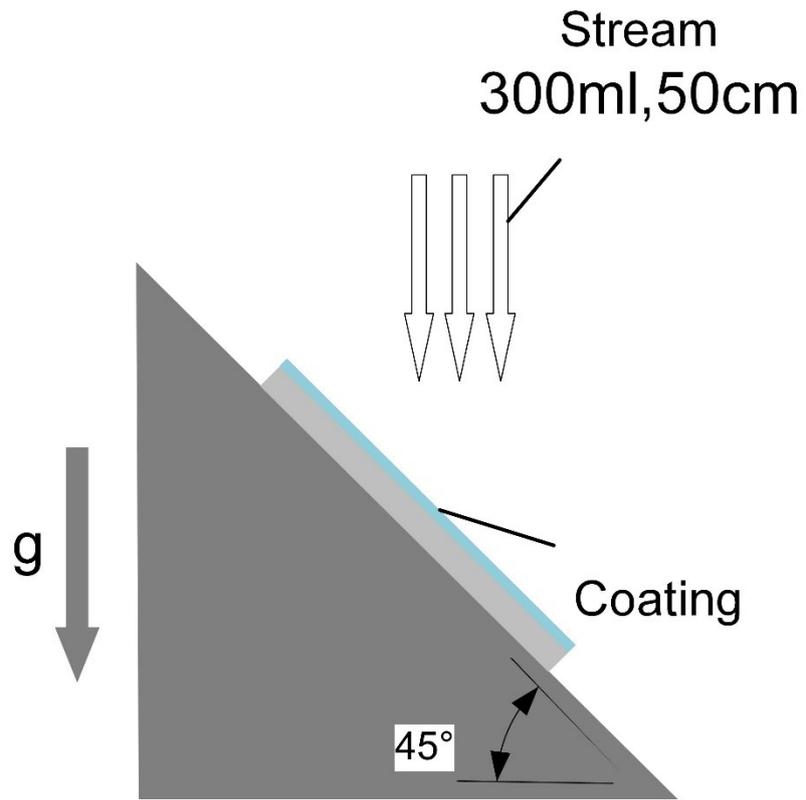
Supplementary Fig. 13 Irradiance during the two tests.



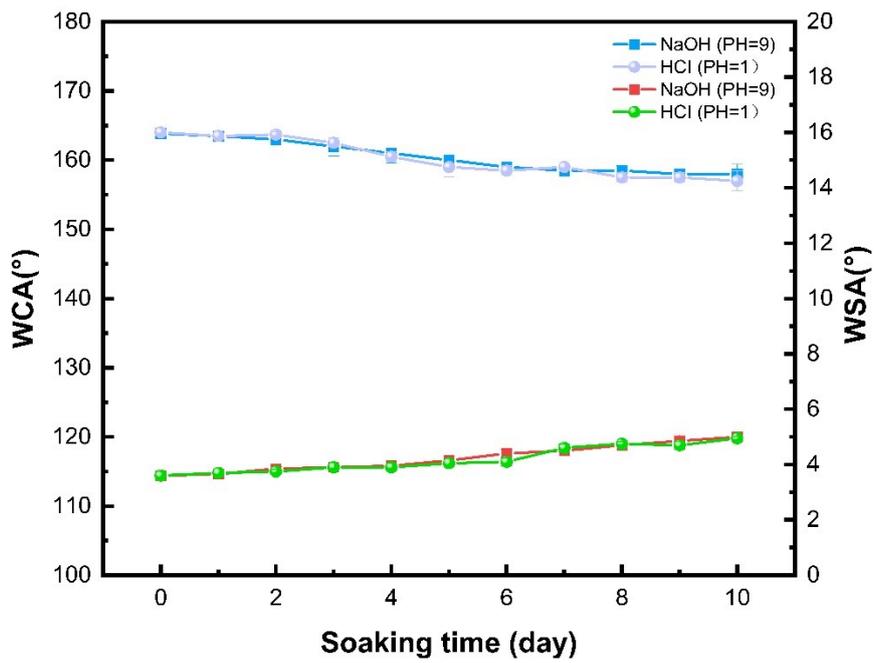
**Supplementary Fig. 14** (a) Schematic of the cooling test chamber. The cooling test chamber was covered with polyethylene film as the windshield. (b) Photograph of the outdoor radiative cooling test.



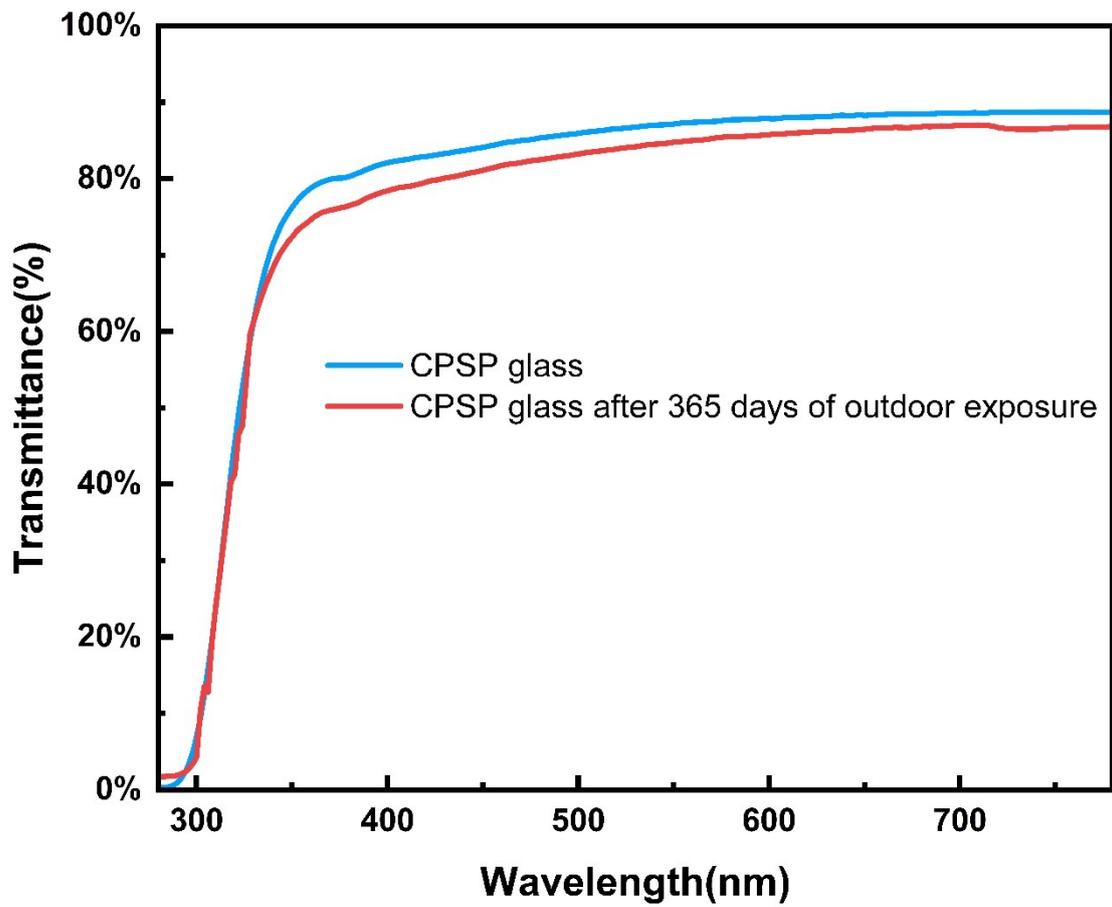
**Supplementary Fig. 15** Schematic representation of surface wear for one cycle



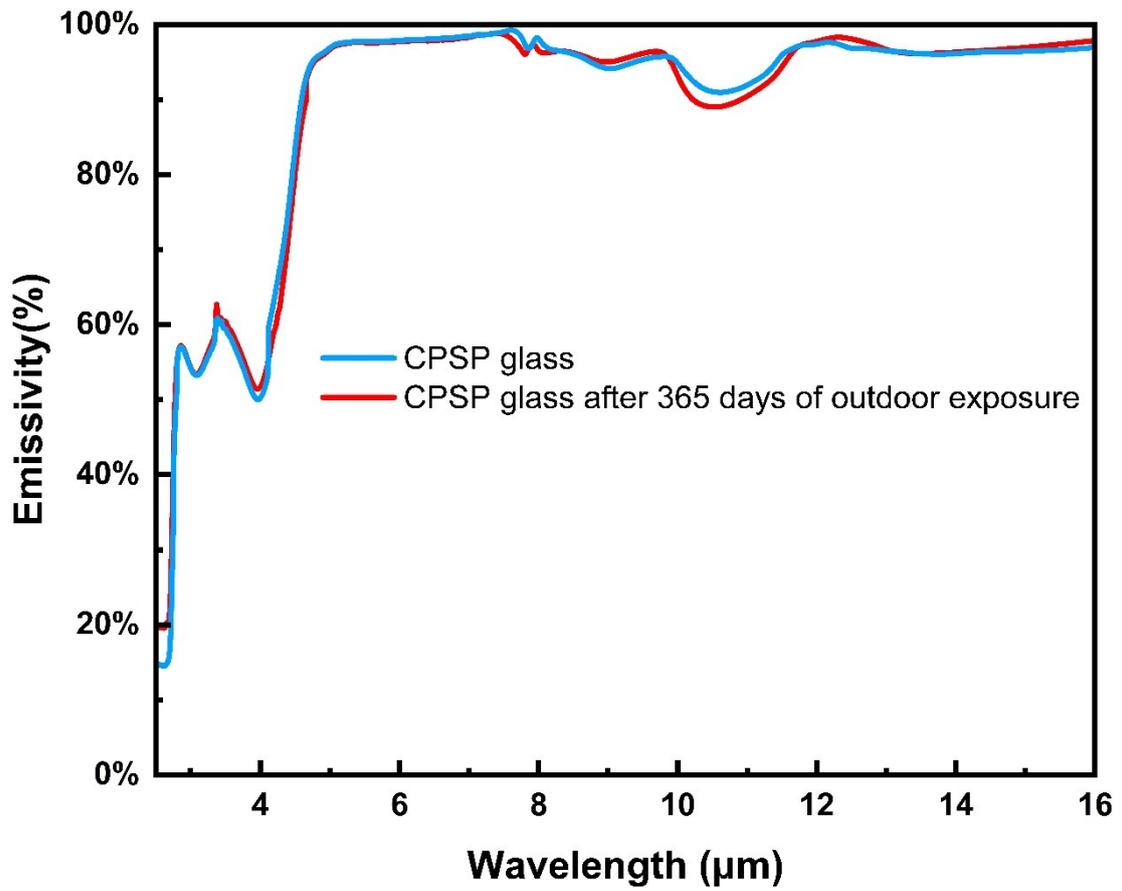
**Supplementary Fig. 16** Schematic diagram of water impact



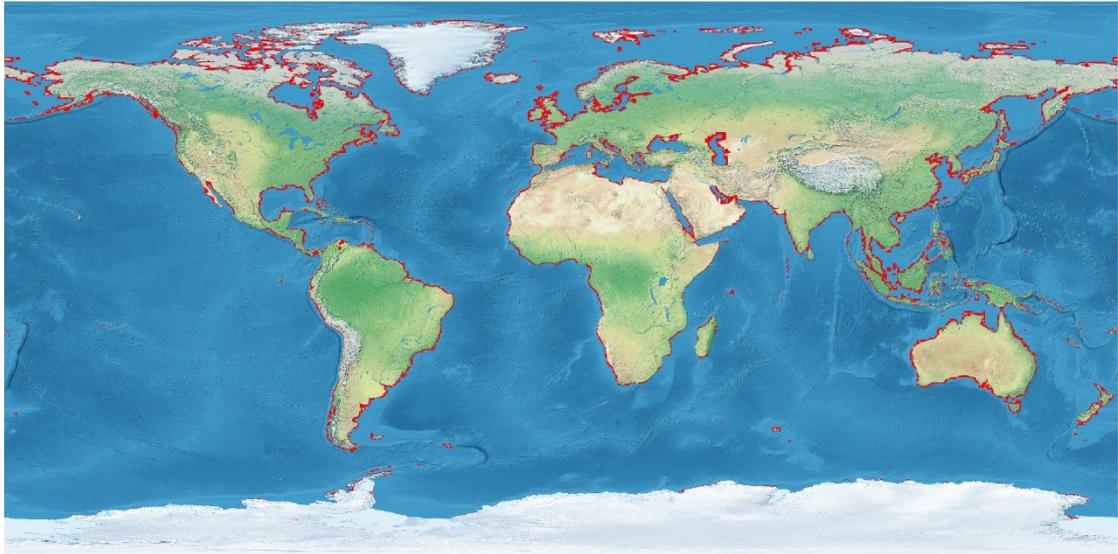
**Supplementary Fig. 17** The WCA and WSA of the coating vary with the length of immersion in acid and alkali solutions.



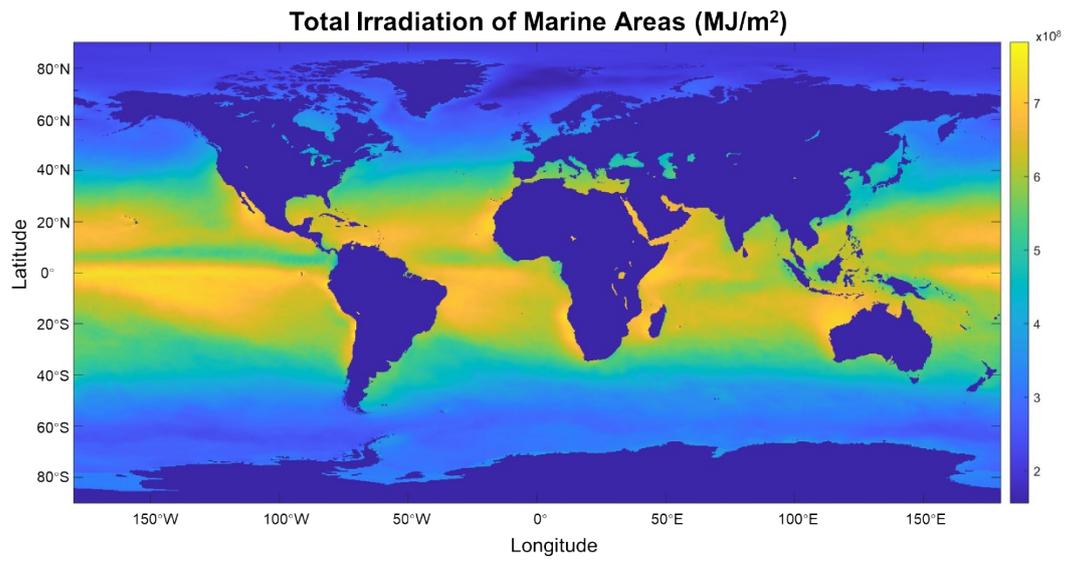
Supplementary Fig. 18 Changes in the Transmittance of CPSP coatings after 365 days of real-world outdoor aging.



**Supplementary Fig. 19** Changes in the Emissivity of CPSP coatings after 365 days of real-world outdoor aging.



**Supplementary Fig. 20** Global MFPV system installation locations.



**Supplementary Fig. 21** Global total irradiance distribution.

# Reference

1. Y. Zhang, C. J. J. o. R. Yuan and S. Energy, 2021, **13**.
2. F. Setiawan, T. Dewi and S. Yusi, 2019.
3. X. Gao, Y. Li, M. Liu, J. Lian, Q. Ma, J. Zhang, S. Wu and Y. Cui, *Renewable Energy*, 2025, **242**, 122439.
4. Y. N. Chanchangi, A. Ghosh, S. Sundaram and T. K. Mallick, *Solar Energy*, 2020, **203**, 46-68.
5. P. Wang, M. Kong, L. Wang and L. J. I. J. o. P. Ni, 2019, **9**, 1727-1732.
6. L. Yin, R. Tan, J. Han, J. Wang, J. Cheng, D. Wu, T. Zhang and L. Wang, **n/a**, e05526.
7. L. Ciani, A. Farina, M. Catelani, L. Pacini, A. Baldi, S. Calastrini, E. A. Carnevale, M. Bruzzi and L. Signorini, 2017.
8. C. Li, G. Chang, S. Wu, T. Yang, B. Zhou, J. Tang, L. Liu, R. Guan, G. Zhang, J. Wang and Y. Yang, *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 2024, **693**, 133983.
9. S. Oh, J.-W. Cho, J. Lee, J. Han, S.-K. Kim and Y. Nam, 2022, **9**, 2202781.
10. D. Wang, Q. Sun, M. J. Hokkanen, C. Zhang, F.-Y. Lin, Q. Liu, S.-P. Zhu, T. Zhou, Q. Chang, B. He, Q. Zhou, L. Chen, Z. Wang, R. H. A. Ras and X. Deng, *Nature*, 2020, **582**, 55-59.
11. D. Du, F. Wang, D. Zhang, J. Bao, Y. Fan, Y. Guo, W. Shen, H. J. J. o. C. Wang and I. Science, 2023, **630**, 795-803.
12. W. Pan, Q. Wang, J. Ma, W. Xu, J. Sun, X. Liu and J. Song, 2023, **33**, 2302311.
13. G. Han, T.-B. Nguyen, S. Park, Y. Jung, J. Lee and H. Lim, *ACS Nano*, 2020, **14**, 10198-10209.
14. H. Li, Q. Jin, H. Li, H. Tong, K. Wang, S. Chen, G. Ouyang, Z. Wang and Y. Li, 2024, **34**, 2309684.
15. G. Chen, Y. Wang, J. Qiu, J. Cao, Y. Zou, S. Wang, J. Ouyang, D. Jia, Y. J. J. o. M. S. Zhou and Technology, 2021, **90**, 76-84.
16. C. Rin Yu, A. Shanmugasundaram and D.-W. Lee, *Applied Surface Science*, 2022, **583**, 152500.
17. Y. Tu, X. Tan, X. Yang, G. Qi, K. Yan and Z. Kang, *Opt. Express*, 2023, **31**, 22296-22307.