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Harnessing floating solar power to decarbonize Southeast Asia's energy sector for carbon neutrality

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ABSTRACT

Floating photovoltaics (FPV) represent a cutting-edge solution for sustainable energy generation in Southeast Asia, a region characterized by abundant water resources and high solar irradiance. This work delves into the potential of FPV in decarbonizing the energy sector, highlighting its dual role in generating clean energy and mitigating water evaporation. With an estimated 300 MW of FPV capacity addition by early 2024, Southeast Asia is set to make significant strides in reducing greenhouse gas (GHG) emissions, aligning with global efforts to combat climate change. The FPV potential in the region is impressive, with Vietnam containing around 21–46 GW in reservoirs and 21–54 GW in natural water bodies alone. The work highlights the role of FPV in strengthening energy security and fulfilling obligations to the 2015 Paris Climate Agreement. FPV integration within the energy mix may help Southeast Asia cut down fossil fuel dependency, and through this, energy transition to a sustainable economy and greener environment can be achieved. The study also focuses on FPV's environmental aspects of functioning as an ecosystem, arguing that these systems can improve land-based and-based generation efficiency by about 15 % and decrease water evaporation by 25 %. Recommended policies include setting appropriate incentive and disincentive structures, advancing support for R&D, and promoting cross-agency collaboration for FPV adoption to accelerate decarbonization goals. This work concludes that proper policy settings and government support can enable FPV technologies to enhance the renewable energy strategy for Southeast Asia, thereby contributing to global climate change mitigation.

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1. Introduction

In 2023, global GHG emissions reached an astonishing 53 Gigatonnes (Gt CO_2e) amidst ongoing attempts to tackle climate change and lessen its impact, signifying an increase in the need for mitigation efforts [1]. As noted in recent assessments, climate change manifests itself as extreme weather, biodiversity loss, and, in Southeast Asia, the destruction of the environment and lives due to rising sea levels [3]. Ultimately, the region's reliance on fossil fuels aggravates the situation, contributing to the rise in GHG emissions. The combination of climate change and energy insecurity poses an imminent risk to the lives, economy, and environment of the region.

Floating photovoltaics (FPV) present the opportunity to increase the capacity for renewable energy resources by using the upper surfaces of water bodies (reservoirs and irrigation canals) (Fig. S1). The rapid popularity gained by FPV technology is due to its ability to expand renewable energy resources without competing for scarce land [2,4]. One of the first countries to embrace this technology is Japan, along with Indonesia, which has an abundance of high-isolation water bodies and solar access, making this technology economically attractive [5,8] (Fig. S2).

Besides taking advantage of unused water bodies, FPV offers the opportunity to enhance microclimate conditions [6]. FPV installations can reduce water body evaporation, decrease water temperatures, and mitigate heat islands [9]. These localised microclimate benefits can lead to panel efficiencies on the systems and thus contribute to a positive feedback cycle on the energy yield. FPV systems can also reduce surface water temperatures by between 2 and 5 degrees Celsius, which has important impacts on the local climate, water bodies, and the ecosystems they contain [10,11].

For the last ten years, previous works have provided an overview of environmentally driven and economically sustainable FPV research in the developed world, aiming to promote green growth and low-carbon energy use (Table 1).

Floating photovoltaics (FPV) is important to reduce GHG emissions and ensure compliance with international climate treaties like the 2015 Paris Climate Agreement to prevent uncontrolled climate damage [28]. Between 2010 and 2019, the region saw a 1.8 % average annual rise in carbon intensity and a 5.1 % increase in CO_2 emissions from the energy sector between 2015 and 2019 [12].

In this context, Southeast Asia emerges as a promising region for FPV deployment due to its abundant tropical water bodies, including reservoirs, irrigation canals, and floodplains. Countries such as Indonesia possess extensive inland water resources coupled with rapidly growing energy demand and increasing commitments to carbon neutrality (Fig. S3). The tropical climate characterized by high solar irradiance, frequent cloud cover, and high ambient temperatures poses both opportunities and challenges for FPV performance and integration [7,13].

While Southeast Asia has not yet seen widespread FPV adoption, the region's climatic and hydrological conditions share similarities with other tropical and subtropical regions globally, such as South Asia and Southwest Asia [16]. Regions like the Indian subcontinent and Middle East experience high solar insolation and water scarcity issues, where FPV could play a role in sustainable energy expansion [18,19]. Comparative analyses with the regions provide insights into potential deployment strategies, environmental impacts, and policy frameworks adaptable to Southeast Asia's unique context.

FPVs can contribute to alleviating the region's solar energy resource gap by providing a dependable and low-emission energy answer for rising demands. As a distinct group of solar PV technologies, FPVs are stationed in areas where there is little or no land available. FPV systems rank high among solar energy technologies because they produce renewable energy without disturbing agricultural or urban land. FPVs remove land competition and significantly increase energy [20,21].

Global and regional technical potential studies also demonstrate large theoretical potential for FPV on reservoirs and other water bodies and indicate FPV can increase yield relative to ground PV while saving evaporation loss. However, these studies are global-scale potential or techno-engineering reviews rather than regionally specific decarbonization roadmaps [22,23]. Their works were also primarily global-scale techno-engineering reviews and lack regionally specific decarbonization roadmaps tailored to Southeast Asia. In the region, where land allocation is a controversial topic because of the need for agricultural, residential, and industrial development, FPVs solve land use problems by transforming water resources like reservoirs into solar power plants. FPVs reduce land competition while increasing energy production [24,25].

FPVs could help improve the energy system resilience in Southeast Asia region because they offer a more decentralized approach to energy generation. FPVs can help reduce the damage to water ecosystems caused by pollution due to water evaporation and algal blooms. Solar panels can help conserve water supplies in areas prone to droughts by reducing surface evaporation. By diversifying power generation sources, FPVs bolster energy security and grid stability while decreasing dependence on centralized fossil fuel infrastructure [26,27]. The advantages benefit remote communities and island nations in the region where access to reliable and affordable energy is hard to come by.

Southeast Asia is expected to add over 25 % to global energy demand growth by 2035 [72]. As FPVs are popular due to the ongoing economic growth, population increase, and the region's increasing adoption as a global manufacturing and industrial center, there are concerns with this scenario as it forecasts a one-third increase in energy-related CO_2 emissions by 2050, which underlines the necessity for a sustainable energy transition.

Decarbonization comes with an increased need for renewable energy within the region. The region is anticipated to hit 800 million of population by 2050, which alongside the robust economic growth, results in an energy demand growing by 3 % annually for the past 20 years [69]. If this shift persists, renewable energy sources will contribute over one-third of electricity produced in the region by 2035, which will, in turn, help satisfy over 50 % of new electricity demand [91].

The adoption of FPVs can drive economic growth by creating jobs in the renewable energy sector, fostering technological innovation, and attracting investments in sustainable infrastructure. It also positions

Table 1
Recent articles on floating photovoltaics (2020–2024).

Reference	Focus Area	Geographic Scope	Key Highlights	Gaps Addressed in This Study
Chen et al. [14]	FPV technology and materials	Global	Overview of FPV system designs and materials innovations	Limited focus on Southeast Asia and decarbonization pathways
Amer et al. [4]	Environmental impacts	Asia-Pacific	Impacts on water quality and aquatic ecosystems	No integration with energy system decarbonization analysis
Aleluia et al. [3]	Economic feasibility and policy	China and neighbouring countries	Cost-benefit analyses and policy frameworks	Broader Southeast Asia region not covered
Chontanawat [15]	Grid integration and storage	Global	Challenges of integrating FPV with storage and grids	Lacks region-specific data and technical potential estimates
Nepal et al. [67]	FPV potential and climate impact	Southeast Asia	Preliminary estimates of FPV capacity and carbon emission reductions	Limited technical and economic analysis; no detailed policy roadmap