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Agrivoltaics in Singapore and Beyond: Unlocking Potential in ASEAN Dr Serena LIN Fen, Head of Solar System Technology Solar Energy Research Institute of Singapore (SERIS), National University of Singapore (NUS)

NATIONAL RESEARCH FOUNDATION PRIME MINISTER'S OFFICE SINGAPORE





SERIS is a research institute at the National University of Singapore (NUS). SERIS is supported by NUS, the National Research Foundation Singapore (NRF), the Energy Market Authority of Singapore (EMA) and the Singapore Economic Development Board (EDB).

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SERIS



Solar Energy Research Institute of Singapore

- □ National Lab founded at NUS in 2008; a global leader in solar research & development
- □ SERIS is supported by NUS, NRF, EMA & EDB
- □ Focuses on applied solar energy research (solar cells, PV modules, PV systems)
- > 110 staff, adjuncts & PhD students; state-of-the-art labs, ISO certified (9001, 17025)
- □ Close collaborations with companies & government agencies





Main R&D areas of SERIS





Solar cells:

- Perovskite/silicon tandem solar cells
- Next-generation industrial solar cells
- Characterisation & simulation



PV modules:

- □ Module testing (indoor & outdoor)
- Module development
- □ Building integrated PV (BIPV)
- Characterisation of optical properties
- □ Module reliability
- □ Recycling
- PV for vehicles



Solar PV systems:

- □ System technologies, incl. Floating solar
- □ Innovative deployment concepts
- □ Urban Solar, incl. agrivoltaics
- PV grid integration
- Solar potential & energy meteorology (solar forecasting)
- □ Smart Operation & Maintenance (O&M)
- Quality assurance of PV systems
- □ Solarisation of Singapore

Agrivoltaics in Singapore: background



- Singapore's "30 by 30" initiative aims to sustainably self-produce 30% of nutritional needs by 2030.
- \Box Singapore also aims to deploy at least 2 GW_p of solar PV systems by 2030.
- □ Singapore is the world second densely populated country. It is wise to use the same space for multiple purposes.
- Traditional meshes and walls used in outdoor farms can be replaced by PV panels for shading purposes, while solar power can be generated on the farms.



A typical outdoor farm at current Lim Chu Kang Credit: SFA



An artist's impression of the "big box" approach for future Lim Chu Kang *Credit: MKPL Architects*

Source: SERIS

Urban Agrivoltaics



SERIS operates 2 test areas for R&D on Agrivoltaics in Yuhua Agri-tech - Solar (YAS) Living Lab



Comparison of different growing configurations





□ Significant biomass difference with additional LED lighting

Research question: How to provide light compensation in more energy efficient manners?

Comparison: biomass vs. solar panel shading





- □ 10-cell module \rightarrow ~ 50% shading, 12-cell module \rightarrow ~ 60% shading
- \Box ~ 10% difference in shading results in 12% 15% difference in biomass for lettuce
- Research question: What are the best design of PV systems with right amount of shading that balance the energy and food production for various local crops?

PRELIMINARY scenario analysis for SG



Assumptions: 1000 m² farm area Leafy green vegies 50% PV coverage Soil-based as reference (only little farmland in SG)



- Highest yield and highest profits for 2layer horizontal hydroponics with PV to power LEDs for 2nd growing bed
- More LEDs consume too much energy
- Vertical towers affected by PV shading

Source: SERIS



Electricity (\$/mth) = Water (\$/mth) = Farm worker (\$/mth) = Raw materials (\$/mth)

Creating impact from SERIS' testbed



停车场屋顶太阳能种菜 裕华首推农光实验室

Sunday, November 26, 2023

SINGAPORE

Rooftop of Yuhua carpark now a living lab for projects

	©8
^{主播} 赵文蓓 在区内的多层停车场	顶楼设立实验农场

停车场屋顶太阳能种菜 裕华首推农光实验室

发布:04/11/2023 16:12 更新: 04/11/2023 20:21 ☆ 收藏

新加坡

Source: SERIS

waste. Ten projects were eventu-Shabana Begum ally selected for test-bedding, and the YAS Living Lab was launched Solar panels on rooftops are a on Nov 4. One group, Project Shine, aims common scene across Singapore, but the ones at a multi-storey carto revive under-utilised urban park in Jurong East have a different story to tell. Underneath the blanket of solar panels on the rooftop of Block 354 solar energy. At the living lab, the team is cur-Jurong East Avenue 1 are leafy greens, muskmelons and even fish and prawns. fruit similar to rockmelon - and It is among the first rooftop prorearing giant freshwater prawns ers in the other. jects in Singapore that link renewwith the help of black soldier flies able energy and urban farming. in managing waste. The Yuhua Agritech Solar (YAS) The flies feed on food waste and Living Lab is a nearly \$400,000 used coffee grounds collected from Yuhua residents and nearby coffee shops, eventually turning the waste into frass or excrement, which will be used as fertiliser for the muskmelons. Black soldier fly

10 projects selected for test-bedding link

renewable energy and urban farming

site for research institutes, companies and heartlanders to run three-year projects. When residents were consulted on the uses of the rooftop space in 2021, they said they did not want it to be just another community garden, said Professor Ang Hak set-up Project Shine is run by Otolith Seng, chairman of the Yuhua Community Club Management Committee "They wanted to see solutions that can improve yield and better its partners utilise scarce resources by leveraging the latest technology. After consulting Minister Grace Fu, we thought, 'Why don't we launch bed to work on difficult-to-grow produce, said founder and managa Yuhua Agritech lab?' Ms Fu, who is Minister for Susing director Ionathan Poh. tainability and the Environment. At YAS Living Lab's launch, Ms is the MP for Yuhua. Later that year, the Yuhua Citipanels over urban farms here. She zens' Consultative Committee (CCC) called for project proposals added that the living lab will allow farms on more carpark and indusin energy production and food se-

midity will be changed, and find ways to optimise farming. The \$390,000 living lab was cofunded by the SG Eco Fund and Yuhua CCC

The National University of Singapore's Solar Energy Research Institute of Singapore (Seris) runs two projects on the rooftop, with agritech partners.

设施。

鱼菜共生。

The solar panels invented by spaces to grow premium urban them can rotate like a window crops such as muskmelons in a flap to track the sun during the closed-loop system that runs on day and maximise the amount of sunshine they can capture. Lettuce, bok choy and chye sim rently growing muskmelon - a are grown in a tiered shelf system in one set-up, and on vertical tow

> A tilapia tank is connected to the vegetable towers to form an aquaponic system

Having a solar roof makes sense because outdoor farms or greenhouses here need a netting or a cover to protect leafy crops against the strong midday sun said Seris deputy chief executive larvae are also used to feed the Thomas Reindl. "So we might as prawns, forming a self-sustaining well take away the netting and use solar panels instead. The plants will not get too much sunlight

Enrichment - an education com- which they don't like, and at the pany for aquaculture, agriculture same time, we generate renewaand environmental science - and ble energy," he said. In 2024, the team is looking to While Otolith is an expert in enclose the stacked shelf system rearing commonly farmed crops in a mini-greenhouse, made of and fish here, it is using the test special windows that double as solar panels.

Seris has also fitted both its projects with sensors to develop a self-learning algorithm that will Fu said the authorities have re- eventually enable the agri-solar ceived proposals to install solar test beds to be fully automated. The aim is to replicate such projects to study the impact of so- trial rooftops, said Dr Reindl.

curity that also use sensors and lar panels over crops, since the the Internet of Things, and reduce amount of sunlight, water and hu-nshab@sph.com.sg



联合日报 2023年11月5日 星期日 八机构入驻实验农场 停车场顶楼菜棚装太阳能板供电

对于设立实验农场的目的,裕华区议员、永续发展与环境 部长傅海燕说,新加坡地方小,政府一直在探索怎么扩大 太阳能板的装置空间, 而农场面积大, 所以就想试试看, 尤其条剪把高科技农业和大阳能光伏系统结合起来。

作,也是将华区议员的永续发展 与环境部长傅海燕星期六(11月 裕华区内一个平时少人使用 4日)主持启用仪式。 的名居佛车场顶楼, 加合转弯成 对于设立实验农场的目的, 牢验农场, 计起步业者, 大专学 她接受《联合早报》访问时说。 府和社区农夫等测试以不同的太 新加坡地方小, 政府一直在探索 阳能光伏系统为菜田供电。 怎么扩大太阳能板的装置空间, 耗资39万元打造的实验农 而农场而积大,所以就想试试 场"裕华农光实验室"(Yuhua 看,尤其希望把高科技农业和太 Agritech Solar Living Lab),位 阳能光伏系统结合起来。 干裕廊车1诸第354座的多层停车 "很多时候,大家的印象是 场顶层。建造经费由新加坡生态 高科技农场需要很多能源,如果 基金 (SG Eco Fund), 以及发 我们可以从太阳取得能源。那能 起项目的裕华公民咨询委员会资 清成木就会大大减任.

团队研发农场运作自动化 实验农场搭有10个棚子,上 头装有不同透光度的太阳能板。 带机器人进入农光实验室 也备有水、电和无线网络等基本 茂丰农场创办人兼主席林宜 谦是这个项目的其中一名顾问。 八个通过筛选受遗入驻的机 他说,种植蔬菜和采集太阳能, 构,未来三年无须缴租,可免费 两者都需要阳光,因此必须相互 在这里测试各种可持续孵作法,

例如营养液膜技术、重直气耕和 农光实验室今年5月开*



永续发展与环境部长傅海燕(前排右一)星期六为"裕华农光实验室"主持启用仪式后参观农场、了解 个别实验项目所采用的科技。在她身旁的是裕华民众俱乐部管理委员会主席洪合成教授(前排右二)和 新加坡太阳能研究所副总裁雷拓博士(Thomas Reindl, 前排左一)。(邝启聪报)

长。我们希望可以找到一个平衡 根据文告,设立实验室的用 其他想要善用屋顶空间的衬器 。 "如果要最大限度地采集太 点,为新一代的都市农耕找到解 意,是为了培育能够大规模利用 提供一个参考蓝图。 阳能,可以把棚子都铺满太阳 决方案,让两者在同一个空间并 太阳能为城市农场供电,并且种 入驻者必须在未来三年定期

> X A O zaobaosq

联合日报 LIANHE ZAOBAO 2023年11月5日星期日 实验农场棚子下 边采能源边栽菜

食品和能源保障,是新加 名为"裕华农米牢险室" 裕华民众俱乐部管理委员 坡国立大学和新加坡太阳能 坡近年来关注的两大课题。裕 (Yuhua Agritech Solar Living 会主席洪合成教授受访时说, 研究所,以及新加坡理工学院 华公民咨询委员会在区内发起 Lab)的实验农场占地约900 这是一个由社区发起的项目, 和本地农场Singapore Indoor 了新项目,把组屋多层停车场 平方公尺,相等于10个四房式 除了开辟一般的社区菜园,人 Farms各组的团队等。 们也希望有个可以实验新科技 顶楼改装成实验农场,测试 组屋单位的面积。农场搭建了 (市启聪摄) 能否在种植蔬菜的同 10个棚子,棚顶安装不同透光 和点子的空间。 信车场莁棚 在农场展开实验项目的包 装太阳能板供电 时,也采集太阳 度的太阳能板,底下则种植各 式游戏。 括农耕领域的起步业者、新加 刊第13页 能为农场供电。

如果要最大限度地采集太阳能 可以把棚子都铺满太阳能板. (庭下的植物就无法生长,我们爱 望可以找到一个亚衡点,为新-代的都市农耕找到解决方案,让 两者在同一个空间并存。 一一茂丰农场创办人兼主席

教育和推广活动。

zaobaoso

拥有建筑系硕士学位的王优 あ(32岁)希望有朝一日可じ 在本地开设农场。他目前正在研 发可以让农场运作自动化的机器 人,不时会把机器人原型带到皮 光实验室测试。 他说,本地缺乏为农业 起步公司而设的政府孵化器

incubator)项目,一般私人孵 化器项目的门槛又太高,所以这 个实验室对他来说有很大帮助。 裕华民众俱乐部管理委员会 的社区园丁是另一组入驻者,他 们采用两种不同的水耕造灌系统 种植茄子、番茄和罗勒等蔬菜。 负责人许能财(72岁);这 日前得來社区草湖起采用传统-1 耕,空间有限能种的东西不多。

他们希望以后可以教导其他社区

菜园使用水耕法, 增加蔬菜的品

Creating impact from SERIS' testbed



+ Follow ...

SERIS is prominently featured during IPOS' World IP Day 2024





Ministry of Sustainability and the Environment.

Singapore

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Ministry of Sustainability and the Environment, ... 22,874 followers 1w • 🕲

This year, World IP Day recognises how innovation and intellectual property play vital roles in achieving Sustainable Development Goals (SDGs).

In Singapore, the Yuhua Agritech Solar (YAS) Living Lab houses urban farming projects, including one between NUS' Solar Energy Research Institute of Singapore (SERIS) and V+Agritech. This test bed processes the waste from farmed fish into nutrients for growing vegetables, all powered by solar energy. Check out the images to see how it works!

Let's take a moment to appreciate these innovations aimed at boosting our food security!

Let's appreciate the innovations that bring us one step closer to achieving a more sustainable future!



With comment by Minister MSE, Ms Grace FU:



Grace Fu • Following

1w •••

Minister for Sustainability and the Environment and Minister-in-charge of ...

Yuhua appreciates the support given to host a living lab for co-locating solar panels with agriculture. With the experience gained from the project we can colocate solar and agriculture deployments.

Source: SERIS

#WorldIPDay

Existing and Announced Agrivoltaics in ASEAN



Cambodia, Indonesia, Laos and Myanmar mainly deploy **solar-powered irrigation systems** (PV systems not vertically integrated with crops)

Solar Energy Researc

Examples of existing Agrivoltaics systems





Agrivoltaics testbed, Indonesia¹



Agrivoltaics project, Thailand²



Agrivoltaic artichoke farm, Vietnam³

References: 1) https://www.linkedin.com/posts/sungyoon123_our-first-ai-driven-dynamic-agrivoltaic-plant-activity-7250034142032109568--kxy?utm_source=share&utm_medium=member_desktop; 2) https://www.bcpggroup.com/en/our-green-businesses/power-business/solar-power; 3) https://www.linkedin.com/posts/sungyoon123_dalatuniversity-sustainableenergy-dalat-activity-7170403581769056256-NrJU?utm_source=share&utm_medium=member_desktop

Agroforestry



- □ Agroforestry: a common type of multifunctional agriculture, characterised by the integration of trees (and other woody permanent or perennial plants) in croplands.
- Agrivoltaics and agroforestry may compete for suitable croplands as solar panels and trees both provide shading for the vegetation below.
- Environmentally-friendly agroforestry practices can contribute to climate change mitigation and local diversity conservation, reduce soil erosion and protect water bodies.
- It is sensible to promote future expansion of agroforestry in environmentally sensitive areas, such as forests, wetlands, water bodies, other wildlife habitats, and the surrounding buffer zones.



Potential of Agrivoltaics in ASEAN (I)



- Southeast Asia is the world's primary home of agroforests, containing 29 % of all global agricultural land with tree cover of at least 30 %.
- The potential of agrivoltaics was analysed while considering the simultaneous goal of expanding agroforestry in environmentally sensitive areas.
- Assumption: NO agrivoltaics to be deployed at croplands in environmentally sensitive areas



Flow chart for calculating geographic potential of agrivoltaics while excluding environmentally sensitive areas

Potential of Agrivoltaics in ASEAN (II)



Geographic potential of agrivoltaics in 10 ASEAN member countries

Country	Initial extent of herbacious cropland (km ²)	After excluding environmentally sensitive areas (km ²)
Brunei	3	0.36
Cambodia	59,699	38,157
Indonesia	87,674	69,326
Laos	13,602	7582
Malaysia	3075	2253
Myanmar	117,392	88,101
Philippines	36,679	17,879
Singapore	5	2
Thailand	173,777	111,077
Vietnam	50,093	35,463
Total	541,998	369,841



Reference: Resources, Conservation & Recycling 209 (2024) 107808

Agrivoltaics vs ASEAN 2050 generation targets



- Only 10% of the geographic potential of agrivoltaics in the ASEAN region could supply >100% of the targeted total electricity generation
- Cambodia and Myanmar can supply more than 10x of their projected electricity generation, and Thailand 2x; they could potentially serve as energy exporters to supply to countries such as Singapore, and Malaysia
- Cross-border transmission systems and energy trading schemes are being developed through the ASEAN Power Grid
- Urban agrivoltaics are needed for scenarios in countries such as Singapore

Country	2020 (TWh)	2050, Baseline scenario (TWh)	2050, APAEC Regional Targets Scenario (APS) (TWh)	Agrivoltaics potential relative to APAEC Regional Target Scenario, if 10 % of the geographic potential is used
Brunei	4.73	7.78	8.99	0 %
Cambodia	11.09	30.95	17.34	1451 %
Indonesia	275.58	960.79	642.27	73 %
Laos	7.78	44.95	48.21	104 %
Malaysia	152.13	485.97	220.88	7 %
Myanmar	20.29	42.04	32.91	1741 %
Philippines	83.24	359.46	231.65	50 %
Singapore	50.78	90.31	67.76	0 %
Thailand	187.26	461.44	355.11	206 %
Vietnam	218.02	904.27	483.16	47 %
Total	1010.91	3388.00	2108.00	116 %

APAEC: ASEAN Plan of Action for Energy Cooperation

Summary



- □ Urban agrivoltaics is critical for densely populated countries like Singapore
- □ Agrivoltaics has huge potential in ASEAN countries also in co-existence with agroforestry
- 10% of the geographic potential (without affecting environmentally sensitive areas) in the ASEAN region can supply >100% of the projected future electricity generation





Many thanks for your attention! <u>lin.fen@nus.edu.sg</u>

More information at:

https://www.seris.nus.edu.sg www.solar-repository.sg

We are also on:



