FINAL TECHNICAL REPORT

Asia Pacific Regional Energy System Assessment

Office of Naval Research

Grant Award Number N00014-17-1-2923

September 1, 2017 through May 31, 2025

Hawai'i Natural Energy Institute
University of Hawai'i at Mānoa

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Table of Contents

EXECUTIVE SUMMARY **4**

INTRODUCTION **8**

HAWAIʻI **13**

Enhancing and Scaling the Aloha+ Challenge Dashboard 13

Indoor Air Quality in Hawaiʻi Classrooms 20

Computer Vision Technology 24

ROTC Test Platform 29

Support to the Institute on Science for Global Policy 32

VIETNAM **34**

Saigon Energy Hub (SEHub) 34

Innovation System Mapping Project 36

Vietnam Low Emission Energy Program (V-LEEP) RPS Development 41

V-LEEP Technical Support for Vietnam's Power Development Plan (PDP8) 42

Institute of Energy Grid Planning 43

THAILAND **44**

Support to Chiang Mai Rajabhat University's PV-Biogrid Project 44

EGAT Variable Energy Integration Study 48

Thailand Regional Solar PV Forecasting 50

Joint Initiatives with Chulalongkorn University (CU) 51

Provincial Electricity Authority of Thailand (PEA) Collaboration 53

Thailand Regulatory Collaboration 56

LAOS **57**

Solar Pilot Auction and Grid Code Development 57

Technical Interconnection Requirements for Solar and Wind Projects in Laos 59

INDONESIA 60

Ministry of Energy Capacity Building 60

University of Indonesia (UI) DC Microgrid Collaboration 61

Support to Indonesia's SINAR Program 62

PHILIPPINES 64

Support for the Philippines Department of Energy 64

Support to the Energy Secure Philippines (ESP) Program 65

PACIFIC ISLAND COUNTRIES (PICs) 67

The Republic of Palau 67

The Cook Islands 69

The Republic of Marshall Islands (RMI) - Majuro 70

The Federated States of Micronesia (FSM) - Yap State 71

The Republic of Fiji 72

SOUTHEAST ASIA AND INDO-PACIFIC REGION 72

ASEAN Interconnection Masterplan 73

Southeast Asia Smart Power Program 74

Support for APEC Working Groups 76

Support of ADB and Asia EDGE Events 78

Sustainable Aviation Fuels Workshops 79

Review of Candlenut for Fuels Potential 81

Final Technical Report
Asia Pacific Regional Energy System Assessment
Grant Award Number N00014-17-1-2923
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EXECUTIVE SUMMARY

This report summarizes work conducted under Grant Award Number N00014-17-1-2923, the Asia Pacific Regional Energy System Assessment (APRESA), funded by the Office of Naval Research (ONR) to the Hawaiʻi Natural Energy Institute (HNEI) of the University of Hawaiʻi at Mānoa (UH). The overall objective of this multi-year grant was to develop comprehensive energy system assessments in the Asia Pacific region regarding energy transition strategy, policy, regulation, technology options, demonstrations, implementation plans, and training based on the specific requirements or needs of the targeted jurisdictions and strategic alliances. Projects were selected based on the specific requirements or needs of the targeted jurisdictions with a focus on geographic regions/countries of strategic United States (U.S.) interest, including but not limited to Pacific Island nations; Department of Defense (DOD) facilities within the U.S. Indo-Pacific Command (USINDOPACOM) operating area (formerly known as the United States Pacific Command operating area); Association of Southeast Asian Nations (ASEAN) countries of strategic interest; as well as Hawaiʻi, the West Coast, and Alaska. The criteria for selection of jurisdictions included: 1) those with significant rates of projected demand growth requiring rapid energy system expansion and transformation; 2) strategic trade and geopolitical opportunities to the U.S.; 3) potential to integrate renewable energy technologies; and 4) a collaborative environment to conduct the work.

Over the seven years of APRESA activities, HNEI provided engagement and support activities to a range of organizations based in Hawaiʻi and with countries in the Asia Pacific region including Vietnam, Thailand, Laos, Indonesia, Philippines, Cambodia, and several Pacific Island countries (PICs) including the Republic of Palau, the Cook Islands, the Republic of the Marshall Islands, the Federated States of Micronesia, and the Republic of Fiji.

HNEI established substantive strategic partnerships with national, regional, and local jurisdictions, as well as private and public stakeholders, including numerous utilities, universities, and other research and international aid and development entities, such as the World Bank (WB), Asian Development Bank (ADB) and DOD organizations in the areas of interest. In addition to the deep local partnerships formed in these jurisdictions, this program has led to a highly successful collaborative relationship with the U.S. Agency for International Development (USAID) and its

implementation of prime contractors throughout the region (e.g., Deloitte, Tetra Tech, Abt Associates, RTI, Chemonics, and Delphos International).

A brief summary of results by projects based in Hawai‘i and then by region/country follows.

Hawai‘i: A number of projects based in Hawai‘i were implemented with the intent to support secure energy development in Hawai‘i and allow transition to the broader Asia Pacific region. Projects included:

- The development and enhanced scaling of a dashboard website that tracks multiple global and statewide sustainability goals and targets. This effort supported dashboard launches in several PICs, including Guam, Palau, and the Northern Mariana Islands.
- Indoor air quality was evaluated through field measurement and computational fluid dynamics modeling, and anonymously measured human-based activity with the intent of better understanding space utilization and energy management.
- HNEI provided in-kind and financial support for a global conference to identify potential plans for future hydrogen energy development in island communities.

Vietnam: HNEI established partnerships with several institutions in Vietnam to support their development of a sustainable and resilient energy system. Projects included:

- Support to a community group to develop a workshop platform and eight seminars covering a range of energy themes to raise awareness of renewable energy.
- HNEI provided financial support and delivered training and expertise to support Vietnam’s development of a renewable portfolio standard mechanism and roadmap for implementation.
- HNEI provided technical planning, capacity building, and scenario modeling in support of Vietnam’s Eighth Power Development Plan’s (PDP8) development.
- HNEI supported Vietnam’s National Institute for Science & Technology Policy and Strategy Studies (NISTPASS) to map the innovation opportunities associated with renewable energy sector development in Vietnam.
- HNEI initiated an effort to support the Institute of Energy, Ministry of Industry and Trade to develop grid modeling capabilities.

Thailand: HNEI established collaborations with several Thai universities, utility providers, grid operators, and energy regulatory commission. Projects included:

- HNEI contracted Chiang Mai Rajabhat University to conduct an assessment of small biomass systems as a firm power option in islanded settings including the design, development, and implementation of a bioreactor system to hybridize a community PV grid system and extend hours of electricity availability.

- Technical collaborations with the Electricity Generating Authority of Thailand (EGAT), the Provincial Electricity Authority (PEA), and Chulalongkorn University enabled comprehensive advancements in grid planning, energy production forecasting, microgrid operations, and regulatory standards. These efforts included technical studies for solar and wind integration, production cost modeling (PCM), scenario analysis, development of robust predictive platforms tailored to Thailand's needs, and hands-on training for utility engineers. Work in Thailand assisted in laying the groundwork for regional regulatory modernization, while also facilitating demonstration projects such as the Koh Phaluai microgrid.

Laos: HNEI supported technical capacity building, grid modernization, and policy advancement in the Lao People's Democratic Republic (LPDR). Collaborations with the Ministry of Energy and Mines (MEM) and Électricité du Laos (EDL) introduced new competitive procurement models and guided the launch of Laos' first market-based solar pilot auction. The team also developed, expanded, and institutionalized technical interconnection and performance standards for solar and wind projects, enhancing reliability in the evolving power sector. Hands-on workshops and targeted capacity building directly equipped Lao practitioners with skills in scenario analysis and grid code management and helped to strengthen institutional knowledge and resilience strategies.

Indonesia: HNEI worked with Indonesian energy partners to provide technical training, capacity building, and collaborative research supporting grid modernization and energy transition. Engagements included training for the Ministry of Energy and Mineral Resources (MEMR), collaborative DC microgrid research with the University of Indonesia, and support for the Sustainable Energy for Indonesia's Advancing Resilience (SINAR) program. These efforts included hands-on workshops, capacity building webinars, and benchmarking tours covering grid modernization, microgrid design, battery energy storage systems (BESS), competitive procurement, and distributed resource integration.

Philippines: HNEI's collaboration with the Philippines Department of Energy (DOE) and Energy Regulatory Commission (ERC) facilitated improvements in their Net Metering Program, increased distributed solar adoption, and delivered regulatory frameworks for off-grid net energy metering and BESS. Support of the Energy Secure Philippines (ESP) program delivered advanced regulatory frameworks, practical training, and targeted technical assistance, which directly enhanced the expertise and operational capabilities of Philippine energy institutions, utilities, and the Armed Forces of the Philippines.

Pacific Island Countries (PICs): HNEI provided technical support for PICs, with specific efforts in the Republic of Palau, the Cook Islands (Rarotonga), the Republic of the Marshall Islands (Majuro), the Federated States of Micronesia (Yap), and the Republic of Fiji. The team delivered targeted analysis, regulatory development, and capacity building for projects addressing each island's unique challenges of maximizing use of local energy resources. Activities encompassed training workshops, stakeholder consultations, modeling studies, grid code development, and demonstration projects on hosting capacity and resiliency assessment.

Southeast Asia and Indo-Pacific Region: HNEI established collaborative technical engagement throughout Southeast Asia and the Indo-Pacific region. Projects included:

- Support of the Association of Southeast Asian Nations (ASEAN) Centre for Energy (ACE) allowed for significant contributions to the ASEAN Interconnection Masterplan Study (AIMS) III through technical review.
- HNEI assisted the Southeast Asia Smart Power Program (SPP) regionally across the ten ASEAN Member States through capacity building workshops, and more specifically in Laos and Cambodia. In Laos, HNEI engaged with EDL and MEM to provide updated feasibility study guidelines for energy projects and an updated grid code. In Cambodia, HNEI supported Electricité de Cambodge (EdC), the national utility, by holding a workshop on power system coordination and flexible resource management to enhance local practitioners' technical capacity.
- HNEI participated in various Asia-Pacific Economic Cooperation (APEC) working groups; forums and capacity building events convened by Asian Development Bank and the Department of State's Asia Enhancing Development and Growth through Energy (EDGE) initiative; and sustainable aviation fuel international workshops.
- A literature review and analysis of a tropical oilseed tree was conducted to evaluate its potential as a sustainable bioenergy resource.

This final report describes the work that has been accomplished in each of the areas identified above. Publications produced through these efforts are noted below and available on HNEI's website at https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

INTRODUCTION

The objective of the Asia Pacific Regional Energy System Assessment (APRESA) was to conduct research supporting the development of comprehensive energy system assessments in targeted jurisdictions throughout the Asia Pacific region with the goal of identifying technological options and operational strategies to enhance the reliability, stability, and resilience of energy systems in the region. Projects were selected based on the specific requirements or needs with a focus on geographic regions/countries of strategic United States (U.S.) interest, including but not limited to Pacific Island nations; Department of Defense (DOD) facilities within the U.S. Indo-Pacific Command (USINDOPACOM) operating area (formerly known as the United States Pacific Command operating area); Association of Southeast Asian Nations (ASEAN) countries of strategic interest; as well as Hawaiʻi, the West Coast, and Alaska. The criteria for selection of jurisdictions included: 1) those with significant rates of projected demand growth requiring rapid energy system expansion and transformation; 2) strategic trade and geopolitical opportunities to the U.S.; 3) potential to integrate renewable energy technologies; and 4) a collaborative environment to conduct the work.

APRESA aimed to strengthen the reliability, stability, and resilience of energy systems in targeted jurisdictions. Goals were centered on developing information and analysis to identify a range of technology solutions and operational strategies tailored to the unique needs of each focus area. To achieve these outcomes, HNEI developed working partnerships with national, regional, and local governments; utilities; private and public stakeholders; universities and research organizations; and relevant DOD entities.

Over the seven years of APRESA activities, HNEI provided engagement and support activities to a range of organizations in countries in the Asia Pacific region including Vietnam, Thailand, Lao People's Democratic Republic (LPDR), Indonesia, Philippines, Cambodia, and several Pacific Island countries (PICs) including the Republic of Palau, the Cook Islands, the Federated States of Micronesia (FSM), the Republic of the Marshall Islands (RMI), and the Republic of Fiji. Throughout the grant's period, the program adapted to significant external challenges such as the COVID-19 pandemic by maintaining momentum with existing partnerships and establishing new collaborations as travel restrictions eased.

Across the Asia Pacific, HNEI engaged in a broad range of activities to strengthen energy system reliability and resilience and to advance modern practices. Collaborators included government ministries, regulators, utilities, and research organizations. The team carried out analytical modeling, resource assessments, policy and regulatory reviews, and provided research and contextually relevant implementation support for the integration of new and distributed energy technologies. Under APRESA, HNEI also facilitated training programs, recommended and/or conducted technology demonstrations in the field, and in some instances, directly supported in-country organizations to conduct relevant research. Collectively, these activities enhanced institutional expertise, improved regulatory and planning frameworks, and accelerated progress toward resilient, sustainable energy systems throughout the region. Faculty from across HNEI as well as select consultants with international expertise were engaged. Significant parts of the overall efforts were conducted by HNEI's Grid Systems Technology Advanced Research Team (Grid***START***).

Over the course of this award, HNEI engaged across a wide range of political jurisdictions and organizations active in the Asia Pacific region. Engagements included information exchanges, collaborative analysis and studies, and in limited cases, direct financial support. A detailed listing of these political jurisdictions and organizations is provided below organized by country/region in which they reside. This report is organized by country or region. Details of HNEI's and our collaborators' research are summarized with notations to specific work products, including journal papers, reports, and presentations. Publications produced through these efforts are noted below and available on HNEI's website at https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

Vietnam:

- Anh Minh Global, Consultant, Ho Chi Minh City, Vietnam
- DAI, USAID contractor, USAID Vietnam Urban Energy Security Project, Hanoi, Vietnam
- Deloitte, USAID contractor, V-LEEP Program; Hanoi, Vietnam
- Energy Conservation Research and Development Center (ENERTEAM); Ho Chi Minh City, Vietnam
- Hanoi University of Science and Technology; Hanoi, Vietnam
- Ho Chi Minh City Power Company; Ho Chi Minh City, Vietnam
- Ho Chi Minh City Union of Science and Technology Associations (HCM-USTA); Ho Chi Minh City, Vietnam
- Ho Chi Minh City University, Departments of Architecture and Urban Engineering; Ho Chi Minh City, Vietnam
- Ho Chi Minh City University of Technology, Electrical and Electronics Engineering, Faculty of Chemical Engineering; Ho Chi Minh City, Vietnam
- Institute of Electricity, Ministry of Industry and Technology; Hanoi, Vietnam
- Institute for Regional and Urban Studies (IRUS); Ho Chi Minh City, Vietnam
- National Institute for Science & Technology Policy and Strategy Studies (NISTPASS); Hanoi, Vietnam
- University of Science and Technology of Hanoi; Hanoi, Vietnam
- Vietnam Academy of Science and Technology (VAST); Hanoi, Vietnam
- Vietnam Initiative for Energy Transition Social Enterprise; Hanoi, Vietnam
- Vietnam Ministry of Industry and Trade, Electricity and Renewable Energy Authority (MOIT/EREA), Institute of Electricity, (MOIT/EREA/IoE); Hanoi, Vietnam
- Vietnam Ministry of Science and Technology, National Institute for Science and Technology Policy and Strategy Studies (MOST/NISTPASS); Hanoi, Vietnam

Thailand:

- Abt Associates, USAID contractor, Clean Power Asia Program; Bangkok, Thailand
- The Asia Foundation, Bangkok, Thailand
- Assumption University; Bangkok, Thailand
- Chemonics, USAID contractor; Bangkok, Thailand
- Chiang Mai Rajabhat University; Chiang Mai, Thailand
- Chulalongkorn University, Faculty of Engineering; Bangkok, Thailand
- Deloitte, USAID contractor, V-LEEP & V-LEEP II Program, Hanoi, Vietnam; USAID South East Asia's Smart Power Program; Bangkok, Thailand
- Department of Alternative Energy Development and Efficiency, Ministry of Energy, Thailand (DEDE); Bangkok, Thailand
- Electricity Generating Authority of Thailand (EGAT); Bangkok, Thailand
- King Mongkut's University of Technology Thonburi; Bangkok, Thailand
- Mitsubishi Motors Corporation (Thailand), Bangkok, Thailand
- Municipal Electricity Authority of Thailand (MEA); Bangkok, Thailand
- National Energy Technology Center of Thailand; Bangkok, Thailand
- National Metal and Materials Technology Center of Thailand (MTEC); Bangkok, Thailand
- National Science and Technology Development Agency; Bangkok, Thailand
- Naresuan University School of Renewable Energy and Smart Grid Technology; Phitsanulok, Thailand
- Office of Energy Regulatory Commission, Thailand (OERC), Bangkok, Thailand
- Office of National Higher Education Science Research and Innovation Policy Council, Ministry of Higher Education, Science, Research and Innovation; Bangkok, Thailand
- Program Management Unit for Human Resources & Institutional Development, Research and Innovation, Ministry of Higher Education, Science, Research and Innovation; Bangkok, Thailand
- Provincial Electricity Authority of Thailand (PEA); Bangkok, Thailand
- Rajamangala University of Technology Thanyaburi; Pathum Thani Province, Thailand
- USAID, Asia-Pacific Regional Mission; Bangkok, Thailand

Laos:

- Department of Energy Management, Ministry of Energy and Mines (DEM/MEM); Vientiane, Laos People's Democratic Republic
- Department of Energy Policy and Planning, Ministry of Energy and Mines (DEPP/MEM); Vientiane, Laos People's Democratic Republic
- Electricite Du Laos (EDL); Vientiane, Laos People's Democratic Republic
- Institute of Renewable Energy Promotion, Ministry of Energy and Mines (IREP/MEM), Laos PDR, Vientiane, Laos People's Democratic Republic
- Numark Lao Sole Co., Ltd, USAID contractor, Laos Energy Security Project; Vientiane, Laos People's Democratic Republic

Indonesia:

- ASEAN Centre for Energy (ACE), Jakarta, Indonesia
- ASEAN Power System Operators (APSO); Jakarta, Indonesia
- Bandung Institute of Technology; Bandung, Indonesia
- Center for International Forestry Research; Bogor, Indonesia
- Directorate General of Civil Aviation; Jakarta, Indonesia
- Gadjah Mada University, The Center for Energy Studies; Yogyakarta, Indonesia
- Indonesian Oil Palm Research Institute; Medan, Indonesia
- Institut Pertanian Bogor University, Surfactant and Bioenergy Research Center; Bogor, Indonesia
- Ministry of Energy, Indonesia; Jakarta, Indonesia
- Perusahaan Listrik Negara (PLN), Indonesia National Electricity Company; Jakarta, Indonesia
- Tetra Tech, United States Agency for International Development (USAID) contractor, Sustainable Energy for Indonesia's Advancing Resilience (SINAR); Jakarta, Indonesia
- University of Indonesia, Faculty of Engineering; Jakarta, Indonesia
- USAID; Jakarta, Indonesia

Philippines:

- Agrea Philippines; Manila, Philippines
- Asian Development Bank (ADB); Manila, Philippines
- Bohol Provincial Government; Philippines
- Armed Forces of the Philippines, Camp General Emilio Aguinaldo, Quezon City, Philippines
- Central Luzon State University; Muñoz, Nueva Ecija, Philippines
- Iloilo Provincial Government; Iloilo City, Philippines
- Manila Electric Company (MERALCO); Manila, Philippines
- MORE Electric and Power Corporation; Iloilo, Philippines
- Philippine Airlines; Manila, Philippines
- Philippine Department of Energy (PDOE); Manila, Philippines
- Philippines Energy Regulatory Commission (ERC); Manila, Philippines
- Philippine Sugar Research Institute Foundation, Inc.; Makati City, Philippines
- Philippines Energy Regulatory Commission (ERC); Manila, Philippines
- RTI International, USAID prime contractor for the Asia-Pacific Energy Secure Philippines (ESP); Manila, Philippines
- Sekretariat Jenderal, Dewan Energi Nasional (Setjen DEN), Secretariat General of the National Energy Council of the Republic of Indonesia; Jakarta, Indonesia
- Siargao Electric Cooperative, Inc. (SIARELCO); Surigao del Norte, Philippines
- Siargao Women's Center; Surigao del Norte, Philippines
- USAID, Bilateral Office; Manila, Philippines

- University of the Philippines Los Baños; Los Baños, Philippines

Pacific Island Countries:
- Commonwealth Utilities Corporation; Saipan, Commonwealth of the Northern Mariana Islands
- Energy Fiji Limited (EFL); Suva, Republic of Fiji
- Marshalls Energy Company (MEC); Majuro, Republic of the Marshall Islands
- National Energy Office, Ministry of Environment; Majuro, Republic of the Marshall Islands
- Nauru Utilities Corporation; Republic of Nauru, Federated States of Micronesia (FSM)
- Pacific Power Association; Suva, Republic of Fiji
- Palau Energy and Water Administration, Ministry of Finance, Ministry of Public Infrastructure, Industries & Commerce; Koror, Republic of Palau
- Palau Public Utilities Corporation; Koror, *Republic of Palau*
- RTI International, USAID prime contractor for the PNG Electrification Partnership; Port Moresby, Papua New Guinea
- Te Aponga Uira (TAU), Power Authority; Rarotonga, Cook Islands

Southeast Asia and Indo-Pacific Region:
- Asia-Pacific Economic Council (APEC), Expert Group on New and Renewable Energy Technologies (EGNRET); Taipei, Taiwan
- Asia Pacific Energy Research Center (APERC); Tokyo, Japan
- Australian Infrastructure Financing Facility for the Pacific (AIFFP), Department of Foreign Affairs and Trade; Barton, Australia
- Delphos International, USAID & World Bank contractor; Asia-Pacific region
- Electricite de Cambodge (EdC); Phnom Penh, Cambodia
- Industrial Technology Research Institute (ITRI); Hsinchu, Taiwan
- Japan International Cooperation Agency (JICA); Tokyo, Japan
- Okinawa Enetech Co.; Okinawa, Japan
- Sustainable Energy Development Authority (SEDA); Kuala Lumpur, Malaysia
- United States Embassy; Kuala Lumpur, Malaysia
- Universiti Malaysia Sarawak; Kota Samarahan, Sarawak, Malaysia
- Universiti Teknologi MARA; Shah Alam, Malaysia
- Universiti Teknologi Malaysia, Faculty of Chemical and Energy Engineering; Johor, Malaysia

The remainder of this report summarizes key activities and project results, organized by country or region.

HAWAIʻI

Funding under this award supported a number of projects based in Hawaiʻi that supported the state, but were also intended to support energy transitions throughout the Asia Pacific region. These efforts included enhancement of a dashboard focused on sustainability to include additional energy tracking; research to achieve indoor comfort and safety with reduced energy requirements; development of a sensor and analysis process that monitors and anonymizes the human location and movement within a space; a building assessment intended to provide a test platform for the built-environment that could also support Navy ROTC on the UH Mānoa campus; and support of a workshop to identify potential hydrogen development plans in island communities. Details of the work conducted in these activities are described below.

Enhancing and Scaling the Aloha+ Challenge Dashboard

Hawaiʻi faces the challenging task of achieving multiple sustainability goals by 2030 to meet the United Nations (UN) 2030 Sustainable Development Goals (SDG) and the state's Hawaiʻi Clean Energy Initiative (HCEI) targets. The UN set forth seventeen SDGs (Figure H.1) to achieve sustainable development in its three dimensions of economic, social, and environmental. While the HCEI set goals to achieve 40% renewable energy by 2030, 70% by 2040, and 100% by 2045. Hawaiʻi must reach its clean energy goal while also increasing food security, meeting affordable housing objectives, and improving local and regional resilience to disruptions such as natural disasters. Given this, the Aloha+ Challenge was launched in 2014. Six priority goals and local metrics were identified: 1) clean energy transformation; 2) local food production and consumption; 3) natural resource management; 4) solid waste reduction; 5) smart sustainable communities; and 6) green workforce and education. The Aloha+ Challenge sought to effectively engage stakeholders and the community, and track progress towards innovative strategies that can be scaled regionally and globally.

Figure H.1. Listing and official posters for the seventeen UN SDGs (Source: United Nations[1]).

The Aloha+ Challenge goals and associated SDGs are shown below:

- *Clean Energy Transformation*: #1 (no poverty), #7 (affordable and clean energy, #10 (reduced inequalities), #13 (climate action), and #17 (partnerships for the goals)
- *Local Food Production and Consumption*: #1, #2 (zero hunger), #3 (good health and well-being), #12 (responsible consumption and production), #13, and #17
- *Natural Resource Management*: #3, #6 (clean water and sanitation), #12, #13, #14 (life below water), #15 (life on land), and #17
- *Solid Waste Reduction*: #3, #12, #13, #14, #15, and #17
- *Smart Sustainable Communities*: #1, #3, #10, #11 (sustainable cities and communities), #13, #16 (peace, justice, and strong institutions), and #17
- *Green Workforce and Education*: #1, #4 (quality education), #5 (gender equality), #8 (decent work and economic growth), #9 (industry, innovation, and infrastructure), #10, #13, and #17

The Aloha+ Challenge Dashboard ("Dashboard"), tracks Hawai‘i's progress towards the SDGs through a broad consensus-based process that convened hundreds of stakeholders statewide. The Dashboard (https://alohachallenge.hawaii.gov/), developed previously by Hawai‘i Green Growth Local2030 Hub (HGG), had been effective in catalyzing action, data-driven decision making and

[1] https://www.un.org/sustainabledevelopment; The content of this publication has not been approved by the United Nations and does not reflect the views of the United Nations or its officials or Member States.

initiating robust dialogue about the tradeoffs between multiple priorities. The United Nations recognized HGG as one of the world's first Local2030 Hub for implementing the SDGs, which prompted multiple jurisdictions to express interest in scaling Hawai'i's model across the Asia Pacific region. However, the applicability of the Dashboard to these other jurisdictions was limited by technology platforms access and staff capacity limitations.

In order to aid the scaling efforts, HNEI provided support to HGG through APRESA to demonstrate the transformation of the Dashboard into a state-of-the-art tool for SDG measurement. This research, conducted in 2020 and 2021, included: 1) building "Dashboard 2.0" with interactive data visualizations tailored to multiple audiences; 2) enhancing data capacity in the areas of energy and resilience; 3) integrating a scenario modeling visualization for Hawai'i's clean energy goals to pilot features for broader sustainable development priorities; and 4) convening multi-stakeholder processes to inform priority content and policy alignment.

The new 2.0 prototype of the Dashboard provided new interactive capabilities, data visualizations for targets and indicators (including electricity efficiency, average fuel use, and total energy use), and a multi-dimensional site customized for priority target audiences including decision makers, technical experts, stakeholders, and community-based constituents. Figure H.2 is an example of the Dashboard's interactive data visualizations. Resilience metrics, additional datasets of community driven data, and scenario modeling information (greenhouse gas emission projections, potential future savings from efficiency programs, energy efficiency forecasting) were also integrated into the Dashboard.

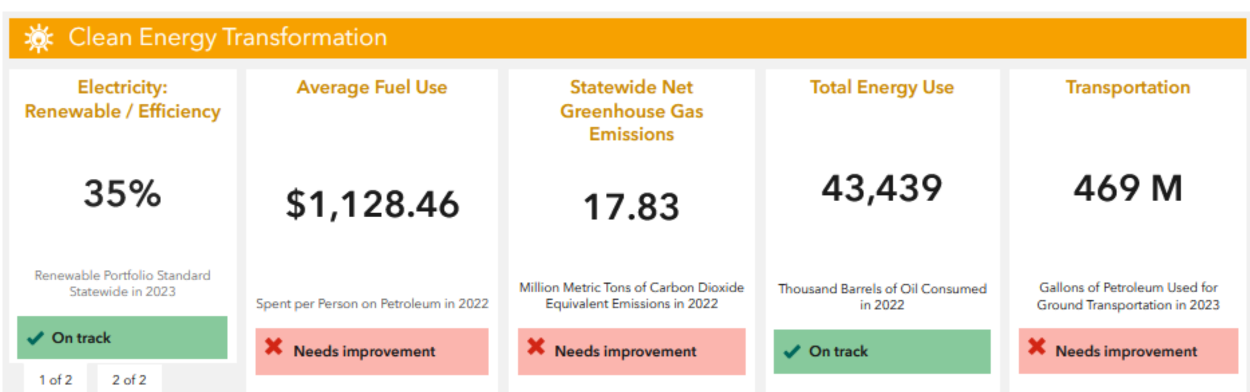


Figure H.2. The Dashboard's Clean Energy Transformation "scorecard" interactive data visualizations, excerpted from the Dashboard.

HGG presented the Dashboard prototype to stakeholders including the County of Kaua'i Mayor, Global Island Partnership, Hawai'i Tourism Authority, and Hawaiian Electric Company. Additionally, the team conducted outreach and provided consultation with the Local2030 Islands Network to support increased multi-stakeholder data and dashboard initiatives in achieving the SDGs. The Local2030 Islands Network was the world's first global, island-led network devoted to advancing the SDGs through locally-driven, culturally-informed solutions. These efforts led to the creation of the Aloha+ Model Template, based on the Dashboard 2.0 prototype, which allowed the framework to be more easily replicated with islands and countries across the Asia Pacific. Based on HGG's methodology, the Guam Green Growth (GGG) dashboard was launched in 2021. Other island nations pursued the same approach.

Expanding upon this work, another contract from 2021 to 2024 between HNEI and HGG (through Hawaiʻi Local2030 Hub) was executed. Its goals were to: 1) enhance Dashboard 2.0 with additional automation and SDG build outs to include additional sustainable development priorities and development of the Aloha+ Framework template for scalability in other regions; 2) expand and enhance metrics and datasets in the areas of energy, transportation, resilience, and statewide greenhouse gas (GHG) emissions; 3) integrate energy scenario modeling visualizations such that projections are developed more broadly across Aloha+ goals; 4) engage community and key stakeholders to inform content and policy alignment; and 5) scale dashboard development and process to Palau. The overall objective of this effort was to increase Hawaiʻi's implementation on sustainability initiatives by 2030, and empower other islands and countries in the Asia Pacific region to track and advance progress on local energy, climate, and resilience efforts through stakeholder processes aligned with the SDGs.

To advance data visualization, data science, and decision science skills, HGG developed application programming interface (API) scripts, which automated interactions with web-based services or applications, and test software capabilities and compatibility currently used. Dashboard improvements included data visualization and modeling, data analysis, data updates and development, community data and education, local-global research, and Dashboard communications. Current students and recent graduates of the University of Hawaiʻi (UH), contributed to these efforts.

A web application data tool was launched to automate the process of updating datasets on the Dashboard that contain information such as electricity prices (Figure H.3). Data came from the U.S. Energy Information Administration (EIA) and U.S. General Services Administration. Numerous additional datasets of local statistics were incorporated into the Dashboard. These included energy use, generation, and pricing; water availability, usage, and pricing; census and population information (i.e. employment, education, size changes); land use; solid waste; wastewater reuse; drought rates; and petroleum usage. An example of the visualizations of these datasets is shown in Figure H.4. HGG integrated the Hawaiʻi State Energy Office's (HSEO) Renewable EnerGIS tool, into the Dashboard as well (Figure H.5). This tool is an online mapping tool that allows landowners, developers, residents, and policy makers to assess the renewable energy potential of sites statewide. The efforts supported under APRESA resulted in a more operational dashboard with an enhanced data governance structure that efficiently scales the localized datasets to the SDGs.

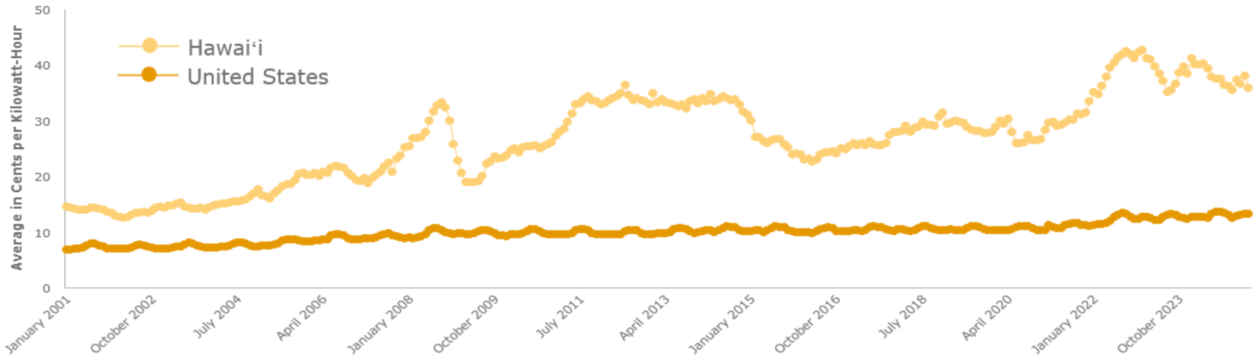


Figure H.3. Electricity prices: Hawai'i vs. U.S., excerpted from the Dashboard (Data source: U.S. EIA).

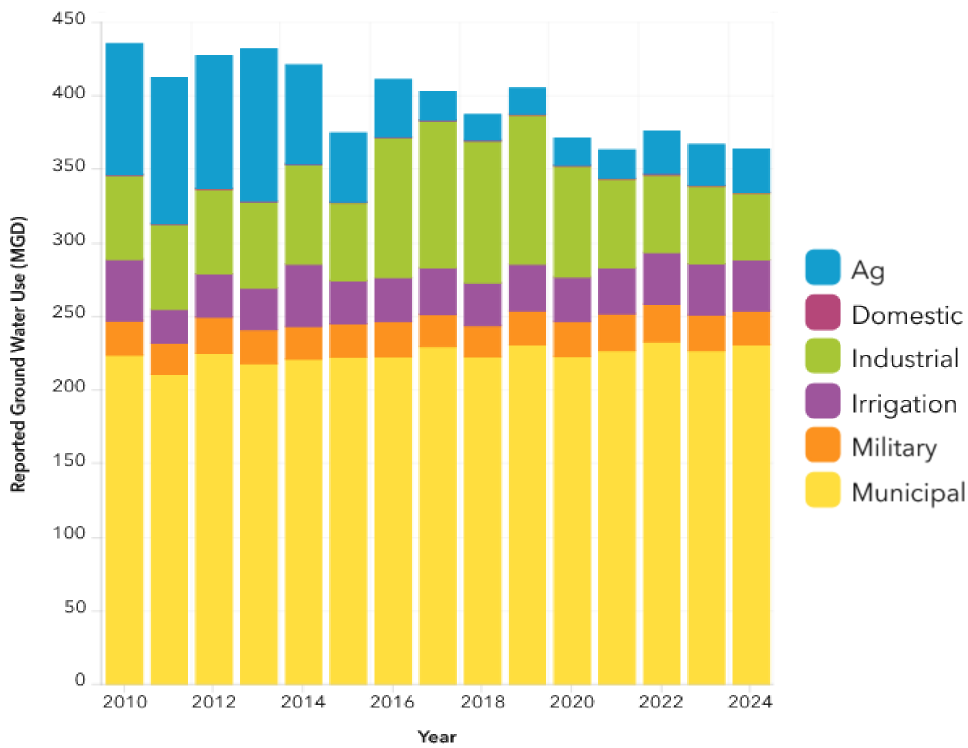


Figure H.4. Statewide water usage by sector, excerpted from the Dashboard (Data source: Hawai'i State Commission of Water Resources Management).

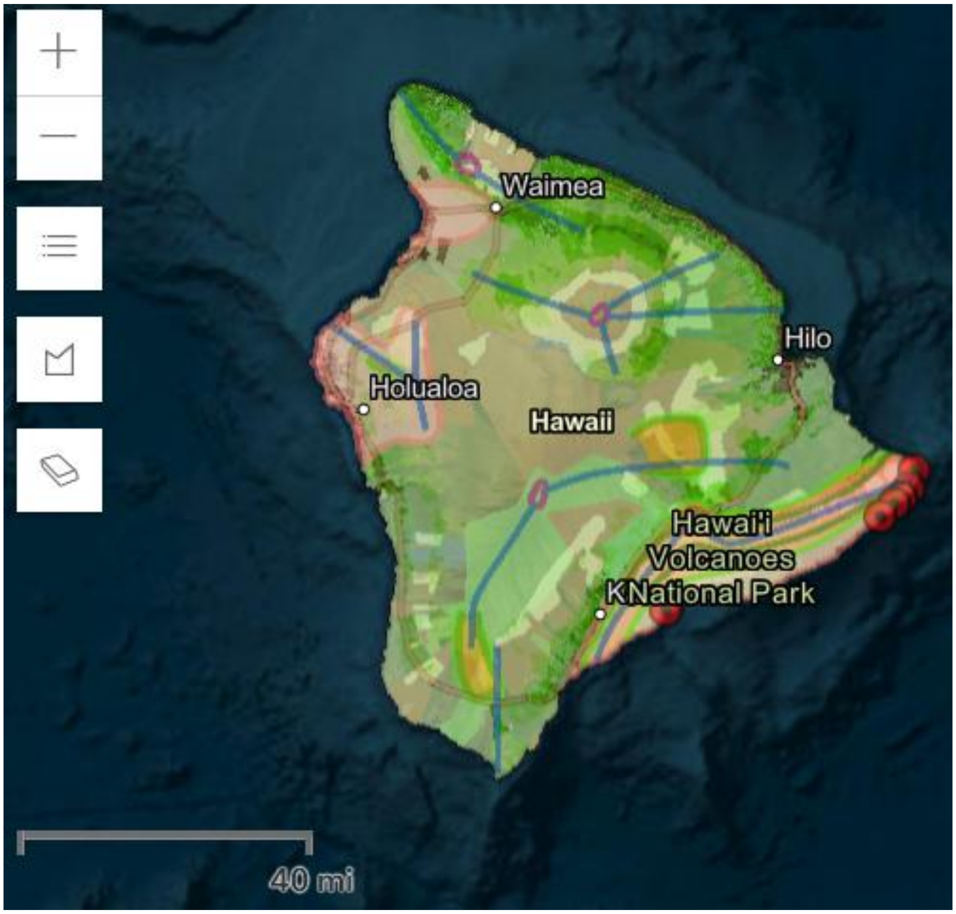


Figure H.5. Hawai'i Island's potential for geothermal technology projects, excerpted from the Dashboard (Source: HSEO).

To further Aloha+ goals and SDGs at a county level, dashboard websites for Oʻahu, Kauaʻi, Maui County, and Hawaiʻi Island were created. Mirrored after the Aloha+ Challenge, the county websites sought to rally communities to live more sustainably to achieve sustainability goals. Individuals, groups, and organizations can participate in this "challenge" by signing up, answering lifestyle questions, and browsing a list of various actions one can take to live a more sustainable life. These actions range from "easy" (retiring an extra refrigerator and switching to LED light bulbs) to "medium" (carpooling, composting) to "challenging" (installing a greywater system).

HGG worked with their partners to build the Aloha+ Framework Template, which allowed users and early adopters to create a localized dashboard that links to the SDGs via a scorecard noting the most relevant indicators and demonstrating progress. Modeled after the Dashboard, this solution delivers a set of capabilities that help governments share progress made on SDGs, encourages community engagement, and combats misinformation. Licensing for a Local2030 Island Network hub to provide ~100 licenses for dashboard development within this network was also secured. The framework template was demonstrated at two events in October 2022 and was received well by participants.

Subsequent development included significant enhancement to metrics expansions for clean energy, resilience, transportation, energy equity, carbon offset, and GHG emissions (i.e. statewide fuel use for air transportation, electricity generation, and ground transportation), and expenditures of petroleum and electricity. An example of this is the addition of vehicle miles traveled (VMT) datasets (Figure H.6). HGG sought to integrate scenario modeling to further the progression of goals and indicators and to make the Dashboard more interactive and informative in real-time for decision makers. Scenario modeling examines a range of potential futures, instead of attempting to predict just one future. For example, HGG examined how multiple land planning uses in Hawaiʻi affect solar power potential to meet HCEI's renewable energy goals. Data used in creation of these models included the City and County of Honolulu, Hawaiʻi Statewide GIS Program, Federal Emergency Management Agency, National Oceanic and Atmospheric Administration (NOAA), and Pacific Islands Ocean Observing System.

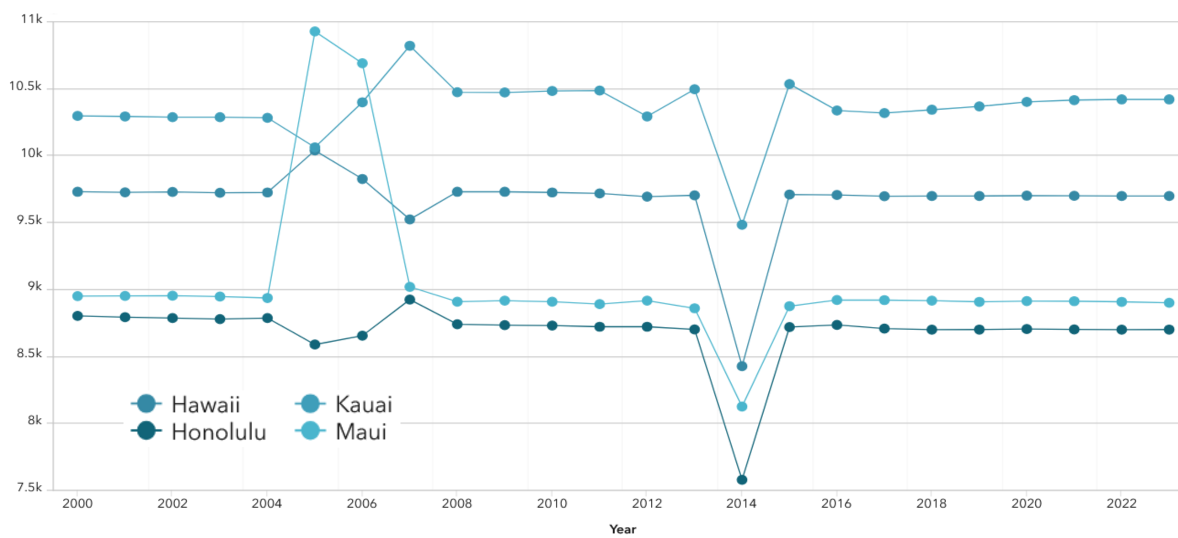


Figure H.6. Total annual VMT by county, excerpted from the Dashboard (Source: Department of Business Economic Development and Tourism).

Building upon scenario modeling, suitability analysis allows users to qualify, compare, and rank candidate sites for development, based on how closely they adhere to selected and defined criteria. HGG integrated suitability analysis through predictive planning to examine how progress in various goals impacts others. As an example, users may examine the interrelationships of multiple variables related to the six Aloha+ Goals, including food, water, and energy datasets. This is possible through a GIS predictive planning model that seamlessly incorporates geographical data and accesses more than 100 feature layers containing datasets organized under HGG's six Aloha+ goals. The model tool aids in: 1) facilitating decision support, 2) facilitating informed decision-making and planning, 3) fostering better communication, 4) research endeavors, and 5) efficient resource allocation by empowering organizations to share maps, data, and insights with stakeholders and the public.

Following the development of the Dashboard for Hawai'i, HGG continued engagement of island countries within the Local2030 Islands Network and expanded engagement to other Small Island Developing States. One of the major activities under this task was HGG and GGG's support of the development of Palau Green Growth (PGG), Palau's localized iteration of the Dashboard. A partnership between HGG, GGG, and PGG was formed that aimed to share best practices and experiences to strengthen stakeholder involvement in Palau's sustainability initiatives. Working closely with Palau partners, the build out of PGG utilized baseline data from the country's Voluntary National Review. The official local launch of the PGG dashboard took place in February 2024.

In a broader context, the PGG dashboard launch represented a significant step forward in the ongoing efforts to localize and visualize sustainable development priorities within the region. Guam initiated its own GGG program in 2021. The Commonwealth of the Northern Mariana Islands unveiled its Green Growth initiative in January 2024. Through the utilization of data-driven planning and adaptive management frameworks, coupled with the establishment of community-managed public-facing dashboards, the Network can facilitate the identification and implementation of local goals and actions across the region.

Indoor Air Quality in Hawaiʻi Classrooms

In recent years, especially since the COVID-19 pandemic, there has been increased attention focused on indoor air quality and its impact of productivity. Under this project, HNEI contracted Miller Kelley Architects (dba MKThink) to characterize room air quality under different use cases and different ventilation typologies. Carbon dioxide (CO_2) concentrations were used as the metric for air quality. The objectives were to gain a better understanding of the impact of ventilation configurations on CO_2 concentrations, to compare modeled and measured CO_2 concentrations under a range of ventilation operations, and suggest guidelines to minimize exposure.

Under previous funding, HNEI and MKThink partnered to monitor previously installed energy efficient platforms being used as classrooms for energy use, temperature/relative humidity, daylighting, and air quality under different operations. These studies used sensor kits and web-based visualization/analysis developed by MKThink. Building upon those studies, MKThink developed a research project analyzing indoor air quality in an educational setting. Specifically, the study aimed to develop protocols to mitigate COVID-19 transmission while minimizing energy use.

CO_2 was used as a proxy given that the particles which carry COVID-19 and other respiratory diseases are exhaled along with CO_2 as a person breathes. Sensors were installed in select classrooms to monitor CO_2 and other environmental conditions. Data was collected for three months. MKThink utilized its proprietary 4Daptive data visualization software to display the CO_2 levels and variations between the sensors. Computational fluid dynamics (CFD) modeling of the air space assuming differing air inlet-exhaust configurations and air exchange rates was developed. The intent was to validate this model with available observational data and then use it to better understand the CO_2 concentration profiles in the rooms and allows insights into scenarios not observed during the data collection period. The research sought to address two questions:

1. What is the CO_2 variation in a room for different vent configurations and air-exchange rates and gain insights into the number of sensors required to ensure all occupants are healthy?
2. Which mitigation measures should be considered to keep occupants safe while also minimizing energy consumption considering differing human activity requirements (time until occupancy, exertion level), health risk (occupation levels, duration of occupancy), spatial attributes (size and shape of room, ventilation type, ceiling fans), and external environmental variables (wind speed/direction, ambient air quality)?

The major objective of this follow-on effort was to further analyze the results of the previous work to provide additional guidance in the placement of ventilation system and to identify possible methods to manage energy from HVAC while maintaining air quality. Results showed that CO_2 concentration profiles were dependent on the air exchange rate (AEC) and location of the exhaust vent compared to the location of the fresh air inlet vent, but the project stopped short of reaching defined conclusions that could be used to manage air quality while minimizing energy use.

Figure H.7 shows the configurations evaluated, each with a population of 21 (20 students plus 1 teacher). Air exhausts relative to inlet were placed on same wall (mid height), at the perpendicular wall at ceiling height, and at two locations on the opposite wall (ceiling height opposite the inlet and ceiling height toward the side wall. CFD models of the CO_2 were conducted for each of these configurations, at three different AEC selected to be within the normal operating range of HVAC systems. The letter-number designations, S1-S12 indicate the specific conditions.

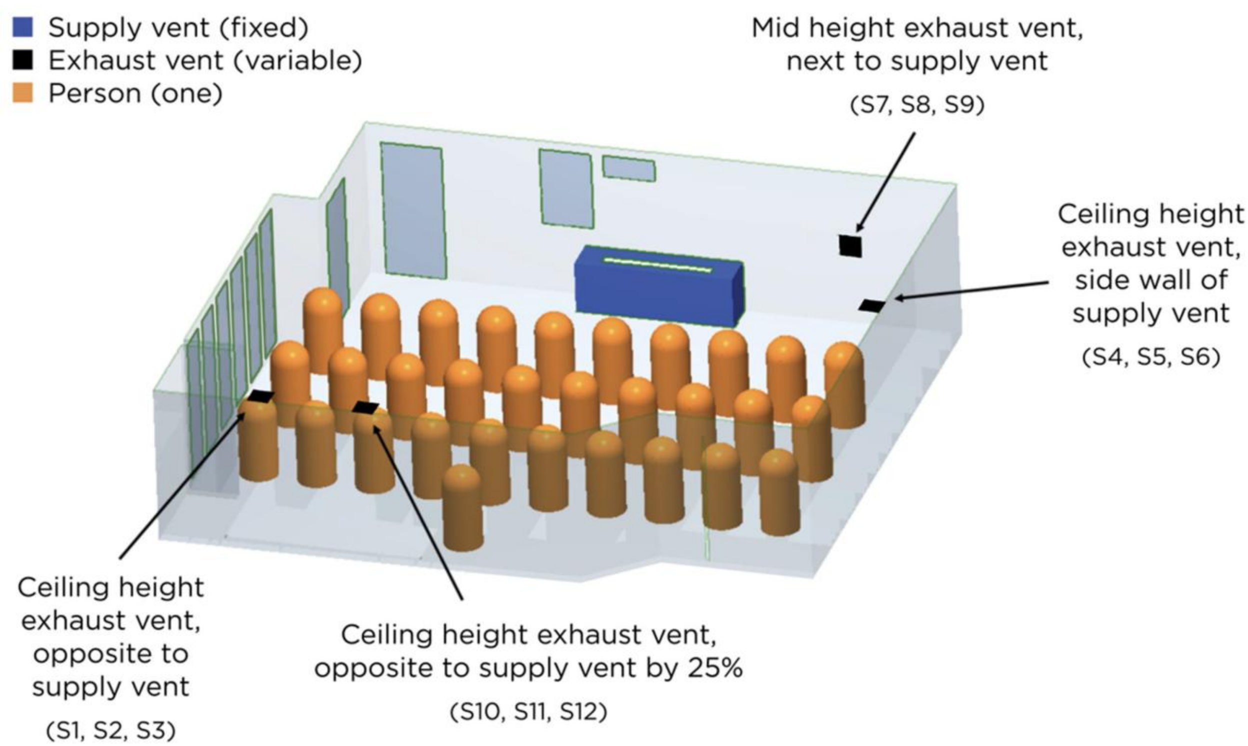


Figure H.7. Modeled classroom with different vent locations.

The results of this analysis are summarized in Figure H.8 below.

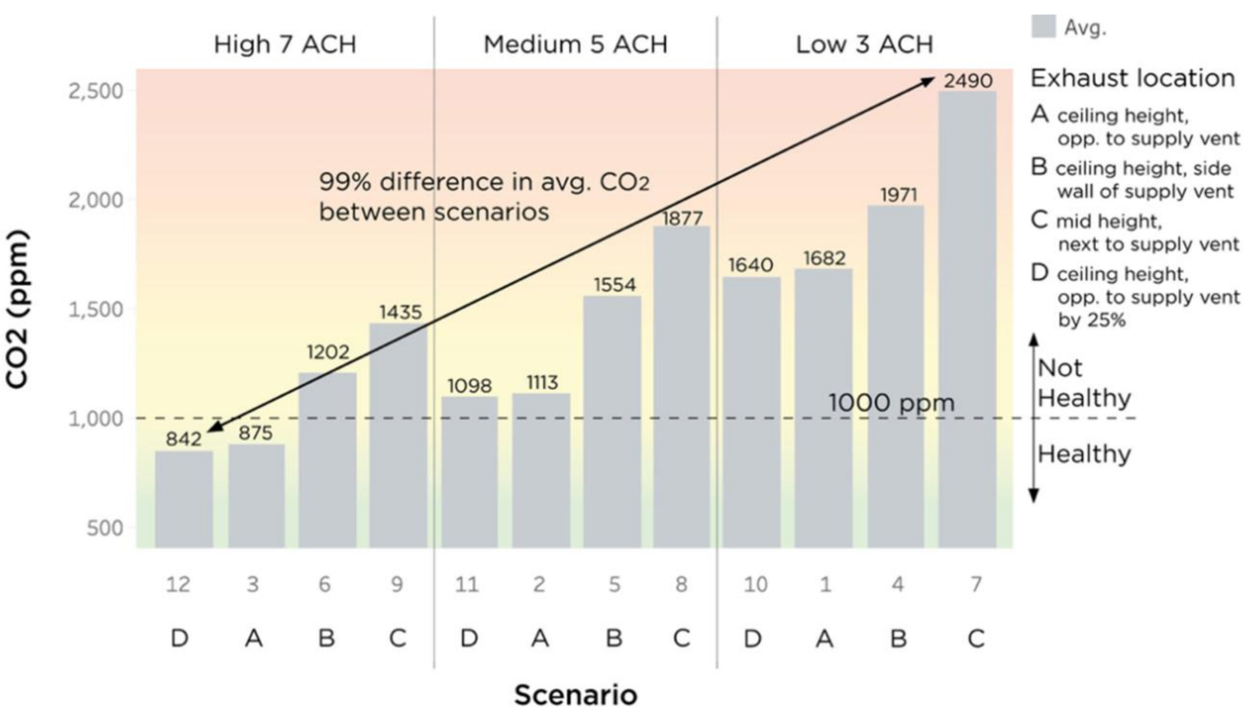


Figure H.8. Average room CO_2 concentrations for the twelve scenarios (combinations of four exhaust vent locations and three air injection velocities).

As expected, for the same vent configuration (A, B, C, or D), the average CO_2 concentration tracked monotonically with the air exchange rate, decreasing as the AEC (inlet clean air flow) was increased. The models indicated that the average CO_2 concentration and the variability (difference from average) differed significantly with different inlet-exhaust configurations.

Results for exhaust vents located on the opposite wall from the primary air inlet (configurations A and D) also showed significantly lower average values and less variability than configurations than scenarios where the exhaust was on the same wall or a wall perpendicular to the inlet vent.

Figure H.9 shows the cumulative percentage of the room volume that exceeded any specified CO_2 concentration. Unfortunately, the CFD models assumed a higher human volumetric breathing rate than a more recent literature search indicates, making direct comparison of the CFD and previous measurement in the classroom difficult, but the trends are expected to be consistent. Reports, publications, and other works resulting from this research are available at https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

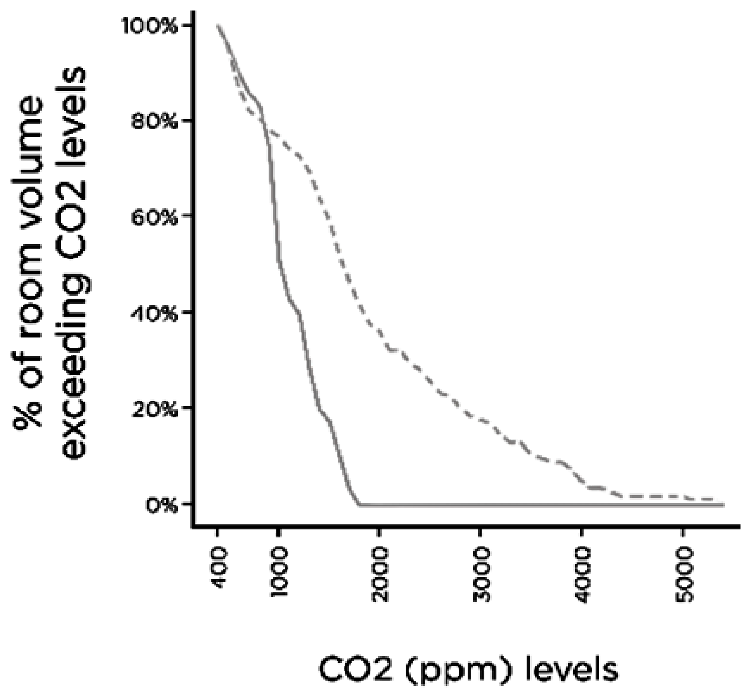


Figure H.9. Percentage of the room volume exceeding CO_2 concentrations (ppm) for vents on the same wall (dotted line) vs. vents on opposite walls (solid line).

In summary, this study found that:

- At the same air exchange rate, the worst configuration (vents on same wall) had average CO_2 concentrations that were 52-77% higher than the best configuration (vents on opposite walls);

- The worst performing configurations also had more uneven distributions of CO_2, resulting in pockets of very high concentrations; and
- Using the better performing vent configuration could allow for a lower ventilation rate while maintaining good air quality and thus save energy.

Computer Vision Technology

HNEI and its collaborators, MKThink (MKT) and RoundhouseOne (RH1), have explored the optimization of space and human flow to maximize energy efficiency, while maintaining comfort conditions. This collaboration led to the development of a series of cost-effective, easily deployable technologies to monitor indoor and outdoor environmental conditions to support studies of indoor comfort.

In support of this research, MKT and RH1 developed a sensor and analysis process titled "Computer Vision," which monitors and anonymizes the human location and movement within a space. The objective was to develop a process to anonymously measure human flow patterns, dwell times, dwell location, occupant spacing, and other metrics for the purpose of optimizing space utilization and energy management. The Computer Vision (CV) technology uses a video camera and real-time on-premise processing to anonymously track human movement by assigning temporary digital markers to each individual within the range of the camera. The digitized data extracted from each image frame is sent via cellular modem to a central server for processing. Locations and movement are then processed and mapped without requiring images to be stored or saved. This process assures absolute anonymity for those in the camera's range. The technology will allow users to associate foot traffic and movement patterns with specific areas of a facility in order to achieve optimal flow patterns. It can also be used to identify areas in which energy systems can be ramped down or turned off when not in use.

MKThink also developed the Air Angel, an outdoor self-contained data collection platform. Air Angel comprises a self-contained trailer integrating solar PV, environmental, communication, and MKThink's CV sensing technologies. The system measures air quality and other indoor environmental factors. As noted above, the CV sensors anonymously detect human activity, recording the number of people and how people are using the building spaces and systems. The environmental and CV data can be used for decision making such as opening and closing windows/vents.

In April 2021, a fully solar powered Air Angel platform was deployed at the Bishop Museum in Honolulu (Figure H.10). Data from this deployment was collected through 2021, documenting both brief and extended contacts in the interior and exterior spaces including time-of-day, location, group size, and distance. Figures H.11 through H.13 illustrate three of the several reporting images: H.11 summarizes visitors' dwell time in an interior zone; H.12 details the number of extended contacts (>5 seconds), proximity, and duration in an interior zone; and H.13 details the number of brief contacts (<5 sec.) and duration in an exterior zone.

Figure H.10. The Air Angel platform at Bishop Museum in Honolulu.

TIME IN TARGET

IN TARGET
During the operating time period observed, you were within your target performance for SAFETY 74.6% of the time.

[See Reference Page for metrics and thresholds covered by this report]

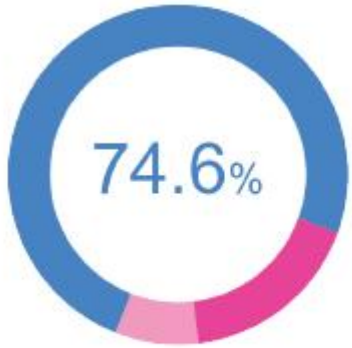


Fig. 01

EXTENDED
During the operating time period observed, you were outside of your target performance for SAFETY 17.5% of the time.

BRIEF
During the operating time period observed, you were at the boundary of your target performance for SAFETY 7.9% of the time.

BY LOCATION

IN TARGET
Target performance was observed in 96.2% of your space where OCCUPANCY was observed.

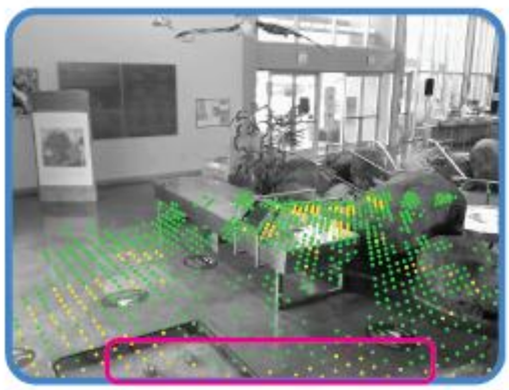


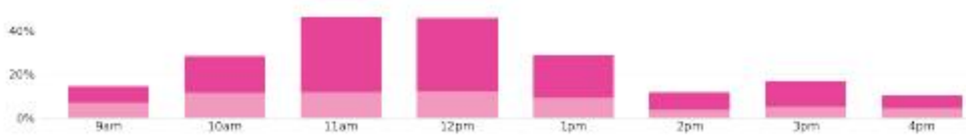
Fig. 02

EXTENDED
Extended contacts were clustered in 1 primary location.

BRIEF
Brief contacts were also clustered in 1 primary location.

BY TIME OF DAY

Fig. 03



BRIEF
65% of boundary performance was observed between 9am-1pm.

EXTENDED
66% of extended performance was observed between 9am-1pm.

Figure H.11. Sample report informing the duration of contacts by time of day for June 28, 2021.

CONTACT DETAILS EXTENDED

Fig. 06

OF OPERATING TIME

EXTENDED

These contacts lasted more than > 5 secs

SUMMARY STATS

Unique Contacts	Avg. Distance	Avg. Duration	Max Duration
14087	2.61 ft	9.05 sec	2min 34sec

Fig. 07

CONTACTS BY LOCATION

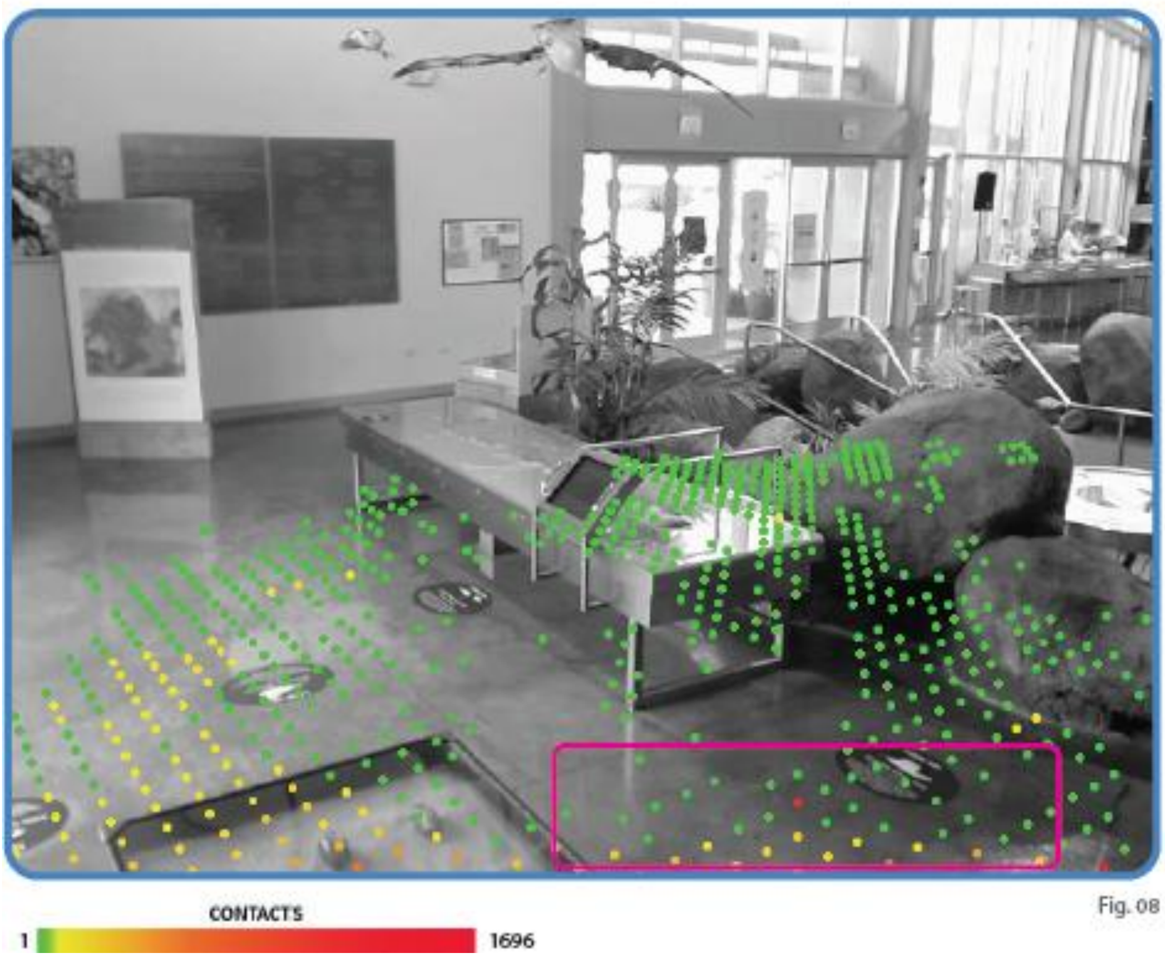
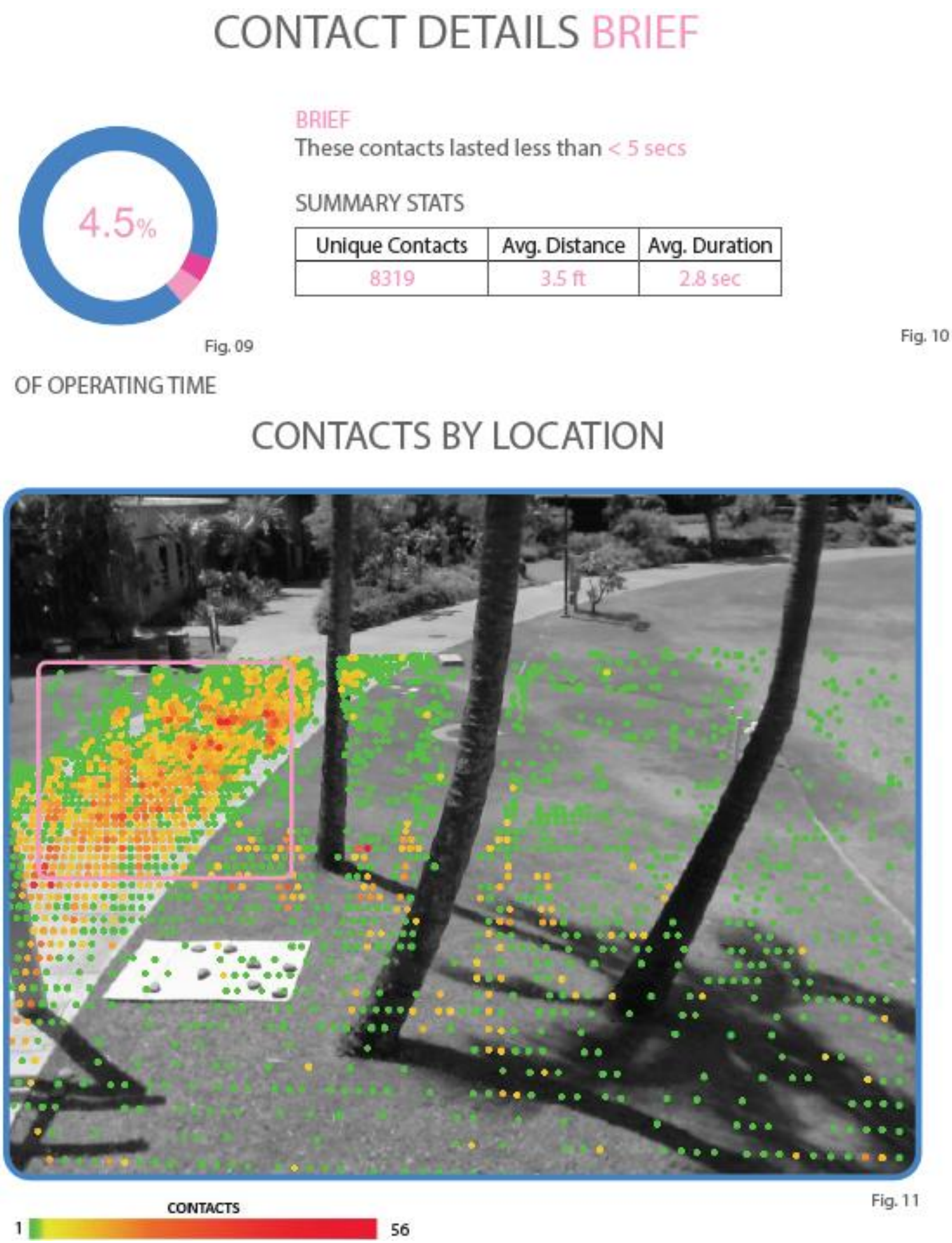


Fig. 08

Figure H.12. Sample report for Central Gallery interior zone, contacts >5 sec for June 28, 2021.



Unique Contacts	Avg. Distance	Avg. Duration
8319	3.5 ft	2.8 sec

Figure H.13. Sample report for exterior zones for contacts <5 sec. for June 28, 2021.

The Bishop Museum deployment was one of several pilot installations in Hawai‘i and California that sought to test the CV technology in different conditions. From October 2020 to February 2021, MKThink tested the Air Angel system in the San Francisco Zoo, on streets within the

Richmond and Sunset Districts in San Francisco, and at the Stanford University Law School. The Stanford deployment occurred under separate funding. When fully rolled out, CV can be deployed anywhere where human flow patterns, dwell times, and densities can help clients make operational decisions based on those factors. Reports, publications, and other works resulting from this research are available at https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

ROTC Test Platform

As a follow on to HNEI's prior development of the FROG project experimental energy test structures and interest in development of a new building to house a future Navy ROTC program, HNEI explored the feasibility of furthering its energy efficiency research while also providing a location that could meet Navy ROTC needs. In 2020, HNEI contracted MKThink to review currently-available, potentially-rapidly-deployable test platforms to be used as platforms for future studies on sustainable solutions in the built-environment.

MKThink conducted a preliminary study that defined a spectrum of platform typologies, ranging from 100% pre-manufactured (pre-fabricated) off-site to 100% rapidly constructable on-site (stick built), and a range of construction types, including wood, steel, and high tensioned fabrics. MKThink's evaluation of the possible designs included an evaluation of the: 1) company's ability to execute, 2) cost, 3) flexibility of size, 4) ease of delivery-to-site, 5) ease of installation, 6) flexibility of design, 7) flexibility of operations, 8) permitability, 9) portability, 10) durability, 11) energy efficiency, and 12) readiness for PV. More than fifty platforms were initially researched and twenty-eight were selected for further investigation. Of those, ten that had either previously delivered projects in Hawaiʻi or were deemed as "high confidence" in their ability-to-deliver were shortlisted for final review.

Subsequently, based on research interests and findings from the preliminary study, a revised problem statement "*How might we 'harden' existing, quick-to-deploy buildings so that they are able to withstand rapid changes in exterior environmental conditions or loss of surrounding infrastructure while maintaining comfort in safe and healthy operations?*" was posed. An investigation of potential platforms allowing tight environmentally controlled was initiated. MKThink identified four platform options (below) and ranked them based on the criteria summarized in Table H.1[2].

- *Option 1 ("Prefab")*: Use of containerized prefabricated structures with high-performance, non-structural insulated panels to create quick-to-deploy, highly controlled interior environment;

[2] Adapted from MKThink's 2020 ROTC Platform detailed report.

- *Option 2 (“SIPS”)*: Use of a structurally insulated panel system (SIPS) on the exterior of the building to create a highly insulated, nearly airtight environment within the entire space;

- *Option 3 (“Envelope + Air-Tight Modules”)*: Uses a structural envelope, such as a pre-engineered steel or high-tension fabric structure with medical-grade, airtight modules contained within the larger structure; and

- *Option 4 ("Edge Structure")*: Uses premanufactured structures designed for extreme climatic conditions, including high altitude and low/high temperature variation.

Table H.1. MKThink's evaluation of the four platform options.

Platform	Benefits	Cons	Cost Estimate for a 2,500 Gross Square Feet Structure	Average Ranking for Methodology Categories*
Prefab (Option 1)	Portability; Cost	Not a purely productized solution; Not as tight	\$1.9M - \$2.5M	2.5
SIPS (Option 2)	Insulated; Air-tight	Not a purely productized solution	\$2.1M - \$2.8M	2.9
Envelope + Air-Tight Modules (Option 3)	Super-insulated module within structure with advanced filtration system	Custom solution; Only a portion is insulated	\$2.0M - \$2.6M	2.6
Edge Structure (Option 4)	Can withstand extreme environments; Designed for off-grid	Generally not outfitted for this purpose (office and classroom)	\$2.4M - \$3.2M	3.3

**Ranking: 1 (low) to 4 (high) is relative to the other platform build options.*

MKThink subsequently developed an experiment plan to assess the performance of the platforms when accounting for variables, such as exterior environmental conditions, the surrounding infrastructure, "comfort" monitoring, and high-performance operational monitoring. Equipment recommendations for further testing and analysis included environmental and motion sensors, energy/water meters, gas detectors/monitors, and a weather station that measured UV/solar radiation, temperature, humidity, rainfall, and wind speed and direction. The intent was to use this assessment to develop a detailed test plan, identify a test site based on testing requirements, and determine the equipment, materials, and platform to acquire. Due to siting and funding limitations, however, these future actions were not undertaken. Reports, publications, and other works resulting from this research are available at https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

Support to the Institute on Science for Global Policy

Hawai‘i has introduced policy objectives to decarbonize its energy system. Major challenges include how to expand the introduction of renewable energy sources, while continuing to meet the immediate needs for energy historically derived from fossil fuels. A comprehensive review and critical assessment was undertaken to examine the potential to incorporate hydrogen into Hawai‘i's energy system to help meet these challenges.

The methodology of this project was to plan and hold an international Pacific Island hydrogen energy conference in Hawai‘i to identify potential plans for future hydrogen development in the region. Through APRESA funding, HNEI provided limited and partial support to the Institute on Science for Global Policy's (ISGP) conference entitled "*Global Pathways to Hydrogen Energy Futures: Island Community Priorities*" (GPHEF-ICP). ISGP states that its program is designed to conduct this type of critical evaluation by engaging a wide range of stakeholders each implementing different aspects of the hydrogen technologies in multiple, integrated, in-person conferences. ISGP conferences feature a debate/caucus format intended to promote candid, productive debates and caucuses to identify areas of consensus (AoC), evidence-based options, and actionable next steps (ANS) focused on supporting real-world decisions. This effort was intended to inform and guide decisions regarding employing and integrating hydrogen energy under various conditions that could help to develop actionable next steps for Hawai‘i. The GPHEF-ICP conference focused on specific hydrogen energy issues for private sector, government, and public stakeholders, with its initial efforts centered on the Asia Pacific region. It examined the critical decisions of individual island communities within vastly different sized archipelagos and the areas of common interest and similar challenges with respect to current and future energy issues.

In the initial planning phase of the conference, ISGP benefited significantly from numerous consultations with and advice from an Informal Advisory Panel (IAP) focused on Hawai‘i interests and ongoing activities in hydrogen-based energy. HNEI staff provided considerable program management support services to ISGP by serving as an IAP co-chair and as a planning team member. The organization of the ISGP GPHEF-ICP conference began with extensive international meetings by ISGP staff (approaching 300) to identify highly credentialed subject-matter experts; and officials in governmental, private sector, and public advocacy communities having expertise, experience, and responsibilities for decisions related to energy topics. In addition to Hawai‘i-based team members including HNEI, Hawaiian Electric Company, and Hawai‘i Gas, these interviews included representatives from islands throughout the Asia Pacific region as well as representatives from Australia, Japan, the United States, United Arab Emirates, and Association of Southeast Asian Nations (ASEAN) members.

From two rounds of interviews, the conference team selected nine individuals—seven focused on describing the energy needs and aspirations of seven Asia Pacific islands including Hawaiʻi; one individual describing the scientific and technological properties of hydrogen as an energy source; and another individual commenting on economic issues from the perspective of the Asian Development Bank. They were invited to prepare a concise position paper on their respective perspectives and priorities. The position papers on hydrogen-based energy were each organized around current realities, scientifically and technologically credible opportunities and potential risks, and next steps. The following position papers were presented and debated:

1. "Do We Need Hydrogen for Sustainable & Zero Emissions Energy Conversion?"
2. "Archipelago (Tuvalu) Perspectives on Energy, Challenges, Priorities, Opportunities for Hydrogen Energy"
3. "Elimination of Fossil Fuel Imports and Decarbonization of County Assets by Way of Hydrogen Energy" (County of Hawaiʻi)
4. "Archipelagos: Perspectives on Energy Challenges, Priorities, and Opportunities for Hydrogen Energy of Tonga"
5. "Hydrogen Production in an Island Energy System" (Tasmania)
6. "Archipelagos: Perspectives on Energy Challenges, Priorities, and Opportunities for Hydrogen Energy in Indonesia"
7. "The Future of Fiji Energy System: Supporting the Transition of Achieving Fiji's SDG7 and NDC Targets by 2030"
8. "Economic Viability Considerations for Green Hydrogen in New Zealand"
9. "How Our Ocean Can Save Our Planet"

Due to insufficient funding necessary to host an in-person conference, ISGP modified the format and agenda to conduct a Hawaiʻi-based internet meeting. The GPHEF-ICP conference was held virtually over three days on June 21-23, 2022 and spanned fifteen time zones. The conference was conducted using an internet format linking approximately 56 participants representing 30 different countries and locations. The ISGP debate/caucus format was modified to have each of the nine position papers debated for forty-five minutes by approximately 56 invited participants following a five minute summary of the position paper by the respective authors. All debates and caucuses were moderated by ISGP staff. Given the exceptionally diverse time zones involved, participants engaged in the debates and caucuses for different periods of time. Nonetheless, all contributions—debates, discussions, and the plenary caucuses to prepare not-for attribution summaries—were integrated into the conference outcomes. The position papers, commentaries, and the not-for-attribution summaries of the AoCs and ANS emerging from the plenary caucus are presented in the ISGP conference book, which is available on ISGP's website at http://scienceforglobalpolicy.org/conference/island-priorities/.

VIETNAM

Through support from the APRESA award, HNEI built strategic partnerships with a number of Vietnamese organizations including non-governmental organizations (NGO) and government ministries and institutions, creating a solid foundation for long-term collaboration and knowledge exchange. Projects with or supporting Vietnam organizations are described below.

Saigon Energy Hub (SEHub)

Under this project, HNEI provided support to Ho Chi Minh City's local NGO, the Institute for Regional and Urban Studies (IRUS) to design and implement the Saigon Energy Hub (SEHub), a virtual, publicly accessible, education platform offering energy-related forums to the community. The development of this public, renewable demonstration and technology center sought to raise community awareness of the needs, feasibility, and benefits of energy efficiency (EE) and renewable energy (RE). This project was comprised of two phases: a planning, design, and construction phase for development of the workshop platform and an implementation phase where contractors present eight publicly accessible energy-related workshops through the workshop platforms.

The project was initiated in July 2018, when HNEI contracted MKThink to facilitate a two-day bilingual, technical workshop in Ho Chi Minh City, Vietnam. MKThink, IRUS (previously named the Center for Regional and Urban Studies), and HNEI collaborated to host this stakeholder workshop on July 24-25, 2018. Fifty-seven attendees including researchers, government officials, businesses, NGOs, and implementation contractors participated in Day 1 of the workshop. The objective was to engage critical stakeholders and potential partners in Vietnam to identify major barriers to the implementation of EE and RE projects, and identify a project addressing one or more of those barriers. Day 1 began with presentations and panel discussions to identify barriers and potential projects, then shifted to a more detailed discussion of potential project, and ended with participants' voting on the needs/solutions that they felt were most compelling for advancing as a demonstration project. Four areas of focus emerged from stakeholders' feedback: 1) solar-enabled energy solutions; 2) waste-enabled energy solutions; 3) energy price – environmental cost parity; and 4) AC use reduction (alternative strategies). On Day 2, HNEI, IRUS, and MKThink held additional discussions from which it was determined to move forward with a solar-enabled energy solution project as it represented strategic interests for both HNEI and IRUS as well as the majority of other workshop participants. The workshop process and outcomes are outlined in MKThink's "*Vietnam Energy Efficiency: Workshop Summary Document*" report, available at https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

IRUS initially planned to design and implement a publicly accessible solar photovoltaic (PV) demonstration project, the Sai Gon Energy Park, to raise public awareness of the feasibility and benefits of RE. It was intended to exhibit RE technologies in a public urban park setting, consisting of an energy self-sufficient pavilion with integrated PV panel, emerging technologies, and educational elements. However, due to project interruptions resulting from COVID-19, the Park project was unable to move forward and was replaced with the Saigon Energy Hub (SEHub), a virtual, publicly accessible, education platform offering energy-related forums to the community.

In 2023, the reconfigured SEHub project began with the planning, design, and outfitting of the workshop platform. The Ho Chi Minh City Union of Science and Technology Association permitted the use of two meeting spaces within their headquarters' building located in District 3, Ho Chi Minh City (Figure V.1, left), allowing IRUS to install video and audio devices and fixed connection equipment system in these spaces for online and offline workshop presentations (Figure V.1, right).

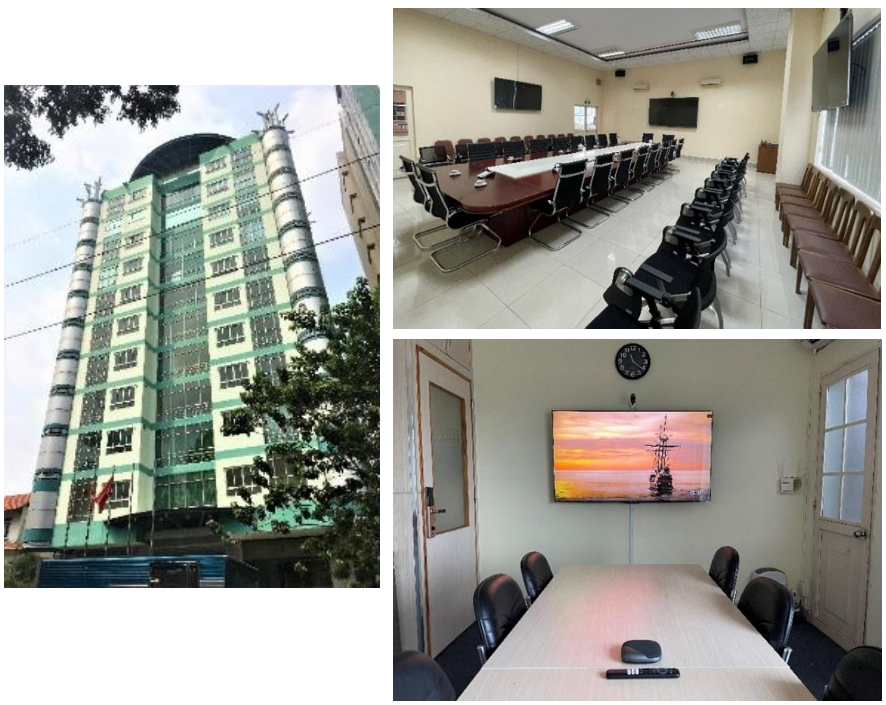


Figure V.1. The Association's headquarters building (left) and the workshop meeting spaces (right).

This was followed by an implementation phase where IRUS presented eight publicly accessible workshops on various energy efficiency and renewable energy themes through the workshop platform. This series, held from March through December 2024, spanned over 38 hours with 10 speakers and 310 participants, with participants representing a range of stakeholders including researchers, technology associations, business owners, and policy makers. The topics of the workshops were:

1. Carbon Credits: How Do Businesses Start?

2. The Development of Can Gio Offshore Wind Power
3. Legal Framework Regarding Energy Saving and Efficiency
4. Energy Management and Energy Management System
5. Proposal of Ho Chi Minh City - Can Tho City Railway Project
6. Ho Chi Minh City Onemap In Vector Grid - An Effective Urban Management Tool in the Digital Transformation Trend
7. Sea Current Power - Green Energy Source of Vietnam in the Near Future
8. Introduction of the Carbon Credit Trading Simulation Mode – Carbonsim

The SEHub project contributed to: 1) community awareness regarding RE and EE; 2) knowledge and experience dissemination among stakeholders including universities, research institutes and centers, businesses, NGOs, NPOs, and local communities; and 3) capacity building for local Vietnamese partners in the fields of RE and EE. This project provided a foundation for future partnership opportunities between HNEI and IRUS. Reports, publications, and other works resulting from this research are available at https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

Innovation System Mapping Project

With rapidly growing industrialization and modernization of the economy, energy demand in Vietnam increased rapidly between 2016-2020 and is predicted to increase by eight percent per annum through 2030, resulting in a four-fold increase in total electricity demand compared to 2014. While the development of renewable energy resources in Vietnam is a government priority, there has been a lack of clarity about the role of many organizations in Vietnam impacting energy development, the relationship between them, and the policies required to foster energy innovation. Under this effort, HNEI provided financial support and guidance to the National Institute for Science and Technology Policy and Strategy Studies (NISTPASS) in the Vietnam Ministry of Science and Technology to map the innovation opportunities associated with renewable energy (RE) sector development in Vietnam.

This project began in August of 2019 and was largely completed at the end of 2023. An objective of this work was to identify which Vietnamese stakeholders in the RE sector would benefit from further policy and institutional support. To meet the aggressive government goals associated with RE innovation, this project focused on identifying relevant organizations in the sector and understanding how they interact with each other and as a system. The analysis involved an exhaustive review of energy producers, energy consumers, business systems, educational and research systems, policies, regulations and statutes, and infrastructure developers.

In 2020, NISTPASS completed its initial assessment of the innovation and RE sector innovation system (SIS) in Vietnam. They concluded that a SIS concept seems the most appropriate to deal with specific features of a sector in terms of innovation dimensions. This mapping, based on the National Systems of Innovation Concept (Figure V.2), adapted from the Organisation for Economic Co-Operation and Development (OECD)[3], included the functions and challenges of the SIS, stakeholders and linkages and mutual learning between stakeholders, and preliminary concepts on policy to promote the SIS. This OECD approach has since found acceptance amongst policymakers, as it provides a more comprehensive approach with more opportunities for input than is provided by the traditional market failure approach, which includes correction through policy intervention.

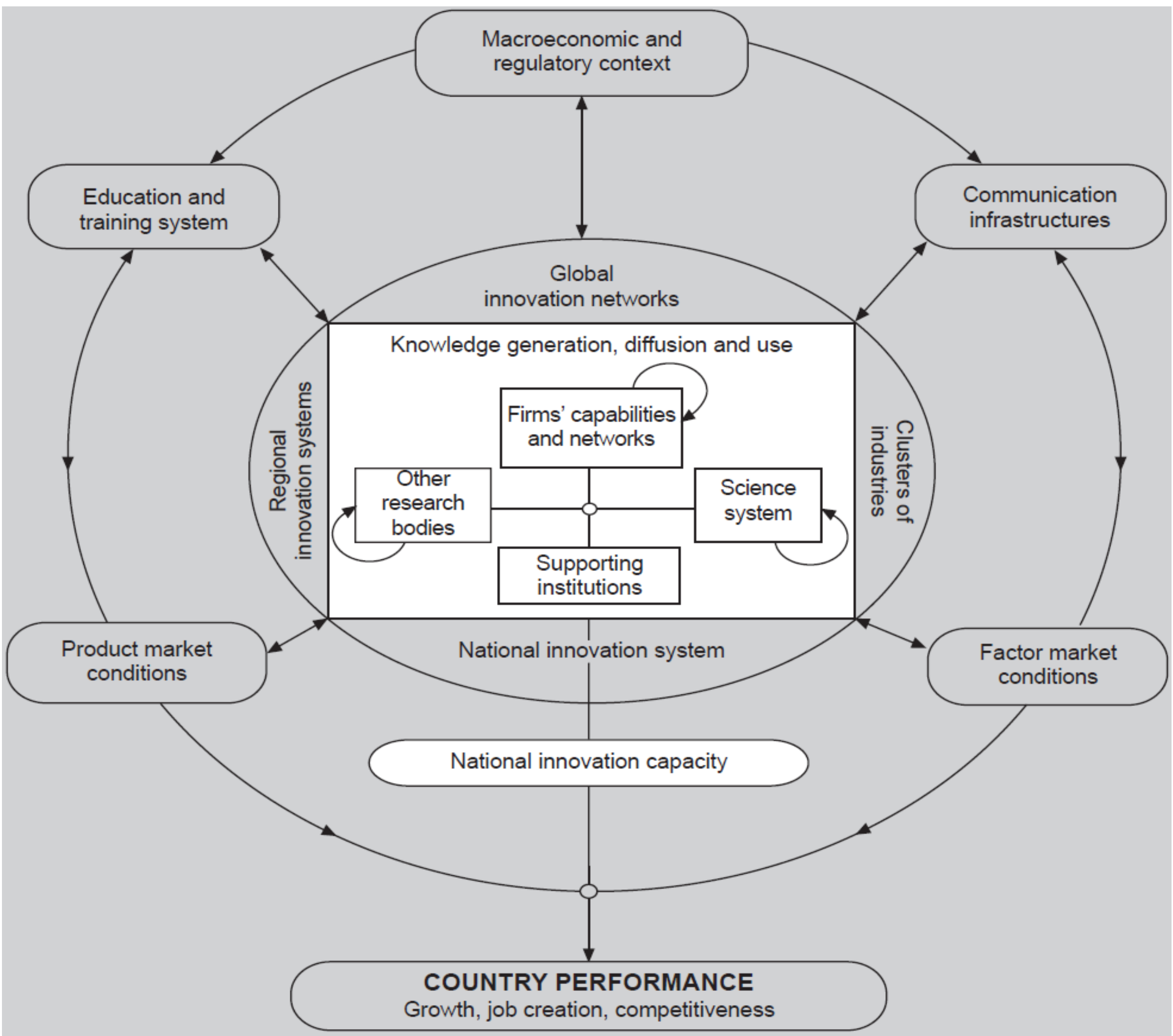


Figure V.2. Actors and linkages in the innovation system (extracted from the OECD's "Managing National Innovation Systems" report[3]).

[3] OECD. (1999). *Managing National Innovation Systems*. https://www.oecd.org/en/publications/1999/05/managing-national-innovation-systems_g1gh2446.html.

During their assessment, NISTPASS drew the following conclusions for mapping sector innovation systems in renewable energies:

- A sector system of innovation includes ingredients such as technologies and key knowledge as well as learning processes of the sector; actors/stakeholders operating in the sectors; institutions that regulate linkages between actors in the sectors; and demand specific to the sector.
- Key knowledge and technologies of the sectors should span across the whole value chain of the sector such as generation/production, transmission, and distribution and sale sub-systems.
- Actors/stakeholders in this sector innovation system include the following groups: firms of different ownership and size, both national and international operating in the market; academic organizations such as research institutes/centers and universities; intermediary organizations such as consulting, financial, information, IP, and technical services organizations; and government agencies issuing institutions, which can be at both national and subnational levels (provinces, cities).
- Linkages among these actors/stakeholders include cooperation, transaction, competition as well as exchange of knowledge, experiences, embodied technologies as well as other forms of knowledge via training, learning, sharing, and co-working.
- Institutional framework that regulates these linkages should include explicit official policy documents and actions, and implicit practices and regulations.

The NISTPASS effort focused on aspects relevant for learning and upgrading technological capabilities of stakeholders for the purpose of fostering localization and indigenous capabilities, and promoting the innovation system rather than addressing the broader issues related to RE development. Solar and wind energy were given a greater focus due to the large generation potential for these resources in Vietnam and the country's official Power Development Plans.

Building upon their initial assessment, NISTPASS held three scientific workshops between March and July 2021. Topics discussed during these workshops included: the existing issues of solar and wind power development in Vietnam, analysis of the institutions and policies affecting RE industry development, and policy recommendations. In 2021 and 2022, NISTPASS completed two rounds of interviews with stakeholders in the renewable energy sector in Vietnam, focusing on solar and wind energies. The 40 stakeholders interviewed in this process were divided into 4 groups:

a) companies working in the energy sector that are using, adopting, and implementing innovative energy technologies (19 firms);
b) academic and educational organizations like research institutes and universities that provide knowledge and human resources via research and training for the renewable energy sector (9 institutions/universities);

c) government agencies that provide oversight, regulatory authority, and energy policy framework on renewable energy (7 organizations); and
d) intermediary organizations that support and facilitate the process of technology and other types of innovation of the sector (5 organizations).

In April 2023, NISTPASS held a workshop with various Vietnamese groups, which was attended by HNEI and ONR personnel. The workshop focused on presenting the key findings of the study, while also allowing further discussion with stakeholders to fine-tune research results. Workshop participants visited a solar farm in Khanh Hoa province and discussed collaboration on RE technology upgrading and utilization.

The project provided a substantial amount of data for analysis due to the combination of an exhaustive literature review, stakeholder analysis, workshop discussions, and two rounds of in-depth interviews with selected key stakeholders.

Incorporating inputs from the scientific workshops and interviews, NISTPASS identified 21 trends and findings and produced a final technical report titled "*Sectoral Innovation System in Renewable Energy: Case of Solar and Wind in Vietnam*." These findings, ranging from opportunities in the supply side of the sector innovation system to the impacts of environmental factors and the COVID-19 pandemic, are summarized briefly below. Reports, publications, and other works resulting from this research are available at https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

1. There is a shortage in the supply and development of human resources (training) for the RE sector from research organizations and universities. Lack of support and funding contributes to this issue.
2. Vietnamese research institutes usually conduct small scale research projects that tend to be for publication and ranking for an academic career rather than for industrial uses.
3. Vietnamese organizations participate very little, almost insignificantly, in the creation of the technology components (solar cells, inverters, wind blades) since most are imported from suppliers abroad.
4. The localization rate of Vietnam in the technologies and equipment of solar and wind power is quite low due to weak manufacturing supply chains; an appropriate policy environment is needed.
5. Vietnamese businesses have developed and mastered the capability to construct and operate solar and wind power projects.
6. The main learning mechanism of Vietnamese businesses in solar and wind power is via short-term training programs and classes at their facilities (on-the-job training) to improve the capacity of their employees.
7. The interactive linkages between components of the innovation system (business, R&D institutions, state management organizations) vary immensely, but are not strong overall.

8. The market of the renewable energy industry is quite nascent and still has many instability problems. There is still a lack of strong, long-term, and stable RE supporting mechanisms and policies to promote the strong development of this industry.
9. After applying for a project license (or after a short period of operation) and receiving short-term benefits, such as feed-in tariffs, many Vietnamese investors have sold projects to foreign investors. Reforms through policy solutions are needed to address this.
10. The institutional system for RE development is quite simple, lacks many options and different forms of support, and is mostly based on using attractive feed-in tariffs price policy to attract investment.
11. The role of the intermediary organizations is not prominent in the RE innovation system.
12. An emerging issue that strongly affects the accumulation of technological capacity and knowledge learning process in the solar and wind power sectors is the mismatch between the power generating capacity of the projects and the power capacity of the transmission system.
13. Technical regulations and standards are another issue that was raised by businesses as a factor that still hinders innovation activities.
14. Environmental factors are cited as a barrier to wind and solar power project development. RE development addresses climate change, but environmental pollution occurs from RE technology component end-of-life waste.
15. The COVID-19 pandemic has affected the development and implementation of projects in Vietnam, such as delayed delivery of equipment/machinery and experts and specialists shortages due to quarantine policies.
16. In addition to innovation of technological hardware, Vietnamese companies have explored innovation in transmission systems such as solutions and system design.
17. Support and engagement of the local government of provinces and cities, stakeholders in the innovation system, vary.
18. Political decisions and considerations can overtake technical and professional factors and change the course of development.
19. Offshore wind development is new, vast, and much more complicated economically, technologically or environmentally, than onshore wind or solar energy. Due to this, companies have asked for a policy to specifically support these projects.
20. The incentive policy for rooftop solar power and floating solar power on hydro-reservoirs, intended for agriculture companies, is being abused, creating quasi-farms for solar energy generation without any agriculture production.
21. Due to the attractive feed-in tariffs price policies, many companies with little to no energy backgrounds simply jump into RE business with little preparation, which result in many short-lived projects.

Vietnam Low Emission Energy Program (V-LEEP) RPS Development

A renewable portfolio standard (RPS) is a public policy tool requiring a certain amount of renewable electricity relative to the entire electricity supply. To complement the Government of Vietnam's National Power Development Plan VII (PDP7) and ensure successful implementation, a policy study of examining effective RPS policies globally was requested. HNEI, in collaboration with the National Renewable Energy Laboratory (NREL), advised Vietnam's Ministry of Industry and Trade (MOIT) and other Vietnamese stakeholders on the design of an RPS mechanism and a roadmap for its implementation. This effort, conducted in support of the United States Agency for International Development (USAID)-funded Vietnam Low Emission Energy Program (V-LEEP), sought to provide guidance allowing an increased deployment of renewable energy projects in Vietnam. HNEI and NREL assessed international RPS models, identified best practices applicable to Vietnam, and prepared a draft RPS roadmap based on research of the Vietnam power sector and power market reforms and other announced changes.

The study provided an overview of RPS internationally and highlighted key design elements and best practices for RPS that included: 1) using analysis to inform RPS design; 2) gathering stakeholder input in developing production targets; 3) identifying eligible renewable resource types and vintages; 4) clearly defining RPS components such as allowable resource types, timing for targets, obligated entities, inclusion of existing or only new generation, and exclusions; 5) enforcing compliance; and 6) providing a cost-containment provision. The team reviewed RPS policies in the United States, Mexico, China, Korea, and Australia, and the Philippines' draft RPS design. This effort produced a technical report titled "*International Best Practices for Implementing and Designing Renewable Portfolio Standard (RPS) Policies*," co-authored with NREL, available at https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

The study was followed by public and private sector consultations to gather input on findings and approaches supporting Vietnam's Renewable Energy Development System (REDS) action plan. Guidance documents and reports co-authored by HNEI were submitted to the Electricity and Renewable Energy Authority (EREA) under the Vietnam Ministry of Industry and Trade. In March 2019, a mission report summarizing the project's work products and outcomes was presented to MOIT, national executive agencies and jurisdictions, utilities, and energy stakeholders in a series of outreach and advisory meetings in Hanoi and Ho Chi Minh City. This project resulted in a replicable structure and framework for evaluating best practices in renewable policy development for this rapidly growing economic region.

V-LEEP Technical Support for Vietnam's Power Development Plan (PDP8)

Working closely with the U.S. government agency-funded V-LEEP program led by Deloitte and in collaboration with the National Renewable Energy Laboratory (NREL), HNEI engaged with key Vietnamese authorities, including MOIT, EREA, the Electricity Regulatory Authority of Vietnam (ERAV) and the Institute of Energy (IEVN). These efforts supported the Government of Vietnam in addressing surging energy demand, enhancing policy and regulatory frameworks, and attracting public and private investment in advanced energy sources. This work, conducted by HNEI's Grid Systems Technology Advanced Research Team (Grid***START***) provided technical support for the development, approval, and amendment of Vietnam's PDP8, which now guides the country's power sector strategy for 2021-2030 with an outlook to 2050. PDP8, first approved in 2023 and amended in 2025 in response to national priorities, sets ambitious generation capacity targets between 183 and 236 GW by 2030 and from 206 to 229 GW by 2050. The plan clarifies a decreased reliance on coal, accelerates adoption of technologies such as battery storage, hydrogen, and ammonia; increases the share of imported liquefied natural gas (LNG); and strengthens commitments to grid modernization, transmission upgrades, rural electrification, and private investment.

The impact of this project extended beyond the PDP8 recommendations by supporting Vietnam's technical planning capabilities. Together with the other project partners, HNEI helped update the longstanding power planning methodology by integrating international best practices by introducing advanced scenario modeling and open stakeholder engagement. A key milestone was supporting the establishment of the Modeling Working Group (MWG) within MOIT/EREA, which became the technical nucleus for scenario analysis and production cost evaluation. Capacity building was a key part of these efforts. In 2019, HNEI, V-LEEP, and NREL delivered two intensive training workshops for the MWG and other key stakeholders:

- The first training (November 19-21, 2019) introduced production cost modeling (PCM) for power development planning. Participants learned to use the PLEXOS simulation tool, which enabled modeling of Vietnam's grid with higher levels of variable and intermittent generation, and gained practical skills in analyzing operational costs and long-term scenarios; and
- The second training (December 18-19, 2020) introduced the System Advisor Model (SAM), applying flexible technologies, assessment of operating reserves, model calibration and least regrets planning techniques.

These capacity building efforts were complemented by a March 2021 technical report, prepared with core analytical and writing input from Grid***START*** and NREL, and delivered to MOIT/EREA. The report evaluated the impacts of integrating significant new energy sources into Vietnam's grid using advanced simulation tools and offered actionable recommendations for generation and transmission planners, including guidance on optimizing PDP8 through data-driven, least regrets approaches. These efforts left Vietnam with a strengthened technical foundation and regulatory capacity, better positioning the country to attract investment, manage rapid economic growth, and accommodate diverse energy technologies and sources into its evolving power sector. A list of presentations by Grid***START*** related to their international efforts, including this topic, is available at https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

Institute of Energy Grid Planning

In 2024, HNEI established a collaboration with the Institute of Energy (IE), an operational arm of the Electricity and Renewable Energy Authority of Vietnam (EREA) under the Ministry of Industry and Trade (MOIT). IE is Vietnam's primary organization for recommending all energy policies, including Power Development Plans (PDPs), and advises the government on energy planning and policy.

HNEI and EREA had previously developed a Memorandum of Understanding (MOU) to identify research and analyze renewable energy policy, strategy, and deployment in Vietnam. Following a pause due to the COVID-19 pandemic, this collaboration resumed through IE, which provides technical input and advice to EREA.

IE identified challenges in determining pricing structures for new energy technologies like solar, offshore wind, and LNG that were being proposed for integration into the Vietnam grid. To address this, IE requested HNEI's training support in energy modeling software to facilitate informed decision-making.

HNEI contracted Telos Energy Inc., an energy consulting company, already actively engaged with HNEI, to conduct similar modeling for the various Hawaiʻi grid systems. HNEI worked with Telos, with input from IE, to develop a training plan for IE. The proposed plan included approximately 14 to 20 two-hour sessions covering: Introduction to PLEXOS, Intermediate Power System Modeling, Resource Adequacy and Stochastic Analysis, and Power Market Modeling. This document can be accessed via https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

This was delayed due to urgent priorities at IE. Training then commenced virtually in March 2025. Between March and May 2025 when APRESA ended, five sessions were completed covering various aspects of Capacity Expansion Modeling (CEM), Production Cost Modeling (PCM), and Resource Adequacy (RA) Modeling. The training materials for Session 1 can be accessed via https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

These sessions also included introductory discussions of electricity market structures and a comparison of modeling tools such as PLEXOS and SAInt (from Encoord). The training aims to establish a foundation for open, transparent, and cross-platform modeling, supporting continuing capacity at IE for integrated energy planning.

The training ended in May 2025 due to the end of APRESA. Other funding is being sought to continue this work.

THAILAND

HNEI collaborated with a number of universities, utility, and the country's regulatory commission to conduct research and projects in Thailand. Through these efforts, HNEI has impacted Thailand's energy sector; supported the country's energy transition by integrating new technology, deploying advanced grid solutions, and building institutional expertise; and built technical capacity in power system planning, grid modeling, energy production forecasting, grid-edge sensing, microgrid operations and regulatory standards. Projects with or supporting Thai organizations are described below.

Support to Chiang Mai Rajabhat University's PV-Biogrid Project

Under APRESA, HNEI supported Chiang Mai Rajabhat University's (CMRU) design, development, and implementation of a bioreactor system to hybridize a community PV grid system and extend hours of electricity availability (Figure T.1). Solar power is one of the most popular renewable power sources; unfortunately, power generation by solar photovoltaic system varies according to environmental conditions such as temperature, light intensity, time of day, and wind speed. Biowaste, which is readily available in local communities in Thailand, can be used to provide firm power to the grid. Under this project, biobased waste to energy potential and technology landscape in Thailand and the Association of Southeast Asian Nations (ASEAN) region were investigated and reported. Anaerobic digestion technology was selected, installed, and tested alongside rooftop and off-grid PV systems at the Chiang Mai World Green City (CMWGC) community at CMRU, Thailand.

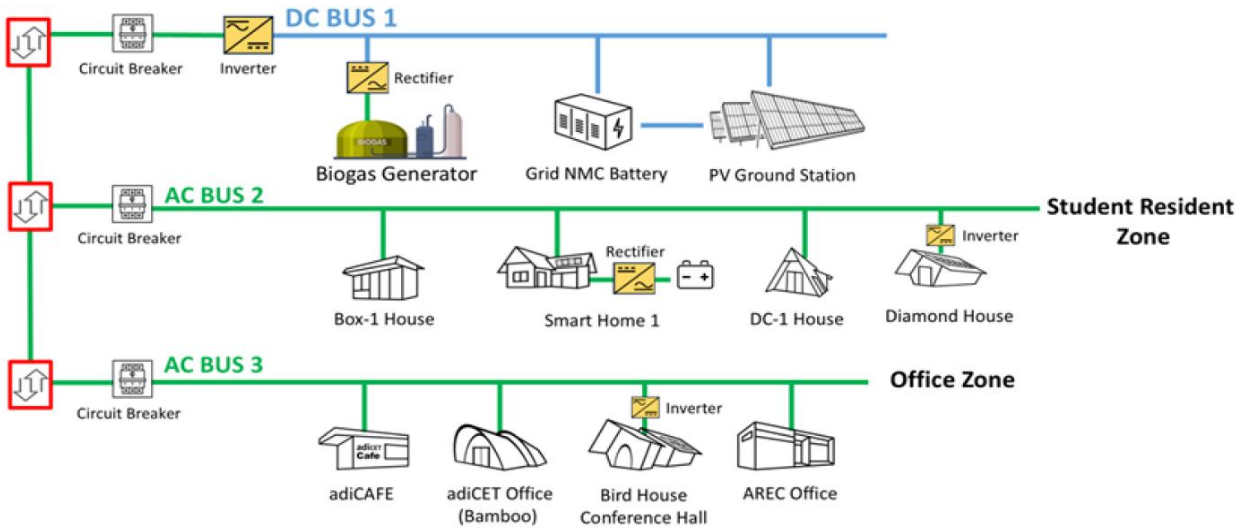


Figure T.1. Diagram of an isolated community PV/biogas microgrid.

The project's final report "*An Integrated Modular Approach: Waste-to-Bioenergy Conversion for Community PV-BioGrid*" is available at https://www.hnei.hawaii.edu/publications/project-reports/apresa/. This provides updates on biobased energy potential for the countries of Thailand, Vietnam, Cambodia, Lao PDR, Malaysia, Indonesia, Myanmar, Singapore, Philippines, and Brunei. Most of these countries have large agricultural sectors that produce copious amounts of underutilized agri-residues. Although regional analysis indicates that policies are being promulgated to encourage use of biomass resources across southeast Asia, it is unlikely that community scale applications would experience shortfalls in supply due to their remote locations and biomass's distributed availability. Access to funding was identified as a key investment barrier to widespread implementation.

Anaerobic digestion (AD) reactor technology was selected for the project due to its versatility in accepting a range of biomass feedstocks, including agricultural residues, household waste, and solid waste and wastewater from homes and animal husbandry. The technology is robust and relatively simple making it amenable to rural, off-grid, community applications. Direct combustion of the biogas product can also be used for cooking and lighting, fulfilling other community needs in addition to electricity generation.

The total electricity demand across all of the buildings at CMWGC totaled roughly 95 kWh with distinct load profiles for offices/businesses and residences (Figures T.2 through T.4). Ground mounted and rooftop PV can produce up to 115 kWh per day and the mid-day production peak typically exceeds the demand. While the scale of the AD unit was insufficient to meet the total demand of CMWGC, the unit provided the opportunity to address integration issues for small, isolated grids.

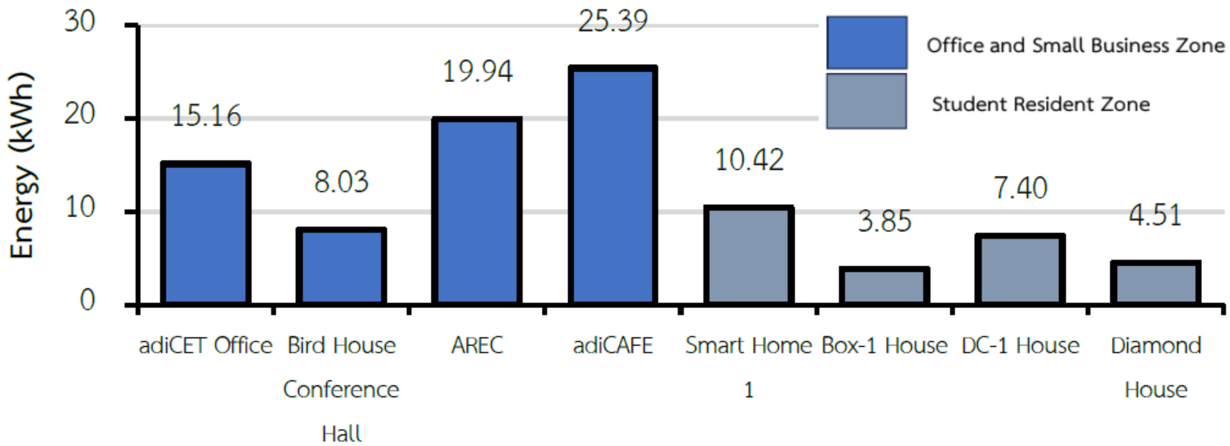


Figure T.2. Energy consumptions of the buildings at CMWGC.

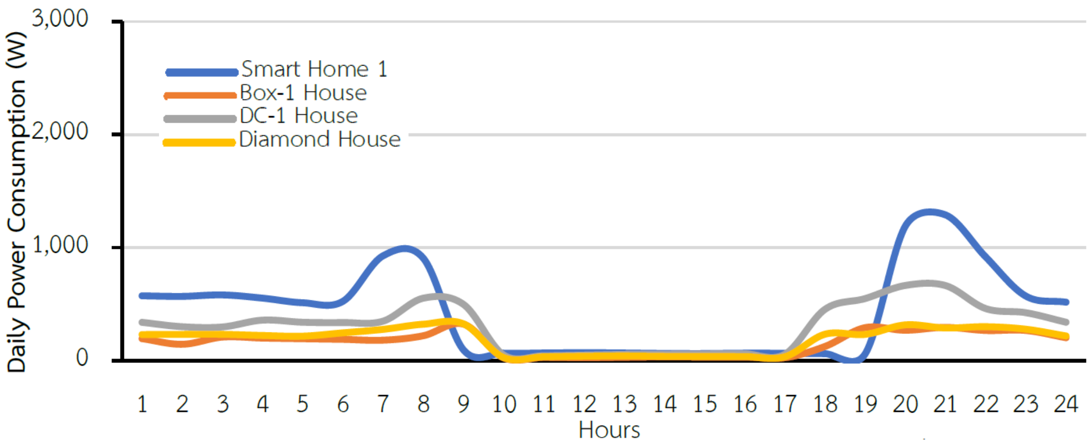


Figure T.3. The load profiles of the four student houses.

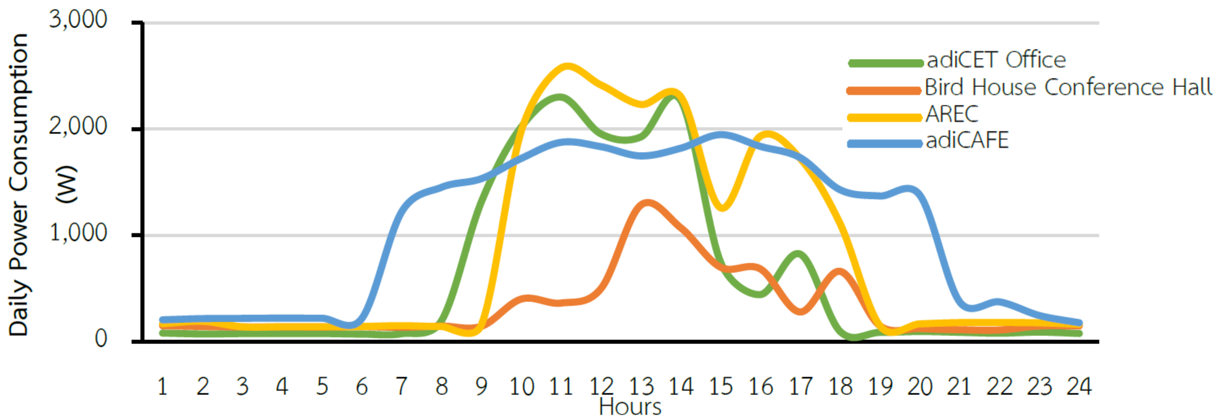


Figure T.4. The load profiles of the offices and small business.

While the scale of the AD unit was insufficient to meet the total demand of CMWGC, the unit provided the opportunity to identify and address integration issues for small, isolated grids operating with intermittent, weather-dependent generation resources and small firm power generators. Figures T.5 and T.6 display additional results from the testing.

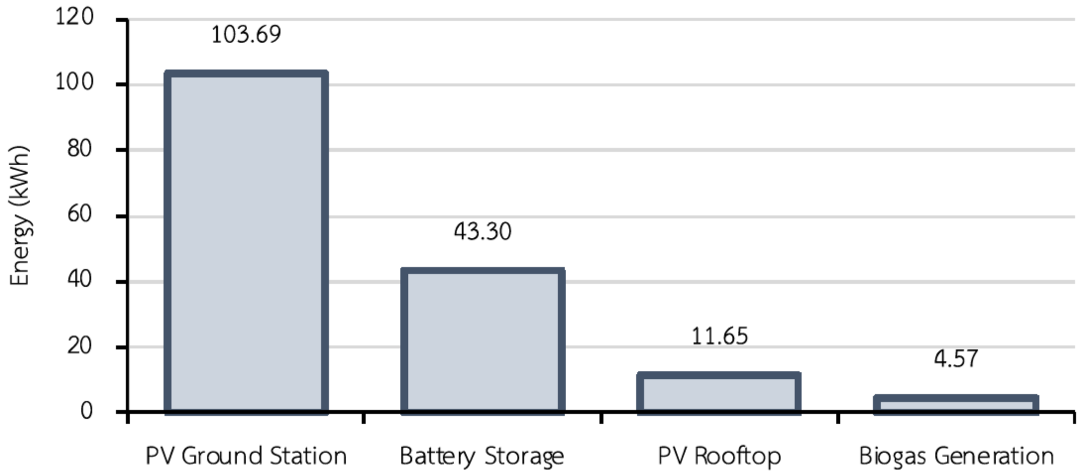


Figure T.5. Daily generation of energy produced per source.

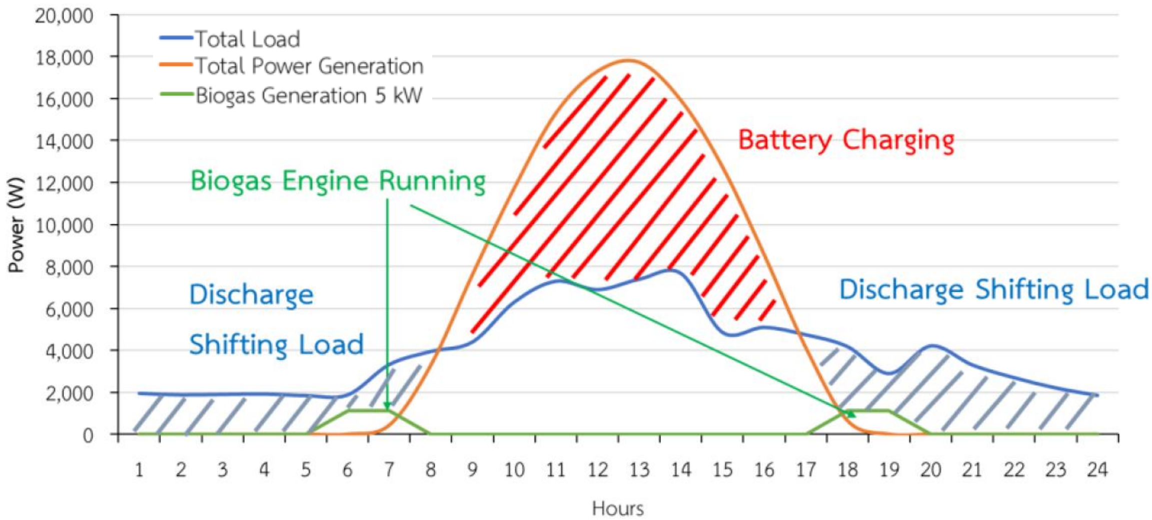


Figure T.6. Load balancing from battery storage and biogas.

This model system offers a potential solution for remote communities, particularly in Thailand and other ASEAN countries, where extending the main electricity grid may not be cost-effective. The proposed microgrid system, backed by real-world testing, demonstrates the feasibility of community-level energy autonomy using hybrid renewable energy sources, contributing to both local development and sustainability goals. The report advocates for further implementation of such systems, with a focus on improving energy storage technologies and optimizing the balance between different energy sources to ensure stability and reliability. Reports, publications, and other works resulting from this research are available at https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

EGAT Variable Energy Integration Study

Beginning in 2017, HNEI engaged a wide network of stakeholders, including the Electricity Generating Authority of Thailand (EGAT), Chulalongkorn University, the Provincial Electricity Authority (PEA), the Office of the Energy Regulatory Commission (OERC), the National Metal and Materials Technology Center (MTEC), the Municipal Electricity Authority (MEA), and the USAID-funded Clean Power Asia (CPA) program. In October 2017, HNEI's Grid***START*** visited EGAT's headquarters for a technical presentation and joined Chulalongkorn University for a session with the Energy Research Institute and MTEC. These initial engagements laid the groundwork for Memoranda of Understanding with EGAT and CU, formalizing collaboration in technical studies, solar PV forecasting, and research. These initial collaborations evolved into significant collaborative projects, some fully supported under APRESA while others drew on a combination of APRESA and additional funding sources.

The partnership between HNEI and EGAT, Thailand's national utility responsible for both generation and transmission, was formalized with a multi-year Memorandum of Understanding (MOU) on February 28, 2018 (Figure T.7). This MOU provided a framework for technical analyses and grid modeling support, education, training, workshops, and exchange programs to enhance EGAT's ability to manage the integration of variable and intermittent energy resources and to build planning and operational capacity for advanced grid management.

Figure T.7. HNEI-EGAT MOU signing ceremony held at EGAT's corporate headquarters in Bangkok, Thailand.

EGAT sought to strengthen its engineers' expertise in advanced analytical methods and grid simulation tools. This partnership was designed to develop a high-fidelity production cost model of the Thai power grid using the PLEXOS platform, an energy modeling software, and to assess both operational and economic impacts of high-penetration scenarios for solar and wind resources over a five- to ten-year planning horizon.

The joint HNEI-EGAT integration analysis began in 2018, focusing on significant penetrations of variable and intermittent resources and identification of effective grid and operational solutions. In May 2018, a three-day training session on generation planning and PCM using PLEXOS for

EGAT planning engineers was held in Bangkok. During 2019, Grid***START*** developed and calibrated a PLEXOS-based production cost model tailored to Thailand's 2018 grid operations, the engineering teams discussed ways to improve the flexibility of the thermal generation fleet, and a three-day workshop on the new model's applications was conducted.

In January 2020, HNEI presented a report to EGAT, documenting the model's design and initial findings. Solar and wind datasets had been developed, scenario analyses with PLEXOS were underway, training and analysis continued in both Thailand and Hawai'i, with hands-on collaboration and mentoring.

In May 2020, EGAT and HNEI renewed their partnership with a four year MOU. EGAT institutionalized these capabilities by creating a dedicated team to focus on generation asset flexibility and incorporating operational enhancements directly into scenario analysis. EGAT also purchased the PLEXOS software, enabling deeper engagement with HNEI.

In March 2021, Grid***START*** conducted a multi-day remote workshop to update and further calibrate the production cost model (Figure T.8). The improved model featured seven regional nodes and transmission limits and comprehensive time series data for various solar and wind scenarios. Distributed PV scenarios were evaluated, identifying operational factors such as excess energy, transmission congestion, reserve adequacy, and thermal unit cycling. An online status update and results from the joint VRE grid integration analysis in two half-day sessions was also presented to EGAT.

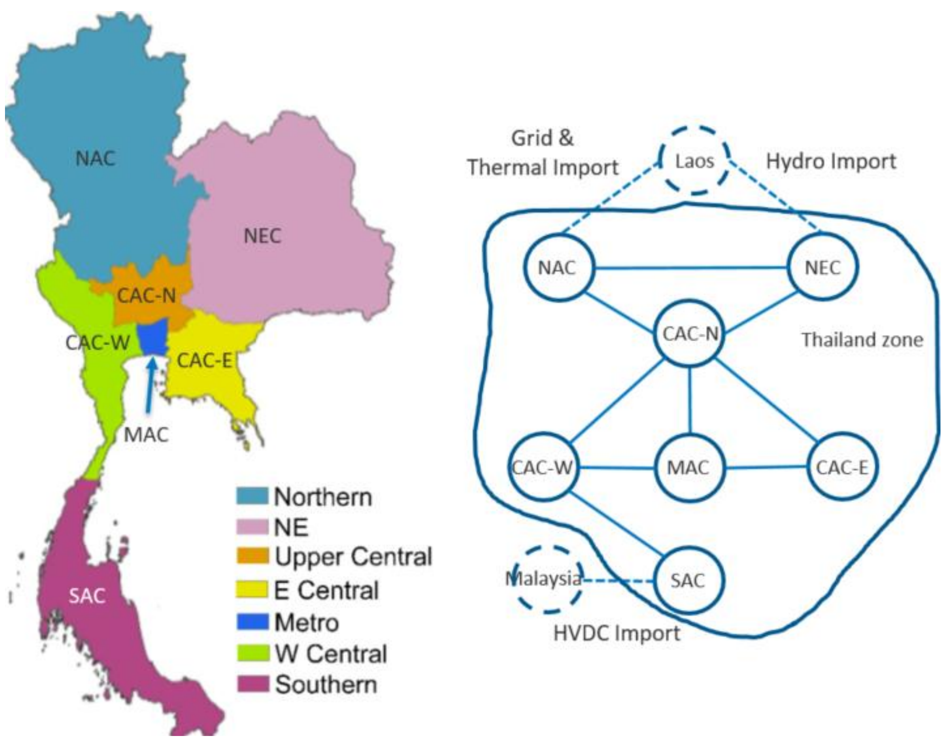


Figure T.8. Thailand PLEXOS "bubble model" topology.

By 2022, the team concluded its integration analysis, delivering EGAT a validated PLEXOS modeling platform for their future assessment. With COVID-19 travel restrictions lifted, HNEI and EGAT began defining new collaborative analysis initiatives using the Thai grid model, aligned with emerging national targets. The findings from multiple scenario analyses have informed EGAT's efforts to assess and develop flexible countermeasures for the Thai grid, empowering its engineers with the modeling expertise and analytical confidence needed to address evolving grid and market demands. This multi-year partnership not only produced a high-resolution and validated production cost model for Thailand's power sector but also fostered lasting institutional capacity within EGAT by equipping EGAT engineers with the tools and skills necessary for independent analysis and strategic planning for Thailand's evolving power system. A list of presentations by Grid***START*** related to their international efforts, including this topic, is available at https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

Thailand Regional Solar PV Forecasting

To support Thailand's rapid solar growth, HNEI partnered with Chulalongkorn University and incorporated feedback from EGAT to develop a regional solar PV forecasting system. This effort was aimed at providing advanced predictive tools for operators to effectively manage increasing solar integration and maintain reliable system operations.

The initiative began in 2018, after the MOUs were executed with EGAT and Chulalongkorn University. Grid***START*** assembled solar and wind datasets to represent future resource additions and helped define research scope for solar forecasting tailored to Thailand's needs. In 2019, HNEI, Chulalongkorn University and EGAT collaborated to develop forecasting algorithms and information and communications technology (ICT) infrastructure. HNEI adapted solar forecasting technology originally developed for Hawaiʻi and later extended to Korea, customizing it for Thailand with operational forecasts updated every fifteen minutes for up to six hours ahead, plus daily forecasts for the next two days.

The completed system integrated data from weather models, satellite imagery, and ground instruments, monitoring real-time solar irradiance and predicting PV output from minutes to days in advance. A dedicated test domain in northern Thailand was established to evaluate performance. Day-ahead forecasts used the Weather Research and Forecasting system, configured with nested grids centered on Bangkok. Hour-ahead forecasts leveraged Himawari-8 geostationary satellite data (Figure T.9). The team produced a month-long series of six-hour irradiance forecasts for over thirty test sites across Thailand, validated against hourly insolation observations, and visualized through a regional aggregate dashboard, giving operators actionable information.

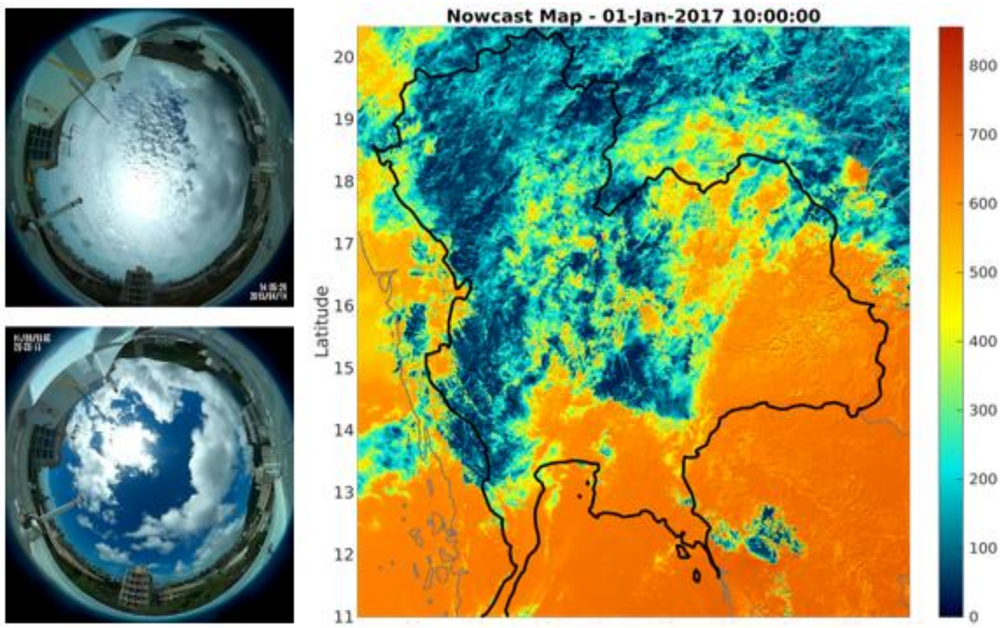


Figure T.9. Sky image samples for minute-ahead solar forecasting (left) and sample irradiance nowcast map derived from Himawari-8 imagery (right).

In 2021, the system was implemented for validation and calibration and presented to engineers at EGAT. By 2022, the project had generated a robust prototype forecasting platform, with six-hour-ahead forecasts delivered for more than thirty sites and displayed through a user-friendly dashboard for EGAT. This multi-year collaboration resulted in a state-of-the-art forecasting system that strengthens Thailand's ability to manage solar integration and supports the nation's energy transition. A list of presentations by Grid***START*** related to their international efforts, including this topic, is available at https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

Joint Initiatives with Chulalongkorn University (CU)

HNEI's MOU with Chulalongkorn University (CU) enabled a diverse portfolio of joint research and technical initiatives supporting Thailand's energy transition. CU sought HNEI's expertise for a project initiated by the Thai Energy Policy and Planning Office (EPPO) to define characteristics of firm alternative energy resources, including dispatch control and ancillary services. Grid***START*** reviewed and advised CU and CPA staff on technical feeder penetration analysis for distributed PV. Upon request, the team also initiated detailed discussions with CU to develop a new funding proposal aimed at establishing a framework for energy data collection, management, analysis, and presentation for planning and policy.

The partnership with CU's Smart Campus Project was central to expanding grid modernization and smart grid initiatives. Under an MOU with CU's Smart Grid Research Unit, this collaboration focused on developing campus-scale applications for energy management and innovation. The team deployed its patented Advanced Real-time Grid Energy Monitor Systems (ARGEMS) (Figure T.10), developed under other ONR funding, with one unit operating in the laboratory and another installed on a Chulalongkorn campus building transformer. Technical support included comprehensive documentation and development of new software to enable remote firmware updates, configuration, and testing—particularly to support the integration of a new type of transducer (Rogowski coil). These efforts positioned CU's Smart Campus as a testbed for advanced grid technologies and contributed to wider smart grid research and deployment in Thailand.

Figure T.10. ARGEMS units, patented custom power meter and controller devices.

The ARGEMS project enabled advanced use cases, such as:

- In-situ distribution transformer health monitoring, supporting predictive maintenance and cost reduction. Hardware and software prototyping was completed, with three related research articles accepted for publication.
- Online distributed PV hosting capacity estimation using local voltage and power measurements, combined with stochastic power flow analysis to streamline hosting capacity assessments and potentially increasing PV hosting capacity on distribution circuits.
- Fault location identification using attenuation of fault-induced grid harmonics, aiming to improve detection, reduce repair costs, and enhance grid resiliency.

The partnership also explored EV technology. Grid***START*** engaged with CU, Hitachi, and Mitsubishi Motors Thailand to propose deployment of bidirectional EV chargers on campus, with HNEI's ARGEMS and optimization algorithm as controllers. Significant planning and stakeholder engagement occurred, but the initiative did not progress to implementation due to COVID-19 travel restrictions and other logistical challenges. A list of presentations by Grid***START*** related to their international efforts, including this topic, is available at https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

Provincial Electricity Authority of Thailand (PEA) Collaboration

HNEI has established a robust partnership with PEA, Thailand's main distribution grid operator serving seventy-four of the seventy-seven Thai provinces. This collaboration began with high-level engagements including a presentation at PEA headquarters in 2017, a workshop and site tours in Honolulu for PEA executives, board members, and regulators in 2018, and a presentation at PEA's Research and Development (R&D) Division focused on advanced power analysis and distributed control with ARGEMS in 2019. During the period of this award, Grid***START*** delivered capacity building programs, technical training, and direct support to PEA engineers, helping to advance expertise in modern grid technologies and operational practices.

Also in 2019, HNEI partnered with Chulalongkorn University faculty to develop a program to expand smart grid expertise among PEA engineers. This included over twenty hours of instructional content and internships for two cohorts of six engineers with travel funded by PEA. The first group completed a nine-week internship at HNEI from March to May 2020. The training engaged PEA interns in mini-projects to develop new real-time health assessment applications for distribution transformers to be field tested on the PEA grid via deployment of ARGEMS units and an EV bidirectional charging optimization algorithm development. Subsequently, the team developed an expanded program in 2020 with sufficient materials to annually host two internship classes of six PEA engineers, combining forty hours of technical lectures with team-based R&D. Training topics included grid operations, smart grid technologies, microgrid assessment, and advanced bidirectional EV charging applications.

While COVID-19 disrupted the planned second cohort's visit in 2020, Grid***START*** delivered twenty-five hours of live online lectures on demand response (DR), distributed system operations, DER technologies, and microgrids in May 2021. When restrictions eased, an in-person component was held from October to December 2021 at HNEI, splitting the class into two subgroups: one developed fault detection and location algorithms for distribution systems, while the other optimized EV fleet bidirectional charging controls using real-world data (Figure T.11).

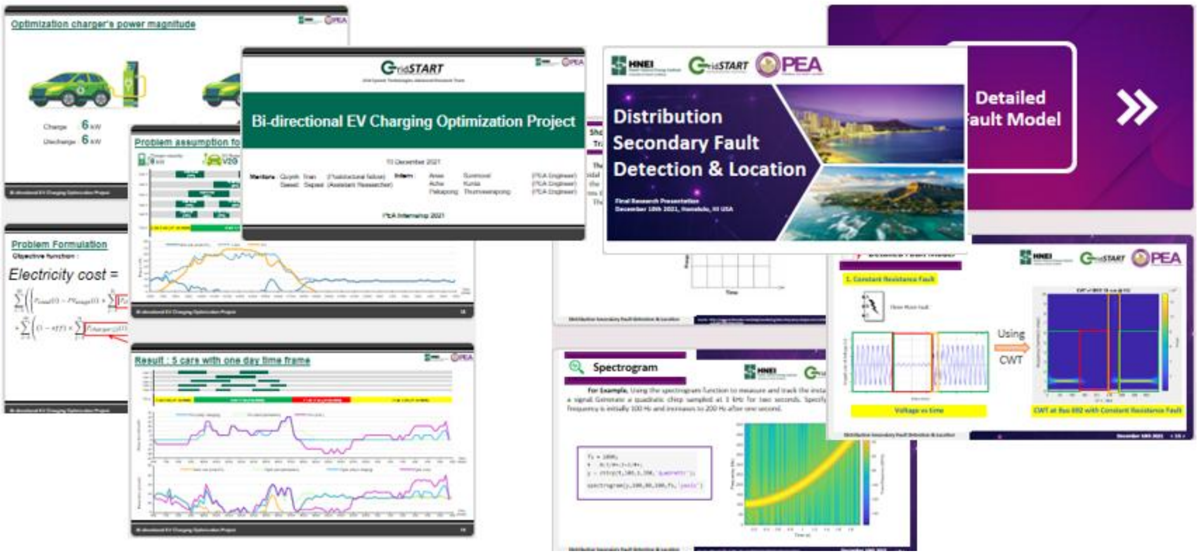


Figure T.11. Final presentations of the two subgroups of the PEA internship program in 2021.

In 2022, the program returned to a full in-person format, hosting two classes of interns at HNEI from June to early August and from late August to October. Each class had over forty hours of technical lecture and worked on mini-projects involving EV energy consumption estimation, virtual power plant (VPP) dispatch and DR, PV hosting capacity methodology, and microgrid system design. These hands-on mini-project activities included improving EV estimation, analyzing PV and battery energy storage systems (BESS) dispatch, applying PV hosting capacity methods, and assessing microgrid sites using the XENDEE technoeconomic optimization platform (Figure T.12). These experiences gave PEA engineers advanced technical knowledge and practical skills in distributed resource technologies and microgrids in Thailand's evolving energy landscape.

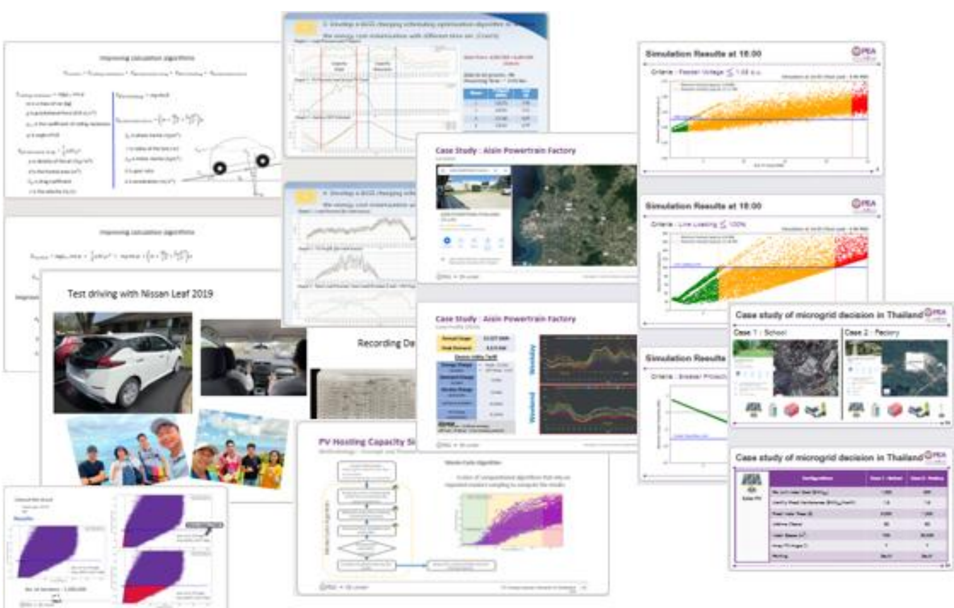


Figure T.12. Final presentations of the subgroups from the 2022 PEA internship classes.

For 2023, Grid***START*** developed new curriculum and mini-projects focused on microgrid design and operation. However, travel to Hawaiʻi was unexpectedly suspended by PEA due to unforeseen circumstances related to political conditions in Thailand following the contested 2023 national elections. The program resumed in early 2025 with a revised format: a ten-day hands-on course for thirty PEA engineers delivered in Thailand (Figure T.13), led by three HNEI personnel, covering microgrid fundamentals, control strategies, regulatory standards, technoeconomic optimization, and scenario-based planning using tools such as XENDEE, Re-Opt, and ETAP, with exercises based on the actual field deployed Mae Hong Son microgrid in Northern Thailand.

Figure T.13. Ten day hands-on course to 30 PEA engineers in Bangkok, Thailand.

The second half of the 2025 internship took place at HNEI, with four PEA engineers receiving immersive training beginning in May. They learned ETAP software fundamentals, worked on system modeling and load flow for the Mae Hong Son microgrid project, and engaged in transient analysis and software-in-the-loop (SIL) and hardware-in-the-loop (HIL) testing. The training concluded with presentations and feedback sessions (Figure T.14).

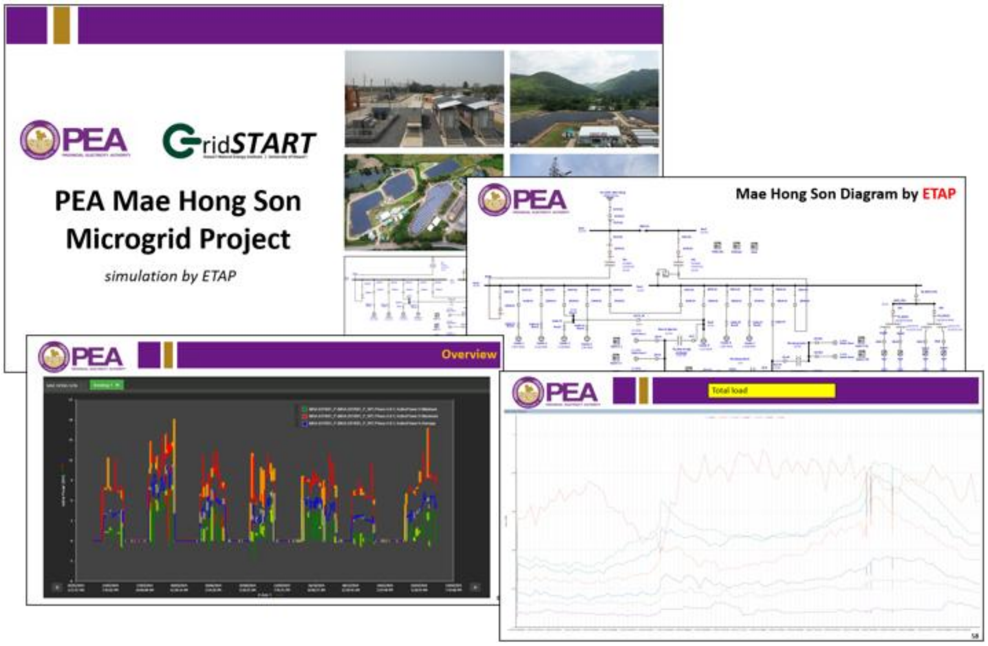


Figure T.14. Final presentations of the PEA engineers from the 2025 PEA internship class.

In addition to internships, HNEI provided technical support for advanced microgrid development. In December 2023, Grid***START*** assisted PEA with commissioning the Koh Phaluai microgrid, which integrates 1 MW of solar PV, a 750 kW/1,500 kWh BESS and two 300 kW diesel generators under centralized microgrid control. This project delivered reliable utility power to island residents and served as a demonstration platform for microgrid operation.

Through years of collaboration, HNEI's partnership with PEA has delivered deep technical knowledge transfer, advanced technical training, technology demonstration, and direct support for the development and deployment of modern grid solutions. These efforts have built institutional knowledge and provided PEA engineers with practical experience in distributed resource management, advanced analytics and microgrid operation, which are key capacities for Thailand's ongoing grid modernization. A list of presentations by Grid***START*** related to their international efforts, including this topic, is available at https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

Thailand Regulatory Collaboration

Recognizing the need for a robust regulatory framework, Thailand's Office of the Energy Regulatory Commission (OERC) aimed to establish foundational standards on engineering, performance, safety, and grid connection. To support this initiative, Abt Associates, lead implementer for CPA, contracted HNEI with partial leveraged support from APRESA funding to provide expert analysis and advice. We provided technical support to Thailand's OERC to guide development of technical standards and recommendations for BESS and to update the national grid code. The declining global cost of BESS has increased adoption among utilities, industries, businesses and homeowners in Thailand, outpacing the country's regulatory environment. This partnership delivered a comprehensive guide and roadmap to develop BESS technical codes and standards for Thailand.

Starting in mid-2020, Grid***START***'s support included reviewing Thai regulations for BESS in detail and participating in stakeholder engagements and analyzing international best practices. The consultative process with a Stakeholder Focus Group began in August 2020 and continued through focused discussions, culminating in a topical index of global best practices and references to leading international codes relevant to BESS and electrical grid integration.

The team presented its recommendations during stakeholder meetings, including the CPA second online focus group in January and the Final Stakeholder Consultation Workshop in Bangkok in February 2021, with broad participation from Thai utilities and sector stakeholders. The final draft of the BESS technical standards guideline report was formally presented and submitted in March 2021 through CPA.

This guide and roadmap provided regulators, utilities, and energy sector participants with practical tools to establish standards and codes for safe, high-quality, and reliable BESS deployment. The framework supported in Thailand was later applied in other ASEAN countries; in 2022, following its success in Thailand, HNEI assisted the Philippines' Energy Regulatory Commission (ERC) in developing a regulatory framework for BESS adoption under separate U.S. government agency's funding.

LAOS

Through collaboration with the Ministry of Energy and Mines (MEM), Électricité du Laos (EDL), and the U.S. government agency's multiple regional initiatives, HNEI has supported technical capacity building, grid modernization, and policy advancement in the Lao People's Democratic Republic (LPDR). These targeted efforts have strengthened institutional capabilities, supported strategic expansion of the national generation portfolio, and laid groundwork for future innovations in Laos' electricity sector. Projects with or supporting Lao organizations are described below.

Solar Pilot Auction and Grid Code Development

Under a cooperation framework signed on August 8, 2017, HNEI's Grid***START*** began supporting CPA and MEM in designing and implementing Laos' first market-based solar pilot auction to facilitate procurement of grid-connected solar PV projects from independent power producers (IPPs). Laos has long relied on hydropower, with more than 80% of its electricity generated by hydro plants and much exported during the wet season. In the years leading up to this initiative, energy policies and projections raised concerns about overreliance on hydropower, especially due to seasonal variability, drought risks, and emerging plans for expanded coal-fired generation and electricity imports to meet dry-season demand. Policymakers and development partners recognized that diversifying the energy mix, including leveraging Lao's solar potential, would be essential for energy security, economic growth, and managing fluctuations in hydro resources.

The pilot auction was designed to introduce a transparent, cost-effective competitive procurement model, moving away from bilateral negotiations and targeting about 40 MW of grid-connected solar PV from IPPs. This marked a shift toward market-driven power sector policies in Laos. Initial grid code development focused on ground-mounted PV systems of no more than 10 MW, reflecting the pilot auction's capacity cap.

Technical grid code requirements directly influence counterparty risk allocation within power purchase agreements (PPAs), affecting commercial and financial terms for projects. Therefore, the application of technical requirements needs to balance the capabilities of modern wind and solar conversion technologies with the "bankability" concerns of financing partners. Drawing on experience in commercial PPA negotiations and grid interconnection standards, Grid***START***:

- Advised on the auction design and associated procurement process;
- Reviewed and analyzed Lao transmission and distribution systems to inform technical requirements for the auction;
- Developed technical interconnection and performance requirements for solar PV projects participating in the auction; and
- Drafted interconnection grid codes and established the PPA structure and terms for the auction's request for proposals.

Technical work included stakeholder engagement, such as presenting solar pilot auction interconnection requirements to the Working Committee on Solar Pilot Auction in Vientiane in January 2019. The committee, established by the Department of Energy Policy and Planning within MEM and including EDL members, offered an important forum for technical review and policy alignment. In March 2019, we prepared and presented draft technical interconnection requirements for solar pilot auction to DEPP and EDL in Vientiane. Finalized interconnection requirements and PPA terms were consolidated into the official auction package and submitted to the Institute of Renewable Energy Promotion (IREP) within MEM for review, ahead of proposal to the Lao National Assembly by September 30, 2020.

Building on this early work, EDL requested further technical support from HNEI to expand standards for projects beyond 10 MW and address additional technologies. This included support for technical interconnection requirements covering distributed PV and wind projects, as described in the next section. A list of presentations by Grid***START*** related to their international efforts, including this topic, is available at https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

Technical Interconnection Requirements for Solar and Wind Projects in Laos

After the foundation laid by the solar pilot auction, supported by APRESA and CPA, HNEI helped develop technical interconnection and performance requirements and grid codes for solar and wind projects in the Lao power grid. Recognizing that the initial grid codes, designed for pilot auction projects up to 10 MW, were not sufficient for larger or more diverse variable and intermittent projects, EDL requested expanded technical support to address both distributed and utility-scale solar as well as wind resources.

Grid***START*** responded by systematically gathering data and reviewing power system infrastructure and operational needs (Figure L.1). Building on this technical analysis, the team developed new interconnection and performance standards for both distributed and utility-scale inverter-based generating facilities, ensuring compatibility with modern solar and wind technologies. These requirements reflected international best practices, addressed system reliability and performance, and incorporated lessons learned from supporting utility project finance and PPA drafting.

*Figure L.1. Grid**START** personnel and EDL officials at a meeting on March 12, 2020, at EDL Headquarters in Vientiane, Laos.*

Draft standards were circulated to EDL, IREP, and other stakeholders for feedback and consultation. After incorporating input, HNEI finalized interconnection standards for distributed solar PV generation facility in December 2020 and transmission interconnection standards for inverter-based generating facility in January 2021; the latter was discussed with EDL during an online session on January 29, 2021. Both standards were jointly presented by Grid***START*** and CPA to EDL and MEM in March 2021.

Practical adoption and long-term management of these requirements were supported through capacity building activities led by HNEI. Approximately thirty institutional representatives participated in subsequent workshops and trainings, including members from the Japan-U.S.-Mekong Power Partnership (JUMPP) Technical Advisory Group, JUMPP workstream coordinators, EDL's Technical Working Group for Developing Rooftop Solar Installation and Management Regulations and Requirements, and other relevant EDL departments and divisions. By expanding and institutionalizing robust technical standards, this project established a foundation for effective integration of solar and wind projects at all scales into the Lao grid, enhancing system reliability and building local capacity to manage diverse new resources. A list of presentations by Grid***START*** related to their international efforts, including this topic, is available at https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

INDONESIA

HNEI's engagement in Indonesia under the APRESA grant has supported national and regional energy transition goals and strengthened the capacity of key energy sector stakeholders. Through technical training, collaborative research, and hands-on knowledge exchange, Grid***START*** contributed to Indonesia's efforts to modernize power systems, integrate advanced energy technologies, and build institutional expertise. These initiatives have collectively fostered technical leadership, promoted regional knowledge sharing, and accelerated Indonesia's progress toward a more resilient, efficient, and responsible energy future. Projects with or supporting Indonesian organizations are described below.

Ministry of Energy Capacity Building

Participation in the Asia Enhancing Development and Growth through Energy (EDGE) Competitive Procurement Dialogue Workshop in Bangkok in November 2019 provided HNEI the opportunity to connect with Indonesia's Ministry of Energy and Mineral Resources (MEMR). As a result of this engagement, MEMR invited HNEI's Grid***START*** to Jakarta in February 2020, where a dedicated capacity building session focused on strategies for sourcing alternative energy in grids with high levels of variable and intermittent energy resources was delivered. The session used Hawai‘i's experience as a practical case study relevant to island power systems in Indonesia. Extending its knowledge sharing efforts, the team presented on island grid integration of extremely high distributed PV as part of the GIZ REEP2 (Indonesia) Energy Transition Master Class and

Virtual Delegation Trip in December 2021. This presentation further supported information exchange on grid integration challenges and provided detailed insights from Hawai'i's experience to Indonesian policymakers and technical staff.

These combined efforts enhanced the capacity of Indonesia's MEMR and relevant stakeholders to address current and future challenges in diversifying their energy systems, equipping them to better manage the integration of a wider range of generation sources in the nation's island grids. A list of presentations by Grid***START*** related to their international efforts, including this topic, is available at https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

University of Indonesia (UI) DC Microgrid Collaboration

Utilizing APRESA funding, HNEI established a collaborative research partnership with the University of Indonesia's Faculty of Engineering to advance direct current (DC) microgrid technology. In 2019, Grid***START*** invited UI to join HNEI's Coconut Island microgrid project on O'ahu. This microgrid research site serves as a testbed for developing efficient and reliable DC-based microgrid operations, with a focus on system resilience, energy assurance for critical loads and locally sourced transportation solutions.

As part of this partnership, UI planned to incorporate and test its in-house developed DC-to-DC converters with other technology elements of the Coconut Island project. These included a 6.2 kW rooftop PV system, DC office lighting and air conditioning, a designated critical load circuit, an 8 kW/8 kWh lithium-ion BESS, custom-built DC microgrid control systems, as well as infrastructure for metering, data collection, and battery charging systems for an EV and an electric boat.

Subsequently, UI refined and enhanced its DC-to-DC converters, with improvements designed and tested in Indonesia (Figure I.1). In November 2021, university faculty and staff traveled to Coconut Island to commission and integrate these converters. The new devices, known as DCON, enabled the conversion of the PV and BESS's 48-volt DC bus to the higher voltages required by various DC microgrid loads, representing a significant advancement over earlier technology previously installed at UI's own facility.

Figure I.1. UI DCON devices.

The collaboration concluded with the completion of joint testing, research activities, and successful integration of the UI-developed DC-to-DC converters into the Coconut Island system, with the outcomes providing valuable experience and technical advancements to inform future applications of DC microgrid technology.

Support to Indonesia's SINAR Program

Utilization of Indonesia's significant alternative energy resources has been limited by a lack of experience and specialized knowledge among key stakeholders in strategic planning, technology deployment and operations suited to local conditions. The Sustainable Energy for Indonesia's Advancing Resilience (SINAR) Program is a USAID five-year initiative aimed at expanding reliable and equitable energy services for sustainable and inclusive economic growth in Indonesia. The program sought to address these challenges by working closely with Indonesia's MEMR and PT Perusahaan Listrik Negara (PLN), the state electricity company, supporting development of clear strategies, frameworks, and roadmaps for the country's energy transition.

In September 2021, HNEI began working with Tetra Tech ES to support the U.S. government agency's SINAR program. The program focused on accelerating the deployment of advanced energy technology, improving utility performance, promoting transparent procurement, and strengthening the institutional framework of Indonesia's energy sector. Grid***START***'s technical support focused on building capacity across a broad range of priority areas, including advanced energy project finance, enabling investment environments, improving cost recovery for utilities, utility planning and modernization, competitive procurement processes, institutional capacity improvement, domestic resource utilization, interagency coordination, and enhancements to policy, regulations, and standards.

As part of its support, a three-day Energy Transition Webinar was prepared and delivered in February 2022 for Indonesia's Directorate General of Electricity, MEMR, PLN, and other energy sector stakeholders. The webinar included modules on Hawai'i's experience with energy transition and lessons learned, competitive procurement in grids with a high proportion of non-conventional resources, grid modernization case studies, the role of BESS in modern power systems, microgrid applications and design, and opportunities for EV charging infrastructure. This event was attended remotely by technical and policy staff from across Indonesia's electricity and grid management sector.

Building on the success of these knowledge-sharing activities, we were invited to Indonesia to deliver additional in-person capacity building. In May 2023, the team provided a one-day energy transition training to the Secretariat General of the National Energy Council (Setjen DEN) in Jakarta. Right after the training session, a three-day workshop was held in Bali for PLN, focusing on small island grid planning, case studies from Hawai'i, grid modernization, microgrids, BESS, strategic energy planning, and competitive procurement. These sessions provided hands-on training and practical insights for Indonesian practitioners tasked with advancing the nation's energy transition, especially for remote and island grids.

Following strong engagement and requests for more practical learning, Grid***START*** organized and hosted a five-day Smart Grid Benchmarking Study Tour in Hawai'i in February 2024. This immersive program brought Indonesian utility executives and government stakeholders to O'ahu and Kaua'i to deepen their understanding of grid transformation strategies. On O'ahu, participants engaged in classroom-based training and field visits, met with the Hawai'i Public Utilities Commission (PUC), Hawai'i State Energy Office, and Hawaiian Electric Company to discuss topics including system planning, regulatory approaches and day-to-day operations (Figure I.2). The Kaua'i segment featured sessions conducted by the Kaua'i Island Utility Cooperative (KIUC), which included in-depth facility tours of the Kapaia Power Station (with its dual-mode turbine/synchronous condenser), Tesla's hybrid PV power and BESS site, and the Port Allen control center (Figure I.3). Instruction included best practices in grid management, advanced metering, operational technologies, and stakeholder engagement.

Figure I.2. Indonesian delegates meeting with the Hawai'i PUC.

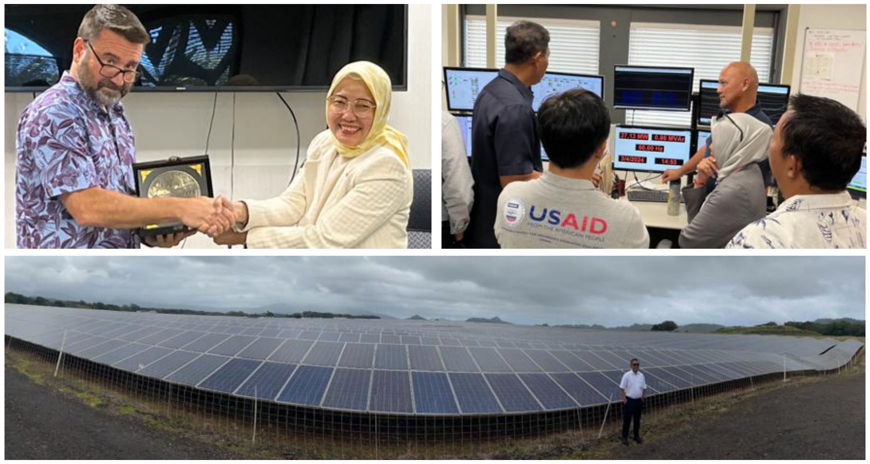


Figure I.3. The Indonesian delegates' visit to KIUC on Kaua'i.

These collaborative activities have significantly expanded the technical capability and institutional knowledge of Indonesia's energy sector, particularly within MEMR and PLN. Our contributions have helped promote regional knowledge exchange, support policy and operational innovation, and advance technical solutions for energy sector modernization and resilience. While plans for additional technical support and exchange, including a proposed internship at HNEI for PLN engineers in 2025, were discussed, program expansion was halted due to the recent closure of the U.S. government agency. Nonetheless, the engagement produced substantial progress and long-term value for Indonesia's efforts to manage its ongoing energy transition. A list of presentations by Grid***START*** related to their international efforts, including this topic, is available at https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

PHILIPPINES

With support from the APRESA grant, HNEI's Grid***START*** assisted the Philippine power sector in ongoing efforts to modernize and build resilience. Participation in presentations, knowledge-sharing activities, and other technical and policy events in 2019 opened opportunities to engage with the Philippines Department of Energy (PDOE), Energy Regulatory Commission (ERC), distribution utilities (DUs), local government units (LGUs), and other organizations. Projects with or supporting Philippine organizations are described below.

Support for the Philippines Department of Energy

Collaboration with Philippines Department of Energy (PDOE) began in 2019, supported by both APRESA and Clean Power Asia (CPA), with technical guidance for the development of a Department Circular (DC) aimed at strengthening the national Net Metering Framework to encourage wider adoption of distributed solar generation. Key areas addressed by the DC included updating the 100 kW system size cap, developing compensation mechanisms to help guide ERC decisions, and streamlining interconnection procedures. Grid***START*** reviewed and provided expert input on PV feeder hosting capacity analysis that had been conducted for CPA by an earlier consultant and delivered in-person technical support and presentations during PDOE's public consultation meetings. This collaborative process ensured that the revised framework was shaped by both industry best practices and diverse local perspectives.

Following the issuance of the updated policy in 2020, the team continued to deliver technical assistance in areas such as equipment standards, supplier accreditation, and distribution impact study screening. PDOE requested further technical support to assist with the development of standards for solar equipment and supplier accreditation, guidelines for distribution impact study (DIS) screening, and targeted capacity building for utilities and regulators. While the main accomplishments during this period centered on capacity building activities addressing PDOE's immediate needs, technical support later expanded to include developing a set of rules for an "off-grid" NEM program designed for rural and island grids not connected to the country's main transmission network. These efforts contributed to a measurable increase in participation in the Net Metering Program, with engagement rising by nearly 15 percent and the sector showing improved capacity for integrating distributed solar systems nationwide. A list of presentations by Grid***START*** related to their international efforts, including this topic, is available at https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

Support to the Energy Secure Philippines (ESP) Program

The ESP program, a five-year $34 million initiative, was launched to stimulate economic growth and energy sector resilience by mobilizing $750 million in private investment and adding 500 MW of new generation capacity. HNEI played a key role in advancing these objectives through the development of regulatory frameworks, targeted capacity building, and practical technical support aligned with ESP's mission to promote modernization, innovation, and system reliability nationwide. Building on its previous collaboration with PDOE and ERC through CPA and APRESA funding, HNEI's Grid***START*** deepened its technical and regulatory engagement under the ESP program. Working in partnership with ESP's implementing partner, RTI, the team assisted national regulators, DUs, LGUs, and the Armed Forces of the Philippines (AFP) General Headquarters at Camp Aguinaldo. These efforts addressed a wide range of priorities in the evolving Philippine energy sector.

Through 2022, working closely with ESP, ERC, DUs, and other Philippine stakeholders, Grid***START*** focused on regulatory advancement for NEM in island systems and BESS. With travel resuming post-pandemic, comprehensive reports recommending NEM rules for isolated small island grids and a national BESS regulatory framework were completed and delivered. These resources provided guiding principles, clear processes for enrollment and interconnection, and pathways for customers in off-grid island systems to export surplus generation to their DUs. The BESS framework addressed streamlined interconnection, operating standards, cost recovery mechanisms, and provisions for third-party ancillary service providers.

In-person presentations of the reports to ESP and the ERC were held, which delivered technical details and facilitated engaged discussion. Following these, a dedicated regulation drafting workshop assisted ERC as it refined the BESS regulation for formal consideration, building technical understanding, and consensus for national implementation.

Support continued through 2023 with further collaborative workshops with the ERC, most notably a second in-person drafting session in February focused on finalizing the BESS regulation. Capacity building featured prominently during the year, as we led in-person training for the ERC on microgrids in June. In parallel, the team delivered capacity building sessions on power system resiliency to PDOE, aiming to help DUs strengthen their ability to manage disruptions and adapt to emerging power sector challenges. Following this, participation in the Philippines' 2023 Energy Resiliency Forum occurred, sharing insights and technical expertise at PDOE's invitation.

Two days of in-person capacity building activities focused on energy storage systems (ESS) for PDOE and DUs were conducted. These sessions were designed to enhance understanding of the costs and benefits of ESS, introduce behind-the-meter BESS applications, and assist policymakers and regulators in identifying and addressing gaps within existing institutional frameworks for the promotion and effective use of BESS nationwide.

In 2024, Grid***START***'s role under ESP expanded further, encompassing a broader spectrum of technical activities and stakeholder engagement. Dialogue with RTI led to a revised scope of work that added new initiatives such as a design review for an all-electric fishing boat, targeted capacity building for additional DUs and LGUs, training on new energy use and system resiliency for the Siargao Women's Center, an electrical system review for Siargao Electric Cooperative (SIARELCO), and a resiliency assessment at Camp Aguinaldo for the AFP. To support this expanded scope, the team conducted site visits across Manila, Bohol, Iloilo, and Siargao, meeting with local officials and energy leaders to tailor project objectives and plans. Two in-person training sessions in Iloilo, one to advance utility improvement and reliability planning with a focus on advanced technology integration and another that addressed technology applications and energy planning best practices were held. Both sessions reinforced provincial capacity for energy innovation and resiliency, fully aligned with ESP's mission of strengthening local expertise and service. Alongside these efforts, a presentation at Camp Aguinaldo outlined an energy resiliency assessment methodology and shared initial findings with AFP stakeholders, which provided a roadmap to identify system vulnerabilities and potential strategies for improved resilience. These collaborations culminated in extending work under ESP through October 2025.

Despite significant progress, several planned activities, including the electric-powered fishing boat design review, a second set of DUs and an LGU training sessions, specialized training at the Siargao Women's Center, and a distribution system assessment for SIARELCO, were ultimately canceled following the suspension and closure of the U.S. government agency's operations in early 2025. Work related to the Camp Aguinaldo Resiliency Assessment and Conceptual Strategies was subsequently rescoped in partnership with RTI to respond to new funding realities. While these changes limited the full breadth of technical assistance originally envisioned, the groundwork and partnerships already established preserved much of the impact.

Even with these unexpected challenges, HNEI's efforts along with the ESP program made a substantial and lasting positive impact on the Philippine power sector. By delivering leadership in regulatory development, practical capacity building, and support for both innovation and resilience at national and local levels, the team advanced ESP objectives and empowered institutional capacity across the country. These collaborative achievements have contributed to the emergence of a more robust, adaptive, and forward-looking energy system that benefits a diverse set of communities throughout the Philippines, including direct support to the headquarters of the AFP at Camp Aguinaldo in Manila. A list of presentations by Grid***START*** related to their international efforts, including this topic, is available at https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

PACIFIC ISLAND COUNTRIES (PICs)

Through APRESA, HNEI expanded its collaborative work with multiple PICs while establishing new partnerships across the region. These efforts enabled targeted technical assistance, deliverance of capacity building programs, and sharing of practical lessons learned from Hawaiʻi's island power systems with utilities and government agencies in the Pacific serving direct U.S. strategic interests. These engagements included presentations and discussions regarding experiences on Hawaiʻi's whole-system energy transition and storage solutions for island grids and planted the seeds for future collaboration. Projects with or supporting work conducted with organizations from the Republic of Palau, the Cook Islands, the Republic of the Marshall Islands (RMI), the Federated States of Micronesia (FSM), and the Republic of Fiji are described below.

The Republic of Palau

The Republic of Palau is a Pacific Island nation working to shift away from reliance on imported fuels for electricity. In 2022, Palau set an ambitious target to meet all electricity needs through non-conventional sources by 2050. Recent expansions in solar and BESS have positioned Palau as a regional leader in innovative energy development—highlighted by the commissioning of a large solar-plus-BESS project and the expansion of rooftop systems. This rapid increase in new generation and storage technologies has brought significant technical and policy challenges for the nation's utility provider, particularly concerning system planning, grid operations, and establishing clear standards for connecting additional sources to the power grid.

HNEI's Grid***START*** provided wide-ranging technical and regulatory support to Palau's Energy and Water Administration (PEWA) and the Palau Public Utilities Corporation (PPUC) in three key areas: 1) the development of energy regulatory frameworks; 2) conducting modeling and analysis of the national electric system; and 3) creating requirements and improved processes for connecting new sources to the grid.

In 2023, Grid***START*** prepared and presented a three-day program on Hawai‘i's energy transition and lessons learned to the newly appointed Director of PEWA and a member of PPUC, covering a range of topics including Hawai‘i's energy transition, alternative energy policies, ratemaking, competitive bidding, and variable/intermittent energy integration and interconnection requirements. At the request of Palau's energy agencies, a technical and financial analysis of PPUC's grid operations, including future excess energy curtailment and energy storage needs was conducted. The team then developed and delivered a new distributed generation interconnection requirements regulation (i.e., a grid code) for Palau in 2024, which PEWA has adopted. To facilitate effective implementation, a three-day training on new energy integration for PPUC and PEWA staff in Koror was held (Figure PIC.1).

Figure PIC.1. Energy transition capacity building at PPUC in June 2024.

In early 2025, HNEI's Grid***START*** conducted a holistic analysis of generation operations, dispatch, and system planning strategies. This work involved evaluating how current generation resources were being managed, analyzing dispatch patterns with existing and planned solar and BESS technologies, and considering various strategies to reduce reliance on costly diesel units. The modeling helped illustrate how different investments in system flexibility, including BESS, could improve operational efficiency and lower overall costs, providing a technical foundation for future planning decisions.

Throughout this project period, HNEI coordinated with major international organizations, such as the Asian Development Bank (ADB) and other entities including Okinawa Enetech and Tokyo Electric Power Company working in Palau under funding from the Japan International Cooperation Agency (JICA), to ensure that technical assistance was aligned and delivered effectively for Palau's unique needs. A list of presentations by Grid***START*** related to their international efforts, including this topic, is available at https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

The Cook Islands

The Cook Islands is an island nation in the South Pacific committed to shifting its power system away from full reliance on imported fuels. The Cook Islands Economic Development Strategy set a goal to meet 60% of the nation's electricity demand from non-conventional sources by 2030. Te Aponga Uira (TAU), a state-owned power company, provides approximately 90% of the country's electricity and serves around 5,000 customers, supporting both the community and economy of Rarotonga. TAU is wholly owned by the Cook Islands Investment Corporation (CIIC). The Rarotonga grid reaches a peak demand of about 5.5 MW, with most power produced by diesel generation and a growing share from customer-owned rooftop solar and utility-scale solar-plus-BESS projects financed by international support entities such as the ADB.

HNEI provided technical and regulatory support to TAU in three principal areas: 1) building and refining the utility's regulatory and planning frameworks; 2) conducting modeling and analysis of the Rarotonga grid; and 3) establishing methodologies for evaluating how much additional distributed generation could be accommodated by the system.

In September 2023, Grid***START*** hosted a training workshop in Honolulu for TAU's senior management and board members, sharing lessons learned from Hawai'i's grid modernization, BESS deployment, and customer rooftop system integration. In addition, a week of presentations and meetings in Rarotonga in July 2024 occurred, meeting with TAU management, the boards of TAU and CIIC, and the Cook Islands' Prime Minister (Figure PIC.2). These sessions focused on system planning, implementation of BESS projects, customer program design, and strategic areas for continued support.

Figure PIC.2. HNEI and TAU leadership with Prime Minister Brown.

A key technical achievement under APRESA was the launch of a distributed PV hosting capacity study for TAU's grid. Building from TAU's existing PowerFactory model, HNEI worked with utility staff to clarify foundational system assumptions, such as daytime minimum loads, that directly influence hosting capacity results. This collaborative process, including multiple rounds of data review and presentation of preliminary results, was essential for ensuring a robust and practical analysis. Following feedback from TAU staff, the team refined its stochastic assessment methodology, creating an improved version of the hosting capacity study for Rarotonga's distribution feeders. Further strategic planning and PCM studies were initiated, including analytical work using the SAInt software platform to assess operational strategies for BESS deployments, evaluate grid performance under various scenarios, and support TAU's long-term planning efforts.

The Republic of Marshall Islands (RMI) - Majuro

RMI is an island nation that relies heavily on imported fuels for power generation, making the development and implementation of energy policy a priority. To advance its 2018 energy roadmap, RMI has been working to establish an energy law and supporting regulations. At the request of the National Energy Office, HNEI provided reviews and feedback on draft legislation and regulatory documents.

With APRESA funding and in partnership with the Pacific Power Association (PPA), Grid***START*** met with key stakeholders in Majuro, including the National Energy Office, the Environmental Protection Authority, and the Marshalls Energy Company (MEC), to gain a better understanding of local challenges and needs in 2024. In 2025, presentations and interactive discussions on system planning, strategies from Hawaiʻi's experience operating island grids, hosting capacity methods for distributed solar, BESS, grid modernization, and approaches for competitive resource procurement were held. HNEI's work in Majuro focused on providing technical assistance, capacity building, and sharing knowledge to support MEC and RMI agencies as they seek to update their energy law and prepare for future changes to the power system. Discussions for further collaboration, such as supporting MEC in creating a grid code, are ongoing but will proceed under separate funding.

The Federated States of Micronesia (FSM) - Yap State

Yap State is part of the Federated States of Micronesia and is served by the Yap State Public Service Corporation (YSPSC), a state-owned utility that provides electricity, water, and sewer services to both Yap Proper and the state's outer islands. Yap Proper has a peak electricity demand of about 1.9 MW, supplied by roughly 11 MW of installed capacity. A portion of this capacity comes from solar and wind systems developed through international funding as well as smaller customer-installed systems. The island is expecting new power projects, increased use of BESS and EVs, and higher electricity demand due to planned U.S. Department of Defense (DOD) facilities. Through APRESA funding and in partnership with PPA, HNEI provided technical and policy support to YSPSC.

In October 2024, on-island training for YSPSC staff occurred, delivering a two-day program covering topics such as system planning approaches from Hawai'i's island grids, management of high levels of variable generation, updated interconnection standards, BESS applications, EV integration, energy resilience considerations, and strategies for competitive resource procurement. Grid***START*** also provided its internally developed Generation Mix Resource Modeling Tool with hands-on instruction for YSPSC personnel. During the visit, the team toured the island's generation and distribution facilities and met with YSPSC management to discuss potential areas for ongoing collaboration. These efforts were intended to assist YSPSC in preparing for anticipated system changes and future growth in demand on Yap's power grid (Figure PIC.3), much of which will be driven by planned DOD activities there. Beyond the work with YSPSC, HNEI has employed a graduate assistant from Yap since January 2024 based on project needs. The position has offered the student professional experience through participation in various energy-related projects.

Figure PIC.3. YSPSC's first on-island training and site visits in October 2024.

The Republic of Fiji

Fiji generates about 60 percent of its electricity from hydro power, with the remainder coming from other sources. The national utility, Energy Fiji Limited (EFL), has set a target to meet all electricity demand from non-conventional sources by 2030, and plans to add a substantial amount of solar capacity to help achieve this goal. In September 2024, HNEI met with EFL to discuss their request for capacity building in planning, procuring, and operating solar projects on a system with a high share of non-fossil generation. Through APRESA funding, a virtual training to EFL was provided in April 2025 on integrating variable generation and shared lessons learned from Hawai'i's island grids. Discussions on potential follow-up support are continuing, although any future activities will proceed under separate funding.

SOUTHEAST ASIA AND INDO-PACIFIC REGION

Funding from this award played a key role in expanding HNEI's engagement across Southeast Asia and the Indo-Pacific region. These connections built relationships with leading energy sector stakeholders from several countries, strengthened technical collaboration, and led to new projects and partnerships throughout the seven years of the award. These engagements across Southeast Asia and the Indo-Pacific region helped to foster meaningful technical exchange and open pathways for collaborative projects. Select regional projects, not described in the country specific summaries above, are described below.

ASEAN Interconnection Masterplan

The Association of Southeast Asian Nations (ASEAN), a regional grouping of ten states in Southeast Asia, aims to accelerate economic growth and social progress and promote regional peace and collaboration among its members. The ASEAN Centre for Energy (ACE) is an organization within ASEAN that represents the Member States' interests in the energy sector. The ASEAN Interconnection Masterplan Study (AIMS), coordinated by ACE and led by the Head of ASEAN Power Utilities/Authorities (HAPUA), is the region's principal initiative for developing an integrated ASEAN Power Grid and advancing cross-border electricity trade. AIMS III, launched in 2019, builds on previous planning efforts by charting pathways for power system integration and market development among the Member States. The study encompasses technical, regulatory, and economic analyses to inform expansion planning and support future market integration efforts across the region.

From 2019 through 2021, HNEI made sustained contributions to the AIMS III process. Upon request, Grid***START*** assembled and served as a core member of the Technical Review Group (TRG), a committee of international experts providing direction on AIMS III study scope, data collection, modeling assumptions, and technical review. The first TRG meeting was convened in December 2019 in Bangkok, where members shared planned contributions and reviewed initial resource assessment results presented by the AIMS III technical consultant. Subsequent TRG meetings were held in 2020, where members provided further feedback on analysis methodologies and scenario development, reviewed resource assessments, and capacity expansion plans, then agreed on the structure of the four planning scenarios.

In addition to technical review, ACE requested support to deliver targeted capacity building for the region. An in-person, multi-day training to ACE staff in Jakarta was held to build the knowledge base and capability of ACE planning/engineering staff in the advanced analytics needed for effective energy integration and power grid modernization and optimization in ASEAN countries. This training focused on advanced grid analytics, PCM, and hands-on use of the PLEXOS simulation tool to strengthen capacity for effective planning and power system modernization. This initiative was designed to empower ACE personnel to work more closely with national authorities in developing and implementing regional energy cooperation plans. While follow-on extended training for ACE personnel had been scheduled to take place at HNEI in Honolulu, it was postponed due to COVID-19 travel restrictions.

Our partnership with ACE continued with participation in technical sessions and meetings involving ASEAN member utilities, with a focus on regional planning strategies, cross-border power trade, and deployment of advanced energy solutions. This collaboration supported ACE's coordination of the ASEAN Plan of Action for Energy Cooperation, a blueprint for advancing regional energy development through increased cooperation and technical exchange among ASEAN Member States.

While the AIMS III project itself remains ongoing, Grid***START***'s core technical and capacity building support provided under APRESA funding, was aligned with the period of CPA's support, which concluded in 2021. The outcomes and experience gained through this collaboration continue to inform regional energy planning and development today as ACE and HAPUA carry forward the work of AIMS III.

Southeast Asia Smart Power Program

With the conclusion of CPA in 2021, HNEI began a new collaboration with the Southeast Asia Smart Power Program (SPP), a five-year, $40 million regional initiative aiming to drive economic growth and power sector development in Southeast Asia by expanding energy capacity, improving resilience, supporting demand-side management (DSM) and DR strategies, advancing utility modernization, and facilitating integration of diverse generation resources. The initiative, managed by Deloitte Consulting LLP, promotes utility modernization and accelerates integration of new energy technologies across ASEAN Member States.

HNEI's work in support of SPP focused on several core activities. These included supporting the creation of a regional Center for Competitive Procurement, participating in resiliency assessments and DSM/DR program development for ASEAN utilities, and contributing to pilot projects that demonstrate advanced technologies and approaches. Knowledge sharing and capacity building across all ten ASEAN Member States occurred under this effort. Grid***START*** played a key role in planning and delivering a capacity building workshop in conjunction with the ASEAN Power System Operators (APSO) Annual Meeting in Manila. This three-day event brought together project developers, utility planners, and grid operators from across the region to address operational strategies for integrating higher levels of variable and distributed energy resources. Leveraging practical experience from Hawai‘i, sessions covered system flexibility, operator coordination, and pathways for regional power trade. These workshops facilitated the exchange of best practices and supported ASEAN utilities in advancing modern, resilient power systems.

Under SPP, HNEI also provided country-specific technical support and training to national authorities and utilities in Laos and Cambodia, as detailed below.

HNEI's support was given to Électricité du Laos (EDL) and Ministry of Energy and Mines (MEM) as part of initial efforts to build capacity, improve grid reliability, and strengthen regional connectivity. Engagement with EDL and MEM included practical guidance on integrating new technologies, multiple rounds of technical consultation and training, and dedicated technical assistance provided through the SPP partnership. Work began with a launch meeting for SPP's Laos activities in January 2023. Among initial technical support tasks, Grid***START*** provided updated feasibility study guidelines for wind, solar, and biomass projects in Laos to EDL and MEM. The team also delivered an updated Grid Code for Laos, incorporating interconnection standards for inverter-based resources (IBRs), and updated requirements for PV at the distribution level, as discussed above.

As part of SPP's commitment to strengthening institutional capacity, HNEI led three sessions for EDL and MEM staff in 2023 and 2024. The first two sessions were for EDL, held in Vientiane in June and October 2023. They focused on the updated Grid Code and new distribution interconnection standards, offering comprehensive training on requirements and best practices for integrating IBRs into the Lao system (Figure S.1).

Figure S.1. Capacity building session in June 2023 in Vientiane, Laos.

The third session was a virtual presentation about IBRs grid connection requirements and their applications in the U.S., delivered at the SPP closing event in Vientiane in May 2024. Attendees included EDL's Technical Working Group for Rooftop Solar Installation and Management and relevant EDL departments. The session covered insights from U.S. and Hawaiian experiences with grid codes, standards, and regulatory practices for variable and inverter-based resources. The 25-minute presentation was followed by a 25-minute Q&A, allowing participants to discuss technical challenges and practical applications for Laos.

These highly interactive sessions, combined with technical deliverables, provided EDL and MEM staff with practical skills and international perspective essential for integrating new generation technologies and enhancing grid reliability. Throughout this partnership, HNEI and SPP stayed in close contact with EDL and MEM to identify further opportunities for technical collaboration. The team explored ways to help Laos advance toward a secure, modern, and market-driven energy sector, with several promising avenues considered with SPP. However, no substantive new activities materialized before the abrupt agency stoppage and program close-out in early 2025, which halted further progress.

Under SPP, HNEI supported Cambodia's national utility, Electricité de Cambodge (EdC), in their efforts to modernize the country's power sector and integrate greater shares of variable and intermittent energy resources. Efforts focused on transferring U.S. best practices and strengthening technical capacity within EdC. These activities contributed to SPP's broader mission to help Southeast Asian countries expand cross-border energy trade and enhance grid resilience.

In March 2024, Grid***START*** collaborated with SPP and the Australian Department of Foreign Trade and Investment to deliver a capacity building workshop at EdC's headquarters in Phnom Penh. The event brought together representatives from forty key institutions and concentrated on advancing Cambodian energy practitioners' understanding of strategies for integrating variable and intermittent resources. Special emphasis was placed on power system coordination and flexible resource management. A list of presentations by Grid***START*** related to their international efforts, including this topic, is available at https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

Support for APEC Working Groups

As a part of its regional activities, HNEI has contributed to key Asia-Pacific Economic Cooperation (APEC) Working Group meetings, workshops, and capacity building events aimed at advancing energy system integration, policy development, and technology deployment throughout the Asia Pacific region. Through these engagements, Grid***START*** has shared technical expertise, facilitated regional knowledge transfer, and fostered partnerships among member economies to address emerging challenges in grid modernization, non-conventional energy deployment, and cross-border collaboration.

In March 2018, HNEI hosted the 50th meeting of the APEC Expert Group on New and Renewable Energy Technologies (EGNRET) in Honolulu. As part of the EGNRET 50 meeting, HNEI organized a full-day capacity building workshop focused on energy policy, integration of variable and intermittent resources into the grid, energy efficiency, and bioenergy. The meeting was complemented by a coordinated technical tour to the Hawaiian Electric Company's (HECO) system control center and a visit to HNEI's Electrochemical Power Systems Laboratory, offering participants direct exposure to Hawai'i's advanced grid operations and energy research facilities (Figure S.2).

Figure S.2. 2018 APEC 50th EGNRET meeting (Source: APEC).

In September 2018, HNEI was invited to present at an APEC project workshop on Off Grid Electrification Option for Remote Regions in APEC Economies held in Chiang Mai, Thailand. The presentation focused on the challenges of maintaining grid stability during increased solar deployment on isolated island grids, highlighting the effectiveness of centralized BESS as a rapid-response, scalable solution to mitigate load shedding, and facilitate higher levels of distributed generation. The workshop's roundtable discussions reinforced that, while non-conventional energy and microgrid technologies are increasingly practical and cost-effective for remote regions, significant barriers persist, including geographic isolation, telecommunications limitations, maintenance needs, limited local engagement, and funding constraints. Participants emphasized the importance of innovative business models and ongoing financial support, noting that DC microgrids, given their current technological maturity, may not yet be the best fit for developing economies

In March 2021, the team participated in the first APEC Workshop on Exploring Co-Benefit Opportunities for Renewable Energy and Energy Efficiency Projects in the APEC Region, originally planned as an in-person event but shifted online due to the pandemic. Presentations on lessons from demonstration projects in Hawaiʻi and Okinawa, including JUMPSmart Maui, the Hawaiʻi virtual power plant, and the Okinawa advanced conservation voltage reduction demonstration. The latter two projects received support from ONR's APRISES program. Grid***START***'s contributions highlighted practical strategies for smart grid integration and operational flexibility, offering participants relevant examples of how energy efficiency and distributed technologies can be leveraged in evolving power systems.

In April 2023, HNEI served as the primary host and organizer for the APEC 58th EGNRET and 34th Expert Group on Energy Data and Analysis (EGEDA) Joint Meeting and a series of associated workshops in Honolulu. Over the course of this multi-day event, staff coordinated logistics and venue arrangements, bringing together representatives from across the APEC region. The program featured a workshop with in-depth sessions on APEC's evolving energy landscape and progress toward carbon-free electricity and discussions on the role of bio-circular-green economy principles in shaping regional strategies for carbon neutrality. Throughout these events, HNEI facilitated knowledge sharing, delivered several presentations, and supported collaboration among regional experts, helping strengthen best practices, and foster strategic partnerships for energy transition across the Asia Pacific region (Figure S.3).

Figure S.3. 2023 APEC 58th EGNRET and 34th EGEDA Joint Meeting and Associated Meetings (Source: APEC).

In April 2023, the team presented at the Asia Pacific Energy Research Centre (APERC) Annual Conference in Tokyo, where the team discussed the complexities of system planning amid evolving priorities for energy security and affordability. Building on this engagement, in June 2023, a training session for APERC senior leadership and modeling experts in Tokyo was conducted, demonstrating an advanced energy resource assessment modeling tool developed by HNEI and providing practical instruction on its application in regional planning contexts. Through these sustained and diverse contributions, HNEI has expanded the technical capabilities of regional partners, promoted knowledge exchange on emerging energy technologies and policy, and strengthened the Asia Pacific network of practitioners advancing collaborative solutions for the region's power sector. A list of presentations by Grid***START*** related to their international efforts, including this topic, is available at https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

Support of ADB and Asia EDGE Events

In an effort to expand outreach and collaborative technical engagement throughout Southeast Asia, HNEI also participated in high-profile forums and capacity building events with the Asian Development Bank (ADB) and the U.S. Department of State's Asia Enhancing Development and Growth through Energy (EDGE). ADB events in which HNEI participated included:

- September 2017: Presentation at ADB headquarters in Manila.
- January 2019: Participation at the International Conference on Energy 4.0.
- June 2018 and 2019: Presentations at the Asia Clean Energy Forums (ACEF).
- June 2023, 2024, and 2025: Presentations to various Southeast Asian power sector practitioners.
- December 2017: Participation in a three-day workshop in Singapore, organized by U.S. government agencies such as the United States Energy Association (USEA).
- October 2019: Presentations at the U.S. government agency-sponsored workshop: Energy Storage Regional Workshop in Thailand.
- November 2019: Participation in the Asia EDGE Competitive Procurement Dialogue in Bangkok.
- July 2020: Participation in regional knowledge exchange through the Asia EDGE Power Sector Learning Series, including two virtual educational sessions on distributed generation program implementation and interconnection policy to utilities and sector practitioners across Southeast Asia.

A list of presentations by Grid***START*** related to their international efforts, including this topic, is available at https://www.hnei.hawaii.edu/publications/project-reports/apresa/.

Sustainable Aviation Fuels Workshops

Sustainable aviation fuels (SAF) workshops were held by in Bangkok, Thailand (2023) and Denpasar, Indonesia (2024). The Bangkok event was supported by the U.S. Federal Aviation Administration's Aviation Sustainability Center, the U.S. Trade Development Agency, and ONR (through APRESA) and co-organized with the Thailand's National Energy Technology Center (ENTEC). The Denpasar workshop was supported by the U.S. Federal Aviation Administration's Aviation Sustainability Center and ONR (APRESA) and co-organized with Thailand's National Energy Technology Center and Indonesian's Directorate General for Civil Aviation. Workshops were attended by participants from across the Southeast Asian region, including Vietnam, Indonesia, LPDR, Malaysia, Philippines, Singapore, and Thailand (Figure S.4).

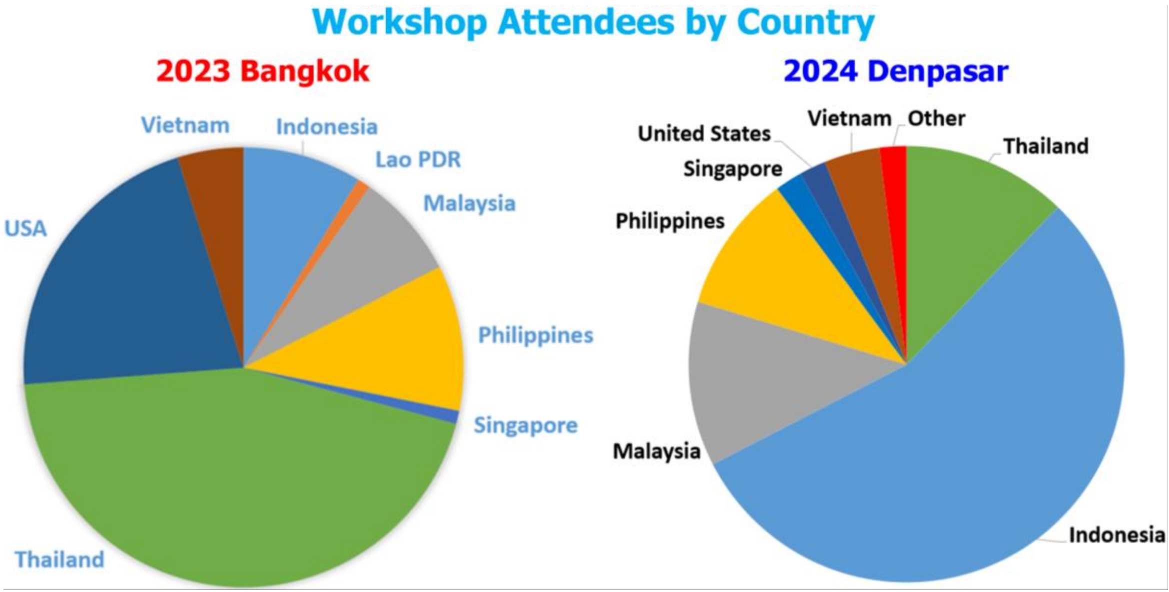


Figure S.4. The breakdown of the two workshop attendees by country.

Attendees represented participants in sustainable aviation fuel supply chains (from feedstock producers to airlines), government agencies with regulatory authority, non-government organizations, and university and research organizations (Figure S.5).

Figure S.5. The breakdown of the workshop attendees by organization type.

Workshops included sessions providing perspectives on SAF from the following groups:

- Civil aviation authorities

- Energy policy makers
- Feedstock producers
- SAF conversion technology
- Airport operations
- SAF system logistics
- SAF university research
- SAF policy development

In 2023, exit surveys of workshop participants identified sessions by civil aviation authorities, energy policy makers, and feedstock producer as the most useful, demonstrating that SAF was a relatively new topic for most participants. Exit surveys in 2024 indicated that participants had moved past the initial information gathering about SAF and were more interested in SAF policy development that would support economic viability. Participants rated both workshops as "9s" on a scale of 1 to 10 and expressed continued interest in participating in future workshops to keep abreast of SAF landscape developments and network with regional counterparts.

Review of Candlenut for Fuels Potential

Candlenut (*Aleurites moluccanus*) is a tropical oilseed tree that furnishes many bioproducts and has a long history of human relationships across its geographic distribution. Its seed has a ~60% lipid content making it a potential source of renewable oil for synthetic fuels production. Characterization of candlenut radiation use efficiency (RUE)—how the tree intercepts solar radiation, converts it to biomass, and allocates that energy—enables process-based modeling of productivity and comparisons to other production systems. Likewise, understanding the genetic, environmental, and management (GEM) drivers of variation in traits that underlie RUE enables assessment of candlenut sustainability, conservation targets, and improvement opportunities. Both RUE and GEM information are lacking for candlenut.

This review takes systematic, metanalysis, and narrative approaches to understand candlenut's productivity potential and variability through the lenses of RUE and GEM. Oil is the most commonly referenced product; however, virtually all aboveground parts of the tree have economic potential. Planting density and rotation length stand out as management tools likely to modify the canopy light environment and RUE and thereby determine candlenut productivity as well as its function within an agroecosystem. Candlenut occupies a wide range of environmental conditions and exhibits signatures of genetic diversity and population structure across its global distribution.

The results of the literature review provide an initial, global synthesis of the productivity and sustainability potential of the tree. Future work should include its interactions within local ecologies across its geographic distribution, characterize existing markets for its products and coproducts, and document cultural practices used in its production systems. The resulting manuscript is currently under review for publication in the *Energy Nexus* journal and will be available via https://www.hnei.hawaii.edu/publications/project-reports/apresa/ upon acceptance.