RE-SAT: Energy Analytics Platform

Renewable Energy planning in Palau

Case study

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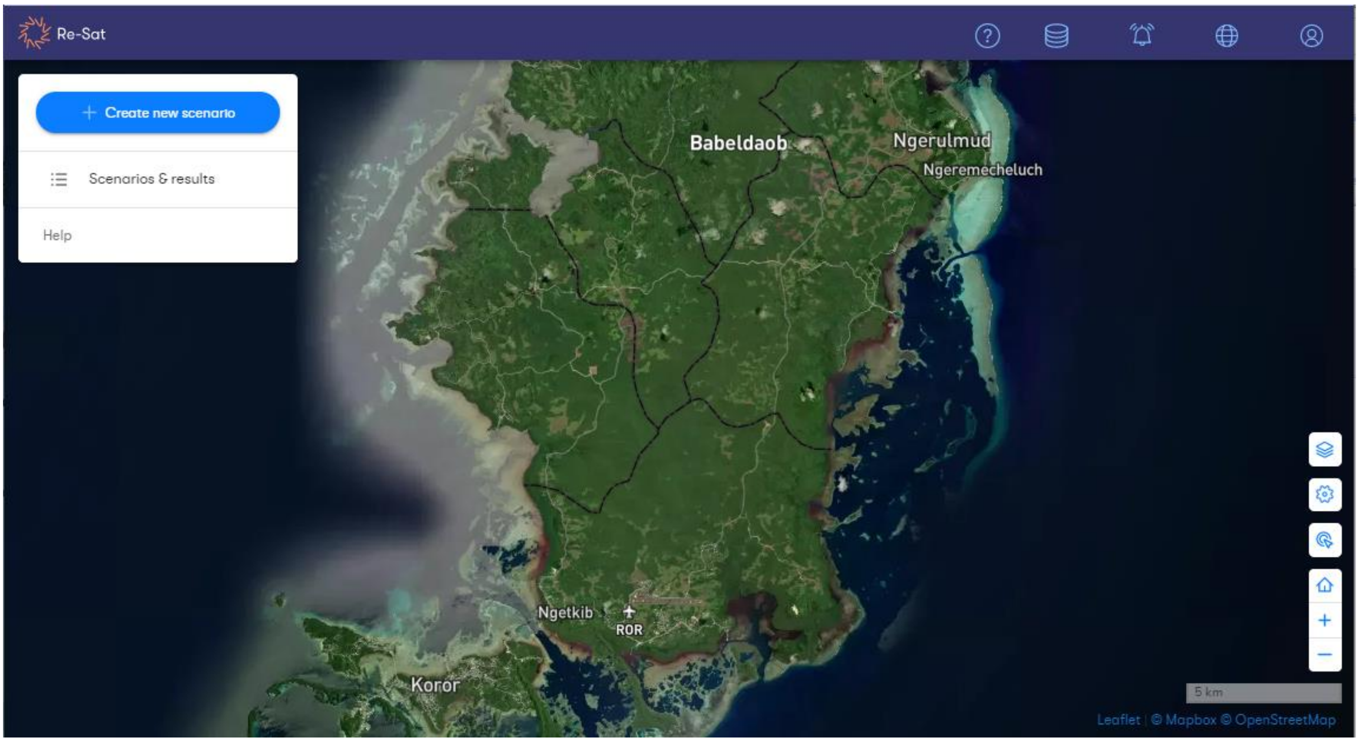

The Institute for Environmental Analytics (IEA)

Founded in 2015, the Institute for Environmental Analytics (IEA) is a research and development centre for big data analytics in the environmental field. The IEA specialises in turning large scale, global environmental data into easy-to-use products for clients in the energy, agriculture and infrastructure markets.

Energy Analytics Platform

RE-SAT is a new, cloud-based energy analytics platform that focus on the pre-feasibility and strategic planning of new renewable energy infrastructure, from single project development through to national energy transition strategies. The platform fuses satellite and in-situ weather data with advanced analytics to provide highly detailed renewable energy information to help users:

- Explore and define the best renewable energy installation mix and their locations.
- Assess the potential financial viability of renewable energy investments.
- Estimate power production and variability, considering seasonal weather patterns.

The RE-SAT project is led by the IEA and funded by the UK Space Agency (UKSA) International Partnership Programme (IPP). RE-SAT Phase 1 (Dec 2016 – Nov 2017) was implemented in partnership with the Government of Seychelles. Phase 2 (Jan 2018 – Nov 2021) has scaled the RE-SAT platform to 6 other Small Islands States to support their transition from fossil fuel electricity generation to renewables. The platform is now operational and ready for its commercial Phase.

The UK Space Agency
International Partnership Programme

The International Partnership Programme (IPP) is a 5-year, £152 million programme run by the UK Space Agency. IPP seeks to use space solutions to make a positive and practical impact on the lives of those living in emerging and developing economies through partnerships with end users in the target countries to increase their capacity and respond to specific challenges. IPP is part of and is funded from the UK Department for Business, Energy and Industrial Strategy's (BEIS) Global Challenges Research Fund (GCRF).

Acknowledgments

The RE-SAT project (Phase 2) in Palau acknowledges the invaluable assistance from the Palau Energy Administration (PEA) under the Ministry of Public Infrastructure, Industries, and Commerce and the Palau Public Utilities Corporation (PPUC).

Palau Energy Administration

"Project management unit for renewable energy and energy efficiency projects in Palau"

Palau Public Utilities Corporation

Today's Conservation is Tomorrow's Prosperity

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1. Executive summary

Small Island Developing States (SIDS) are heavily dependent on expensive, vulnerable, petroleum-based power generation and can spend 15-20% of disposable income on electricity (versus 5-10% in the OECD). Whilst having abundant renewable energy (RE) resources ranging from solar and wind to geothermal and hydro, the current level of installed renewable capacity is low.

To support the planning and development of renewable energy projects, the Institute for Environmental Analytics (IEA) was awarded a grant from the UK Space Agency International Partnership Programme to develop an energy analytics platform (RE-SAT) with associated data products and modelling to support SIDS to plan and undertake their transition from fossil fuel electricity generation to renewables.

Phase 1 (2017) of the project developed a proof-of-concept platform for Seychelles, with Phase 2 (2018 – 2021) scaling the concept to 6 other SIDS and operationalising the platform ready for commercial exploitation after the end of the funded phases.

Through a collaborative process of co-creation with our country partners, the RE-SAT platform was tailored for Palau under three categories of development:

1) Data and modelling:
    a. Tailored weather data to drive the power calculations in RE-SAT. These are high-resolution multi-year simulations of key weather variables creating using modelling techniques combined with satellite[1] and in-situ data.
    b. Resource maps as a guide to the abundance of energy available for a particular type of RE installation by location.
    c. Geographical information maps to assess, in combination with the resource maps, suitable locations for renewable energy installations.

2) Platform capabilities and features:
    a. Variable Renewable Energy (VRE) simulation - RE-SAT models the energy generated and its variability from a combination of VRE installations (wind, solar and wave) (renewable energy scenario) as specified by the user in the platform. The power contributions from hydro, geothermal and biofuels can also be added if required.
    b. Demand comparison - If the demand for electricity is added, RE-SAT compares the RE generated by the combination of installations (the scenario) versus the demand, giving an indication of the amount of energy that still needs to be generated by other sources to meet demand and help with future energy planning.
    c. Financial analysis - RE-SAT performs a levelized cost of renewable energy calculation to assess the relative cost of one technology of combination of technologies versus another.

[1] Satellite data is being used to enhance our estimates of Global Horizontal Irradiance (GHI). Surface radiation products from: OSI-SAF (Meteosat and GOES-East) and JAXA (Himawari 8) are used as RE-SAT's primary source of data for the estimation of solar power production.

   d. CO_2 and fuel saved – RE-SAT calculates the CO_2 saved and amount fossil-fuel displaced (and related costs) by the modelled RE installation.

3) Capacity building:
   a. Working Group meetings and Training Workshops to explain the data and gather feedback on the platform – A two-way exchange of expertise and data was essential for the development of the project.
   b. Data repository – The RE-SAT platform includes a repository which contains all the data developed with the partner country for easy access and collaboration.
   c. Technical Manual – A comprehensive online Technical Manual is available from the RE-SAT platform with step-by-step explanations of how to use RE-SAT.

Our **partnership in Palau** was led by the Palau Energy Administration (PEA) under the Ministry of Public Infrastructure, Industries, and Commerce, working closely with the Palau Public Utilities Corporation. PEA is the project management unit for renewable energy and energy efficiency in Palau. Other agencies involved included the Bureau of Land and Survey.

During the 4-year project, the platform evolved in response to user requirements and feedback. The **commercial ready platform** (version 2) was successfully launched in Palau in July 2021 during our final training workshop (due to the pandemic this took place online). A session to discuss the way forward of how the platform would be made available to Palau after the funded project ends was also included.

The **performance of the RE-SAT platform in Palau** was tested against actual power produced by the carport solar array at Koror Airport. The errors, expressed as a percentage of the installed capacity, measured on the 10-minute average power accounted to 11%. When averaging over a day the errors are reduced to 2%.

The **impact** that RE-SAT has had in Palau is the ability to explore potential scenarios to achieve the new 45% energy target by 2025. Palau expects to achieve this mainly through solar PV and they are already on that path with a 16MW solar farm expected to be in operation in 2022. RE-SAT was used to test the performance of those Independent Power Producer that bided to installed and operate the 16MW farm. By using RE-SAT, planners have also realised that adding the second Phase of solar will need to include battery storage as the energy produced will exceed the demand in some instances. Palau has now a common platform for officers in different department to use common data and analytics for efficient and effective collaboration and decision-making.

Based on stakeholder feedback, the **benefit and value** that RE-SAT is adding include:

- Improved accuracy of data for decisions about the energy mix, required grid infrastructure and battery sizing – leading to potential government savings on infrastructure costs.
- Better power estimation for a mix of RE developments based on robust data – leading to investor confidence and a greater likelihood that RE investments occur, thus reducing reliance on imported (and expensive) fossil fuels.
- Appropriate RE technology capacity building – leading to partners being better equipped to plan their future RE infrastructure.

For Palau specifically, RE-SAT is:

- Supporting the national planning process to facilitate the targeted increase in the use of renewable energy in Palau to 45% by 2025.
- Enabling the Government and power organisations to leverage the tools, knowledge and results to apply for other large-scale investment funding (e.g., Green Climate Fund) in support of their RE targets.

"The project met the need for an independent third-party source of technical validation for the IPP procurement process." Ramon Manny Adelbai, Mechanical Engineer (PPUC)

"With this new advantage we are in the right path towards achieving our goals."[2] Hon. Minister Charles I. Obichang, Office of the Ministry of Public Infrastructure, Industries & Commerce

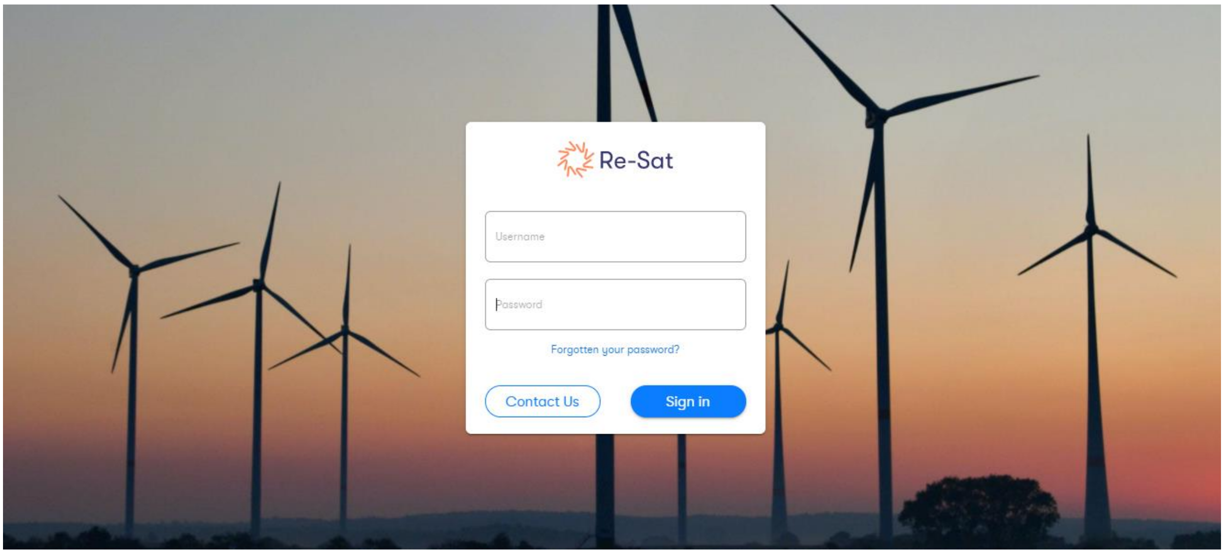


***Figure 1**: Landing page of the RE-SAT platform.*

[2] Extract from a Letter of appreciation to UK Space Agency from the Government of Palau (2019)

2. Project overview

2.1. The energy and data challenges facing Palau

2.1.1. About Palau

Palau is located in the western Pacific Ocean and contains 340 islands with an area of $466km^2$. The population of Palau is around 21,000. Its most populous islands are Angaur, Babeldaob, Koror and Peleliu. The latter three lie together within the same barrier reef, while Angaur is an oceanic island several kilometres to the south. About two-thirds of the population lives on Koror. The capital Ngerulmud is located on the island of Babeldaob.

Palau lies on the edge of the typhoon belt. Tropical disturbances frequently develop near Palau every year, but significant tropical cyclones are quite rare. Palau is vulnerable to the impacts of climate change, mainly from sea level rise and the impacts of extreme events.

Palau is a presidential republic in free association with the United States, which provides defence, funding and access to social services.

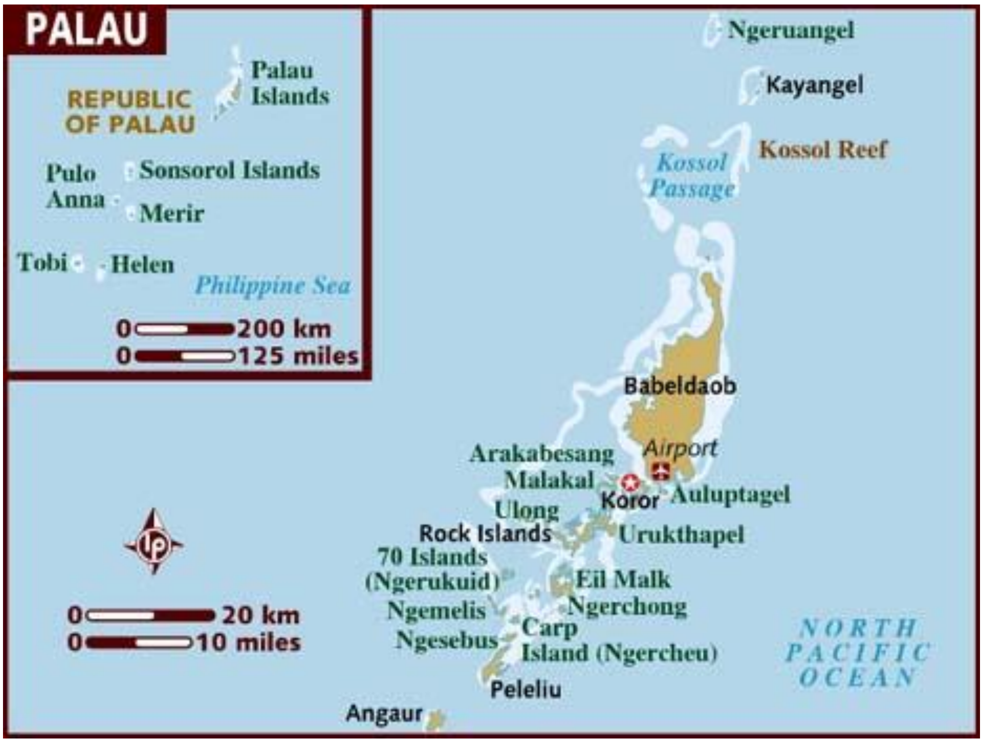


Figure 2: Map of Palau.

2.1.2. Electricity in Palau – Energy targets

Palau has a target of achieving 45% of electricity from renewable energy sources by 2025. (NDC targets (2015)[3]

The IRENA Palau Energy Roadmap has suggested that the deployment of large-scale solar farms and wind on the main grid of Koror-Babaldaob together with battery storage could support this ambitious target. The combined grid Koror-Babeldaob main grid has consistently accounted for ca. 98% of national electricity demand.

Palau's electricity generation system is owned and operated by the Palau Public Utility Corporation (PPUC), a government-controlled utility with national responsibility for electricity and water services. The generation capacity consists of 30MW of diesel generation and 2.3MW of PV rooftop systems.

The Palau Energy Administration, part of the Ministry of Public Infrastructure, Industries and Commerce, in collaboration with the Palau Public Utilities Corporation (PPUC), is responsible for the management, implementation and maintenance of new energy projects and infrastructure on behalf of the Government of Palau.

The Palau National Energy Policy (NEP) (2010)[4] sets out the policies around climate change, renewable energy and security of energy supply both in terms of reliability and resilience. The NEP provides a framework to make informed decisions and to manage the energy sector. There is also a Strategic Action Plan[5] with a more detailed action program.

In 2018, the Government of Palau awarded a contract to an Independent Power Producer to develop a dispatchable utility-scale solar PV project for 35MW of RE and 45MWh of energy storage. The IPP would build, operate and sell the power to PPUC for an agreed price and terms as negotiated in the Power Purchase Agreement. However, the government had to re-launch the request for proposal (RFP) for internal reasons, which delayed the development of the solar project. The new IPP bid is for a 20MWp solar generation and was selected at the beginning of 2021. The current renewable energy penetration in Palau is 4% (personal communication from government official) mainly through solar rooftop PV (on commercial facilities and the airport carport), but with this new IPP solar development, the country is on its way to meet its goal of 45% renewable energy use by year 2025.

2.1.3. Challenges in renewable energy planning - common to Small Island States

Planning and managing renewable energy production require a good understanding of the variability in the natural phenomena such as clouds, wind, wave etc. In SIDS, there are a limited number of weather stations, therefore there is limited data to understand significant geographic variability, and records may be interrupted by operational disturbances leading to missing periods of data. These may

[3] Palau Intended Nationally Determined Contributions (2015). https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Palau%20First/Palau_INDC.Final%20Copy.pdf

[4] Palau National Energy Policy (Aug 2010). https://policy.asiapacificenergy.org/sites/default/files/Palau%20National%20Energy%20Policy%202.pdf

[5] Strategic Action Plan Energy Sector (2009) http://prdrse4all.spc.int/system/files/essap_final_draft_23-10.pdf

be supplemented from time to time by specific site surveys or research projects, however these will be limited in location or timeframe.

Satellite based measurements can be used to generate data products that can regularly estimate weather parameters over large areas. However, the spatial resolution (typically in the order of kilometres) and time resolution may not always be suitable for renewable energy planning.

A key consideration in renewable energy planning and management is the need to anticipate short period (within 10 minute) fluctuations in production, as short-term drops in renewable production need to be rapidly compensated by backup conventional fossil fuel generation, battery storage or other measures. As renewable energy production is distributed across a region, the risk of 'intensity drops' in renewable output can be lessened as, for example, not all installations will be affected by changes in cloud or wind at the same point in time. This means that a good understanding of the variability in these natural resources by location and time is essential, and this is not always supported by current sources of data.

A lack of confidence in the current data observations can lead to over-conservative assumptions about the requirements for back-up (leading to increased operational costs), or increased perception of risk from investors (leading to increased costs of lending).

2.2. The RE-SAT solution

The RE-SAT project has addressed these challenges by **developing an energy analytics platform** to support the transition to renewable energy and by **using weather observations, satellite data products and modelling techniques** to enhance and fill in gaps in the weather data record. The software platform allows users to access these enhanced datasets and use them to provide improved renewable energy resource estimates for investing and planning purposes.

RE-SAT Phase 1 (December 2016 – November 2017) focused on Seychelles and the IEA engaged with a team of end users drawn from the main energy-related government agencies within Seychelles. Through a series of workshops and training sessions the IEA refined the functional requirements for RE-SAT under three categories of development:

1. Data and modelling.
2. Platform capabilities and features.
3. Capacity building.

RE-SAT Phase 2 built on what was learned and developed in Phase 1 to apply the platform to a range of other SIDS including Palau, in order to prove its usefulness and commercial viability in different countries with separate renewable energy demands. The ability to expand the concept's geographical scope is a key strength of an Earth Observation based solution.

2.3. Targeting the UN Sustainable Development Goals

RE-SAT supports the transition towards low carbon energy in SIDS and contributes towards two key aspects: energy reliance and climate change mitigation.

- **Sustainable Goal 7 – Affordable and Clean Energy** - SIDS are heavily dependent on expensive, vulnerable, petroleum-based power generation (~85% across all the SIDS (IRENA[6], 2014) and spend 15-20% of disposable income on electricity (versus 5-10% in the OECD). Paradoxically, SIDS have abundant RE resources ranging from solar and wind to geothermal and hydro. However, the cumulative RE adoption across SIDS is less than 15% of total capacity (IRENA, 2014).

- **Sustainable Goal 13 - Climate Action** – Despite emitting less than 1% of global greenhouse gases, SIDS are very vulnerable to the effects of climate change including rising sea levels, seawater infiltration, land erosion and severe storms.

Increasing the use of renewable energy on island states will improve energy security and tackle climate change, leading ultimately to a more sustainable economic growth in the SIDS.

Our programme aligns primary to SDG 7 and the specific target 7.2: “By 2030, increase substantially the share of renewable energy in the global energy mix”, with its indicator: 7.2.1 “Renewable energy share in the total final energy consumption”.

In addition, part of our work also contributes to SDG 10 Reduced Inequalities (e.g., through better targeting renewable energy projects at low-income groups) and SDG 11 (Sustainable Cities and Communities).

[6] IRENA: International Renewable Energy Agency

3. Project partners

Our **partnership in Palau** was led by the Palau Energy Administration (PEA) under the Ministry of Public Infrastructure, Industries, and Commerce, working closely with the Palau Public Utilities Corporation (PPUC). PEA is the project management unit for renewable energy and energy efficiency in Palau. Other agencies involved included the Bureau of Land and Survey.

The role of PEA has been to facilitate access to the progress regarding renewable initiative in Palau by providing expert knowledge into the particular RE requirements and potential sources of data. PPUC has provided regular updates on the status of the project planned under the request for proposal as well as valuable power data from the solar array at the airport carport for our validation purposes.

***Figure 3**: Palau participants at the RE-SAT workshop tother with member so the IEA team (Nov 2018)*

"The close working group relationship with the IEA team and Palau-side team [was a key factor leading to project achievements]." Ramon Manny Adelbai, Mechanical Engineer (PPUC)

4. Developing the RE-SAT platform

4.1. Understanding user needs - common high-level functionalities

After initial assessments with all stakeholders in each island, the value chain displayed in the figure below was captured to show how RE-SAT capabilities were intended to benefit the SIDS stakeholders

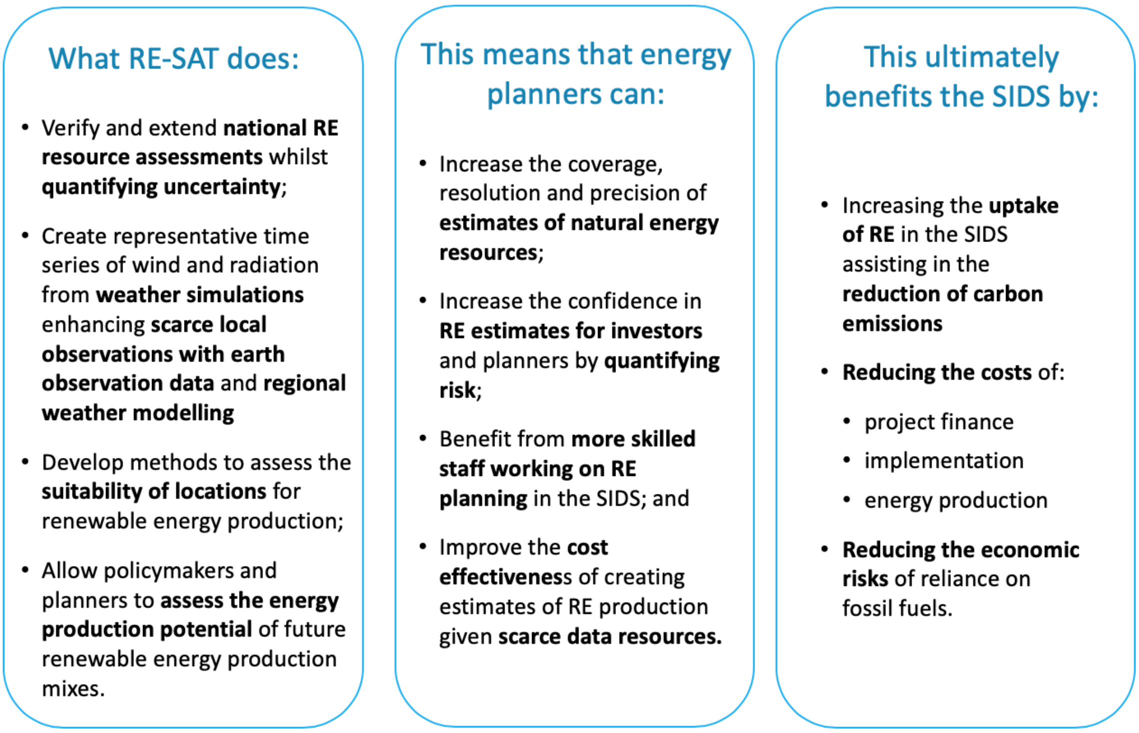


Figure 4: RE-SAT intended value chain.

The following high level functional requirements were identified, common to all partner SIDS.

High level Requirement
Resource maps - Identify the likely aggregate variation in weather variables affecting energy production (insolation, wind speed, wave height) by location and represent in the form of a map.
Weather data - Quantify the expected variation in weather variables affecting energy production by location over a simulated time period. The simulated weather variables will: • Range over multiple years (sufficient to capture modes of multi annual variation e.g., ENSO). • Reproduce as far as possible the climatology for each nominated location. • Preserve realistic meteorological inter-area correlations. • Provide simulated data points at nominated time resolutions with no missing gaps, at a nominated spatial resolution.

High level Requirement
Location assessment - Identify potential feasible and optimal locations for the placement of RE installations considering multiple decision criteria and constraints (environmental, regulatory and legal). Functionality is needed to: • Facilitate the overlay of GIS layers for location identification. These layers are likely to include: resource maps, terrain models, land use, transport networks, electric grid infrastructure, optical imagery, building outlines, flooding, landslide, storm hazards, existing RE installations.
Power output estimation Create future scenarios for power output from new RE installations, required for: • Strategic planning. • Response to national communications to the UNFCCC. • Procurement exercises for RE or grid infrastructure. • Support proposals for new infrastructure. Users need to be able to: • Load pre-selected site locations for installations. • Load existing installation specifications into a scenario. • Locate installations 'by hand' on a map. • Define the technical specification of wind and solar installations, sufficient to allow estimates of power production from simulated realistic weather conditions. • Define financial attributes for each scenario and installation, sufficient to estimate a "first order" levelised cost of energy (LCOE) over the installation lifetime (e.g., attributes such as capital expenditure, operation expenditure, inflation, financial discount rates, installation lifetime). • Compare the output of a group of installations with a user specified range of demand scenarios, in order to estimate how much renewable production will fall short of or exceed demand throughout each day in simulated weather years. • Simulate the energy production from a specified mix of RE installations against a range of realistic weather conditions. Estimate the total amount of power that would be generated, and its variability over a nominated time resolution. • Quantify the uncertainty of given levels of energy generation for installations in a scenario, known as exceedance probabilities P10, P50 and P90. • View the results of the simulation by individual installation and at varying time resolutions (hourly, day, week, month, year). Guide the user to significant conditions in the weather simulations (for example periods of maximum or minimum generation or rate of change of power production). • Allow variations on scenarios at different points in time to be easily developed, compared and evaluated, accounting for installation aging and changes in demand. • Allow users to collaborate by sharing and developing scenarios within and between stakeholder teams.
Training and knowledge sharing • Deliver training to nominated users on how to use the data products and software platform. • Provide a way to exchange knowledge within the country and across countries regarding the use of RE-SAT and renewable energy related issues.
Access to RE-SAT • Provide secure access to the platform, through unique logins to key stakeholders.

4.2. Specific requirements in Palau

The following specific requirements were requested by stakeholders in Palau

Resource maps – to support location assessment of the future solar and wind RE installations:

- Solar map
- Wind map
- Wave map

Weather data:

- Global resolution data (30 x 30 km) for a national assessment for combined solar, wind and wave.
- High resolution[7] solar data products and wind products to support the investment cases for Koror and Babeldaob islands.

Probabilistic power calculations:

- To minimise the risks in sizing new RE developments (assessing the range of potential power results)

Cost assessment

- Add economic cost analyses calculations for renewable installation types within RE-SAT.

Capacity building

- Training package to help users navigate through the software platform.

Dispatch modelling

- Modelling the integration of intermittent renewables with other forms of generation, storage and reserve, allowing better quantification of fossil fuel cost and also emission savings. Note that this requirement was not in scope for the current project, but the IEA team is taking this forward as a future enhancement.

Meeting these requirements through developing new functionalities in RE-SAT meant that that those responsible for RE planning in Palau would be able to:

- Increase the coverage, resolution and precision of estimates of natural resources needed.
- Increase the confidence in RE estimates for investors and planners.
- Benefit from more knowledgeable and skilled staff working on RE planning.
- Improve the efficiency and effectiveness of creating estimates of RE production.

Over time these will contribute towards improved decision-making, reduced costs of implementation and increased uptake of renewable energy in Palau, helping to reduce the cost of energy production and reducing the economic risks of reliance on fossil fuels.

[7] 'High resolution' means products that have been derived by the IEA team, typically using combining global resolution products and ground truth with complex data intensive modelling. Typically, the resolution is of the order of 1km x 1km spatial, 10-minute time resolution.

4.3. Responding to requirements – the technical solution

Through a collaborative process, the IEA team tailored the project to the needs of the Government of Palau and its agencies and developed a set of agreed targeted objectives with short-term benefits for Palau as well as long-term benefits.

The RE-SAT functional requirements, as developed in consultation with Palau partners, were separated into three categories:

a) Data and modelling
b) Platform capabilities and features
c) Capacity building

4.3.1. Data and modelling

1. Weather data: Analysed and simulated weather data for coupled wind and solar resources. These weather datasets were created based on a bespoke local area high-resolution (1km x 1km) numerical weather model configured by the IEA for Palau.

   The weather data products created include wind speed, incoming shortwave radiation, temperature, and Global Horizontal Irradiance (GHI). A wave dataset was also generated directly from the 30kmx30km Reanalysis data (ERA5) used to drive our high-resolution weather model.

   Satellite data is being used to enhance our estimates of GHI. Surface radiation products from: OSI-SAF (Meteosat and GOES-East) and JAXA (Himawari 8) are used as RE-SAT's primary source of data for the estimation of solar power production. Satellite derived estimates of the incoming flux of shortwave radiation are generally preferred over the estimates from our weather model simulations due to the difficulty of accurately simulating cloud cover. The situation is reversed towards local dawn and dusk when the remotely sensed estimates become unreliable, at which point we fall back to the weather model data.

2. Resource maps: A guide to the abundance of energy available for a particular type of renewable generation by location. Resource maps were developed for: solar, wind and wave (see Figure 5).

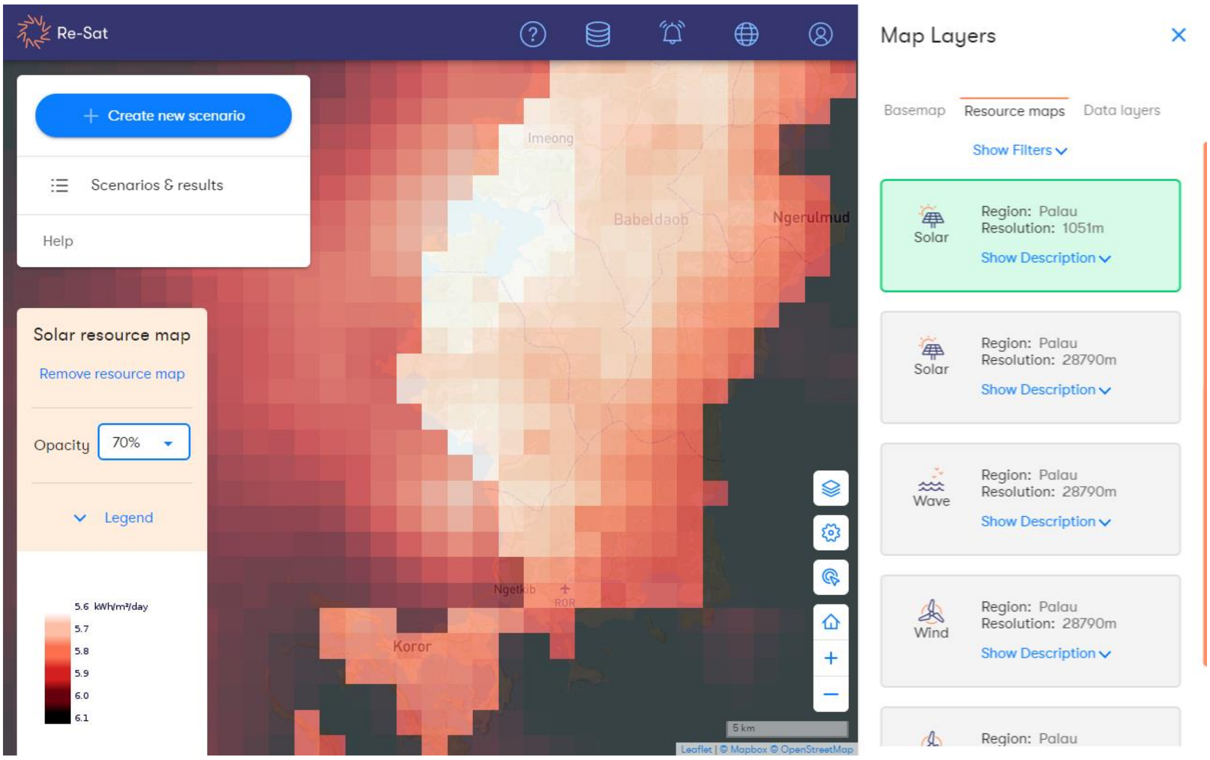


***Figure 5**: Solar resource map for Palau.*

3. GIS map layers: These are layers, either provided by the partner country or created by the IEA (Figure 6). Conservation is very important in Palau, so GIS layers for conservation areas and protected areas were important to show places where development should not take place.

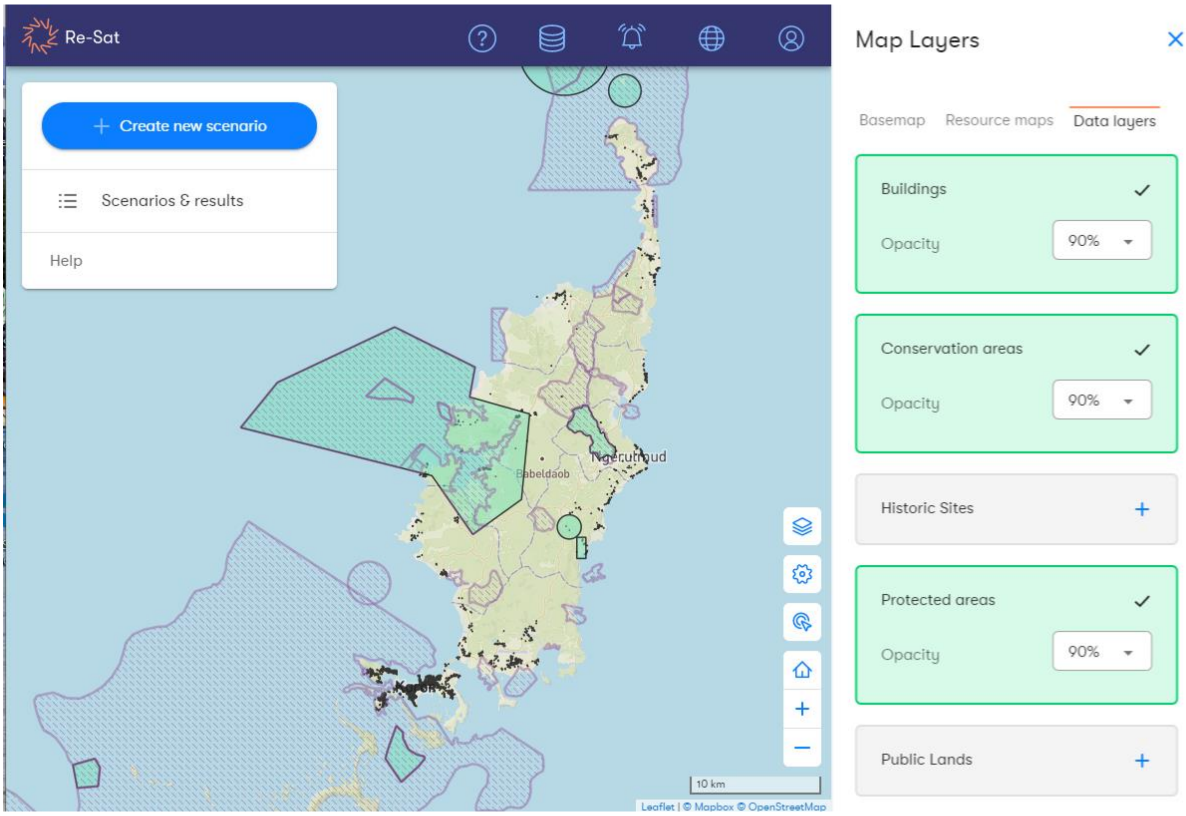


Figure 6: *Example of some of the GIS layers available in the RE-SAT platform for Palau.*

4.3.2. Platform capabilities and features

1. <u>Location assessment</u>: A capability to use the resource maps together with a combination of GIS layers to assess suitable locations for new renewable energy installations.

2. <u>Renewable scenario settings and installations characteristics</u>: The capability to create future configurations of mixed renewable energy installations. RE-SAT offers templates of generic installation types and those that have been already used or specified by the user, adding to the bespoke nature of the application.

3. <u>Variable Renewable Energy simulation (VRE simulation)</u>: RE-SAT models the energy generated and its variability from a combination of VRE installations as specified by the user. The results are based on the multi-year weather data developed and tailored for Palau.

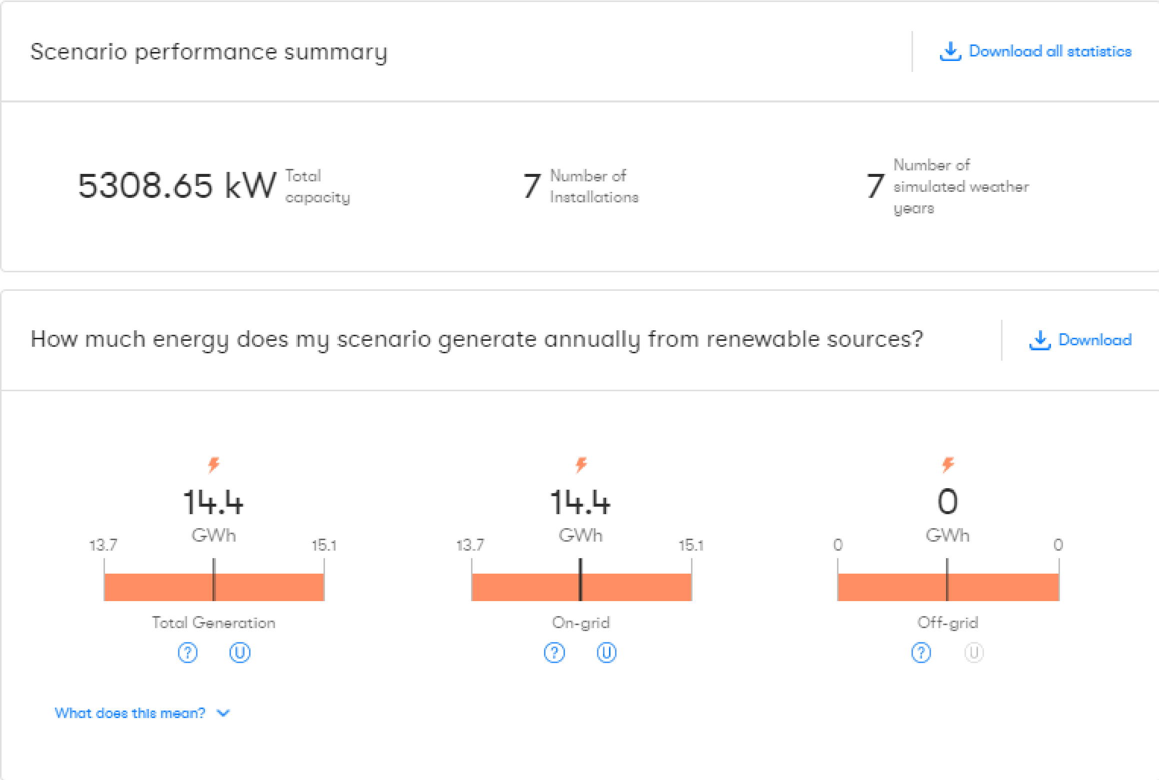


Figure 7: *Example of the scenario performance summary display in RE-SAT.*

4. <u>Geothermal, hydro and biofuel contributions</u>: Capability to add power estimated from these installation types. These are added by the user as fixed outputs or predetermined time-series of production.

5. <u>CO2 and fossil fuel displacement</u>: RE-SAT calculates the potential for displacement of fossil-fuel related costs and CO2 emissions saved from the modelled renewable energy scenario.

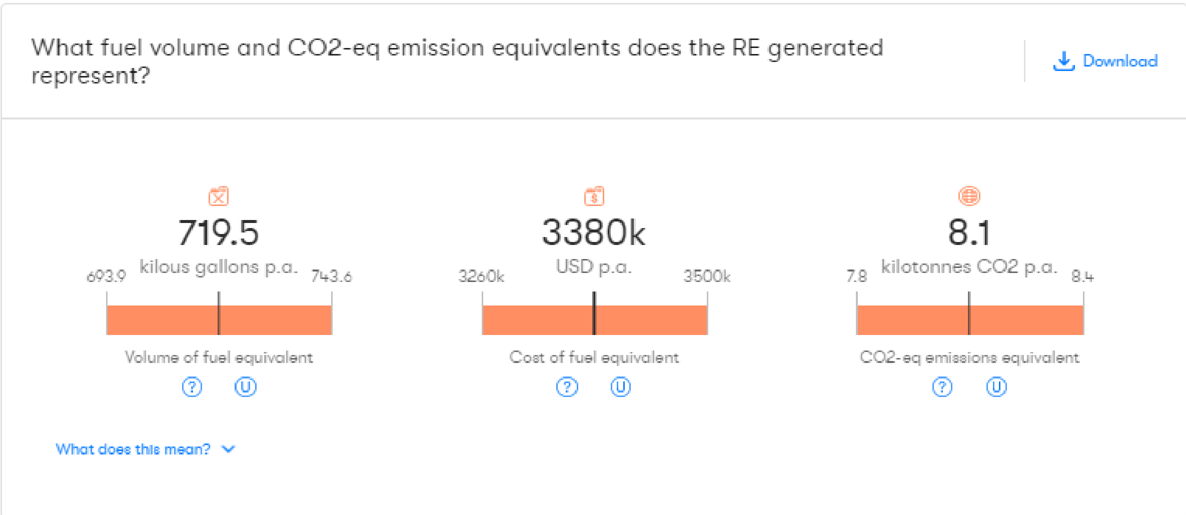


Figure 8: *Example of the results of the CO2 and fossil fuel displacement calculations in RE-SAT.*

6. Uncertainty quantification: RE-SAT reports generation estimates at different exceedance probabilities, expressing how often it is likely that a given annual quantity will be exceeded when measured repeatedly over several years (to account for year-on-year variability). Confidence interval on each of these estimates are also provided (to account for modelling uncertainty).

7. Demand comparison: If a yearly load curve (demand for electricity) is provided for the scenario, RE-SAT compares the RE generated by the scenario versus the demand, e.g., the platform quantifies what residual load remains after considering the renewable contribution. This gives an indication of the amount of energy that still need to be generated by other sources to meet that demand.

Figure 9: Example of summary results for the demand comparison analysis in RE-SAT.

8. Financial analysis: Capability to assess the relative cost of one scenario or technology type versus another. RE-SAT performs a levelised cost of renewable energy calculation (LCORG). All the financial assumptions regarding costs of installations, inflation, etc. were tailored for Palau and arrived at in consultation with partners.

Generation Sensitivity

Exceedance probability	Annual RE Generation (MWh)	Capacity Factor	Weighted LCORG* in 2021 (USD/kWh)
10%	293	14.2%	0.320
25%	292	14.1%	0.322
50%	289	14%	0.325
75%	286	13.8%	0.328
90%	285	13.8%	0.330

* LCORG - Levelised Cost Of Renewable Generation

Figure 10: Example of performance indicators at different Exadance probabiilities together with the Lecelised Cost of Renewable Generation results.

Figure 11 shows an extract from a discounted cash flow model automatically created from a scenario in the RE-SAT application. The model can be downloaded by the user in the form of an EXCEL spreadsheet and shows all assumptions made and the basis of the calculation. This allows the user to perform sensitivity analysis on all input assumptions when calculating a levelised cost of energy (known in RE-SAT as a levelised cost of renewable generation or LCORG) for the energy generated from a specific installation to account for uncertain knowledge. The levelised cost of energy is a common industry metric used to estimate and compare energy costs. The use of satellite data reduces the uncertainty in production estimates and therefore cost estimates.

LEVELISED COST OF RENEWABLE GENERATION CALCULATION								
Scenario name	#2 1000kW Solar Scenario 2021							
Installation name	750kW Lookout							
Exceedence probability	50.00%							
Bound	middle							
Installation year	2021							
Installation AC capacity	652.00 kW							
Year	y	0	1	2	3	4	5	6
REPLACEMENT								
Generator residual due	-	0	0	0	0	0	0	0
Inverter age	years	0	1	2	3	4	5	6
Inverter residual due	-	0	0	0	0	0	0	0
Inverter replacement due	-	0	0	0	0	0	0	0
Inverter value after depreciation	USD_2021	250,074.60	222,288.53	194,502.47	166,716.40	138,930.33	111,144.27	83,358.20
Degradation Factor	-	1.00	1.00	0.99	0.99	0.98	0.98	0.97
Degraded Annual Energy	kWh		1,139,620.72	1,133,922.62	1,128,253.00	1,122,611.74	1,116,998.68	1,111,413.69
NOMINAL CASHFLOW								
Nominal Discount Factor	-	1.00	0.93	0.87	0.81	0.75	0.70	0.66
Nominal Inflation Factor	-	1.00	1.02	1.04	1.06	1.08	1.10	1.13
Nominal Discounted Degraded Energy	kWh		1,062,088.28	984,881.49	913,287.12	846,897.19	785,333.37	728,244.83
Nominal Cumulative Energy	kWh		1,062,088.28	2,046,969.76	2,960,256.88	3,807,154.07	4,592,487.44	5,320,732.26
Nominal generator residual inflated	USD_2021		0.00	0.00	0.00	0.00	0.00	0.00
Nominal inverter residual	USD_2021		0.00	0.00	0.00	0.00	0.00	0.00
Nominal inverter replacement	USD_2021		0.00	0.00	0.00	0.00	0.00	0.00
Nominal inverter value on generator en	USD_2021		0.00	0.00	0.00	0.00	0.00	0.00
Nominal Opex	USD_2021		-11,735.10	-11,969.80	-12,209.20	-12,453.38	-12,702.45	-12,956.50
Nominal Opex of production	USD_2021		0.00	0.00	0.00	0.00	0.00	0.00
Nominal Total Cashflow	USD_2021	-1,400,724.60	-11,735.10	-11,969.80	-12,209.20	-12,453.38	-12,702.45	-12,956.50
Nominal Discounted Cashflow	USD_2021	-1,400,724.60	-10,936.72	-10,396.51	-9,882.98	-9,394.82	-8,930.77	-8,489.64
Nominal Cumulative Discounted Cashfl	USD_2021	-1,400,724.60	-1,411,661.32	-1,422,057.83	-1,431,940.81	-1,441,335.63	-1,450,266.40	-1,458,756.04
Nominal Total Cost	USD_2021	-1,400,724.60	-11,735.10	-11,969.80	-12,209.20	-12,453.38	-12,702.45	-12,956.50
Nominal Discounted Cost	USD_2021	-1,400,724.60	-10,936.72	-10,396.51	-9,882.98	-9,394.82	-8,930.77	-8,489.64
Nominal Cumulative Discounted Cost	USD_2021	-1,400,724.60	-1,411,661.32	-1,422,057.83	-1,431,940.81	-1,441,335.63	-1,450,266.40	-1,458,756.04
REAL CASHFLOW								
Real Discount Factor	-	1.00	0.95	0.90	0.86	0.82	0.78	0.74
Real Inflation Factor	-	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Real Discounted Degraded Energy	-		1,083,330.04	1,024,670.70	969,187.60	916,708.75	867,071.49	820,121.96
Real Cumulative Energy	-		1,083,330.04	2,108,000.74	3,077,188.34	3,993,897.09	4,860,968.58	5,681,090.54
Real generator residual inflated	USD_2021		0.00	0.00	0.00	0.00	0.00	0.00
Real inverter residual	USD_2021		0.00	0.00	0.00	0.00	0.00	0.00
Real inverter replacement	USD_2021		0.00	0.00	0.00	0.00	0.00	0.00
Real inverter value on generator end of	USD_2021		0.00	0.00	0.00	0.00	0.00	0.00
Real Opex	USD_2021		-11,505.00	-11,505.00	-11,505.00	-11,505.00	-11,505.00	-11,505.00
Real Opex of production	USD_2021		0.00	0.00	0.00	0.00	0.00	0.00
Real Total Cashflow	USD_2021	-1,400,724.60	-11,505.00	-11,505.00	-11,505.00	-11,505.00	-11,505.00	-11,505.00
Real Discounted Cashflow	USD_2021	-1,400,724.60	-10,936.72	-10,396.51	-9,882.98	-9,394.82	-8,930.77	-8,489.64
Real Cumulative Discounted Cashflow	USD_2021	-1,400,724.60	-1,411,661.32	-1,422,057.83	-1,431,940.81	-1,441,335.63	-1,450,266.40	-1,458,756.04
Real Total Cost	USD_2021	-1,400,724.60	-11,505.00	-11,505.00	-11,505.00	-11,505.00	-11,505.00	-11,505.00
Real Discounted Cost	USD_2021	-1,400,724.60	-10,936.72	-10,396.51	-9,882.98	-9,394.82	-8,930.77	-8,489.64
Real Cumulative Discounted Cost	USD_2021	-1,400,724.60	-1,411,661.32	-1,422,057.83	-1,431,940.81	-1,441,335.63	-1,450,266.40	-1,458,756.04
FINANCIAL MEASURES								
Lifetime measures								
LCC	USD_2021	1,784,249.61						

***Figure 11**: Extract from a discounted cash flow model automatically created from a scenario in the RE-SAT application.*

9. Results exploration: RE-SAT presents results via interactive visualisations that show generation by year, month, day, hour or even at the 10-minute level. Charts can be customised for the different sources allowing the user to look at the expected intermittency and what good and bad production looks like. Generation profiles can be overlaid with demand curves, residual load curves and potential curtailment.

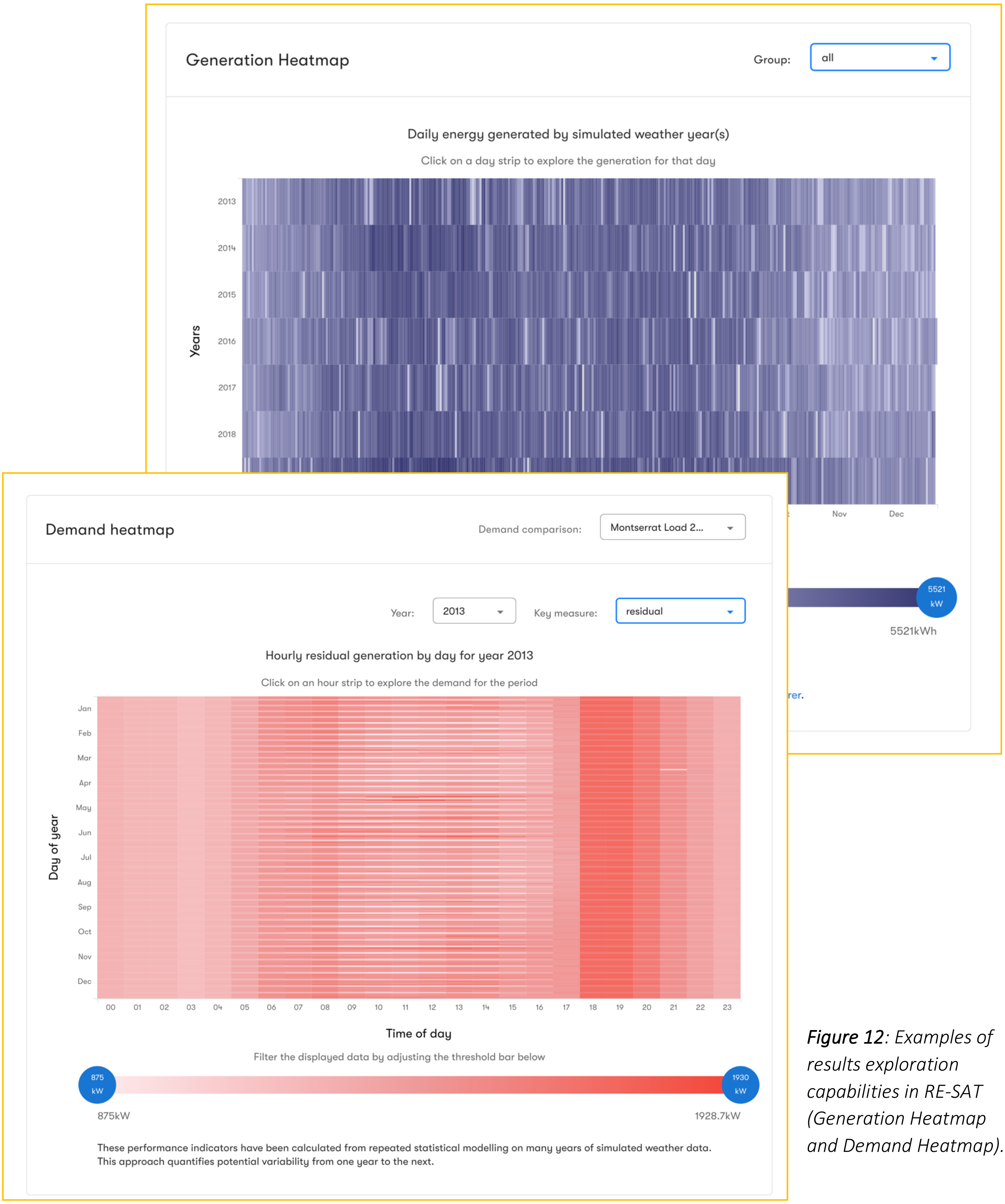


Figure 12: Examples of results exploration capabilities in RE-SAT (Generation Heatmap and Demand Heatmap).

Figure 13*: Examples of results exploration capabilities in RE-SAT.*

10. <u>Data repository</u>: All dataset developed (weather data, GIS layers and resource maps) and results from scenarios are stored under a data repository, for easy access and download.

11. <u>Technical Manual:</u> An online Help Manual with step-by-step explanations of how to use RE-SAT together with technical explanations is also available from the platform.

4.3.3. Capacity building

One of the key aspects of the project is the exchange of knowledge and expertise with our partners regarding the use of earth observation data, environmental modelling, data analysis and renewable energy. This has been realised through the Working Group meetings and a series of visits and interactive workshops. A total of 13 people in Palau have access to the platform.

Figure 14: Palau participants during the RE-SAT workshop in May 2019

Figure 15: Palau participants at work during the RE-SAT workshop in May 2019

4.4. Delivering value and benefits – innovations

The main two areas where RE-SAT is pushing the boundaries within renewable energy planning are:

- **Strategic support for national energy planning:** The intuitive interface and workflow allows rapid modelling of different renewable generation scenarios. Scenarios provide a convenient way to explore options for achieving a range of renewable energy-related objectives:
  - Nationally Determined Contributions - Quantifying the extent to which renewable energy projects can contribute towards more ambitious Nationally Determined Contributions.
  - Integrated Resource Plans - Developing strategies for ensuring future supplies of electricity as part of integrated resource (and resilience) planning.
  - National Energy Transition Strategies - To inform planning, policy and procurement strategies for increasing the penetration of renewable energy as part of generation expansion aspirations and overarching energy transition.

- **Project pre-feasibility evaluation:** The software is designed to make it quick and easy to complete a pre-feasibility renewable energy analysis.
  - Site selection - Our high-resolution resource maps combined with integration of geospatial data (GIS layers) inform strategic site selection of new installations - providing a pre-feasibility check without the need for lengthy site surveys.
  - Generation profiles - The platform analytics provide detailed characterisations of renewable energy generation profiles and generation versus demand, which provides information about the utilities company power needs - leading to potential government savings on unnecessary infrastructure costs.
  - Portfolio effects - The ability to model single installations or complex combinations of different plants in different locations supports the exploration of potential portfolio effects.
  - Investment cases - The platform provides a comprehensive suite of energy metrics that can support the development of robust investment cases and more bankable project proposals.
  - Proposal assessment – RE-SAT provides an independent and standardised method or assessing renewable energy proposals received.

The RE-SAT weather datasets are the engine behind the platform and what drive the calculations of our energy metrics. The performance of installations exploiting variable renewable energy sources, like solar and wind, relies on weather. RE-SAT calculations are driven by our high-resolution weather datasets. These are multi-year simulations of key weather variables that we create using a regional high-resolution weather model combined with satellite data and any available local weather observations. The result is a high spatial (1km) and temporal resolution (10-minute timestep) weather dataset which is tailored to a particular geography.

The project has also delivered the following benefits regarding capacity building

- Training in EO, weather modelling and RE concepts leading to partners being better equipped to plan their future renewable energy infrastructure needs.
- More knowledgeable and skilled staff working on renewable energy planning – delivering technical support and training to deploy and utilize RE-SAT for in-country decision-making.
- A knowledge-sharing platform to foster a wider exchange of experiences in the use of the data and the platform for in-country users.

4.5. Validation exercise - how does RE-SAT performs in Palau?

The RE-SAT platform was used to simulate the power produced by the existing solar arrays installed at Koror International Airport. These total 236kW of generation capacity. The output from RE-SAT was compared with the actual power produced by the installations from January to December 2019. The power data was kindly provided by the PPUC.

***Figure 16**: The solar array installed at the airport carport (Palau).*

The comparison considered two key elements:

1. The accuracy of the simulations.
2. The calibration of the uncertainty estimates.

4.5.1. Accuracy

This was assessed using the Bias and the Mean Absolute Error (MAE). These quantities measure how far RE-SAT's power estimates are from the truth. Figure 17 below compares the simulated power from RE-SAT (red line) with the observed production (black dots).

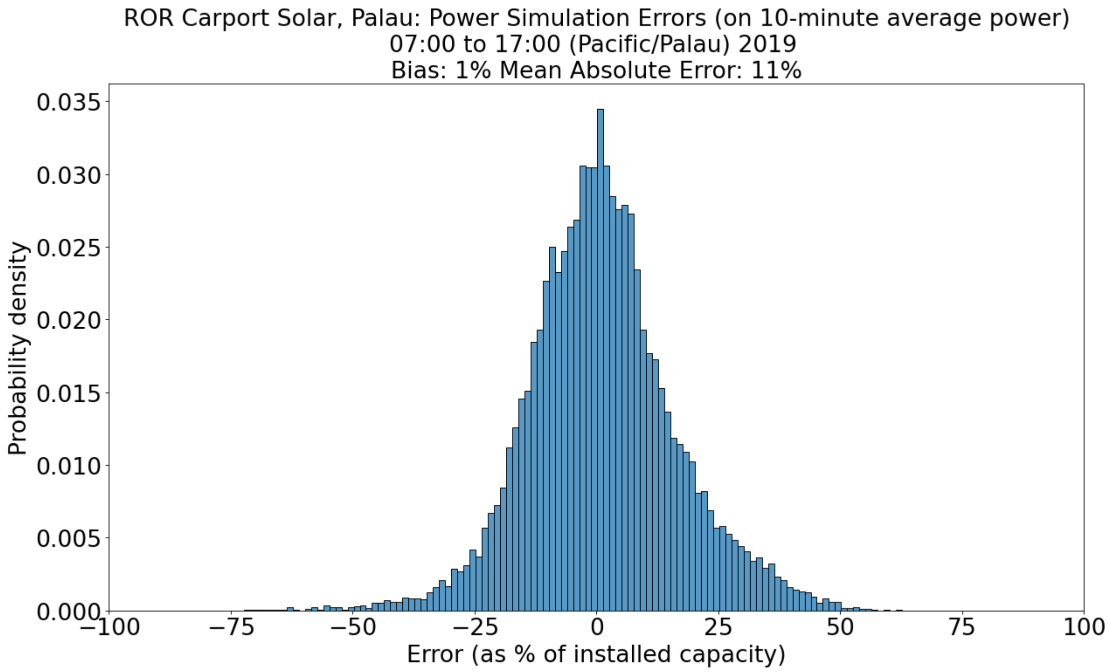
The bias is defined as the mean distance of the black dots from the red line. If the simulated values are consistently higher than reality (red line typically above the dots) the bias is positive. Similarly, a negative bias would mean that the dots typically lie above the line and the simulation would be systematically under predicting the power.

Low bias is a necessary condition for a 'good' simulation, but it is not sufficient. A good simulation will have low bias with all points scattered close to the red line (the production simulated by RE-SAT). A poor simulation may also have low bias but with points scattered widely about the line (equal numbers of under and over predictions compensate on average). The mean absolute error is used to distinguish between the two cases.

In summary, a good simulation will have both low bias (the simulation is accurate) and low MAE (the simulation has high precision).

***Figure 17**: RE-SAT performance compared with observed production for the 236kW solar installation at Koror International Airport. The black dots represent the overserved power produced, the red line is the simulated production by RE-SAT, the colour bands are a representation of the uncertainty (1 sigma or 2 sigma)*

The comparison shown in Figure 17 is for power measured in (kW). This is useful for a particular generator, but it is difficult to compare bias and MAE between generators of different sizes. Thus, it is normal to report errors, and likewise bias and MAE, expressed as a percentage of the installed capacity. Figure 18 summarises the simulation errors for the Vaini site as measured on the 10-minute average power (upper panel) and the average daily power (lower panel). Since solar simulation errors are trivially zero at night-time only values for daytime are included in the analysis.



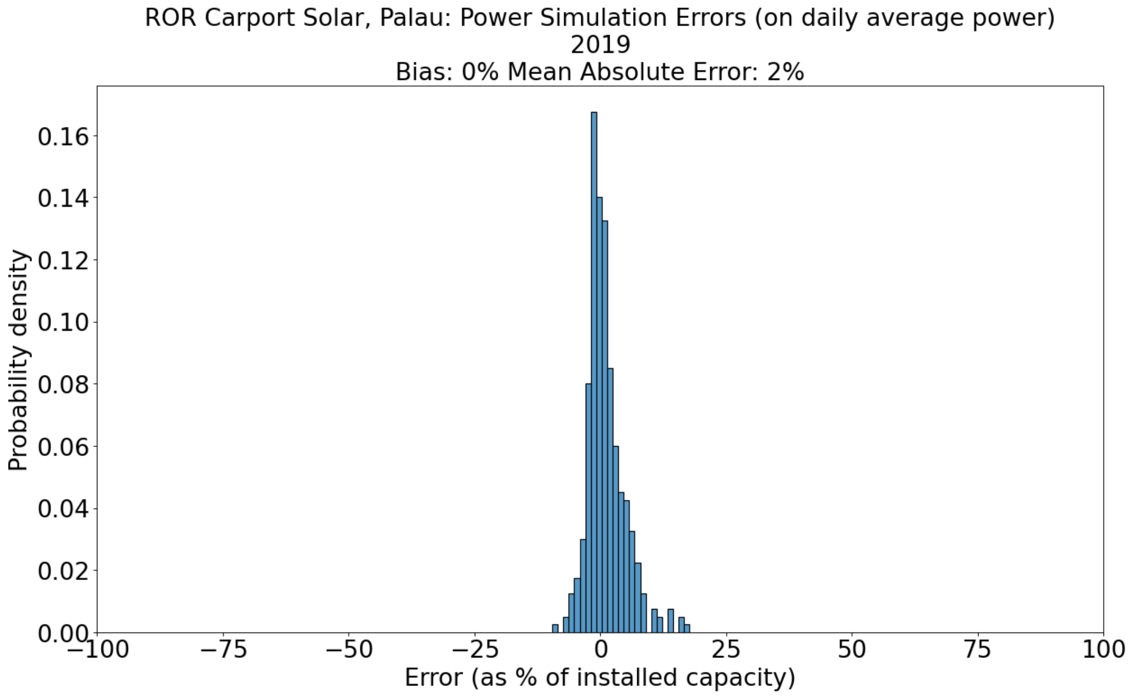


***Figure 18**: Histogram of RE-SAT simulation errors for the carport solar installations as measured on the 10-minute average power (upper panel) and the average daily power (lower panel).*

4.5.2. Uncertainty calibration

The orange and green bands shown in Figure 17 represent the uncertainty bands which are reported for each simulated quantity estimated by RE-SAT. The uncertainty bands are reported in terms of the expected standard deviation of the power estimate in the hypothetical situation that the comparison could be repeated many times. If we treat each power estimate in the time series of the simulation as likely as any other, then under the assumption that the errors (the difference between simulation and reality at each time) are normally distributed then we expect to find a fixed proportion of the observations (the black dots in Figure 17) to fall outside of the uncertainty bands.

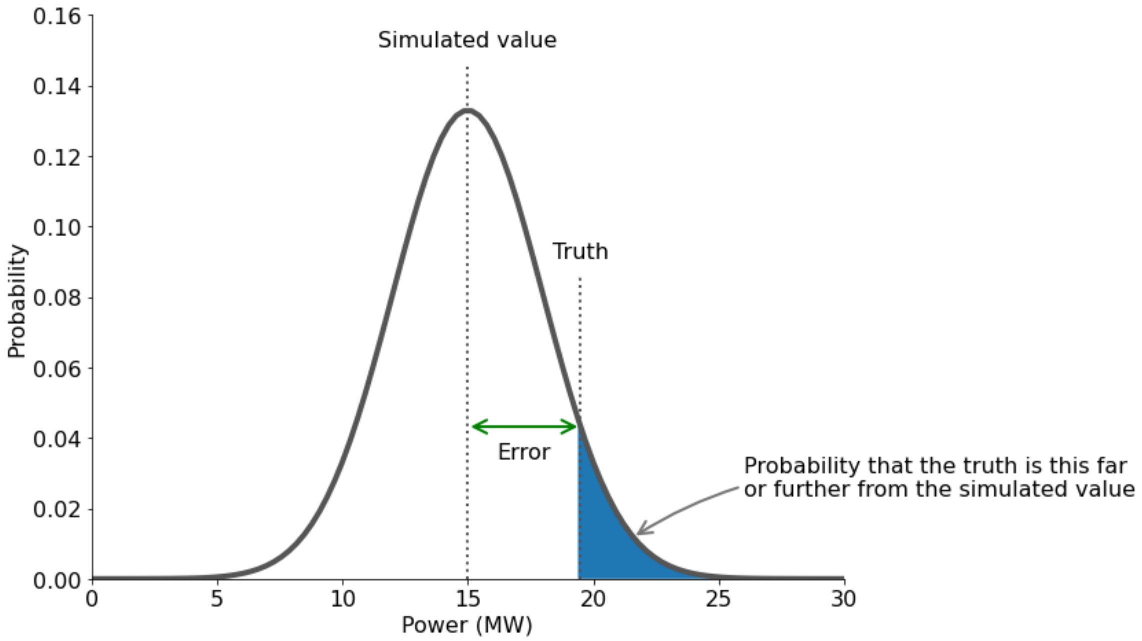


Figure 19: *Normal distribution of the simulation errors.*

Under the assumption that the simulation errors follow a normal distribution (as shown in Figure 19) then the probability of a particular observation of the power falling outside of the top of the one-sigma band is 13.6% and there is a similar 13.6% chance that the observation falls below the band. Thus, if the uncertainty bands are well calibrated, we expect around 75% (100% – 2 x 13.6% ≈ 75%) of the observations to reside within the one-sigma band. Similarly, we expect approximately 95% of all observations to reside in the two-sigma band. This is illustrated in Figure 20.

The distribution of the simulation errors is shown in the histograms of Figures 18. Whilst not perfectly normal, the distributions are close enough to normal to warrant a reasonable judgement to be made of the width of the sigma bands reported by RE-SAT. To this end, the proportion of excursions (black dots outside of the bands in Figure 17) were computed:

- Reality was inside of the one-sigma for solar approximately 63% of the time.
- Reality was inside of the two-sigma for solar approximately 90% of the time.

These numbers are smaller than the 75% and 95% expected and indicate that the uncertainty bands reported by RE-SAT are too narrow.

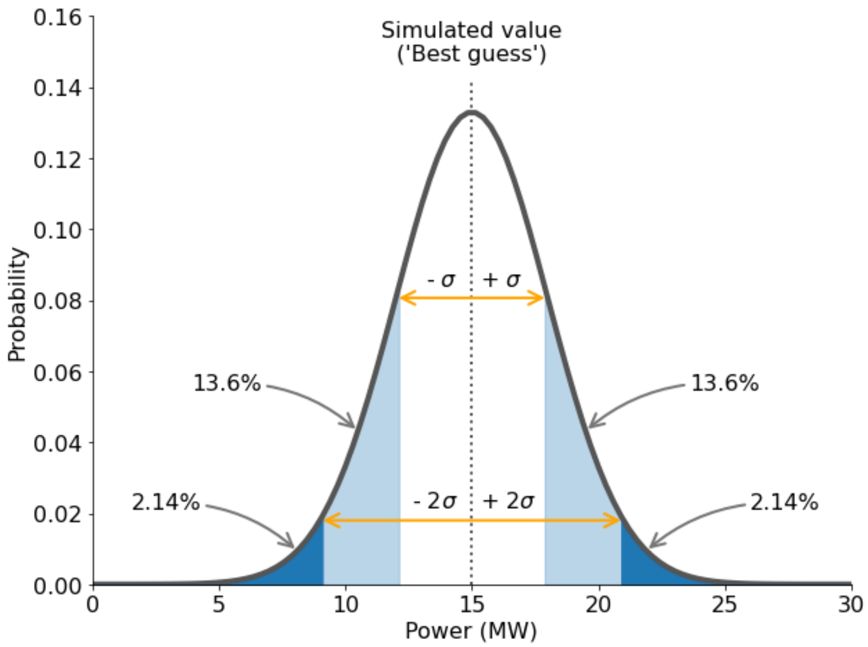


Figure 20*: Probabilistic interpretation of sigma-bands under the assumptions of normally distributed errors.*

In summary:

- RE-SAT was used to simulate the Carport solar array at Koror Airport.
- Simulation was compared with reality for January to December 2019.
- Results typically within: **11% for any given 10-minute average.**
  2% for any given daily average.
- Negligible bias.
- Errors should improve when we begin blending Himawari 8 weather satellite observations into the simulated weather data.
- Uncertainty bands are too narrow. We could widen them by calibrating against local production data. Ideally require additional production data for 'out of sample' testing (to avoid overconfidence).

4.6. Launch of RE-SAT in Palau

The RE-SAT platform was launched in Palau during a virtual one-day Training Workshop (16 July 2021), where the IEA team trained participants on the use of RE-SAT and developed some real energy scenarios with them. A session to discuss the way forward of how the platform would be made available to Palau after the funded project ends was also included.

"Over 10 people from PPUC have participated in the training seminars in-person as well as the virtual seminar (due to COVID-19). PPUC has definitely benefitted from the development realized by the project." Ramon Manny Adelbai, Mechanical Engineer (PPUC)

5. Sustainability model

RE-SAT has successfully reached market readiness, though still with much potential to evolve. Efforts are now focused on transitioning from the funded project phases to the unfunded commercial phase. Sustainability requires users to pay a subscription fee to use the platform.

The sustainability model focuses on making RE-SAT available to users via a commercial licensing model based on the development of the platform and data products for each new region/country. The funded phases have allowed for the co-design of the platform functionality in collaboration with 7 countries, for which relevant weather data and customised platform for their needs have been prepared.

A commercial model has been developed to support the transition to the unfunded commercial phase, which includes:

- a bottom-up cost model.
- a pricing model (including mechanisms to scale certain parts of the cost base in response to changing customer requirements), and
- a service agreement defining the terms under which the application will be licensed.

Revenue modelling is challenged by the potential for variability in terms of numbers of customers, types of customers, areas to be modelled, durations of subscriptions, uptake for renewals, complexity of modelling etc.

A marketing and sales strategy is in place to take the product to market beyond the project and realise revenue opportunities. Channels include:

- conversion of our project stakeholders to clients,
- activities to establish market presence,
- affiliations to develop leads and opportunities,
- bidding and project work,
- advice from domain leaders, and
- traditional marketing activities.

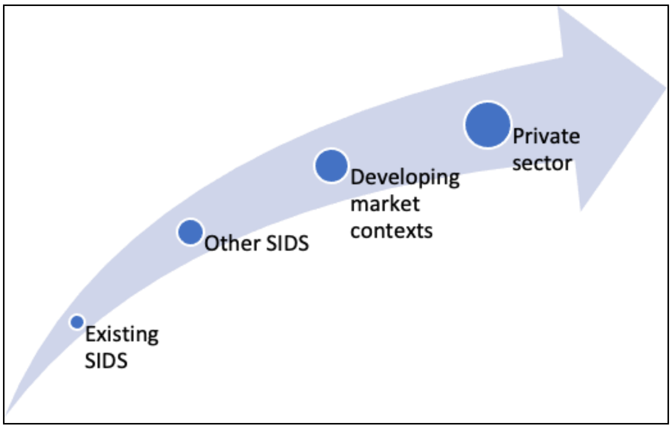


Figure 21: *RE-SAT commercial trajectory plans.*

Two broad categories of users have been identified, these are broadly governmental institutions and private sector organisations. The tables below summaries what each of these broad categories needs and why. RE-SAT contributes to the evidence required by these organisations to address their needs.

Institutional side	They NEED to:	So…they require EVIDENCE to:
Energy Ministry	• Reduce fossil fuel imports, cost of energy and GHG emissions	• Support policies, plans and strategies to increase penetration of renewable energy
Public utilities	• Maintain supply • Balance supply and demand • Minimise costs	• Plan for generation expansion • Justify expansion and investment

Private sector side	They NEED to:	So…they require EVIDENCE to:
Independent Power Producers	• Understand generation potential and economic risks	• Develop bankable project proposals
Energy companies (energy developers)	• Prospect for new plant locations • Develop sustainable energy infrastructure	• Justify site selection • Demonstrate acceptable risks profile for development

In summary, we are building market presence and developing evidence for application potential.

6. Evaluating the results

Our project was set to support the national planning process in Palau to contribute to their transition from fossil fuel electricity to renewables.

The Monitoring and Evaluation approach was based on a common framework which included:

1. M&E Plan – laying out our M&E approach and indicators.
2. Baseline evaluation – assessment of the starting conditions of indicators to be measured.
3. Midline evaluation – assessment of the progress towards targets at midline.
4. Endline evaluation – assessment of the final outcomes and impacts.
5. Cost-effectiveness analysis – quantitative account of why the solution was a cost-effective method of addressing the problem compared to alternatives.

The activities undertaken for these evaluations included:

1. Design: Definition of the Terms of Reference for the endline evaluation, which complements the overall M&E Plan.
2. Monitor: Continual monitoring of progress against Outputs, Outcomes and Impacts.
3. Implementation: Data and information collection through literature review, Working Group meetings, visits, workshops, evaluation interviews.
4. Learning and recommendations.
5. Report writing and acting on findings.

6.1. Process evaluation

Effectiveness

IMPLEMENTATION: The project was delivered effectively through a robust implementation plan and by continual engagement with stakeholders.

> "*Aside from the impact of COVID-19 on logistics, the project was implemented quite well*" Ramon Manny Adelbai, Mechanical Engineer (PPUC)
>
> "*IEA has been a good role model for such effective communication efforts.*"
> Former WG member from PEA

PARTNERSHIP ARRANGEMENTS: The Working Groups have been effective in ensuring relevant stakeholders are consulted.

> *"Communication is key. IEA and PEA are doing a great job with transferring and sharing information constructively."* Ramon Manny Adelbai, Mechanical Engineer (PPUC)

MANAGEMENT ARRANGEMENTS: The project is being managed effectively by utilising collaborative working methods within the IEA team and with partners.

> *"Mutual understanding of RE-SAT has brought about prudent work collaborations."* Former WG member from PEA

Relevance

WORKING TOGETHER: The project brought together relevant organisations within Palau to jointly support the project allowing for new ideas and perspectives.

> *"The close working group relationship with the IEA team and Palau-side team* [was a key factor leading to project achievements]*."* Ramon Manny Adelbai, Mechanical Engineer (PPUC)

USEFUL: The RE-SAT project will contribute to Palau's transition from fossil fuel to renewables.

> *"This project was relevant to PPUC's efforts in bringing in an independent power producer under a power purchase agreement. The platform provided an independent third-party source of technical validation for the IPP procurement process."* Ramon Manny Adelbai, Mechanical Engineer (PPUC)

ALIGNED: RE-SAT is aligned with Palau Government strategies.

> *"There have been two workshops conducted by the Institute for Environmental Analytics (IEA) held in our island nation. These workshops provided capacity building of utilizing computer software to identify land sites which may yield favourable renewable energy locations. We thank you for sponsoring this effort. With this new advantage we are in the right path towards achieving our goals."*[8] Hon. Minister Charles I. Obichang, Office of the Ministry of Public Infrastructure, Industries & Commerce

BUILDING CAPACITY: The RE-SAT project successfully built the capacity of stakeholders in Palau.

> *"The [2nd] workshop was good. I wish I attended the first one. But all in all, it was great. I'm sure I'll learn something from the handout of the booklet you gave us."* Jelynd Ngirmang, Office of the President of Palau

[8] Letter of appreciation to UK Space Agency from Government of Palau 2019

6.2. Impact evaluation

The RE-SAT projects has provided the Government of Palau with a new renewable energy platform that has been used to support their transition to renewables and a climate resilient future. Renewable energy has the potential to reduce dependency on imported fuels and to reduce Palau's vulnerability towards price shocks.

The current renewable energy penetration in Palau is 4% mainly through solar rooftop PV[9], but with this new IPP solar development, the country is on its way to meet its goal of 45% renewable energy use by year 2025.

To support the government in achieving these targets RE-SAT has been used for some specific applications to test the performance of different combination of renewable energy installations. The IEA team provided face-to-face training, assistance by video conference and practical workshops on how to use the RE-SAT platform to support Palau in its transition towards renewable energy. Some examples of use are detailed in the following sections.

PPUC was in charge of issuing the RfP for Independent Power Producers to bid for the installation of a 20MWp solar energy generation. PPUC used RE-SAT to compare the IPP figures from the bids, which added value to the exercise (personal communication from PPUC engineers).

> *"With this new advantage we are in the right path towards achieving our goals."*[10] Hon. Minister Charles I. Obichang, Office of the Ministry of Public Infrastructure, Industries & Commerce

> *"[RE-SAT] … is very helpful in anticipation of the coming in of IPP solar facility."* Tito Cabunagan, Power Plant Manager (PPUC)

> *"I can use it to model any future IPP scenarios to get a first-order indication of relevance and utility of any future RE project (IPP or PPUC-funded)."* Ramon Manny Adelbai, Mechanical Engineer (PPUC)

> *"The project provides valuable 3rd party technical validation for other projects in Palau, IPP-1 and any future IPPs."* Ramon Manny Adelbai, Mechanical Engineer (PPUC)

6.2.1. Testing the renewable energy configuration at the airport with RE-SAT

The performance of RE-SAT was tested by creating a scenario of the current variable renewable energy installations at the carport in Koror airport (see Figure 22). The total installed capacity is

[9] 150kW on a supermarket, 220.5kW on a warehouse, 236kW at Koror airport carport.
[10] Letter of appreciation to UK Space Agency from Government of Palau 2019

236kW, generated by 2 solar PV installations. This configuration of installations was run through 7 simulated weather years to capture year on year variability.

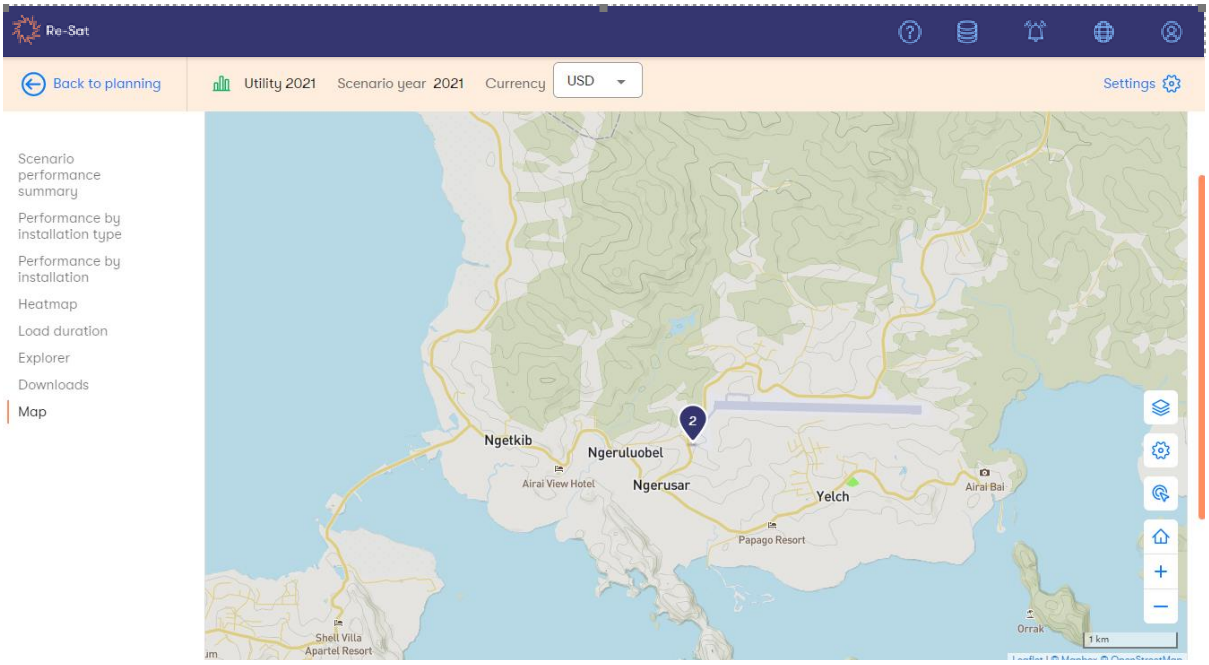


Figure 22: *Map as displayed by RE-SAT with the solar installations at Koror airport (Palau).*

RE-SAT estimated an average annual RE generation of 289 MWh, which meant a capacity factor of 14%. This performance compared well with the actual annual production from these installations as communicated by PPUC.

Power generation by installation type Download

Figures Graph view

	Installed AC capacity	Annual RE generation (50%EP)	Capacity factor (50%EP)
Utility solar	236 kW	289 MWh	14 %

Figure 23: *Summary statistics from RE-SAT*

Another important metric that RE-SAT calculates is the fuel volume, cost and CO2 equivalence that the renewable energy generated represent. RE-SAT assumes a liner conversion of the renewable energy generation to the equivalent quantity. With this in mind, the existing installations are saving almost 74 kilolitres of fuel and around 200 tonnes of CO2 emissions per year.

6.2.2. Exploring potential renewable futures using the RE-SAT platform

A. Adding IPP – Phase 1 solar installation in Babeldaob (2022 scenario) – Kokusai 1

Palau used RE-SAT to estimate the power performance when adding the planned solar farm (Phase 1) to the existing configuration of installations at the airport (Figure 24).

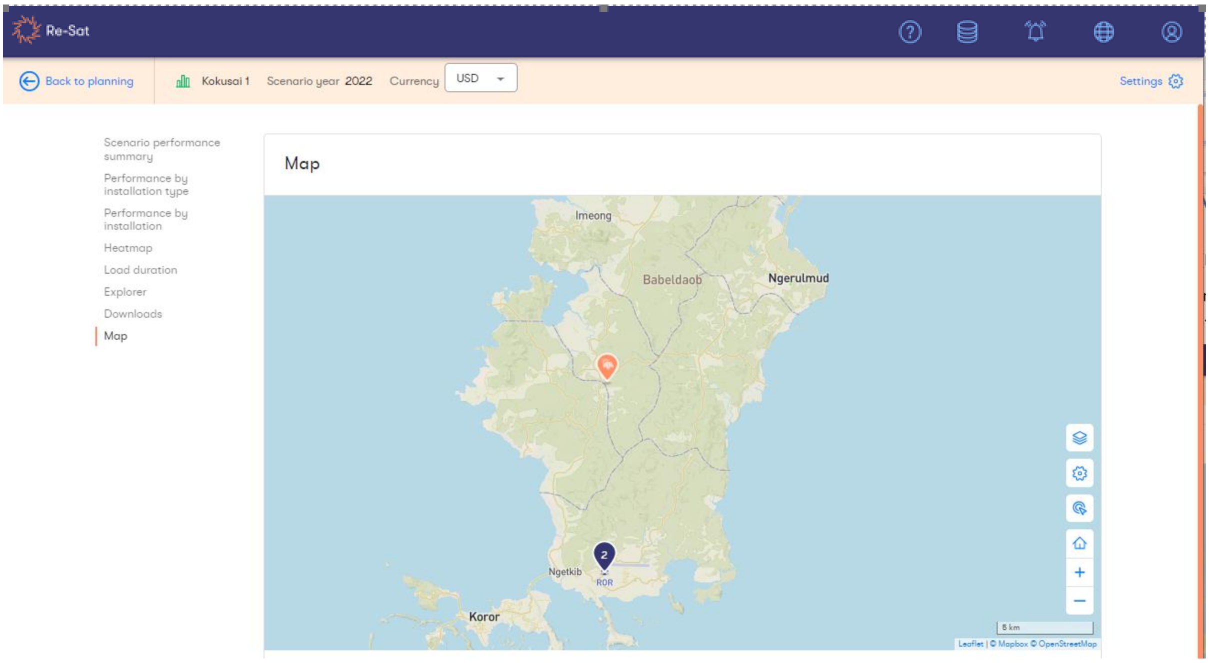


Figure 24: *Map display from the RE-SAT platform with the locations of installations for the scenario*

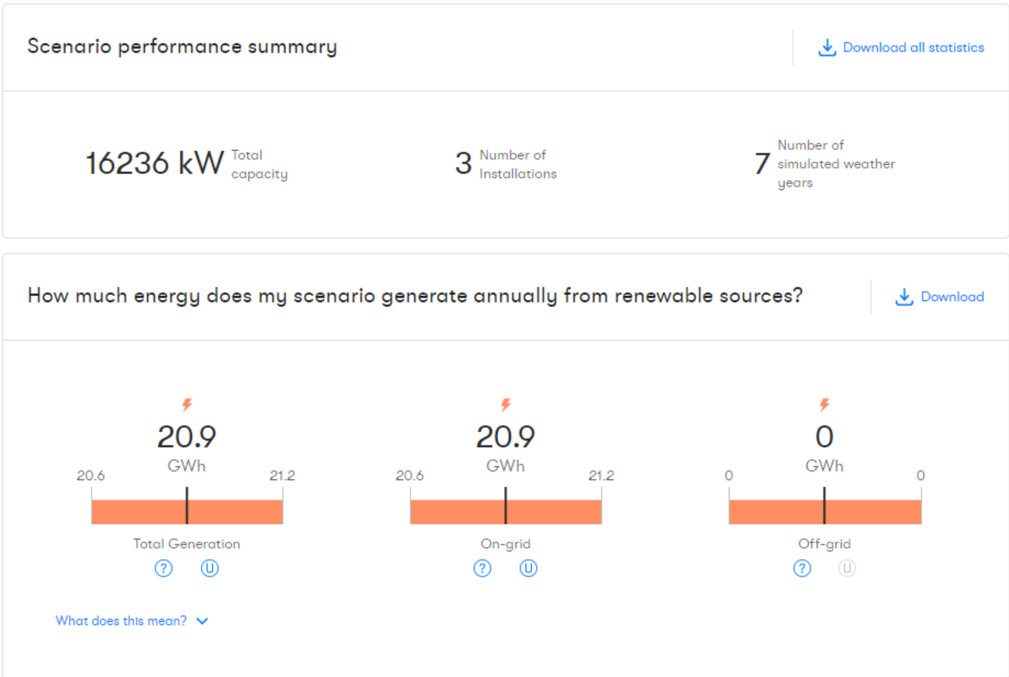


Figure 25: *Summary performance for the kokusai-1 scenario in 2022*

The scenario was set for year 2022, when the new IPP solar farm with a capacity of 16MW is expected to be in full operation. The combines generation of this scenario achieved a renewable energy penetration of 23.3%. The expected annual energy demand for this scenario for 2020 was set at 87.6 GWh. This was a welcome results for Palau, as they were on the path to achieve their RE targets. For Palau, the new solar farm will take them from a very low penetration of RE to around 20%. With this amount of variable renewable integration, Palau will be in Phase 3[11] which means that VRE operations will determine the operation pattern in the system. During periods of high penetration greater flexibility in the system will be needed, with improvements in grid infrastructure probably required.

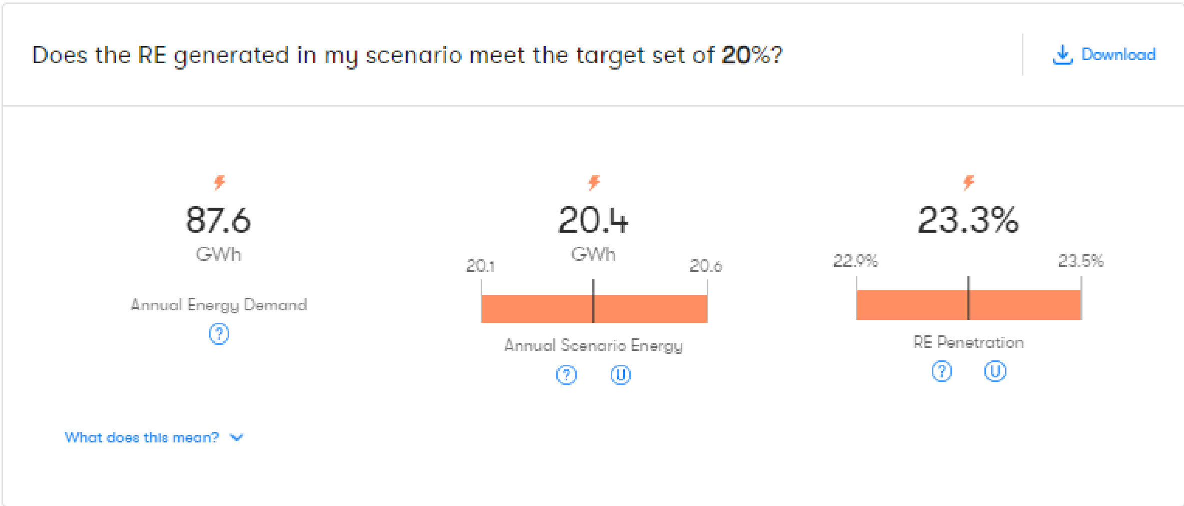


Figure 26: Summary statistics on RE penetration percentage for the kokusai-1 scenario in 2022

A demand load curve was added to this scenario so RE-SAT estimated that the RE generated would exceed the demand in some instances (Figure 27).

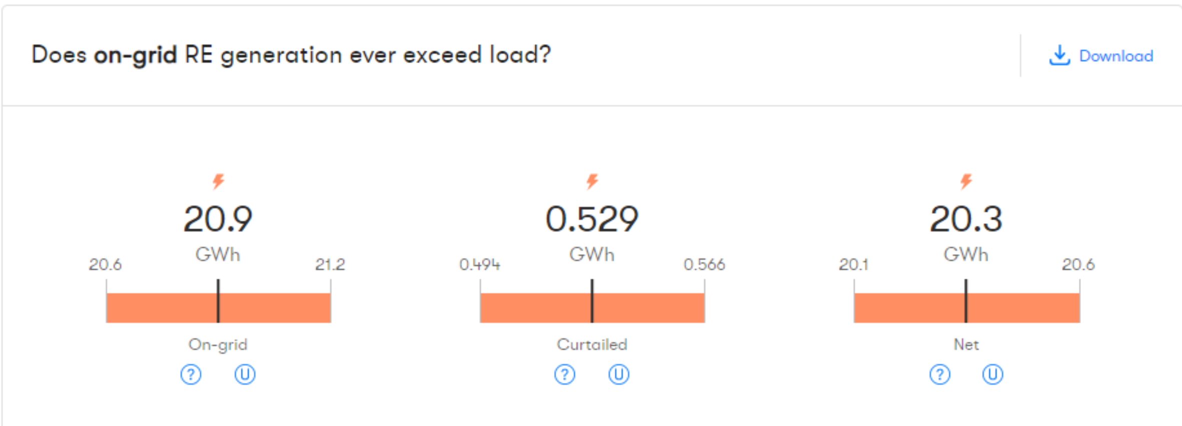


Figure 27: Demand comparison summary results for the scenario

[11] The International Energy Agency has developed a phase categorisation to capture the evolving impacts that VRE may have on power systems, as well as related integration issues. Status of Power System Transformation (2019) https://www.iea.org/reports/status-of-power-system-transformation-2019

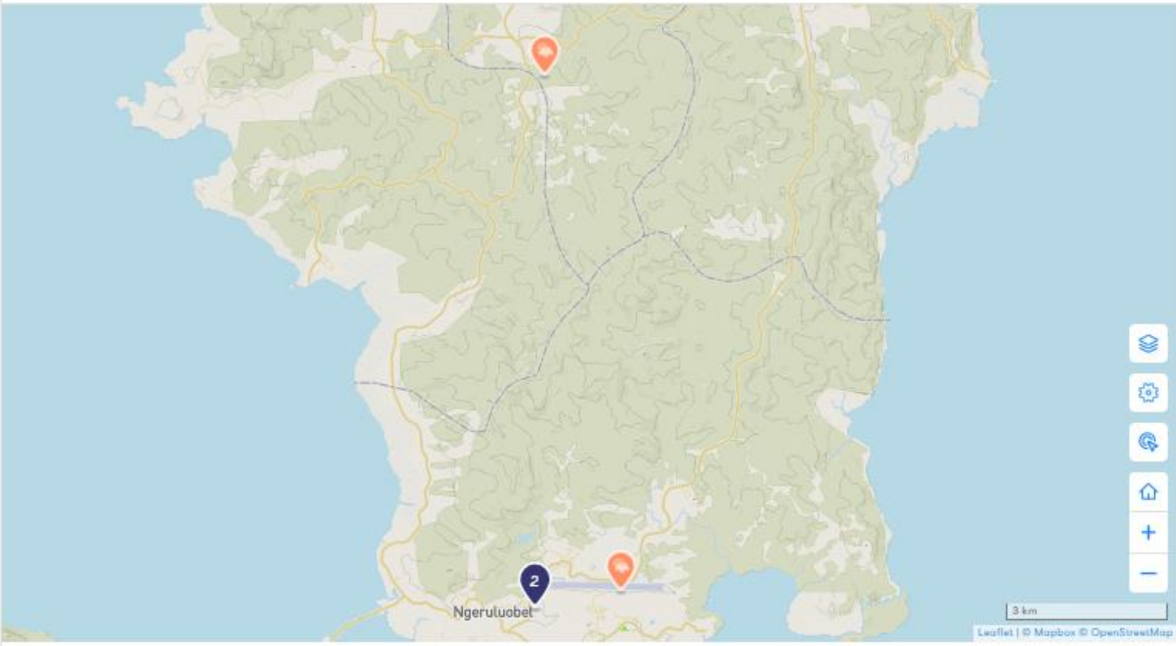
This scenario achieved a 23.3% RE penetration, but during some days, the generation exceeded the demand and some of the energy generated was lost (curtailed). RE-SAT illustrates this through the summary statistics and also through the some of the graphics displays (see Figure 26 for an example week in August where there are some days (see 4th August) where the energy generated (including the uncertainty) during the middle of the day exceeds the demand).

Figure 26: Demand comparison in RE-SAT. An example of a week generation at 1hour timestep. Note how for some days in that week, particularly on 4th August, the energy generated, taking account the uncertainty, exceeds the energy demand as set by the load curve.

A. Adding IPP – Phase 2 solar installation in Babeldaob (2025 scenario) – Kokusai 1 + airport

Palau investigated the performance of RE-SAT when adding the planned Phase 2 solar installation, which is expected to be for a 22MW. PPUC sited this planned farm near the airport (Figure 27).

Map



Download all installations

Installation type / Unit	Installation year	Tags	AC Capacity kW	Capex per capacity USD per kW	Find on map
Utility solar			**38,200**		
Airport IPP	2025		22,000	728	
Koror Airport 1	2011		118	2,890	
Koror Airport 2	2011		118	2,890	
Kokusai 1	2022		16,000	914	

Figure 27: A scenario with the current airport facility, plus the IIP Phase 1 and Phase 2 solar farms.

Creating this scenario informed planners that the scenario would generate an annual production of 51.4 GWh of energy, offsetting 9.1 megalitres of diesel (estimated at a cost of 5980k USD) and 24.6 kilotonnes of CO_2 per annum (see Figure 28).

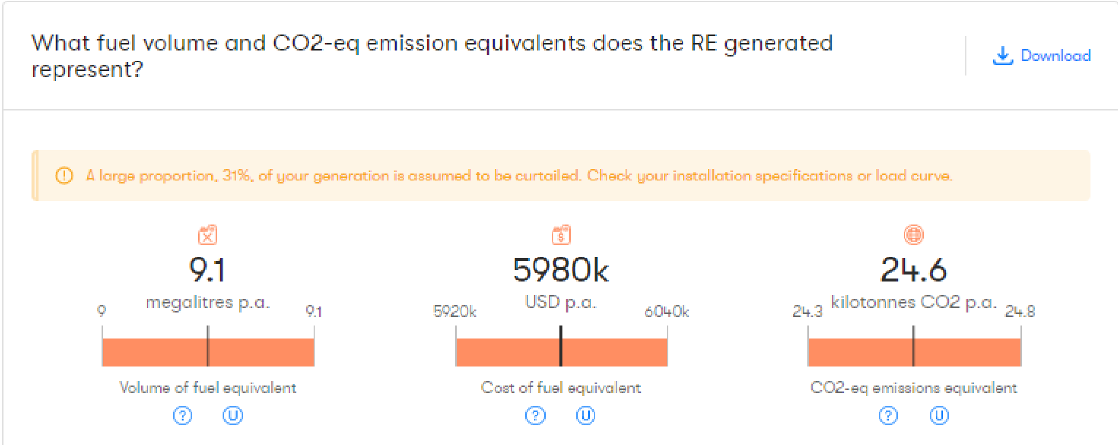


Figure 28: *Volume of fuel and CO2 emissions offset by the scenario.*

Planners also learned that this scenario would exceed the demand load curve as provided and assumed for 2025. VRE would represent about 36%, however, a large proportion of the RE generation exceeded demand and was assumed to be curtailed (lost) (see Figure 29)

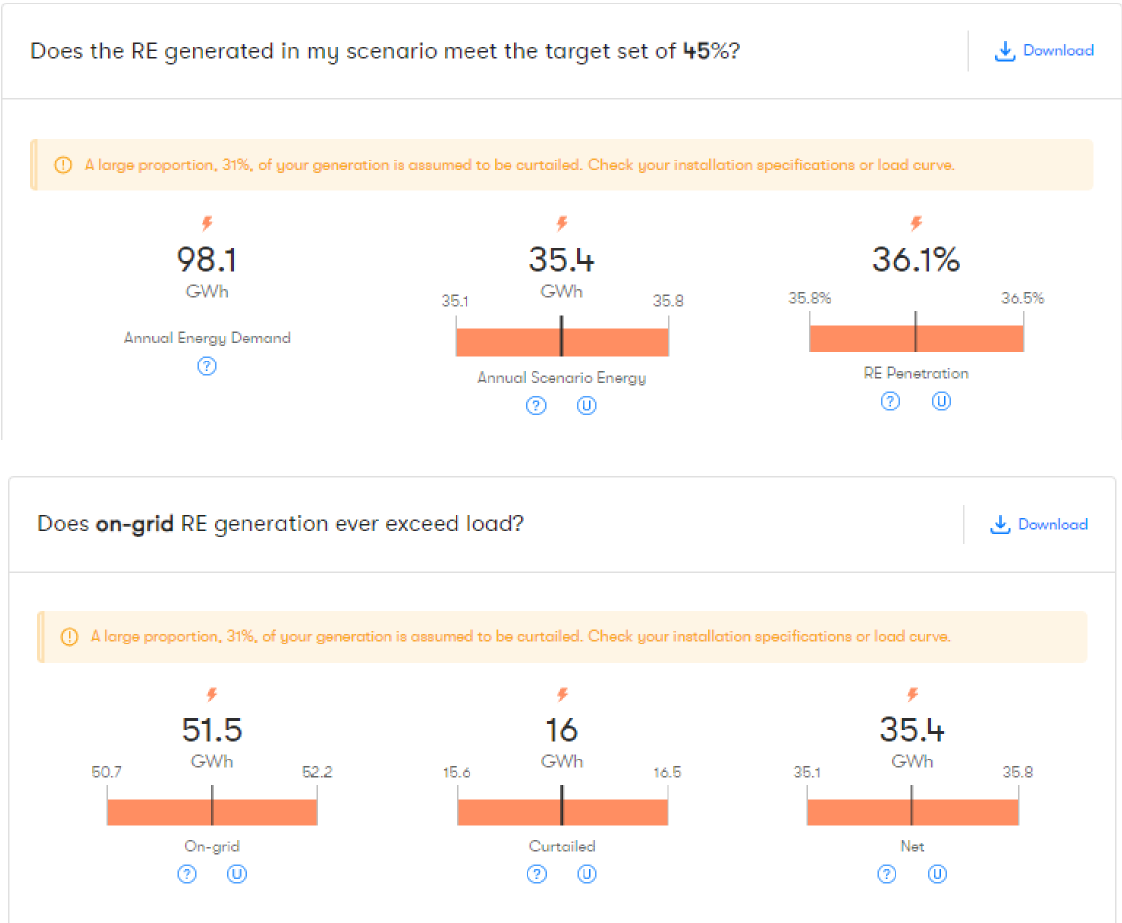


Figure 29: *Demand comparison summary statistics.*

The curtailment is clearly seen when exploring the data for each of the simulated days. Figure 30 shows how during the middle of the day, generation (blue line) exceeds demand (yellow line). In RE-SAT this energy is assumed to be lost (curtailed).

Figure 30: Demand comparison in RE-SAT. An example for 1 day generation at 1hour timestep

In summary, planners in Palau have been able to simulate the performance of the IPP Phase 1 and 2 solar farms. They have realised that sometimes, the new solar farms will make up almost all the generation. Storage of excess generation for load shifting will need to be considered, as curtailment is present in this scenario. This will need to be modelled separately by Palau planners, to ensure maximum use of renewables is achieved.

7. Lessons learnt

The main learnings relating to our engagement with in-country partners, the technical challenges encountered, and the implementation of RE-SAT are presented here and are common to all SIDS. Some specific leaning remarks to highlight aspects relevant to Palau are also included.

In-country challenges:

- Timing and relevance are important for co-production: The RE-SAT project was well received by Palau due to their ambitions to transition to renewables as they saw an immediate opportunity to exploit the platform to their advantage.
- In-country commitment is vital for the success of partnership projects: The lead partner in Palau, the Palau Energy Administration, facilitated the engagement with other organisations, especially with the Palau Public Utilities Corporation.
- There is a lot of competition for workshop time in the recipient SIDS: Many nations and suppliers are operating in Palau. Officials are engaged in several project which compete for their time. Feedback received from partners confirmed that our workshops were fun and informative compared to others.
- Data and knowledge sharing is essential for the development of tailored products in countries. The power data shared by PPUC were crucial for the validation and calibration of the tailored RE-SAT application in Palau. They also shared handwritten log sheets, which were digitised for data analysis.
- Local capacity to receive knowledge transfer varies across countries and therefore delivery methods need to adjust accordingly. For some of the organisations involved in some of the workshops in Palau, learning about renewables was a new concept, but they reported gaining understanding and knowledge due to our project.

Implementation challenges

- Establishing a clear management and working structure (internal and external) from the start makes everyone within the partnership know their responsibilities within the project. The establishment of a Working Group in Palau was welcome and crucial for the co-development of the platform that is fit-for-purpose.
- Capacity building was challenging during the pandemic and has limited the delivery of value. Less participants attended the virtual training workshops compared to the face-to-face workshop that were held in Palau, reducing the impact of the project. Even though the virtual sessions were shorter, we could not have ad-hoc meetings, external conversations and presentation to others within the country, which are very important for impact, awareness raising and sustainability.

- The community of practice was a welcome addition to share knowledge among the Island States. Palau contributed a few articles to the Community Newsletter.

Technical challenges

- Estimating uncertainty of power production is a complex process. It is believed that the quantification of uncertainty is a unique capability for RE-SAT and may be a compelling feature in the commercial marketplace although more market testing is currently being carried out to confirm this.
- Scalability is important for the commercial future of RE-SAT. Scalability of processing resources is now understood to be a critical requirement and we are migrating the system to a more flexible Web Services provider to address this.
- Preparation for version release and training workshops. A robust procedure for application version release and training is now in place to ensure application updates work at time of release and material is ready on time for training.
- Weather data preparation evolved during the project, and we now have a robust and efficient workflow to produce these datasets ready for our commercial phase. Different configurations of the weather model have been tested and new procedures to gain efficiencies in our processes implemented.
- A new user journey has made the application more intuitive and user friendly. A UX (User Experience) consultancy specialist was sub-contracted mid project to advice on application user interface design. This was very valuable and in future would be commissioned earlier in the project lifecycle.

Delivering value from big data

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