RE-SAT: Energy Analytics Platform

Renewable Energy planning in Vanuatu

Case study

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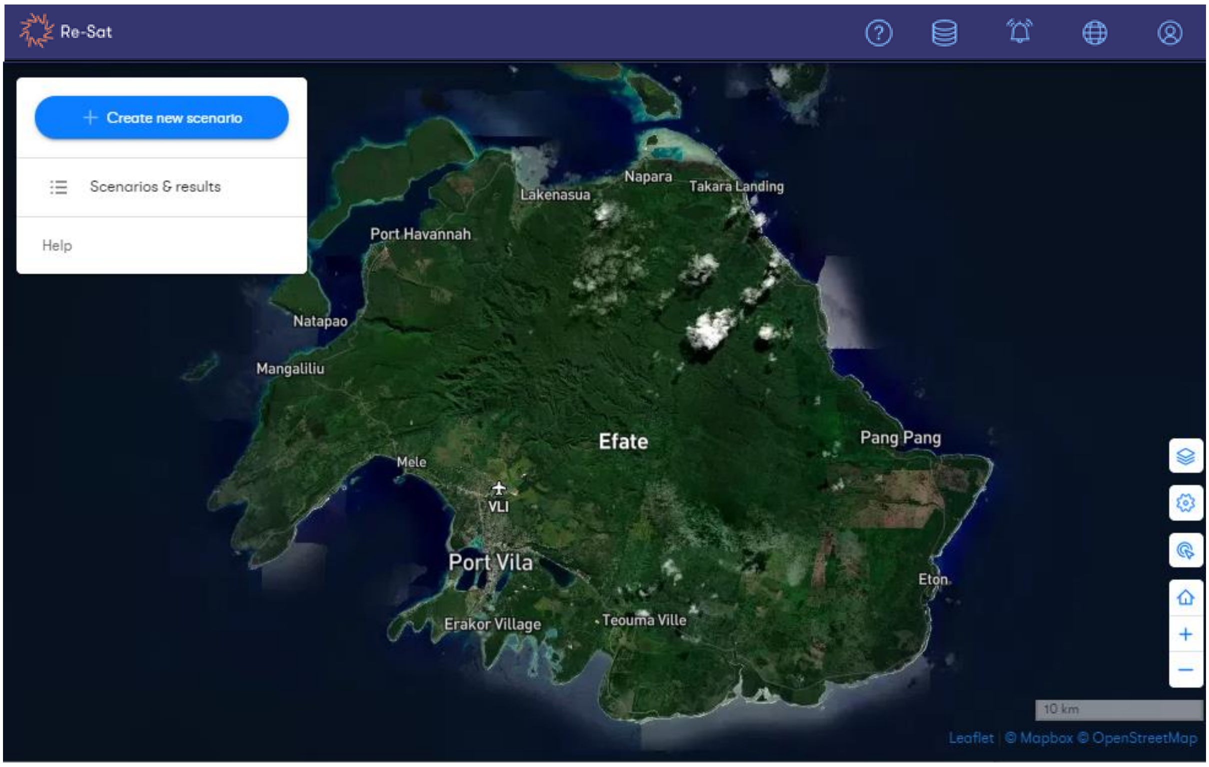

The Institute for Environmental Analytics (IEA)

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.

Re-Sat 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 Vanuatu acknowledges the invaluable assistance from the Ministry of Climate Change Adaptation, Meteorology, Geo-Hazards, Environment, Energy and Disaster Management (MoCCA), The Ministry of Lands and Natural Resources (MLNR), Utilities Regulatory Authority (URA), UNELCO ENGIE, Vanuatu Utilities & Infrastructure (VUI)

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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 Vanuatu 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 Vanuatu** was led by the Department of Energy (DoE) at the Ministry of Climate Change Adaptation, Meteorology, Geo-Hazards, Environment, Energy and Disaster Management (MoCCA). Other government departments and agencies involved in the project included the Meteorology and Geo-Hazards Department within MoCCA, the Ministry of Lands and Natural Resources (MLNR), Utilities Regulatory Authority (URA), UNELCO ENGIE and Vanuatu Utilities & Infrastructure (VUI).

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 Vanuatu 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 Vanuatu after the funded project ends was also included.

The **performance of the RE-SAT platform in Vanuatu** was tested against actual power produced by the by the existing solar arrays installed at Kawéné, Tagabé and Météo (which total 1.2MW of capacity) together with the 3.4MW Kawéné wind farm. The errors for solar, expressed as a percentage of the installed capacity, measured on the 10-minute average power accounted to 15%. When averaging over a day the errors are reduced to 4%. Estimates for the mean absolute errors on monthly wind energy production were around 4%.

The **impact** that RE-SAT has had in Vanuatu is the ability to explore potential scenarios to achieve their ambitious renewable energy targets of 100% by 2030. RE-SAT is currently used to identify potential sites for the next 5 MWp solar PV projects to be constructed in the next 2 to 3 years. The utilities company in Efaté have also explored the capacity of RE-SAT to identify the best locations for the next wind farm projects on Efaté Island and to spot the location for a wind LiDAR[2] to monitor wind speed, direction and wind distribution at different heights.

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.

[2] LiDAR: Light Detection and Ranging o Laser Imaging, Detection and Ranging

- 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 Vanuatu specifically, RE-SAT is:

- Supporting the national planning process to facilitate the targeted increase in the use of renewable energy in Vanuatu to 65% by 2020 and 100% by 2030.
- 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) to support their RE targets.

"The Government of Vanuatu, in its NDCs, has committed to 100% Renewable Energy (RE) in 2030. Being able to simulate and spot best location for solar PV and/or wind energy will definitely help towards having more RE in the energy mix of the country and then achieve the first part of the SDG7 (Clean energy)." Vanuatu Working Group Member

"[RE-SAT offers a] Way forward to utilize the earth observation and other data sources to support Vanuatu in the transition from fossil fuel electricity generation to Renewable Energy." Vanuatu Working Group Member

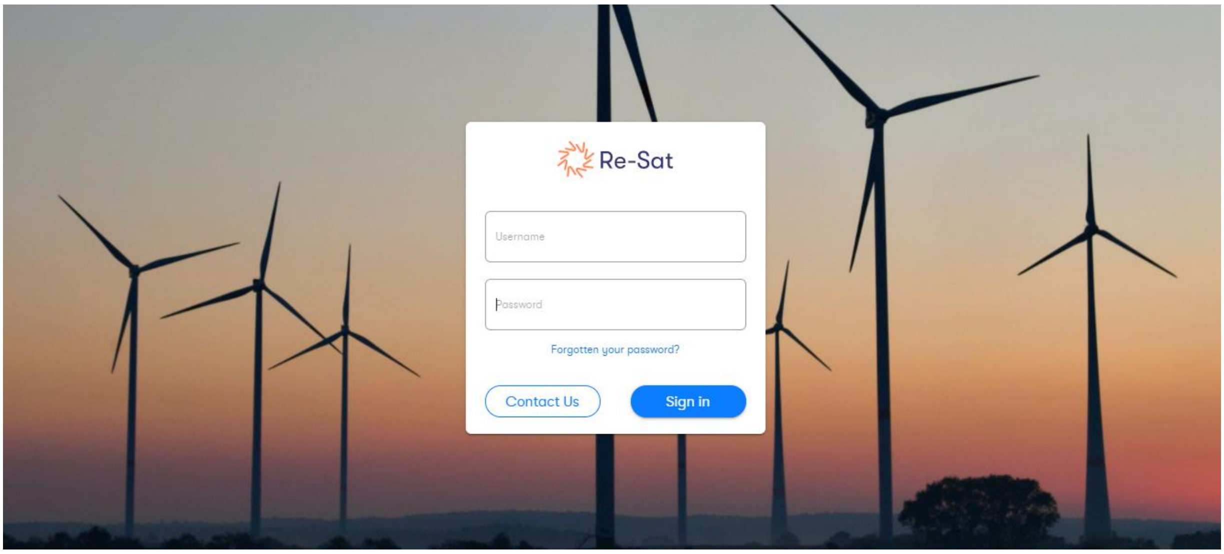


***Figure 1**: Landing page of the RE-SAT platform.*

2. Project overview

2.1. The energy and data challenges facing Vanuatu

2.1.1. About Vanuatu

Vanuatu consists of approximately 80 islands spread over 710,000 square kilometres of the western Pacific Ocean, between latitude 13oS and 21oS and longitude 165oE and 170oE. The total land area of all islands is 12,281 square kilometres. 65 of the islands are inhabited. The capital city is Port Vila on the island of Efaté and the second biggest is Luganville on Espiritu Santo (the largest island). The major islands are volcanic and hilly. Vanuatu is situated along the Pacific Rim volcanic belt and strong earthquakes (magnitude 7 and above) occur frequently.

The population of Vanuatu was estimated at 307,150[3] in 2020 with 75% of the population living in rural areas. 19% of the population live in Port Vila and 6% in the smaller urban district of Luganville.

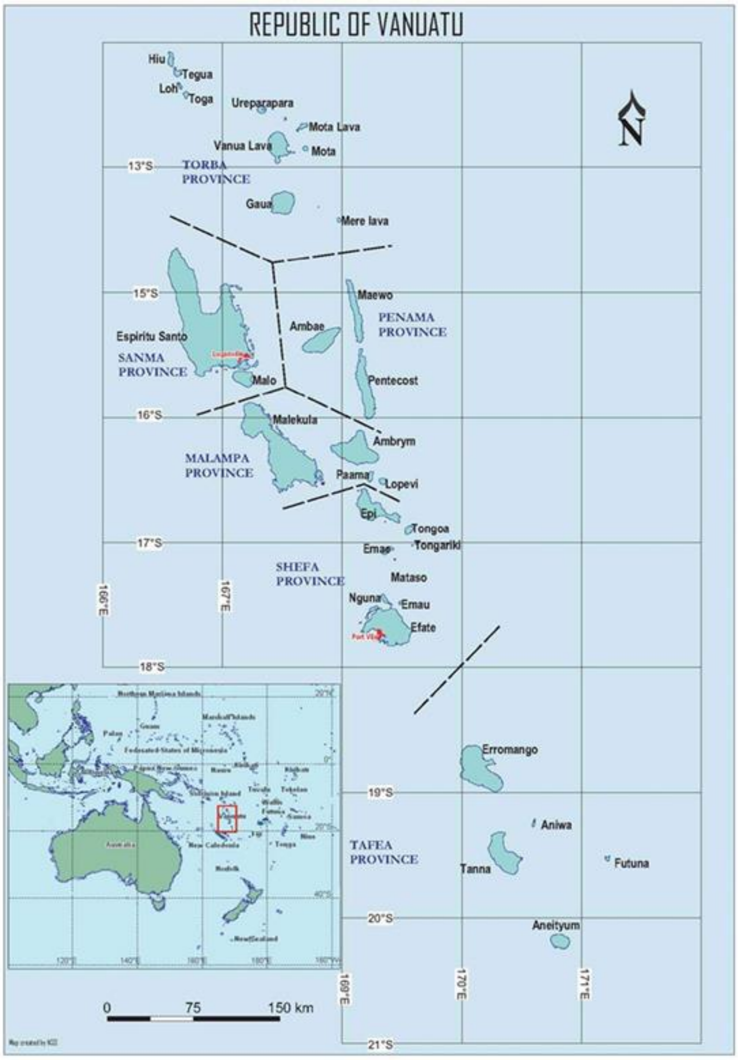


Figure 2: Map of Vanuatu

The Vanuatu region has a tropical rainforest climate and is subject to south-east trade winds. These trade winds are weaker from November to April and increase in the winter from May to October. Cyclone season ranges from November to April. Vanuatu has been hit by 20 to 30 cyclones in the last 10 years, 3 of which caused catastrophic damage. Flooding is associated with the occurrence of cyclones. La Niña years can give rise to pluvial flooding in low altitude floodplains. Droughts are also associated with El Niño years.

[3] World Bank data

The risk of cyclones and flooding in conjunction with the risk of earthquakes has resulted in Vanuatu being assessed as having the highest disaster risk of all countries in the world based on exposure to natural hazards and susceptibility [WordRiskReport Analysis and Prospects 2017][4].

Vanuatu has a gross national income (GNI) per capita of approximately USD 3,000 [World Development Indicators from World Bank 2016]. Many inhabitants of rural areas have less than a dollar a day in cash income [IRENA, Vanuatu Renewables Readiness Assessment, 2015][5]. Agriculture, fishing and tourism are the main contributors to the economy.

2.1.2. Electricity in Vanuatu – Energy targets

Unusually among independent SIDS in the Pacific, Vanuatu has most its electricity provided by private sector companies. More than 90% of electricity is generated and delivered by Union Electrique du Vanuatu Ltd (UNELCO ENGIE) and Vanuatu Utilities and Infrastructure (VUI), with the remainder produced by small private producers at tourist facilities.

In 2016, 29% of households were connected to an electricity grid. Electricity supply through major grids is operated through a concession mechanism. In 2018, UNELCO ENGIE provided services in Port Vila (Efaté island), Malekula and Tanna, whilst VUI serves Luganville. At the moment UNELCO no longer supply services to the islands of Tanna or Malekula. The suppliers produce electricity and maintain the distribution network to customers. The assets used remain under government ownership.

The Utilities Regulatory Authority (URA) published rules in 2014 for net metering and feed-in tariffs for customers of UNELCO ENGIE wishing to install their own solar generators connected to the grid. This programme is limited to 500kWp in total for up to approximately 80 customers. Any energy generated in excess of consumption is provided to UNELCO ENGIE without credit or payment.

It is estimated that around 67% of households do not have access to electricity - this includes households inside and outside the concession areas. The Government of Vanuatu is implementing several projects to increase electrification including the Vanuatu Rural Electrification Projects (VREP). The first phase of this project aimed to increase access to basic lighting and battery charging using subsidised 5-10W solar home systems. The subsidies are 50% of the retail price in Phase 1. Phase 2 funding ($12.50m) to cover larger capacity installations was approved by the World Bank in 2017 and work is currently underway.

[4] WolrdRiskReport Analysis and Prospects 2017
https://reliefweb.int/sites/reliefweb.int/files/resources/WRR_2017_E2.pdf

[5] Renewable Readiness assessment: Vanuatu (IRENA, 2015)
https://www.irena.org/publications/2015/Jul/Renewables-Readiness-Assessment-Vanuatu

Vanuatu submitted its first NDC to the UNFCCC in September 2016. The main mitigation contribution under this submission is to achieve the targets under the National Energy Road Map (NERM)[6] and Second National Communication (SNC) extended to 2030. The mitigation contribution for the Vanuatu INDC submission is a sector specific target of transitioning to close to 100% renewable energy in the electricity sector by 2030[7]. This target would replace nearly all fossil fuel requirements for electricity generation in the country and be consistent with the National Energy Road Map (NERM) target of 65% renewable energy by 2020.

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 to understand significant geographic variability and records may be interrupted by operational disturbances leading to missing periods of data. These may 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**

[6] Updated Vanuatu National Energy Road Map (2016 – 2030)
https://www.greengrowthknowledge.org/sites/default/files/downloads/policy-database/Updated%20Vanuatu%20National%20Energy%20Road%20Map%202016-2030_1.pdf

[7] Vanuatu's First Nationally Determined Contribution (updated submission 2020)
https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Vanuatu%20First/Vanuatu%E2%80%99s%20First%20Nationally%20Determined%20Contribution%20(NDC)%20(Updated%20Submission%202020).pdf

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 Vanuatu, 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[8], 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).

[8] IRENA: International Renewable Energy Agency

3. Project partners

Our **partnership in Vanuatu** was led by the Department of Energy (DoE) at the Ministry of Climate Change Adaptation, Meteorology, Geo-Hazards, Environment, Energy and Disaster Management (MoCCA). Other government departments and agencies involved in the project included the Meteorology and Geo-Hazards Department within MoCCA, the Ministry of Lands and Natural Resources (MLNR), Utilities Regulatory Authority (URA), UNELCO ENGIE and Vanuatu Utilities & Infrastructure (VUI).

The role of the DoE at the MoCCA has been to facilitate access to the findings regarding the actions from the Vanuatu National Energy Road Map (NERM) regarding renewable energy by providing expert knowledge into the particular RE requirements and potential sources of data. UNELCO ENGIE has provided regular updates on the status of RE projects planned in Efaté island, as well as valuable power data for our validation purposes.

Figure 3: Vanuatu Visit 1 workshop participants and the IEA team (October 2019).

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

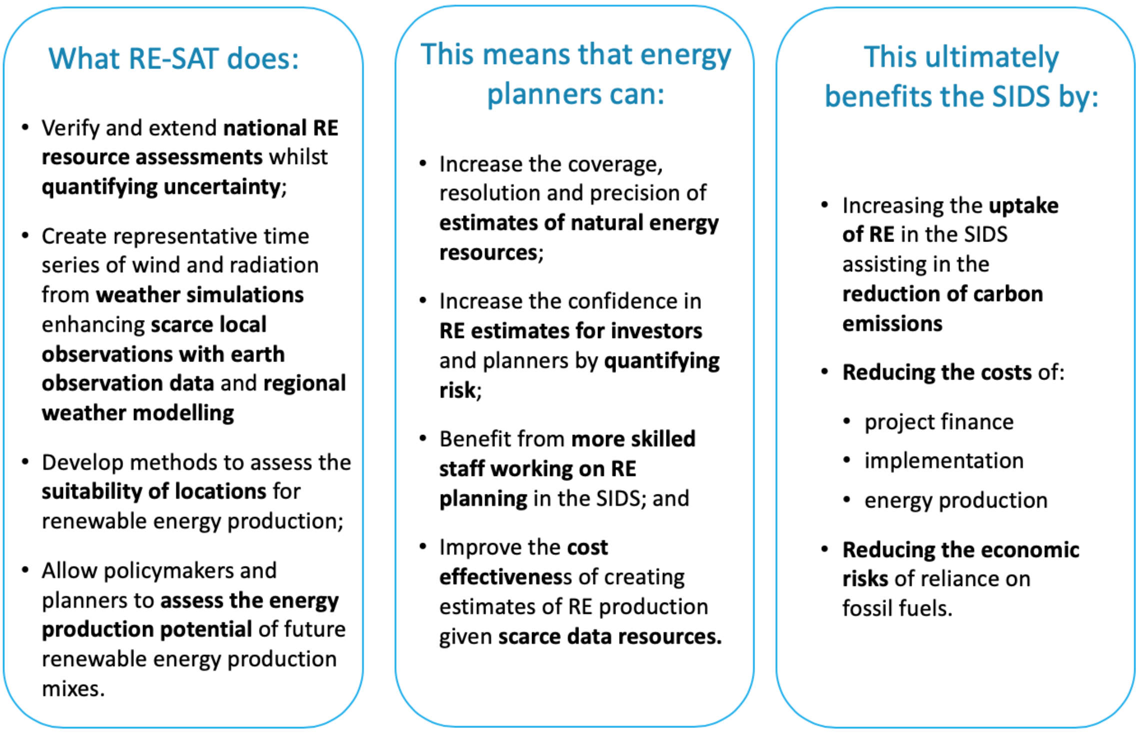


Figure 4: RE-SAT intended value chain.

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.
Location assessment - Identify potential feasible and optimal locations for the placement of RE

High level Requirement
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 Vanuatu

The following specific requirements were requested by stakeholders in Vanuatu:

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.
- Intermediate resolution (5km x 5km) for Vanuatu North and Vanuatu South regions for more detailed assessments of combined solar and wind.
- High resolution[9] solar data products and wind products to support the investment cases for grid connected projects in Efaté.

Cost assessment

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

Biofuels

- Ability to model copra biofuel as a replacement for diesel in a generator. Include contributions from coconut oil resources when developing renewable energy scenarios.

Hydropower contributions

- The island of Espiritu Santo is mostly powered by hydropower with the expectation that Malekula will also benefit from hydro. Taking into account the contribution of these exiting installations would be a good addition to the platform when using RE-SAT to explore different RE scenarios and penetration targets for the whole country.

Capacity building

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

Meeting these requirements through developing new functionalities in RE-SAT meant that that those responsible for RE planning in Vanuatu 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 Vanuatu, helping to reduce the cost of energy production and reducing the economic risks of reliance on fossil fuels.

[9] '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 Vanuatu and its agencies and developed a set of agreed targeted objectives with short-term benefits for Vanuatu as well as long-term benefits.

The RE-SAT functional requirements, as developed in consultation with Vanuatu 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 numerical weather model configured by the IEA for Vanuatu. The model was run for three domains:
   (i) North region covering Espiritu Santo and Malekula at 5km x 5km,
   (ii) South region covering Efaté and Tanna at a resolution of 5km x 5km,
   (iii) One sub-region centred in Efaté at 1kmx1km

   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).

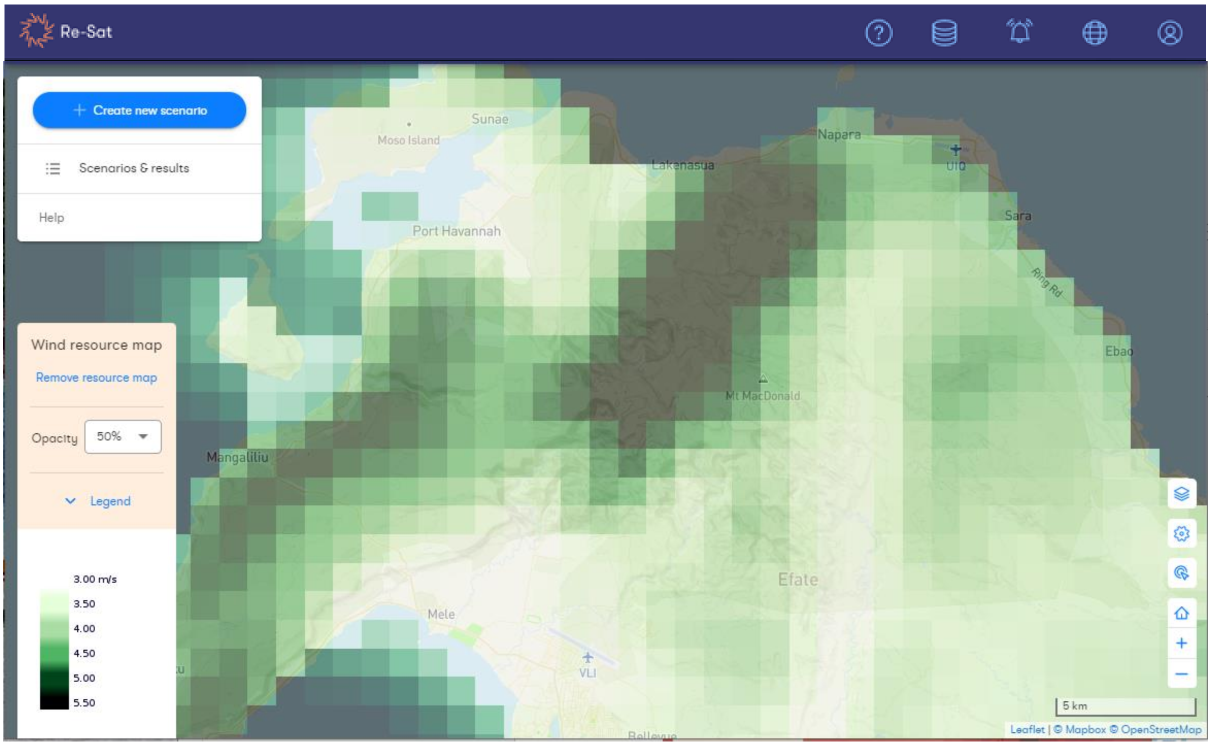


Figure 5: Wind resource maps for Efaté (Vanuatu).

3. GIS map layers: These are map layers, either provided by the partner country or created by the IEA to support planners when assessing installation locations.

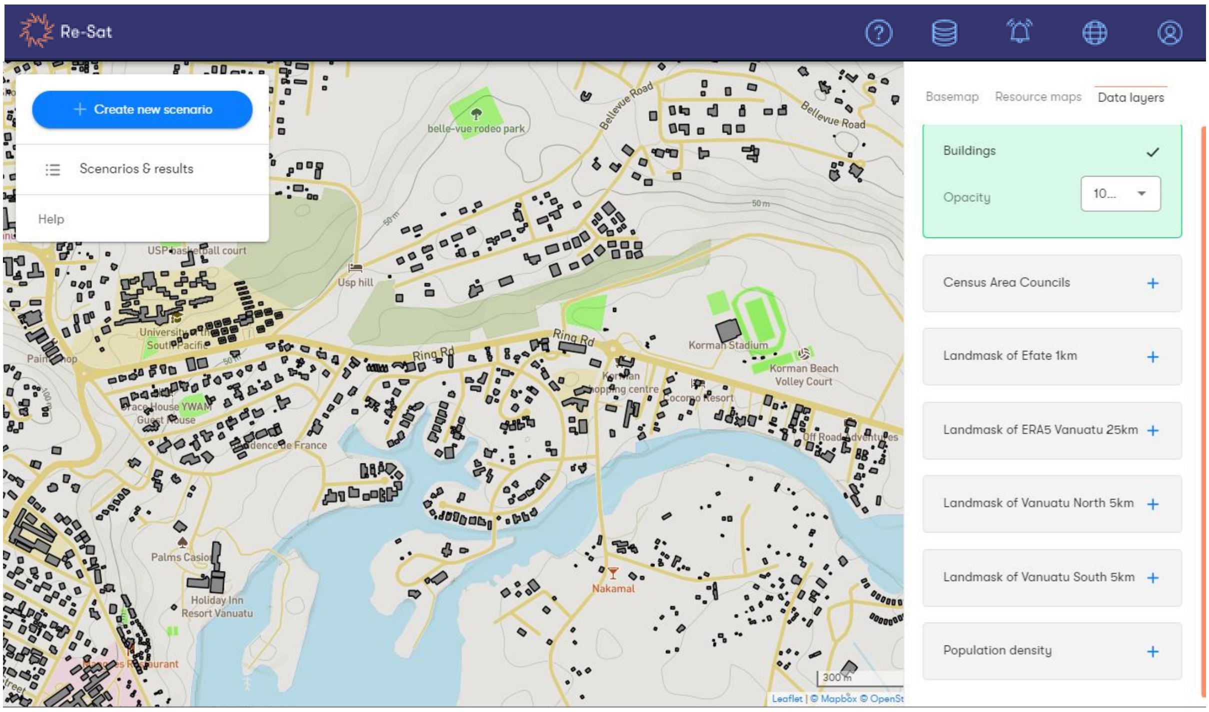


Figure 6: Example of some of the GIS layers available in the RE-SAT platform for Efaté (Vanuatu).

4.3.2. Platform capabilities and features

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

2. Renewable scenario settings and installations characteristics: 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. Variable Renewable Energy simulation (VRE simulation): 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 Vanuatu.

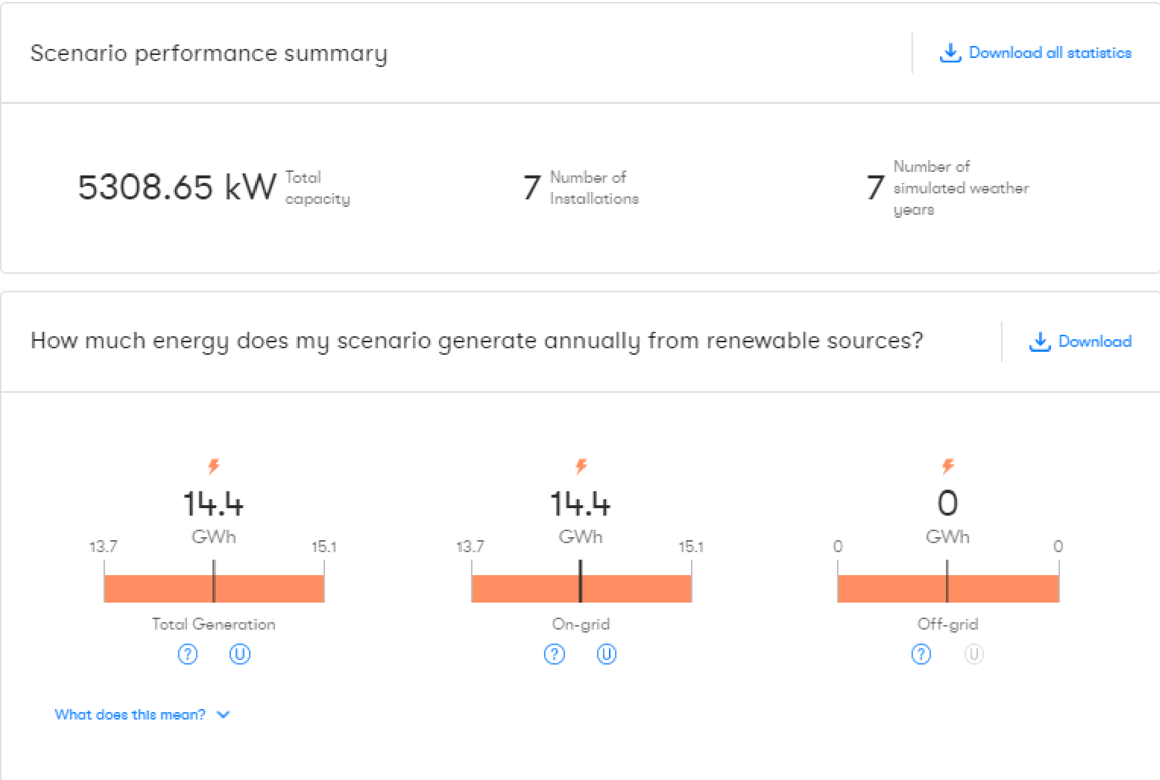


Figure 7: Example of the scenario performance summary display in RE-SAT.

4. Geothermal, hydro and biofuel contributions: 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. CO2 and fossil fuel displacement: RE-SAT calculates the potential for displacement of fossil-fuel related costs and CO2 emissions saved from the modelled renewable energy scenario.

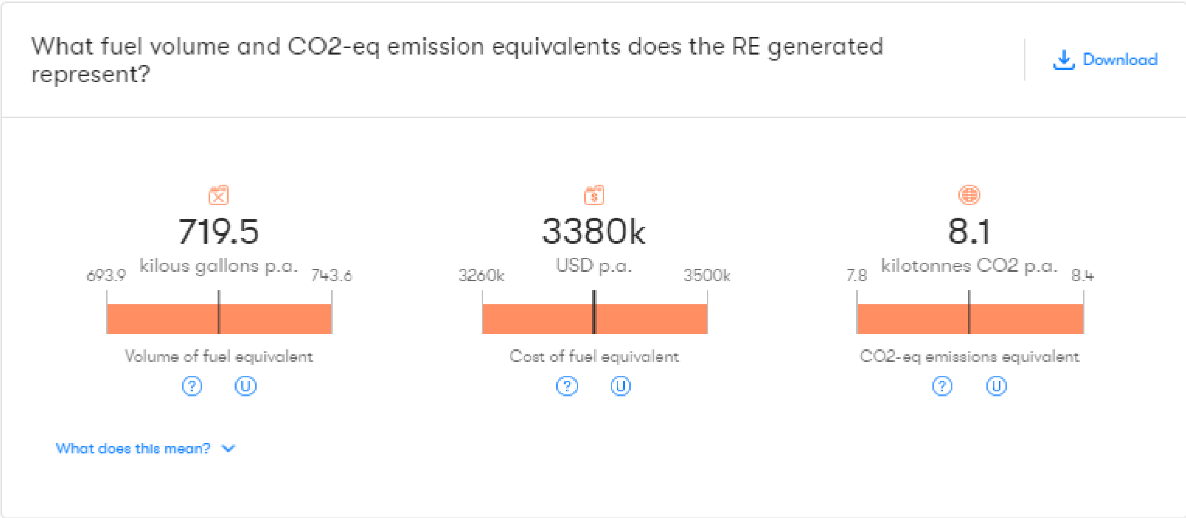


Figure 8: Example of the results of the CO2 and fossil fuel displacement calculations in RE-SAT.

6. <u>Uncertainty quantification</u>: 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. <u>Demand comparison</u>: 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. All the financial assumptions regarding costs of installations, inflation, etc. were tailored for Vanuatu and arrived at in consultation with partners.

   Figure 10 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 Cashflo	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 10*: 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 11**: Examples of results exploration capabilities in RE-SAT (Generation Heatmap and Demand Heatmap).*

***Figure 12**: Examples of results exploration capabilities in RE-SAT.*

10. Data repository: 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. Technical Manual: 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.

"RE-SAT allows the user to model what would be the performance of a wind or a solar PV farm based on weather statistics for a location and real generation statistics which [we] provided. The results of various simulations on RE-SAT are a key factor for at least eliminating bad locations and also feeding financial models." Vanuatu Working Group Member

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 9 people in Vanuatu have access to the platform.

***Figure 13**: Vanuatu participants during the RE-SAT training workshop in October 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 perform in Vanuatu?

The RE-SAT platform was used to simulate the power produced by the existing solar arrays installed at Kawéné, Tagabé and Météo (which total 1.2MW of capacity) (Figure 14). See the position of one of these solar arrays Kawéné in the map that RE-SAT displays (Figure 15). This solar array is next to the 3.4MW Kawéné wind farm (Figure 16), as seen in the map. The RE-SAT platform was also used to simulate the power produced by the wind farm. The output from RE-SAT was compared with the actual power produced by the installations from January 2018 to December 2020. The power data was kindly provided by UNELCO ENGIE.

***Figure 14**: Existing solar arrays at Kawéné, Tagabé and Météo (total 1.2MW capacity) in Efaté (Vanuatu)*

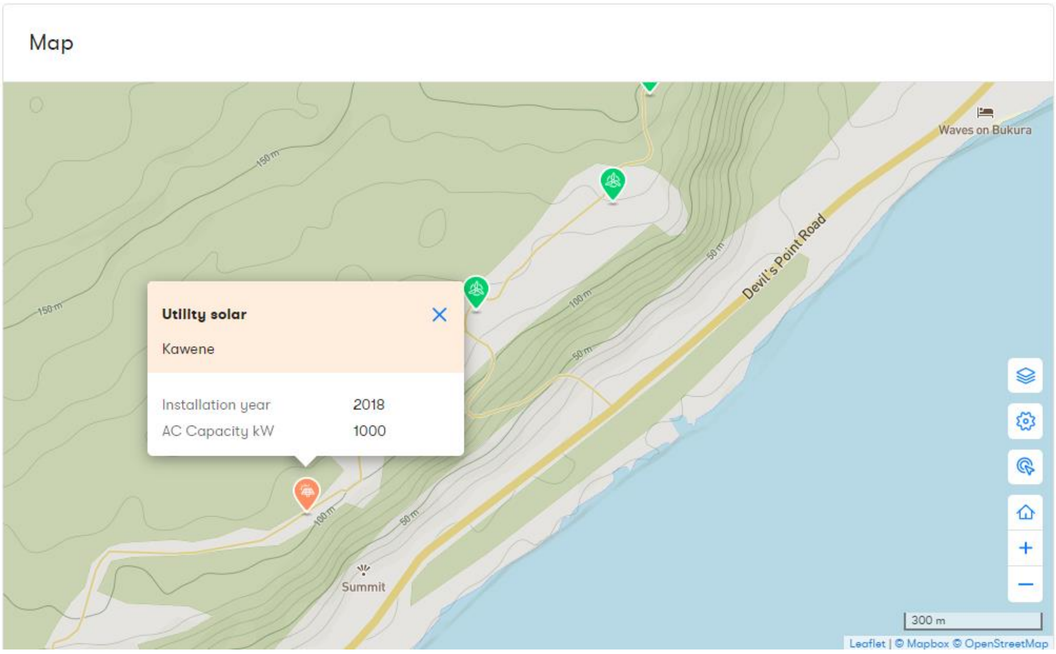


***Figure 15**: RE-SAT map showing the eexisting solar array and wind farm at Kawéné in Efaté (Vanuatu)*

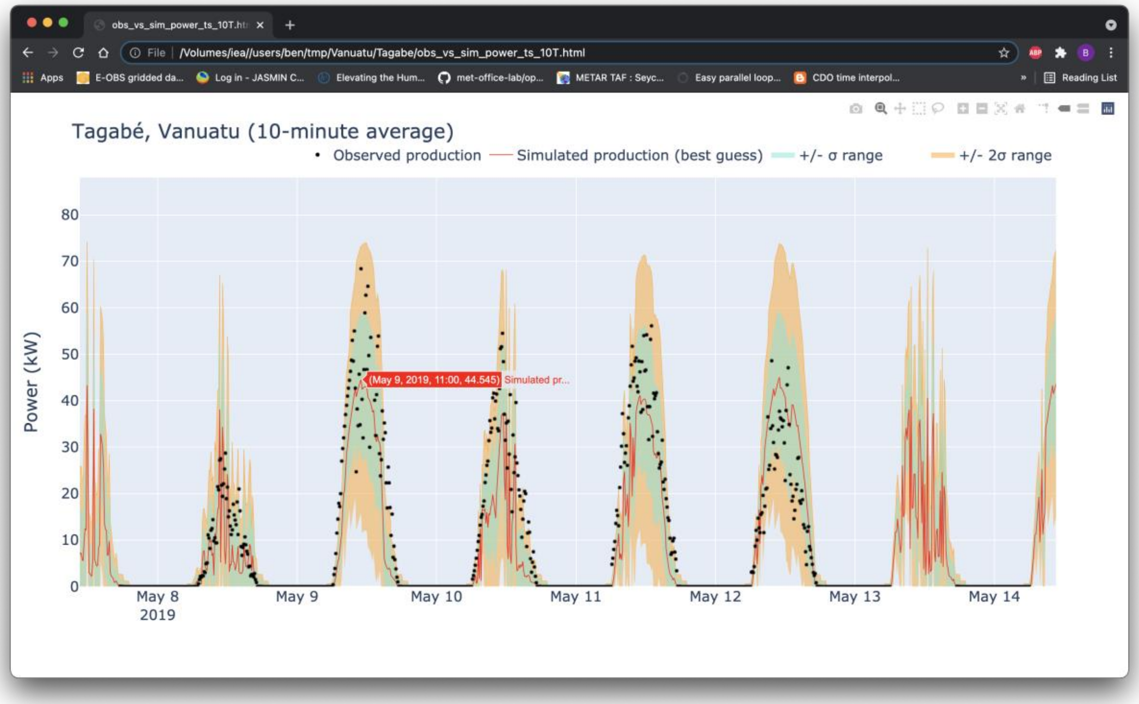
***Figure 16**: The Kawéné 3.4MW wind farm in Efaté (Vanuatu).*

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).



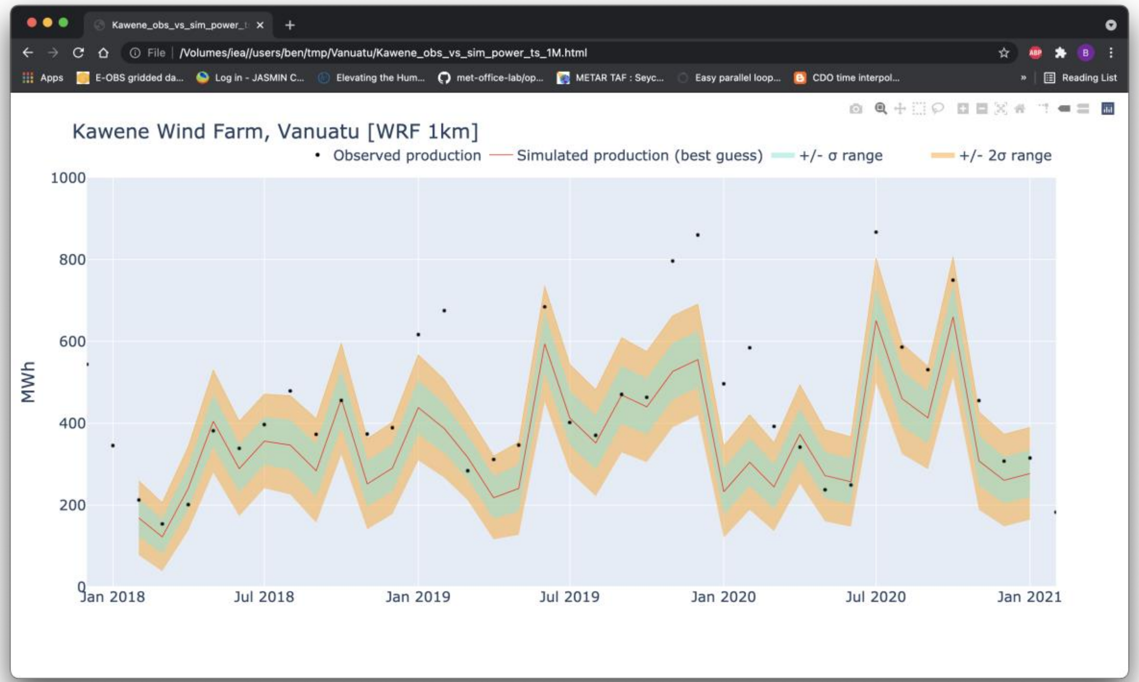


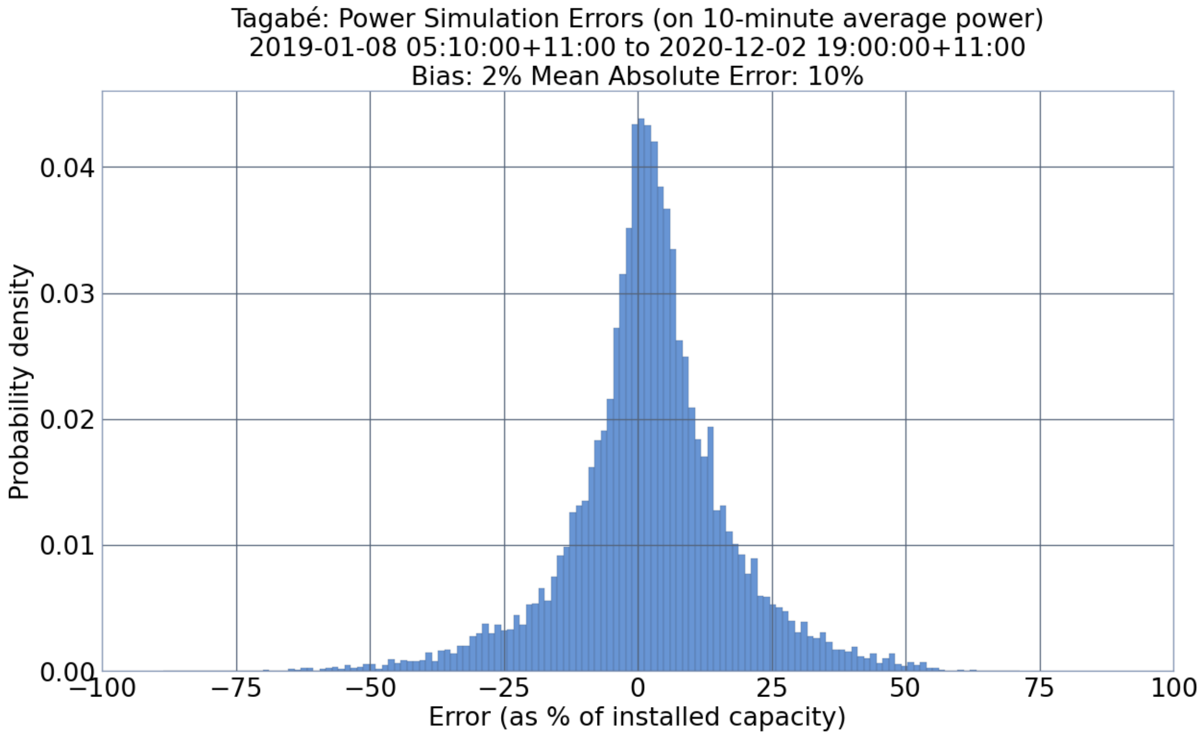
***Figure 17**: RE-SAT performance compared with observed production for the 80kW solar array installed at Tagabé (10-minute averages) and the 3.4MW Kawéné wind farm (monthly mean energy production). The black dots represent the observed power produced, the red line is the simulated production by RE-SAT, the colour bands are a representation of the uncertainty (1 sigma or 2 sigma)*

The 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).

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 Tagabé solar 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. Errors on the daily averages are much smaller since the errors on the individual 10-minute estimates tend to cancel out over time.



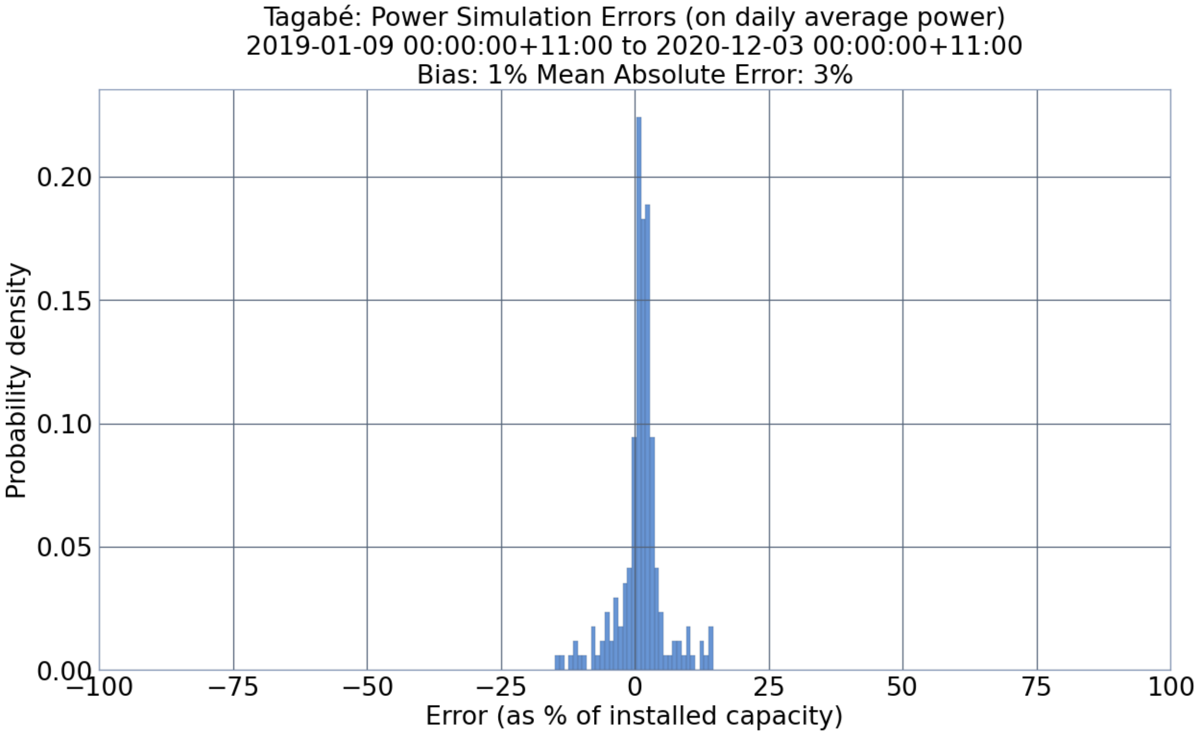


***Figure 18**: Histograms of RE-SAT simulation errors for the 80kW solar installation at* Tagabé (for 10-minute average power and for daily average power)

Summary error statistics for each of the solar generation sites are provided in Table 1 for comparison.

	Bias 10-minute	MAE 10-minute	Bias 1-day	MAE 1-day
Kawéné	3%	15%	0%	6%
Tagabé	2%	10%	0%	3%
Météo	6%	12%	0%	3%

***Table 1** Summary error statistics for the solar power simulations in Efaté (Vanuatu)*

Histograms of simulation errors for wind power are shown in Figure 19 for the facility at Kawéné but here for monthly total production (sub-daily data were unavailable). All times (day and night) are included in the assessment.

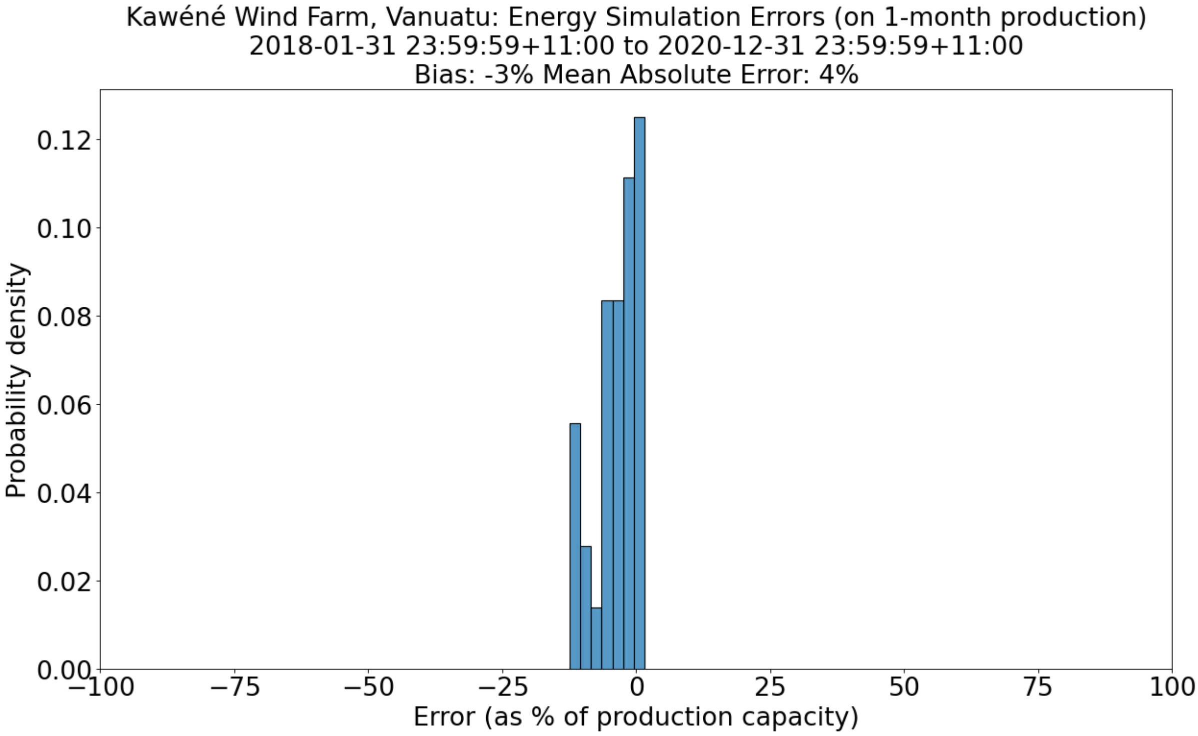


***Figure 19**: Histograms of RE-SAT simulation errors for the 3.MW wind farm at Kawéné.*

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.

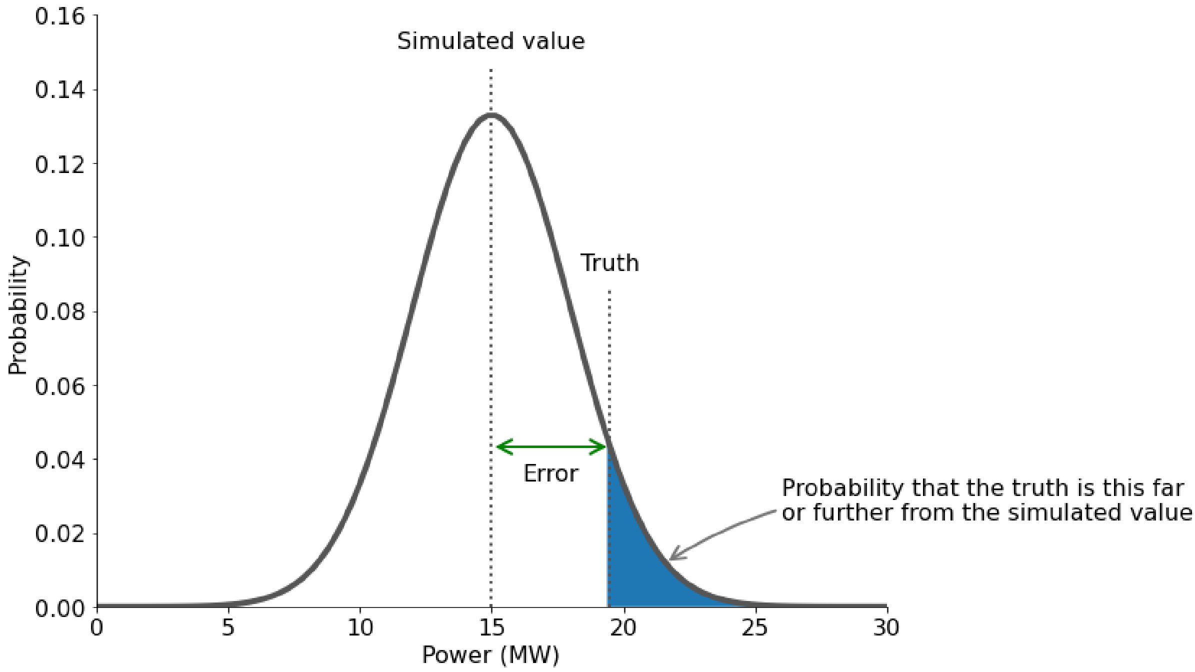


Figure 20: *Normal distribution of the simulation errors.*

Under the assumption that the simulation errors follow a normal distribution (as shown in Figure 20) 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 21.

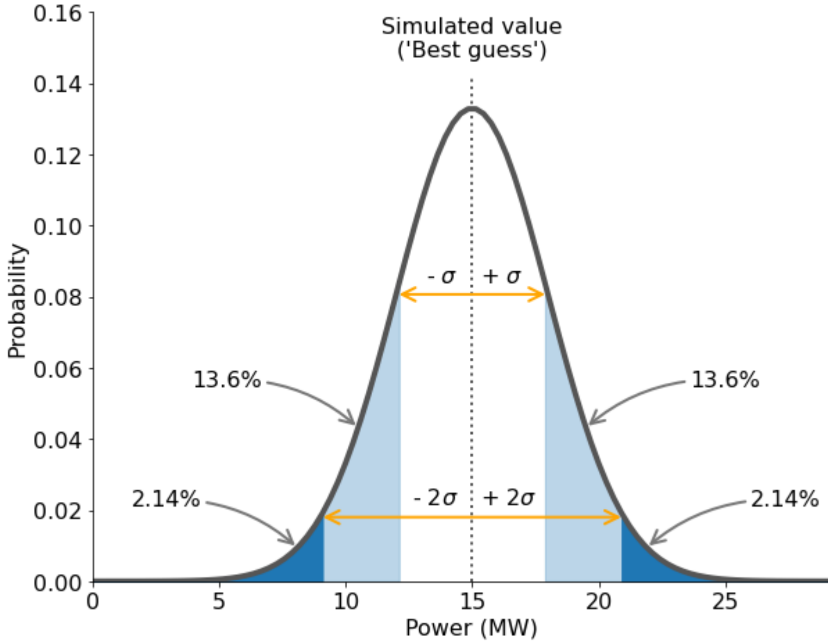


Figure 21: *Probabilistic interpretation of sigma-bands under the assumptions of normally distributed errors.*

The distribution of the solar simulation errors is shown in the histograms of Figure 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. These are summarised in Table 2. The proportion of measured production (‘reality’) falling inside the one-sigma band was approximately 87%. This number is larger than the expected 75% and indicates that the 1-sigma uncertainty band reported by RE-SAT is too wide (overly conservative). In contrast, the 2-sigma band was found to be well calibrated and with reality falling inside of the two-sigma approximately 95% of the time as expected. The mismatch between the two is attributable to the non-normality of the error distributions. In particular, the ‘fat’ tails of the empirical distribution (Figure 18) compensate for the conservative (over wide) tendency of the assumed normal distribution. Overall, with these distributional differences in mind, the uncertainty calibration is seen to be reasonable for the solar simulations.

	% of Simulations outside 1-sigma band	% of Simulations outside 2-sigma band	Bias 1-day	MAE 1-day
Kawéné	13.1%	7%	0%	6%
Tagabé	11.1%	4.9%	0%	3%
Météo	12.5%	6%	0%	3%

***Table 2**: Summary of uncertainty calibration for solar power simulations in Efaté, Vanuatu.*

Since only monthly production totals were available for wind it was not possible to test the uncertainty calibration due to having an insufficient number of samples to make a meaningful comparison.

In summary:

- Re-Sat was used to simulate the Kawéné, Tagabé and Météo solar farms.
- Simulation compared with reality 2019 to 2020 (inclusive).
- Results typically within: 15% for any given 10-minute average.
4% for any given daily average.

- Slight positive bias bias.
- Uncertainty bands on solar simulations are well calibrated.
- Estimates for the error on monthly wind energy production are Bias: -3%
MAE: 4%

4.6. Launch of RE-SAT in Vanuatu

The RE-SAT platform was launched in Vanuatu during a virtual two-day Training Workshop (20-21 July 2021), where the IEA team trained participants on the use of RE-SAT and developed some real energy scenarios with them. An estimate for a quote was presented to the Government of Vanuatu for continued use of the platform beyond the RE-SAT project period.

"The Department of Energy is working towards achieving the goals of the National Energy Road Map (NERM) 2030, and it is timely that this project comes to fruition. The RE-SAT Platform will greatly benefit the Department of Energy in the Pre-feasibility stages of Renewable Energy deployment around the Islands of Vanuatu." Minister of Climate Change, on the occasion of the RE-SAT Launch in Vanuatu.

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.

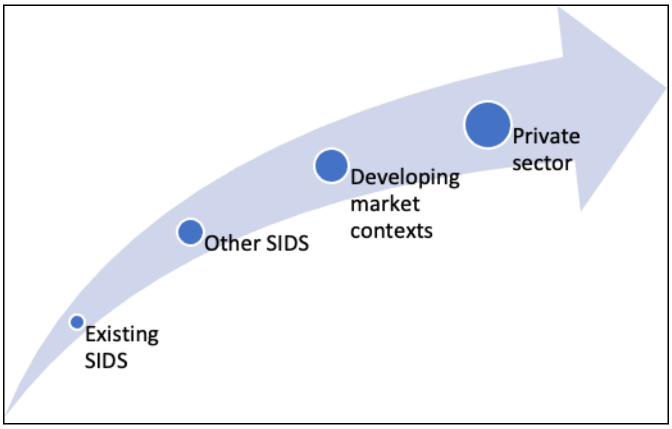


Figure 22: *RE-SAT commercial trajectory plans.*

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 Vanuatu 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.

> *"Despite this period being tough for international project, the implementation of the activities has been smooth and efficient."* Vanuatu Working Group Member

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

> *"The platform will not benefit the Department of Energy only but also accessible to other Government Departments, the Regulator and Power Companies that make up the RE-SAT Vanuatu working group. The platform will be an information library for these key Energy stakeholders to access information, implement renewable energy projects and assist the Government in addressing its NERM 2030 targets."* Minister of Climate Change, on the Occasion of the RE-SAT Launch

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

> *"The model is operational, [we] have already set based scenarios. The results have been implemented in various RE plans. All this means the project has achieve its goals."* Vanuatu Working Group Member

Relevance

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

> *"The relations developed between partners in the project have helped understanding view points and needs."* Vanuatu Working Group Member

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

> *"The Government of Vanuatu, in its NDCs, has committed to 100% Renewable Energy (RE) in 2030. Being able to simulate and spot best location for solar PV and/or wind energy will definitely help towards having more RE in the energy mix of the country and then achieve the first part of the SDG7 (Clean energy)."* Vanuatu Working Group Member

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

> *"The Department of Energy is working towards achieving the goals of the National Energy Road Map (NERM) 2030, and it is timely that this project comes to fruition. The RE-SAT Platform will greatly benefit the Department of Energy in the Pre-feasibility stages of Renewable Energy deployment around the Islands of Vanuatu."* Minister of Climate Change, on the Occasion of the RE-SAT Launch

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

6.2. Impact evaluation

The RE-SAT projects has provided the Government of Vanuatu with a new renewable energy platform that has been used to support their transition to renewables and a climate resilient future.

"[RE-SAT offers a] Way forward to utilize the earth observation and other data sources to support Vanuatu in the transition from fossil fuel electricity generation to Renewable Energy...

The main key factor has been the close exchange of the model functionalities and the provision of real operation statistics from the existing RE facilities." Vanuatu Working Group Member

Under Paris agreement and through its NDCs[10], the Government of Vanuatu has set some ambitious target for its transition to 100% renewable energy in 2030. This target would replace nearly all fossil fuel requirements for electricity generation in the country and be consistent with the National Energy Road Map (NERM) target of 65% renewable energy by 2020.

With the RE-SAT model for wind and solar PV generation, the Department of Energy of Vanuatu and UNELCO ENGIE, the utility in charge of the concession contract for the generation and supply for the Island of Efaté, have a powerful yet simple tool to explore various scenarios to achieve the NDCs of Vanuatu. RE-SAT is currently using to identify potential sites for the next 5 MWp solar PV projects to be constructed in the next 2 to 3 years.

To support the government in achieving this 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 Vanuatu in its transition towards renewable energy. Some examples of use are detailed in the following sections.

6.2.1. Testing the current renewable energy configuration in Efaté with RE-SAT

The performance of RE-SAT was tested by creating a scenario of the current variable renewable energy installations in the island of Efaté (see Figure 23 for the existing installations in Efaté as of November 2021). The total installed capacity is 6042 kW, generated by 5 solar PV installations and 1 on-shore wind farm (installed in 4 phases). This configuration of installations was run through 3 simulated weather years to capture year on year variability.

[10] Vanuatu's First Nationally Determined Contribution (updated submission 2020) https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Vanuatu%20First/Vanuatu%E2%80%99s%20First%20Nationally%20Determined%20Contribution%20(NDC)%20(Updated%20Submission%202020).pdf

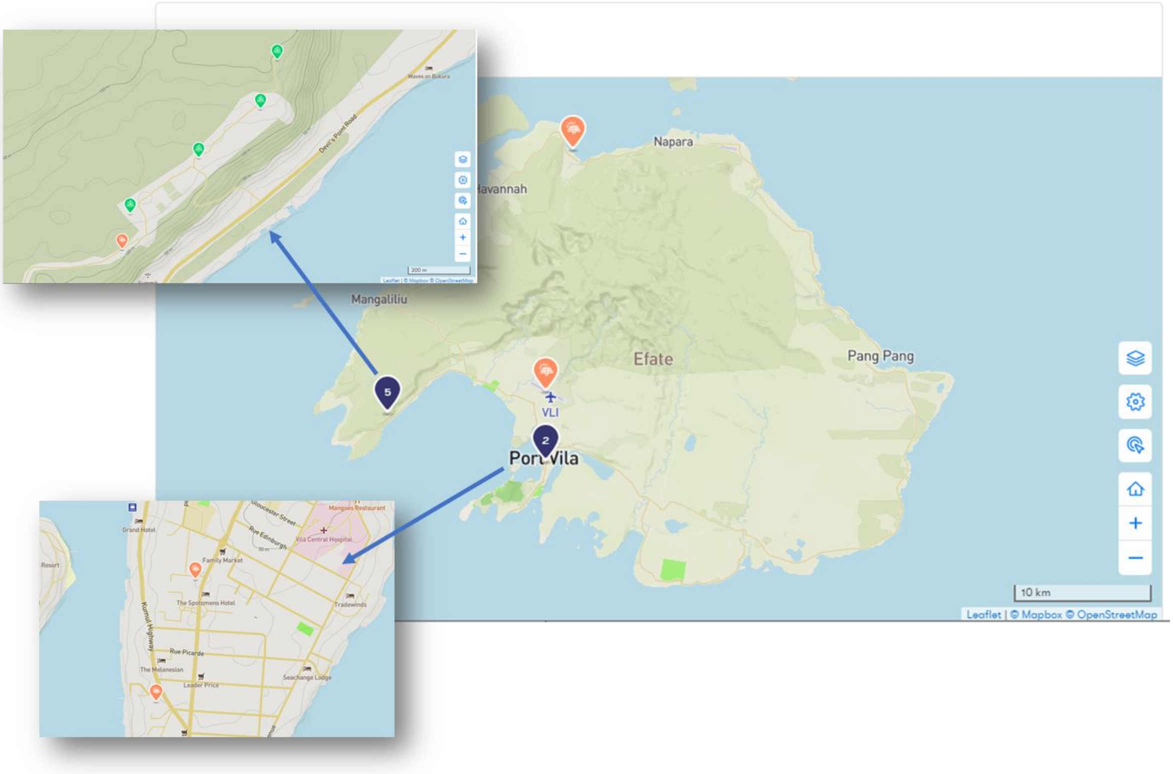
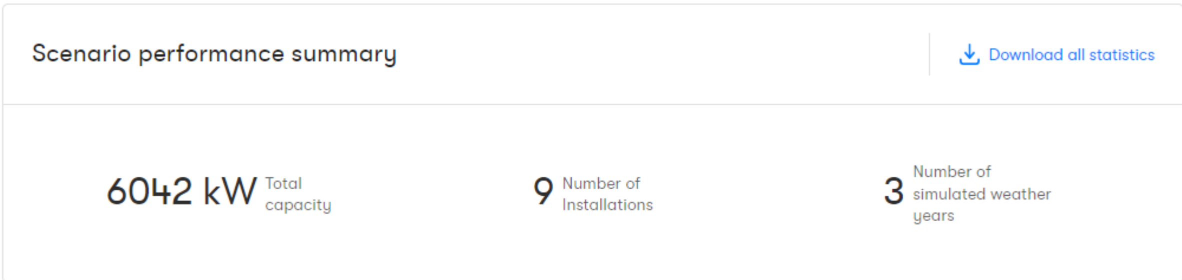


Figure 23: Existing wind and solar installations in Efaté (Vanuatu) as of 2021.



The Table below shows some of the summary statistics for each of the installations. The scenario is for year 2022, therefore all the installations that are producing power until that year are included. To take into account the degradation of assets installed previous to the year of the scenario, RE-SAT takes into account the degradation of each of the installations through the loss factor. For example, the first wind farm in Devils Point in Efaté was installed in 2007, with the last one installed in 2017 so to reflect this in financial calculations they are represented at each of the years.

Installation	Installation capacity MW	Installation year	Annual RE Generation Mid (50% EP) MWh	Capacity Factor Mid (50% EP) %	CO2-eq emission equivalent Mid (50% EP) tonnes C02 p.a.	Volume of Fuel equivalent Mid (50% EP) kilolitres Diesel	Nominal LCORG at 50% EP USD /kWh
Utility solar	**2.37**		**3,120**	**15.1**	**1,980**	**825**	
Kawene	1	2018	1,310	15	833	347	0.179 Σ
Meteo	0.122	2015	157	14.9	99.5	41.5	0.262 Σ
Parlement	0.645	2015	829	15	526	219	0.262 Σ
Tagabe	0.080	2011	98.5	14	62.5	26.1	0.537 Σ
Undine Bay	0.520	2016	724	15.9	459	192	0.218 Σ
Wind	**3.67**		**4,390**	**13.6**	**2,780**	**1,160**	
Efate #1	0.275	2007	385	16	244	102	0.186 Σ
Efate #2	2.75	2008	3,210	13.3	2,030	848	0.218 Σ
Efate #3	0.550	2014	639	13.3	405	169	0.255 Σ
Efate #4	0.100	2017	155	17.6	98	40.9	0.181 Σ

Table 3: *Summary statistics calculated with RE-SAT for each of the installations.*

The scenario simulated by RE-SAT generated an annual energy average of 76000 MWh [4,390 MWh generated by wind from a 3.67MW installed capacity and capacity factor of 13.6%), 3,120 MWh generated by solar (2.37MW installed capacity and 15.1% capacity factor. This performance compares well with the actual annual production from these installations as communicated by UNELCO ENGIE.

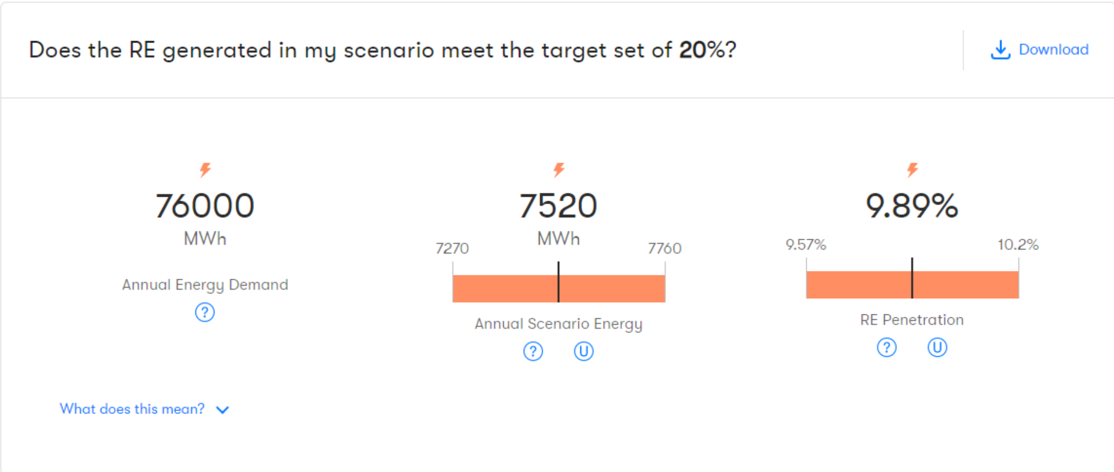


Figure 24: *Summary statistics from RE-SAT*

RE-SAT also calculates what percentage of the annual energy demand is met by the renewable installations simulated in the scenario. In other words, it calculates the renewable energy penetration achieved by any combination of installations as defined in the scenario. The existing installations in Efaté represent almost a 10% RE penetration assuming an annual energy demand of 76,000MWh.

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 825 kilolitres of fuel and around 2 kilotonnes of CO2 emissions per year.

6.2.2. Assessing locations for lidar survey (wind)

The utility company UNELCO ENGIE, in charge of power generation and distribution in Efaté (Vanuatu), has been recently selected by the Pacific Power Association to install a LiDAR for monitoring potential new wind power generation project.

The selection of a wind project requires a proper monitoring of wind in terms of speed, direction and the distribution of wind speed at different altitude. Wind LiDAR is a technique where a low-noise light is used to measure wind speed and direction with high accuracy. It is comparatively new in the wind industry, as normally a wind mast to monitor wind is needed to be installed for a year prior to the development of a wind farm. In both techniques, LIDAR monitoring and wind mast monitoring, their measurement capabilities remain local. Therefore, both need an a-priori location to be identified as suitable regarding wind resource as a LIDAR survey has a significant cost in the range of $40,000 to $100,000

UNELCO ENGIE used RE-SAT to identify the best locations for the best wind farm projects on Efaté Island and to spot the location for their LiDAR to operate. They modelled some 45 sites around the island to finally figure out that the best potential was on the north of the island. They will definitely install the LIDAR there to confirm these preliminary results.

Significantly, the analyst in Vanuatu was not expecting locations in the north of the island to be suitable for consideration, however the RE-SAT resource maps showed that there were in fact sites of good potential. This shows RE-SAT demonstrating value in the selection of potential sites for survey, which is a key part of the renewable energy prospecting stage.

Using the wind resource map for guidance (Figure 25), it is very easy to drop installation on the map. RE-SAT calculated the average annual energy that each of these installations would produce.

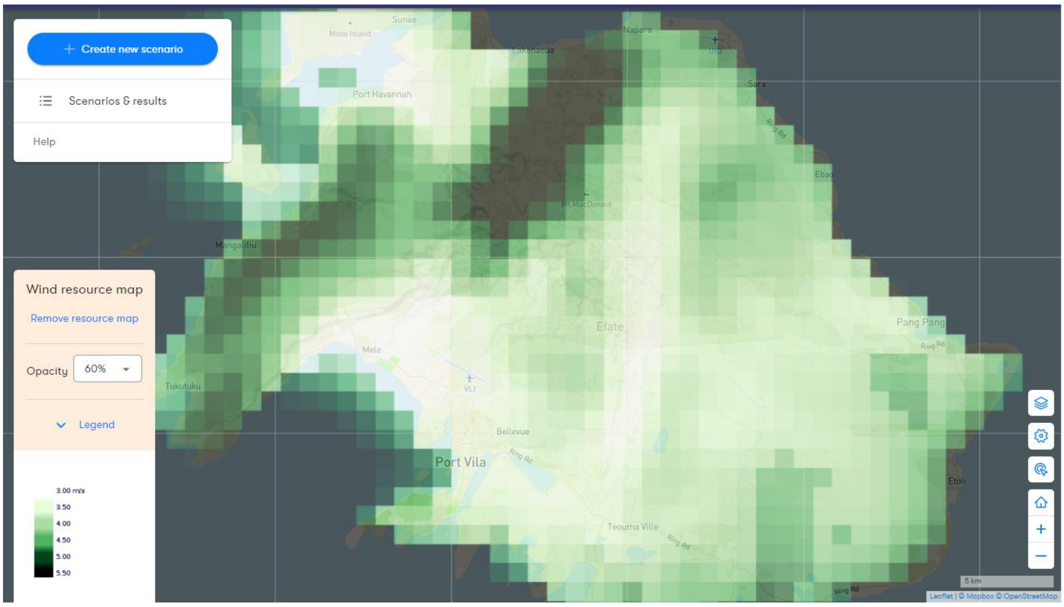


Figure 25: Wind resource map for Efaté (Vanuatu) (wind speed at 10m)

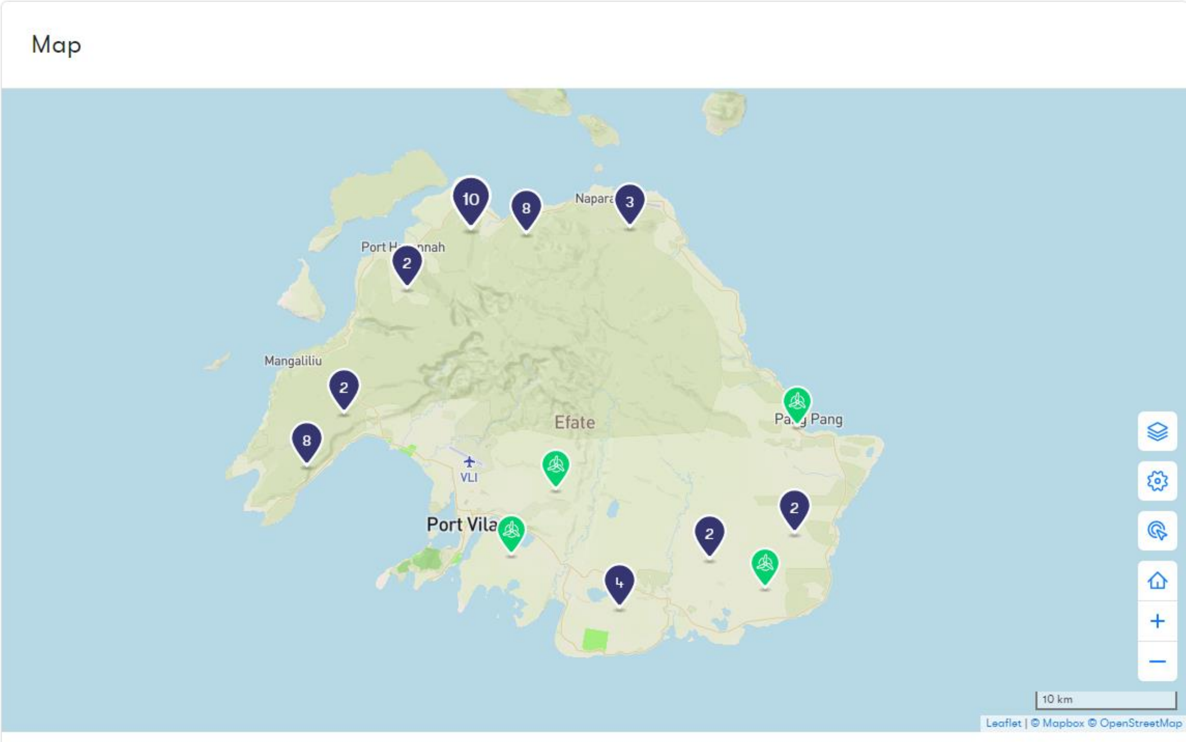


Figure 26: *Map displaying the scenario created with RE-SAT with multiple wind locations to assess best performance location.*

6.2.3. Example scenario for off-grid solar installations

As mentioned earlier, The Vanuatu Rural Electrification Project is aimed at increasing electrification in rural households. Th project is targeting 17,500 households, 230 aid posts and 2,000 not-for-profit community halls unable to access affordable, safe and healthy electricity and located in dispersed off-grid areas. This is being deployed through access to Solar Home Systems and mini-grids in rural areas. As a theoretical demonstration of RE-SAT capability, a "whole nation" scenario was created, based on 2016 mini census data, in which 1.3 kw of rooftop solar was assumed on every household in the Vanuatu archipelago (see Figure 27). The scenario combined 32MW of household rooftop solar with 5.5MW of utility solar and 1.3MW of utility wind generation

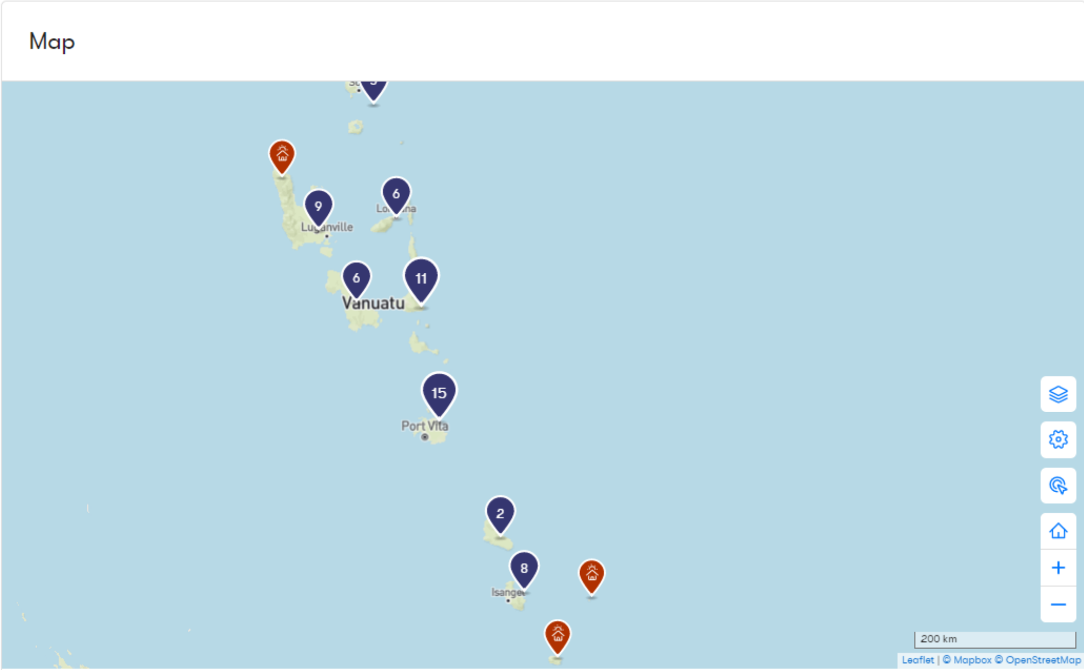


Figure 27: *A scenario assuming 1.3 kw of rooftop solar on every household in the Vanuatu archipelago*

Creating this hypothetical scenario informed planners that this extreme scenario would require an investment of USD 55.7m and generate an annual production of 73.8 GWh of energy (see Figure 28), offsetting 19.5 megalitres of diesel (estimated at a cost of 20.1m USD) and 46.8 kilotonnes of CO2 per annum.

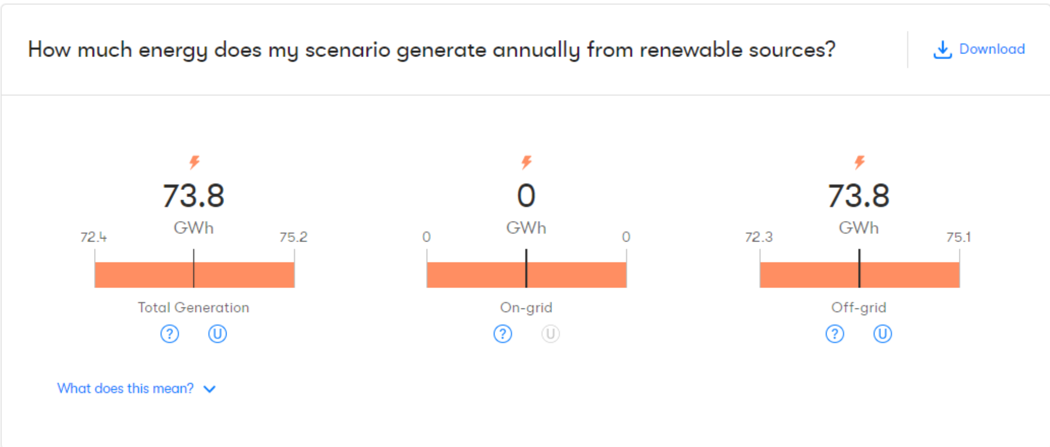


Figure 28: *Summary performance of the hypothetical scenario*

Whilst the 1.7kW of PV solar on every household might not be a realistic option for a number of practical constraints (such as not all roofs are suitable for PV and significant logistics in installing to the outer islands), this gives planners a sense of the cost scale and savings on this "what-if scenarios" to inform strategy .

An example of the type of Report that can be downloaded from RE-SAT is shown in Figure 29.

Installation	Installation capacity	Installation year	Annual RE Generation Mid (50% EP)	Capacity Factor Mid (50% EP)	CO2-eq emission equivalent Mid (50% EP)	Volume of Fuel equivalent Mid (50% EP)
	MW		MWh	%	tonnes C02 p.a.	kilolitres Diesel
rooftop solar	**51**		**73800**	**16.5**	**46800**	**19500**
Central Malekula	1.12	2021	1610	16.5	1020	426
North Ambrym	0.858	2021	1240	16.5	788	329
North East Malekula	2.1	2021	3040	16.5	1930	804
North West Malekula	1.51	2021	2170	16.5	1380	575
Paama	0.503	2021	730	16.5	463	193
South East Ambrym	0.593	2021	859	16.5	544	227
South East Malekula	1.24	2021	1790	16.5	1140	475
South Malekula	1.15	2021	1660	16.5	1050	438
South West Malekula	0.995	2021	1440	16.5	910	380
West Ambrym	0.833	2021	1210	16.5	765	319
Central Pentecost 1	0.748	2021	1080	16.4	683	285
Central Pentecost 2	1.16	2021	1670	16.4	1060	441
East Ambae	0.682	2021	982	16.4	623	260
North Ambae	1	2021	1450	16.4	917	383
North Maewo	0.694	2021	999	16.4	634	264
North Pentecost	1.58	2021	2270	16.4	1440	601
South Ambae	0.426	2021	614	16.4	389	162
South Maewo	0.355	2021	511	16.4	324	135
South Pentecost	1.27	2021	1840	16.5	1160	486
West Ambae	1.06	2021	1530	16.4	972	405
Canal - Fanafo	0.915	2021	1320	16.5	837	349
East Malo	0.566	2021	815	16.4	517	216
East Santo	0.95	2021	1370	16.4	867	362
Luganville	0.937	2021	1350	16.4	856	357

Figure 29: *Example of a download from RE-SAT reporting on installation performance in a "1.3kWPV solar installation for every household hypothetical scenario".*

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 Vanuatu are also included.

In-country challenges:

- Timing and relevance are important for co-production: The RE-SAT project was well received by Vanuatu 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 Vanuatu, the Department of Energy at the Ministry of Climate Change Adaptation (MoCCA), facilitated the engagement with other government organisations. The utility company UNELCO ENGIE, which services Efaté, was also very engaged in the project from the start.
- There is a lot of competition for workshop time in the recipient SIDS: Many nations and suppliers are operating in Vanuatu. 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 UNELCO ENGIE were crucial for the validation and calibration of the tailored RE-SAT application in Vanuatu.
- Local capacity to receive knowledge transfer varies across countries and therefore delivery methods need to adjust accordingly. For some of the organisations involved in the workshops in Vanuatu, 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 Vanuatu was welcomed 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 we held in Vanuatu, 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. Vanuatu contributed come articles to the Community Newsletter throughout the project.

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. In particular for Vanuatu, the IEA team experimented with weather data development at a 5km spatial resolution, given the large extension that Vanuatu covers.
- 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.
- Large scale and close proximity of islands in Vanuatu presented modelling challenges. Modelling Vanuatu presented a significant challenge for the applied meteorologists in the Data team. Made up of 83 islands and covering a total area of approximate 12,200 square km, its landmass is 6.5x larger than the island of Mauritius and 100 times bigger than Montserrat. This means it required significantly more time and computing power to simulate historic weather to the spatial and temporal standards required to get the best possible estimate of potential renewable energy. Where the islands are so close to one another they have a significant impact to each other’s weather.

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