RE-SAT: Energy Analytics Platform

Renewable Energy planning in Mauritius

Case study

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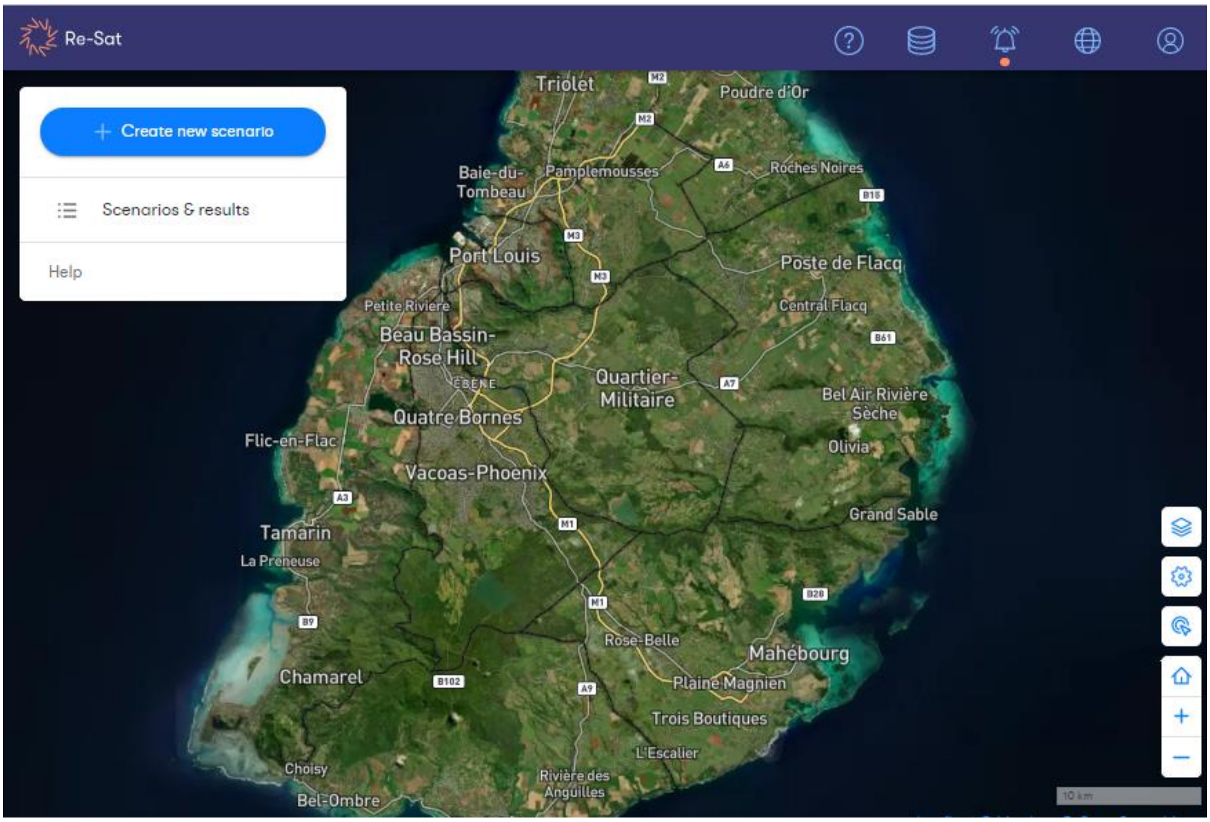
November 2021



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 Mauritius acknowledges the invaluable assistance from the Ministry of Energy and Public Utilities (MEPU), Central Electricity Board (CEB), Mauritius Renewable Energy Agency (MARENA), University of Mauritius (UoM), the Mauritius Meteorological Services (MMS) and The Ministry of Housing and Land Use Planning.

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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 Mauritius 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 Mauritius** was led by the Ministry of Energy and Public Utilities (MEPU). Other government departments and agencies involved: Mauritius Central Electricity Board (CEB), Mauritius Renewable Energy Agency (MARENA), University of Mauritius (UoM), the Mauritius Meteorological Services (MMS) and The Ministry of Housing and Land Use Planning.

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 Mauritius 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 Mauritius after the funded project ends was also included.

The **performance of the RE-SAT platform in Mauritius** was tested against actual power produced by the 15MW solar PV farm (Sarako) and the 9.3MW wind farm (Eole). The errors, expressed as a percentage of the installed capacity, measured on the 15-minute average power accounted to 11% for solar and 7% for wind. When averaging over a day the errors are reduced to 2% for solar and 4% for wind.

The **impact** that RE-SAT has had in Mauritius include:

- the ability to explore potential scenarios to achieve the new 60% energy target, taking into account contributions from the exiting hydropower installations and biofuel plants.
- the potential to use RE-SAT to explore the impact of a smother generation profile from Small Scale Distributed Generation (SSDG), a scheme that allows customers that consume up to 200 kWh per month to produce electricity from PV panels.
- The ability of RE-SAT data to model correlations between generation from a specific installation site and other regions. This can be used to inform planning of grid upgrades and the roll out of the SSDG in a way that smooths the generation impact as renewable generation penetration increases.

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 Mauritius specifically, RE-SAT is:

- Supporting the national planning process to facilitate the targeted increase in the use of renewable energy in Mauritius to 60% by 2030 (target increased from 40% at the start of the project).
- 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.

"There is a project which is going forward where the intention is to reach 100% renewable by 2050. So, we will be able to use this tool to plan for future installations. I think the tool will be very helpful in order to plan and in writing the roadmap for Rodrigues." Nirkita Seeburn, MEPU

"I will give an A+ to the IEA for what they have been doing in terms of training and capacity building and helping us in using the software." Rakesh Dhununjoy, CEB

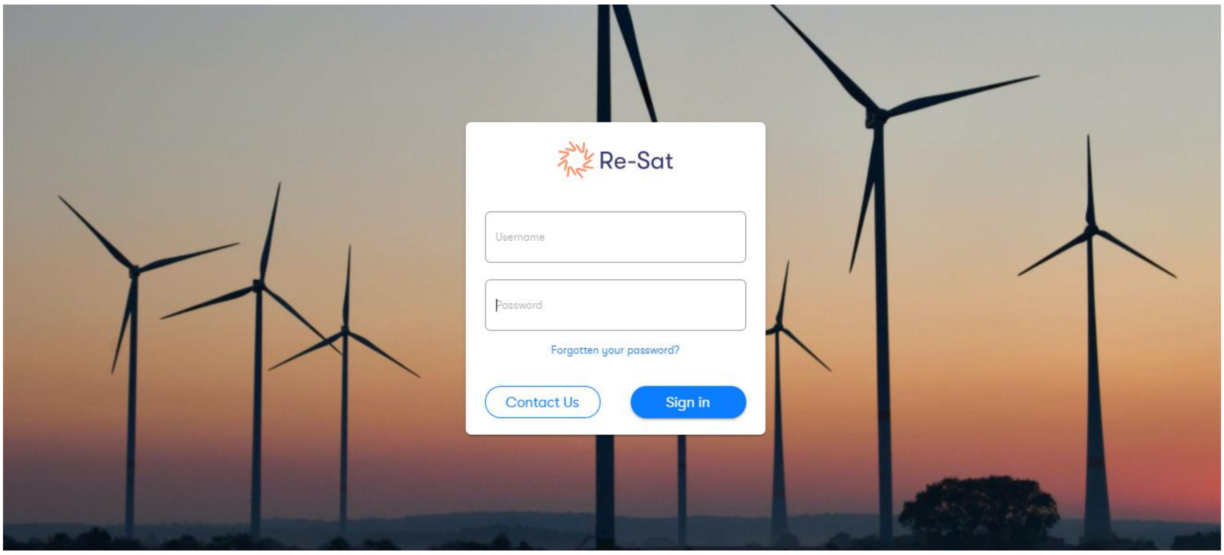


Figure 1*: Landing page of the RE-SAT platform.*

2. Project overview

2.1. The energy and data challenges facing Mauritius

2.1.1. About Mauritius

The Republic of Mauritius is an island nation off the south-east coast of the African continent in the south-west Indian Ocean, approximately 900 km east of Madagascar.

In addition to the island of Mauritius, the Republic includes the islands of Cargados Carajos, Rodrigues and the Agalega Islands, totalling a population of 1.3 million inhabitants and a total land area of around 2,000 km^2.

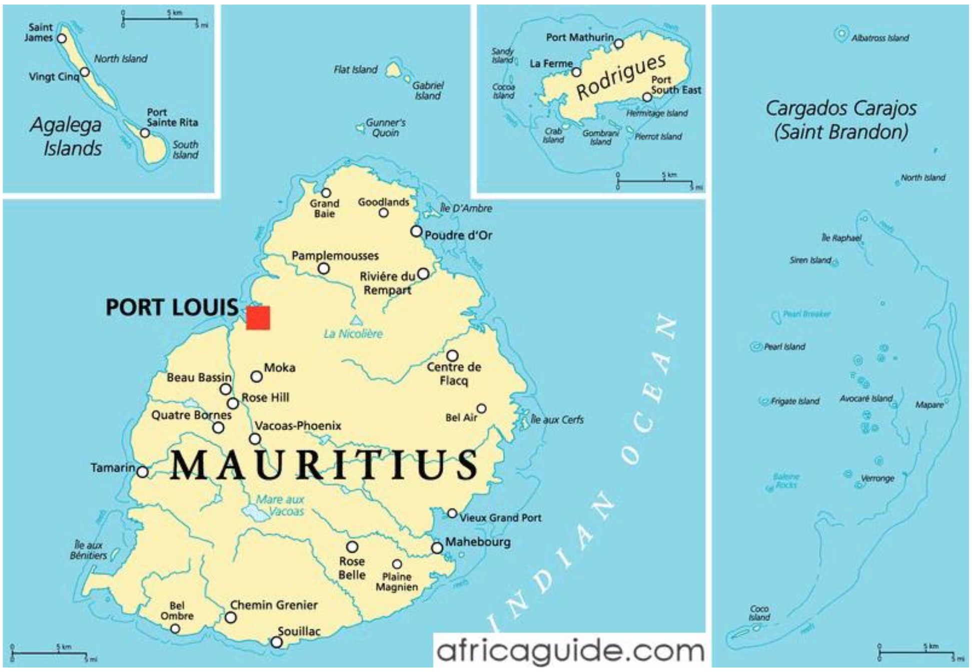


Figure 2: *Map of Mauritius.*

2.1.2. Electricity in Mauritius – Energy targets

At the start of the RE-SAT project Mauritius already had a renewable energy penetration of 22%. The key source of renewable energy was bagasse (sugar-cane waste) with 16% of the total, while the rest came from hydro, wind, landfill gas and solar. The government had plans to increase the penetration of renewable energy to 35% by 2025 through wind farms, solar energy, biomass and waste-to-energy projects as stated in its Long-Term Energy Strategy 2009-2025[2].

[2] https://sustainabledevelopment.un.org/content/documents/1245mauritiusEnergy%20Strategy.pdf

In August 2019, Mauritius also developed a Renewable Energy Roadmap 2030[3] for the electricity sector, defining a pathway for the development of RE technologies and diversifying the electricity mix to achieve the target of 35% RE by 2025 and maintain it until 2030. A Renewable Energy Strategy Plan 2018-2023[4] was produced by MARENA, aligning Ing with the Government targets for RE mix in the electricity production and also including the wider potential for RE in the energy sector , including transportation and Heating & Cooling.

The Central Electricity Board (CEB) also developed an Integrated Electricity Plan (2013 – 2022)[5]. CEB is the national agency for the transmission, distribution and sale of electricity. CEB produces 40% of the total power requirements (mainly from 4 thermal power stations and 8 hydroelectric plants). The remaining 60% is purchased from Independent Power Producers (IPP) (mainly private generators from the sugar cane industry using bagasse and imported coal).

Mauritius has now submitted an update to the RE target through the updated National Determined Contributions (NDC)[6] with a pledge for the production of 60% of the energy needs by green sources by 2030. (NDC submitted on 10/05/2021).

Figure 3 shows a map created by RE-SAT with the exiting solar and wind installations in Mauritius. Table 1 shows the capacity installed and the energy generated on average per year.

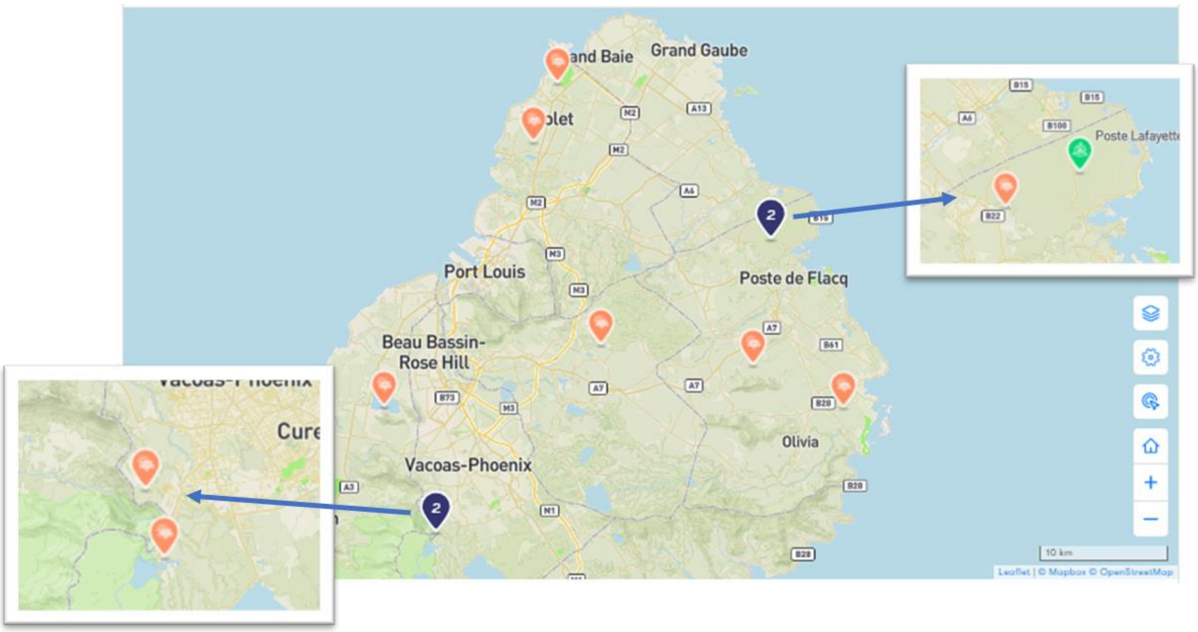


Figure 3: *Existing installations in Mauritius (map produced by RE-SAT). When two or more installations are closed together, RE-SAT groups them for display purpose. Therefore, a blue marker with the number 2 indicates that there are 2 installations in close proximity, by zooming the installations and then displayed.*

[3] https://www.climate-laws.org/geographies/mauritius/policies/renewable-energy-roadmap-2030-for-the-electricity-sector
[4] https://www.marena.org/strategic-plan/resp-overview
[5] https://ceb.mu/files/files/publications/IEP2013.pdf
[6] https://www.wri.org/insights/understanding-ndcs-paris-agreement-climate-pledges

Installation	Installation capacity MW	Installation year	Annual RE Generation Mid (50% EP) MWh	Capacity Factor Mid (50% EP) %
Utility solar	**79.5**		**115,000**	**16.7**
Akuo/Medine, Henrietta	17.5	2019	25,800	16.8
CEB Green, Henrietta	2	2016	2,910	16.6
Helios, Beau Champ	10.3	2019	14,600	16.3
Sarako, Bambous	15.2	2014	22,200	16.7
Solar Field, Mont Choisy	1.99	2016	2,920	16.7
Synnove, L'Esperance	1.95	2017	2,500	19.9
Synnove, Petite Retrait	1.92	2017	2,660	21.2
Voltas Green, Queen Victoria	15	2019	20,800	15.8
Voltas Yellow, Solitude	13.6	2018	20,800	17.4
Wind	**9.35**		**13,600**	**16.6**
Quadran, Plaine Des Roches	9.35	2015	13,600	16.6

***Table 1**: One of the summary Tables within RE-SAT showing someof the inputs and outputs from the calculations.*

In common with many Small Island States, Mauritius is: (i) import-dependant; (ii) dependant on tourism; (iv) reliant on overseas aid; and (v) vulnerable to the impacts of climate change.

The three key principles underpinning the Government of Mauritius' strategy for electricity generation and supply are (i) availability, security and diversity of supply with particular focus on renewable energy; (ii) affordability with a view to ensuring socio-economic development of the country taking into account the financial sustainability of the utility, and (iii), energy efficiency and conservation, given the high volatility of the prices of fossil fuels, in particular oil. The county is focused on diversifying its energy supply and increasing the penetration of Renewable Energy.

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 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 Mauritius, 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.

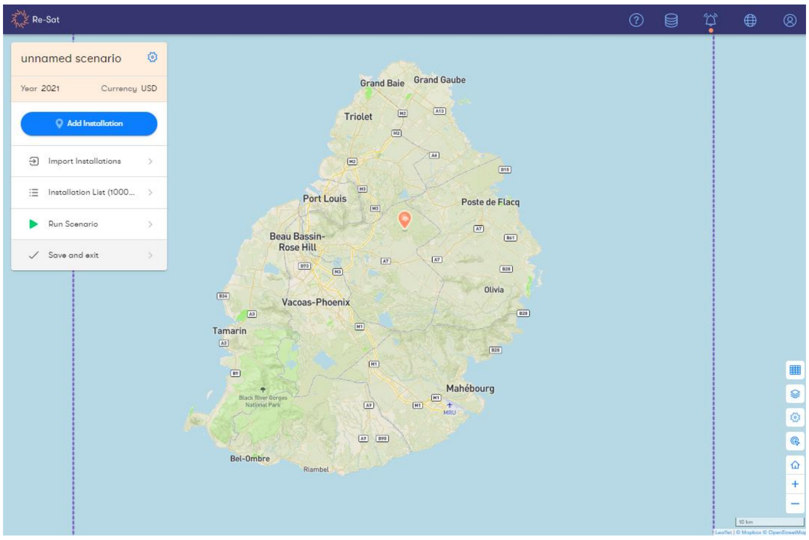


Figure 4: Example scenario for the RE-SAT application (re-sat.com). The user can create renewable energy scenarios and explore the results of those already run.

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[7], 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".

"The project is relevant to SDG7 because one of the goals of SDG7 is to integrate more Renewable Energy in the energy mix of the island." Nirkita Seeburn, MEPU

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).

[7] IRENA: International Renewable Energy Agency

3. Project partners

Our **partnership in Mauritius** was led by the Ministry of Energy and Public Utilities (MEPU). Other government departments and agencies involved in the project included: the Mauritius Central Electricity Board (CEB), Mauritius Renewable Energy Agency (MARENA), University of Mauritius (UoM), the Mauritius Meteorological Services (MMS) and The Ministry of Housing and Land Use Planning.

The role of the government (MEPU) has been to facilitate access to the findings regarding the actions from the energy policies and the Roadmap towards renewable energy by providing expert knowledge into the particular RE requirements and potential sources of data. MARENA complemented the role of the government very well as the agency was set up in 2-16 to oversee and promote the development of renewable energy in Mauritius. The CEB has provided regular updates on the status of the renewable installations planned as well as provided valuable power data from a solar installation and a wind installation for our validation purposes. The Ministry of Housing and Land Use Planning provided early on in the project some of the GIS layers that are available in the platform. These are a visual aid when siting new installations. The MMS shared her local meteorological expertise and pointed us to relevant in-situ data to validate our weather simulations. MAR

***Figure 5**: Mauritius project partners at RE-SAT workshop with part of the IEA team (July 2019).*

"We had all the important elements; all the important stakeholders were around for this working group and task group. Be it from the Ministry, the Met services, the University of Mauritius, from our side. I think we have a good team, very good synergies so that it was useful to all of us in our everyday application, we are going to use it in future" Rakesh Dhununjoy, CEB

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

What RE-SAT does:

- Verify and extend **national RE resource assessments** whilst **quantifying uncertainty**;
- Create representative time series of wind and radiation from **weather simulations** enhancing **scarce local observations with earth observation data** and **regional weather modelling**
- Develop methods to assess the **suitability of locations** for renewable energy production;
- Allow policymakers and planners to **assess the energy production potential** of future renewable energy production mixes.

This means that energy planners can:

- Increase the coverage, resolution and precision of **estimates of natural energy resources**;
- Increase the confidence in **RE estimates for investors** and planners by **quantifying risk**;
- Benefit from **more skilled staff working on RE planning** in the SIDS; and
- Improve the **cost effectiveness** of creating estimates of RE production given **scarce data resources.**

This ultimately benefits the SIDS by:

- Increasing the **uptake of RE** in the SIDS assisting in the **reduction of carbon emissions**
- **Reducing the costs** of:
  - project finance
  - implementation
  - energy production
- **Reducing the economic risks** of reliance on fossil fuels.

Figure 6: 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 Mauritius

The following specific requirements were requested by stakeholders in Mauritius.

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 for a national assessment of potential solar and wind generation.
- High resolution solar and wind data to support the investment case for grid connected project, required for a more detailed assessment of regional potential and to inform evidence-based decisions and support financial investment. For Mauritius, the resolution of the weather data developed for the island of Mauritius was of 1km, but for Rodrigues it was of 330m, due to the small size of the island.

Cost assessment

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

Biofuels

- Ability to model the use of biofuels as a replacement for diesel in a generator. Include contributions from biofuels resources when developing renewable energy scenarios. Around 60% of the island's electricity is generated fir four sugar companies, each running its own thermal power station. The fuel is bagasse, the leftover churched sugar cane stalks and tips. The contribution from this fuel type was requested.

Hydropower contributions

- Mauritius has 8 hydropower plants with a total installed capacity of 55MW. 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..

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 the Mauritius 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 Mauritius, helping to reduce the cost of energy production and reducing the economic risks of reliance on fossil fuels.

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 Mauritius and its agencies and developed a set of agreed targeted objectives with short-term benefits for Mauritius as well as long-term benefits.

The RE-SAT functional requirements, as developed in consultation with Mauritius 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 Mauritius. Th model was run for two sub-regions: the island of Mauritius at 1km x 1km and the island of Rodrigues at 330m x 330m. 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 7).

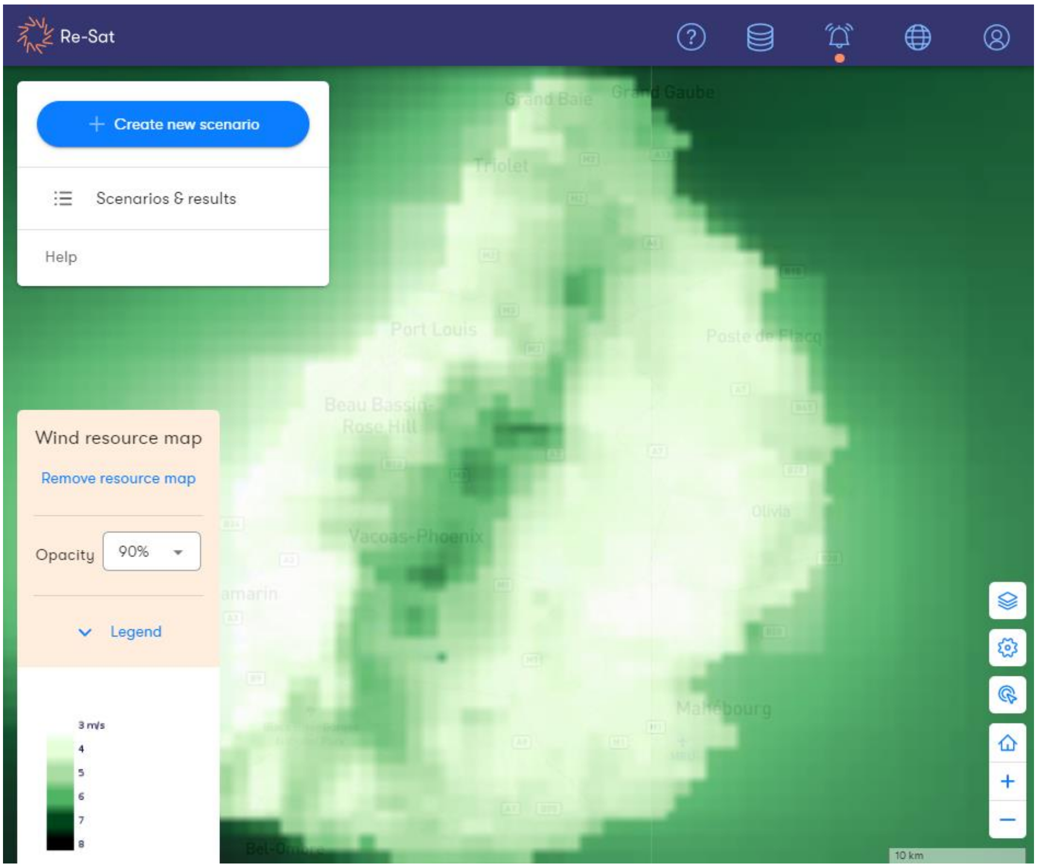


Figure 7: Wind resource map for Mauritius.

3. GIS map layers: These are layers, either provided by the partner country or created by the IEA. For Mauritius, these are the GIS layers in RE-SAT: nature reserves, point of interest, railroads, roads, transmission network and tropical cyclone tracks. .

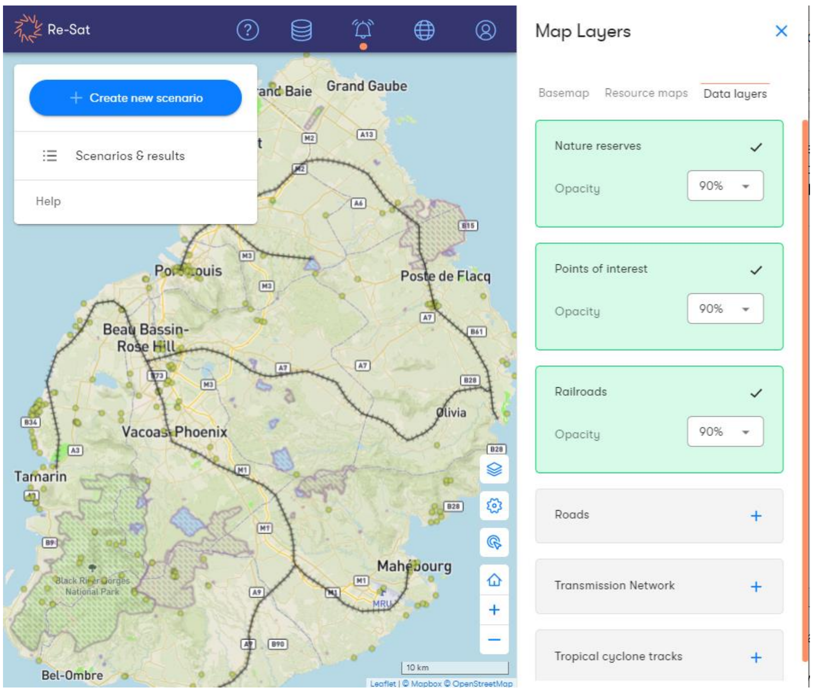


***Figure 8:** Example of some of the GIS layers available in the RE-SAT platform for Mauritius.*

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 Mauritius.

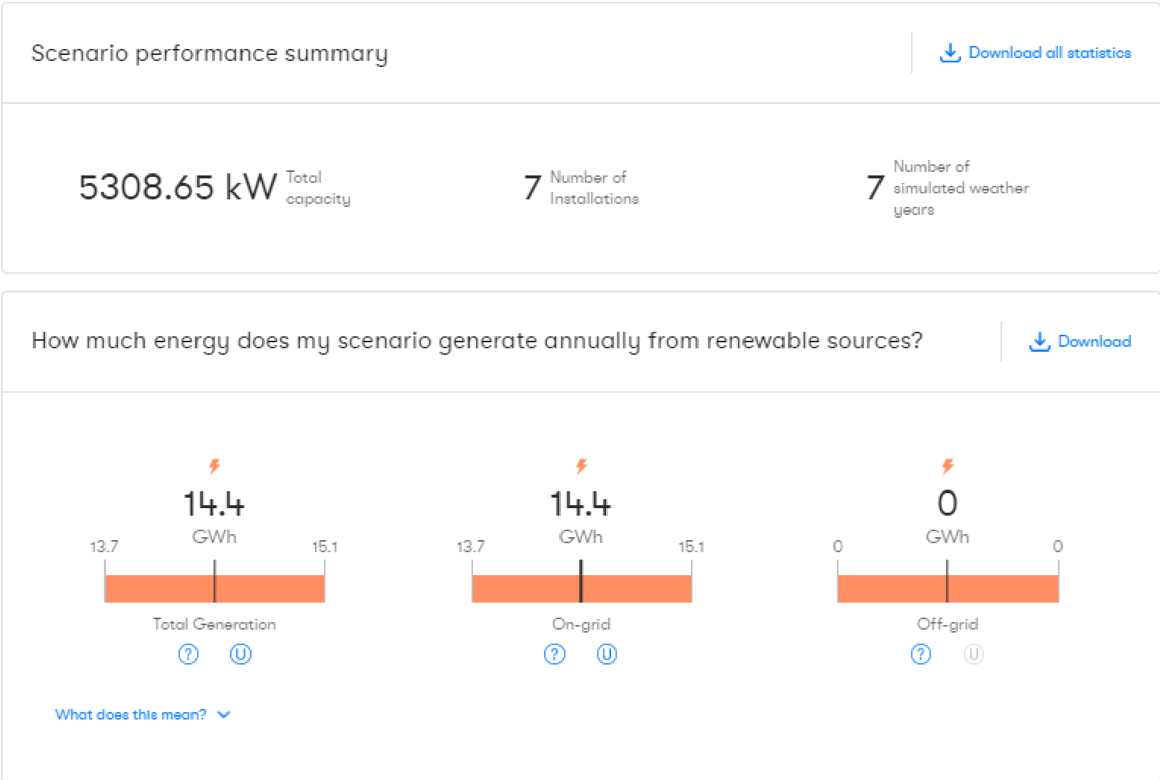


Figure 9: Example of the scenario performance summary display in RE-SAT.

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.

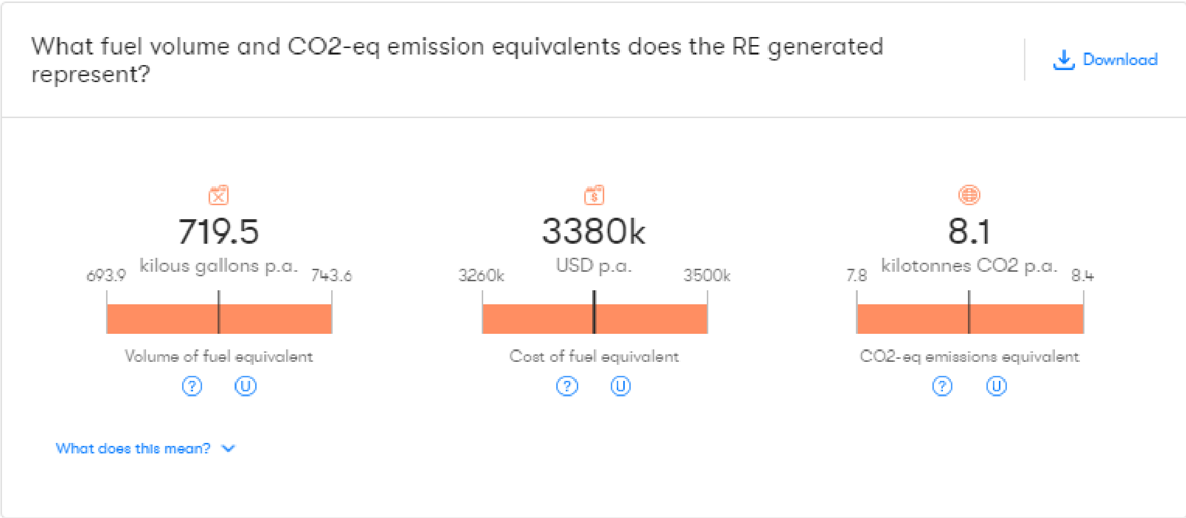


Figure 10: *Example of the results of the CO2 and fossil fuel displacement calculations in RE-SAT.*

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 11: *Example of summary results for the demand comparison analysis in RE-SAT.*

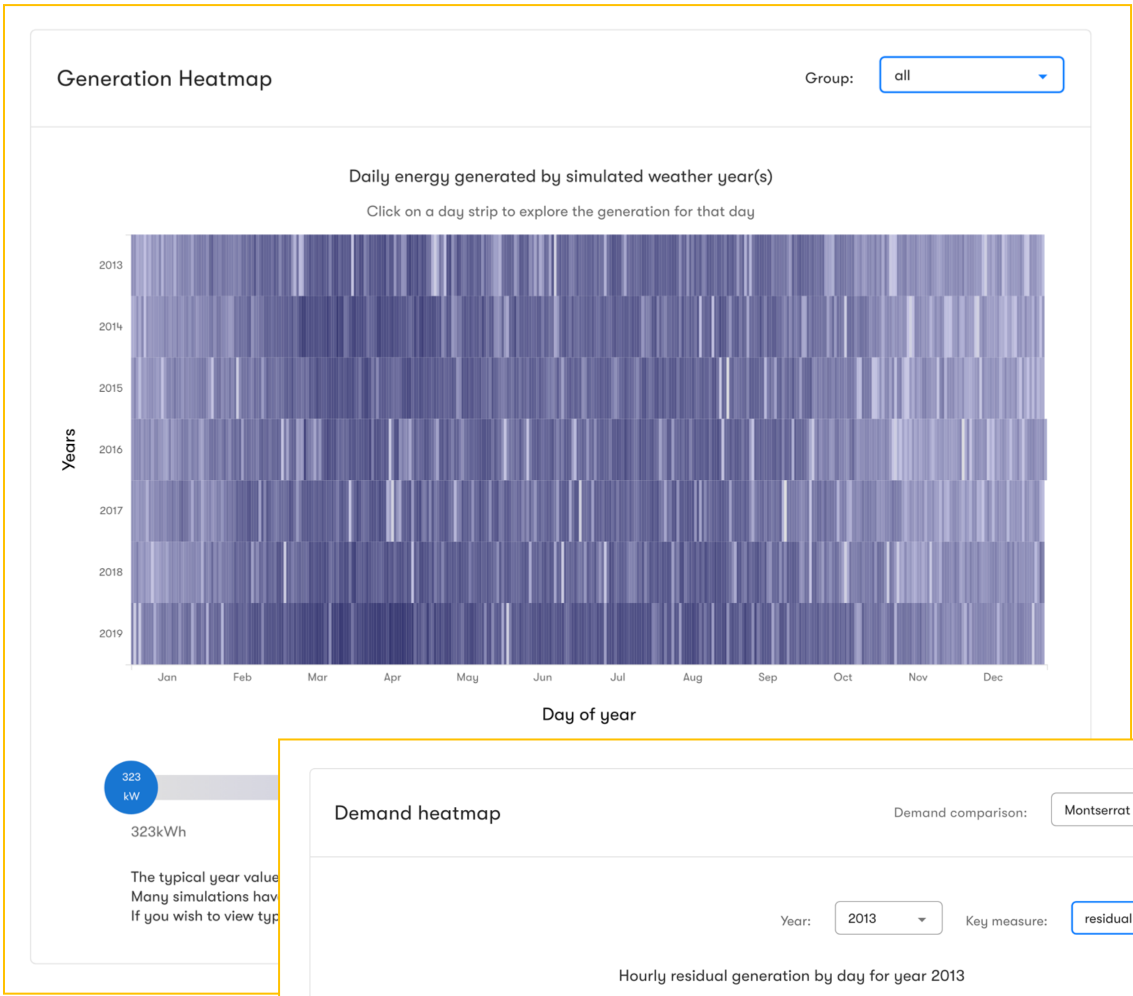
8. Financial analysis: Capability to assess the relative cost of one scenario or technology type versus another. RE-SAT performs a levelised cost of renewable energy calculation. All the financial assumptions regarding costs of installations, inflation, etc. were tailored for Mauritius and arrived at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

   Figure 12 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 12**: 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.



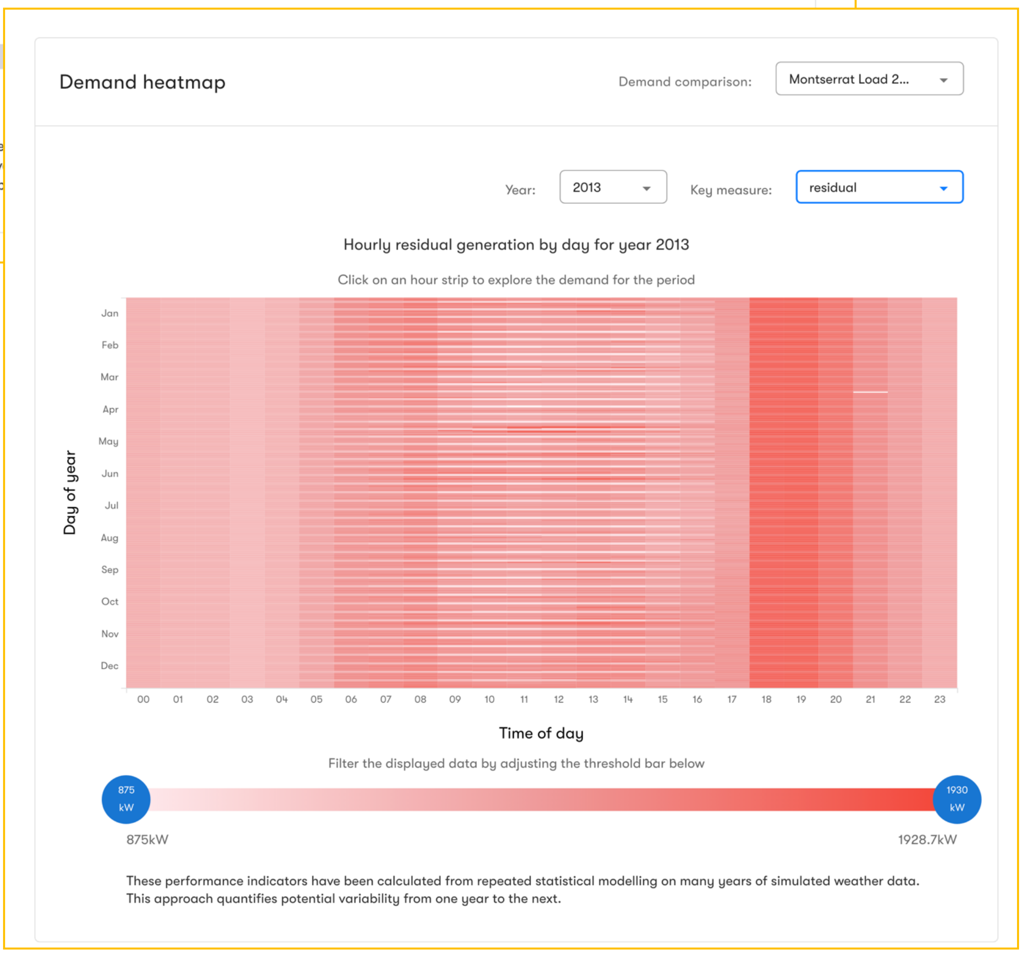


***Figure 13**: Examples of results exploration capabilities in RE-SAT (Generation Heatmap and Demand Heatmap).*

Figure 14: 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.

"The IEA has been very useful and cooperative in providing all the necessary support and trainings on the use of software. In fact, they have taken note of all of our concerns, our points, our views while designing the software so it is user friendly. I can say it is very practical and I think it is very user friendly to use and generate results." Rakesh Dhununjoy, CEB

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 Mauritius have access to the platform.

"With weather forecast models, every time you explained it very well, for people with my background, it clicked... The [IEA] team was able to explain that in very simple terms but getting the right points." Kajal Fowdar, MARENA

***Figure 15**: Members of the Mauritius Working Group during the July 2019 Workshop*

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 Mauritius?

The RE-SAT platform was used to simulate the power produced by the existing 15MW solar array installed at La Ferme – Bambous (Sarako) (Figure 16a) and the 9.3MW wind farm at Eole (Figure 16b).

The output from RE-SAT was compared with the actual power produced by the installations from January to December 2017. The power data was kindly provided by the Central Electricity Board (CEB).

Figure 16a: *The 15MW Sarako PV solar installed in Mauritius (Bambous).*

Figure 16b:. *The Eole 9MW wind installation in Mauritius (Paline des Roches).*

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 (top for the solar installation and bottom for the wind one) below compares the simulated power from RE-SAT (red line) with the observed production (black dots).

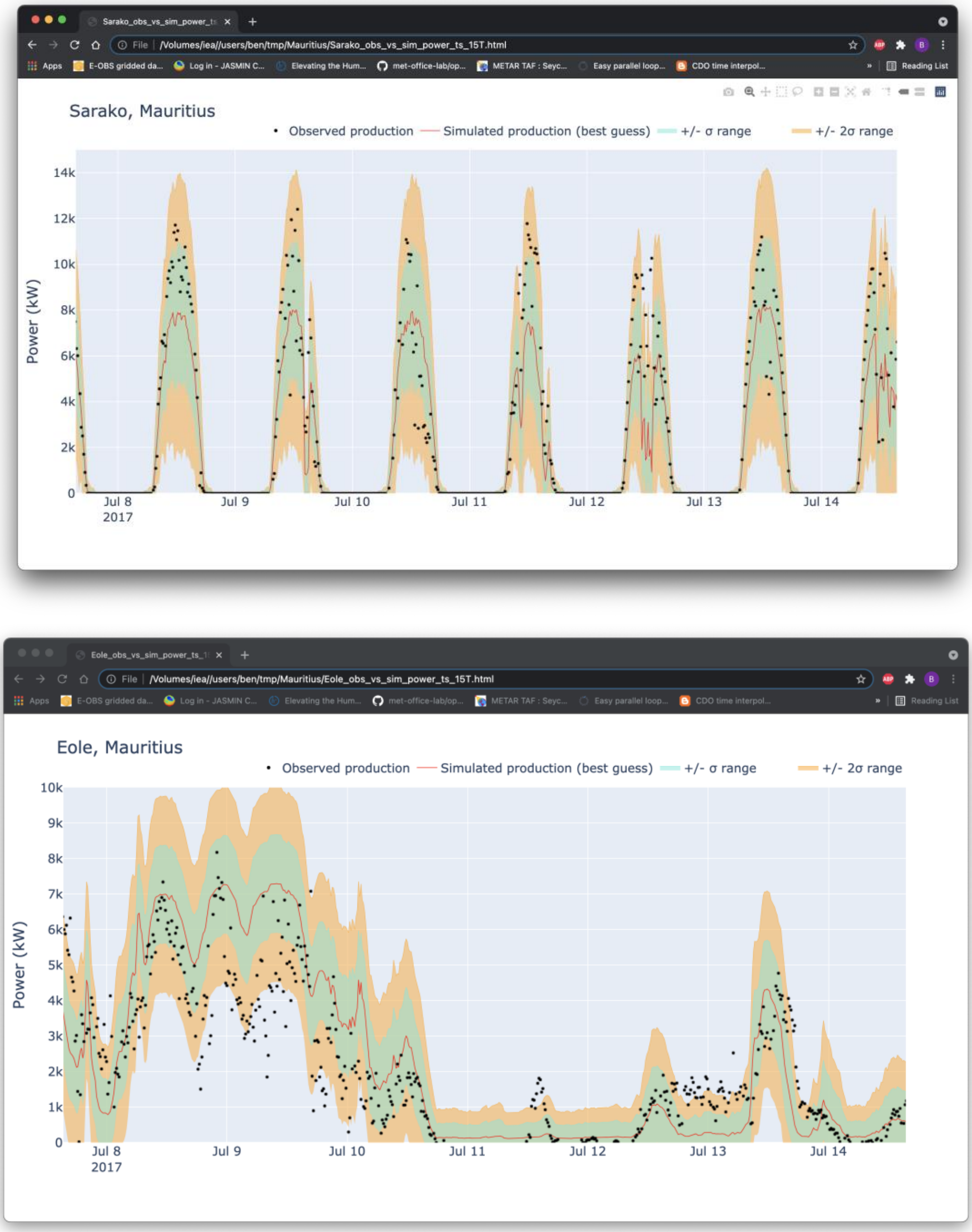


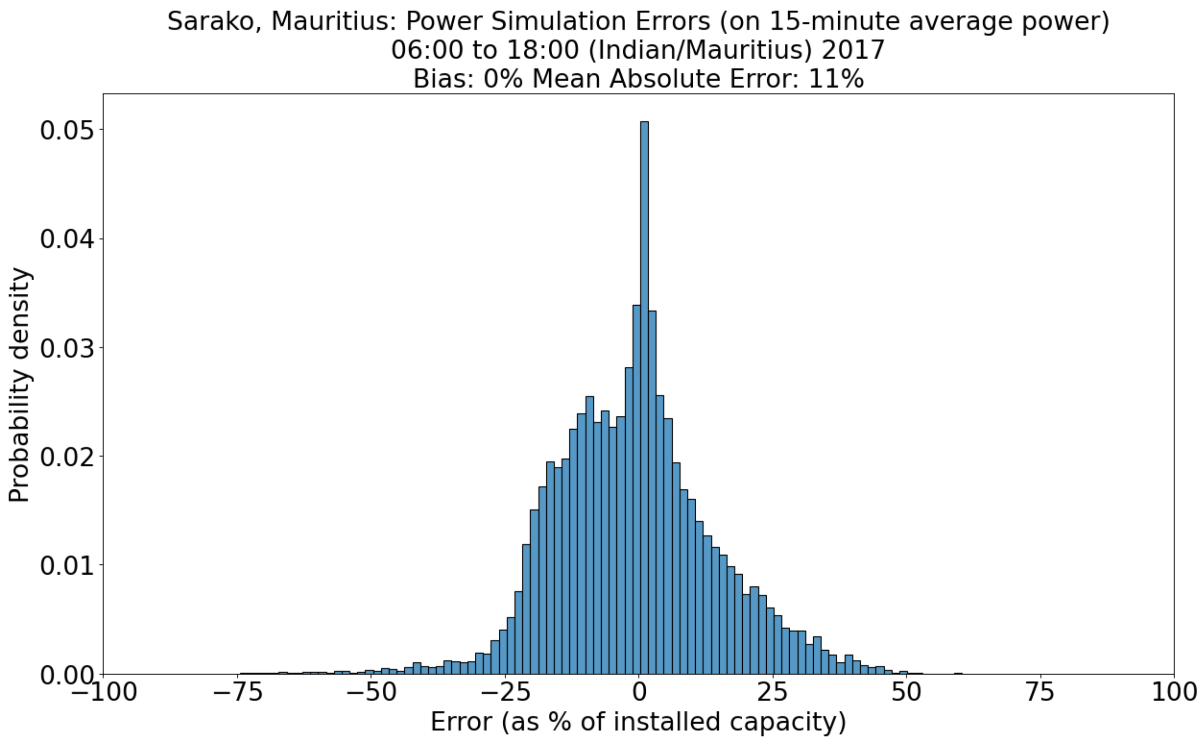
***Figure 17**: RE-SAT performance compared with observed production for the 15MW solar installations* at La Ferme – Bambous (Sarako) (top panel) and the 9.3MW wind farm at Eole *(bottom panel). The black dots represent the overserved power produced, the red line is the simulated production by RE-SAT, the colour bands are a representation of the uncertainty (1 sigma or 2 sigma).*

The 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 Sarako site as measured on the 15-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.



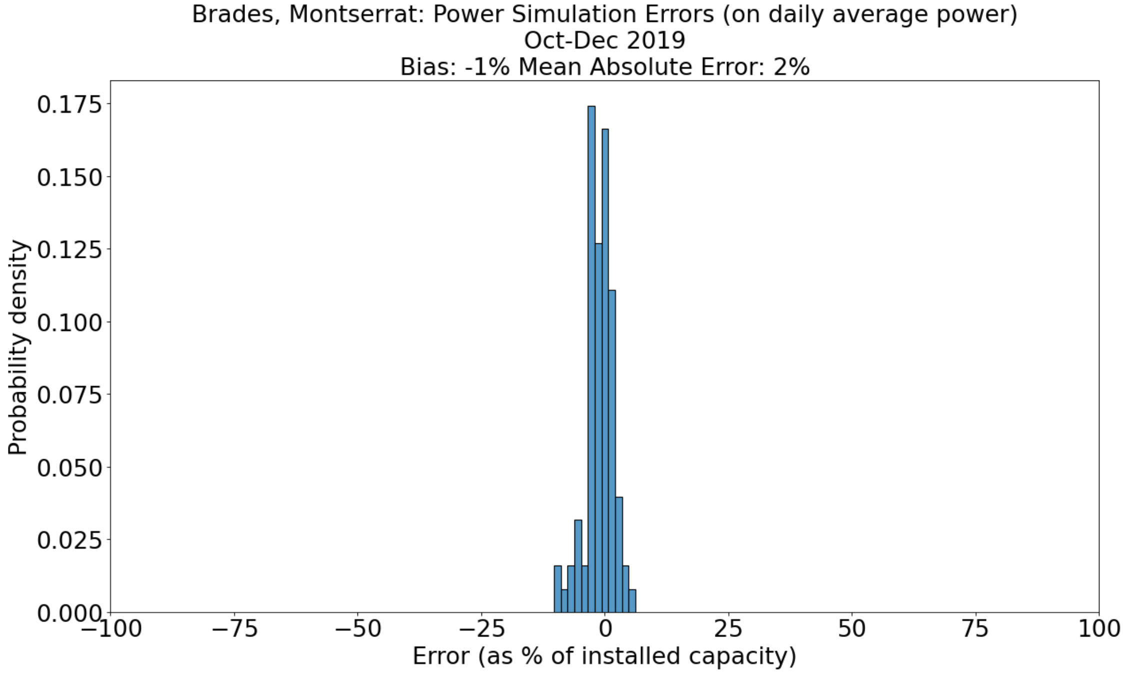
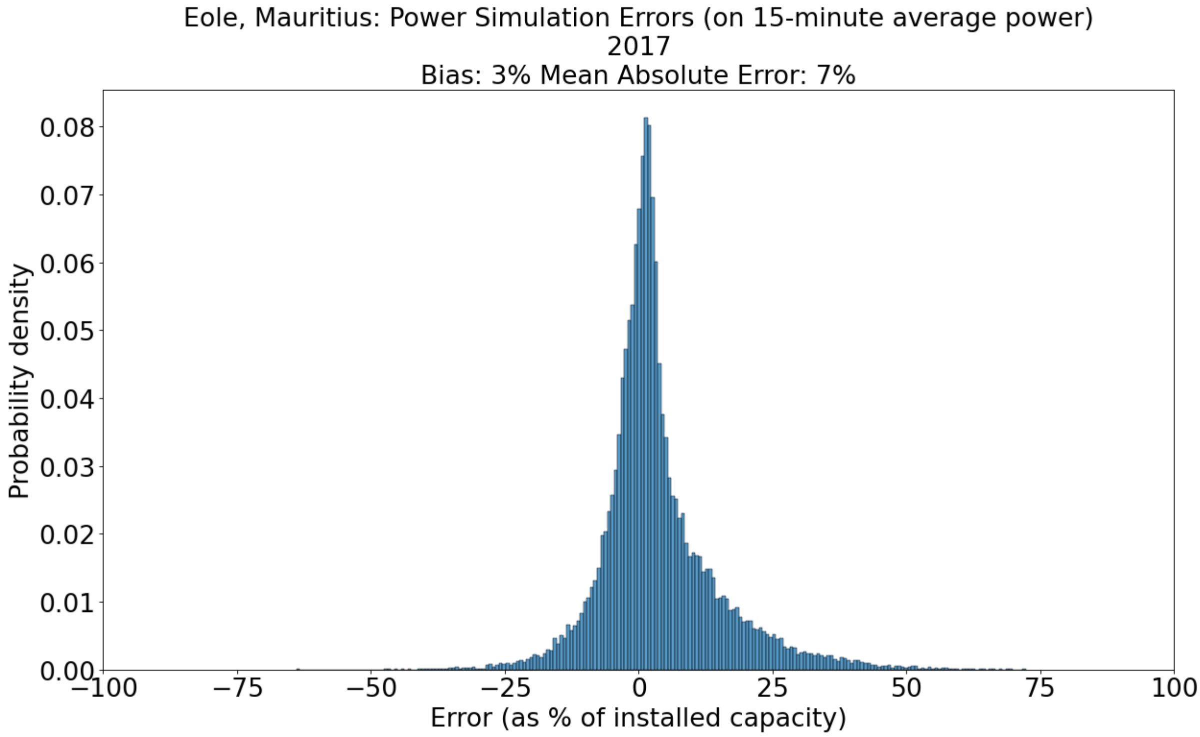


Figure 18: Histogram of RE-SAT simulation errors for the Sarako solar installations as measured on the 15-minute average power (upper panel) and the average daily power (lower panel).

Similar histograms for wind power are shown in Figure 19 for the wind farm at Eole but here all times (day and night) are included in the assessment.



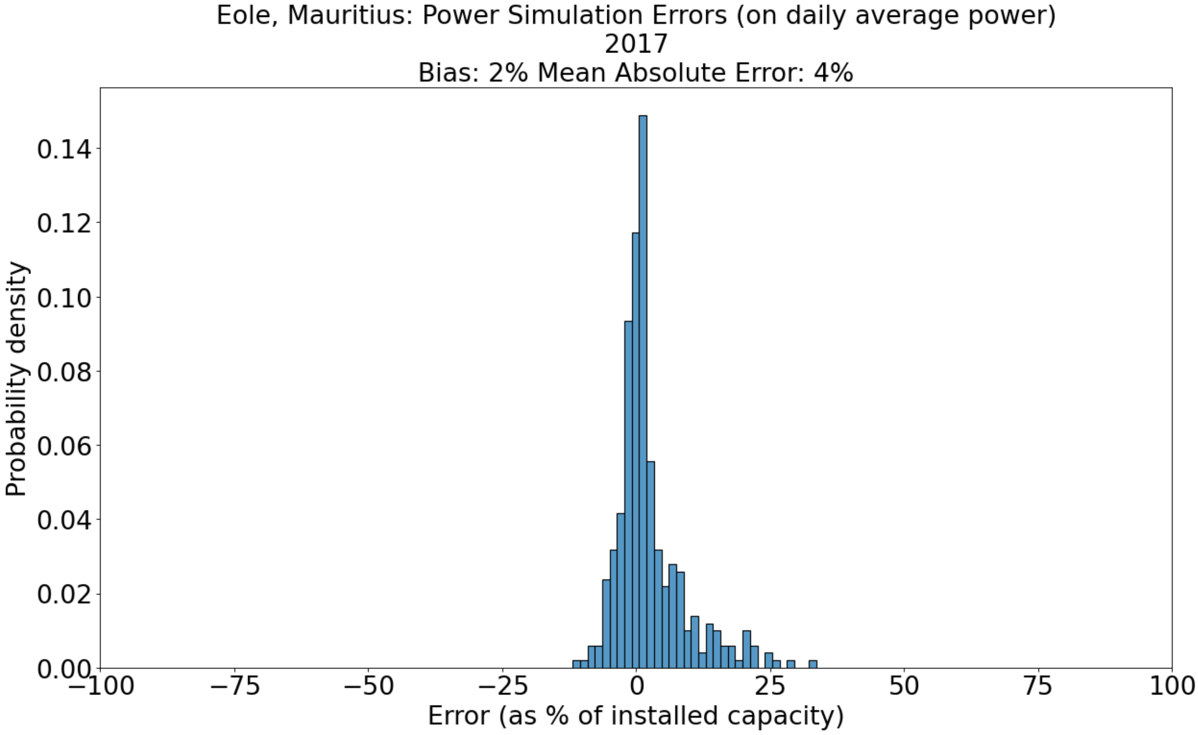


Figure 19: *Histogram of RE-SAT simulation errors for the 9.3MW Eole wind farm as measured on the 15-minute average power (upper panel) and the average daily power (lower panel).*

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.

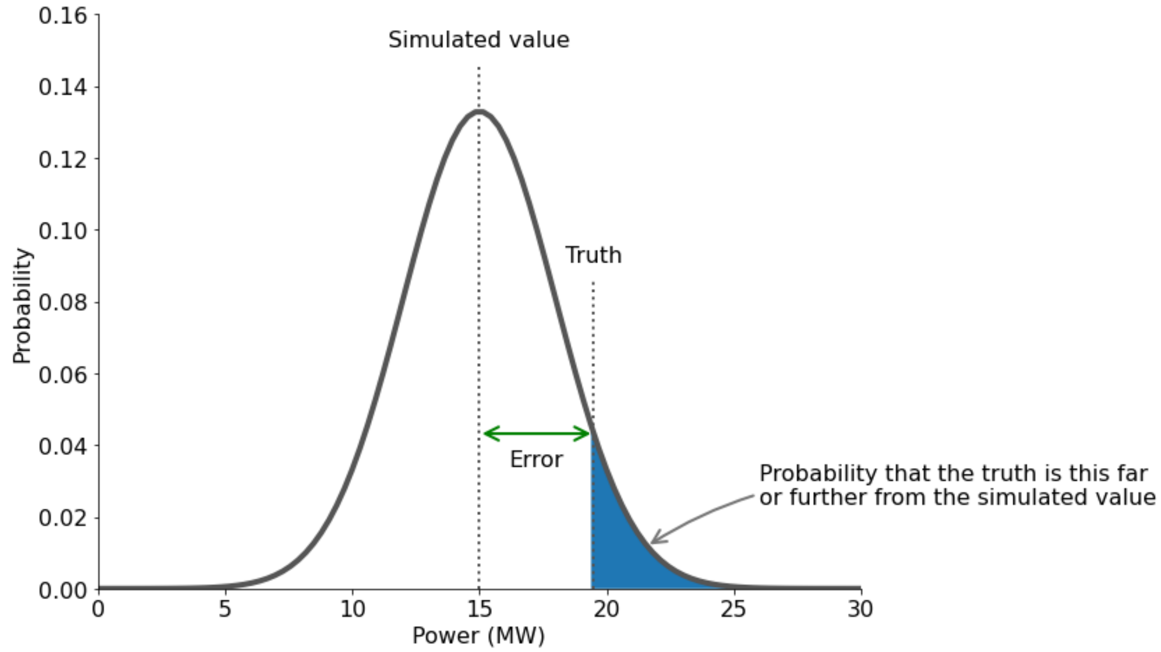


Figure 20: Normal distribution of the simulation errors.

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.

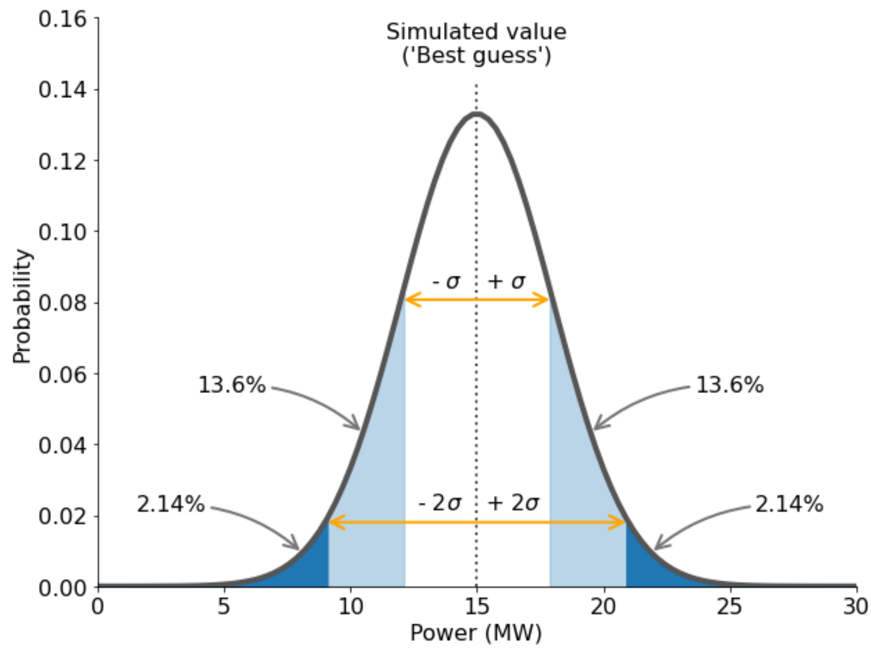


Figure 21: Probabilistic interpretation of sigma-bands under the assumptions of normally distributed errors.

The distribution of the simulation errors is shown in the histograms of Figures 18 and 19. 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 74% of the time. Reality was inside of the two-sigma for solar approximately 96% of the time.
- Reality was inside of the one-sigma for wind approximately 79% of the time. Reality was inside of the two-sigma for solar approximately 95% of the time.

These numbers are consistent with the theoretical estimates, and the uncertainties reported by RE-SAT are found to be well calibrated.

In summary:

- RE-SAT was used to simulate the Sara
- RE-SAT was used to simulate the Sarako Solar Park (Bambous) and the Eole Wind Farm (Plaine-des-Roches).
- Simulations were compared with reality for the year 2017.
- Results typically within: Solar 11%; wind 7% for any given 15-minute average.
  Solar 2 %; wind 4% for any given daily average.
- Negligible bias for solar. 2% to 3% positive bias (overprediction) for wind.
- Uncertainty bands are well calibrated.

4.6. Launch of RE-SAT in Mauritius

The RE-SAT platform was launched in Mauritius during a virtual two-day Training Workshop (7 – 8 July 2021), where the IEA team trained participants on the use of RE-SAT and developed some real energy scenarios with them.

"We are able to run the model and get good results with it, in light of training and capacity building we have received from you. [IEA]" Rakesh Dhununjoy, CEB

"We have moved 1 step up the ladder, we have a tool that we didn't have before we can now generate some things and simulate." Doumeraj Jahajeeah, MEPU

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.

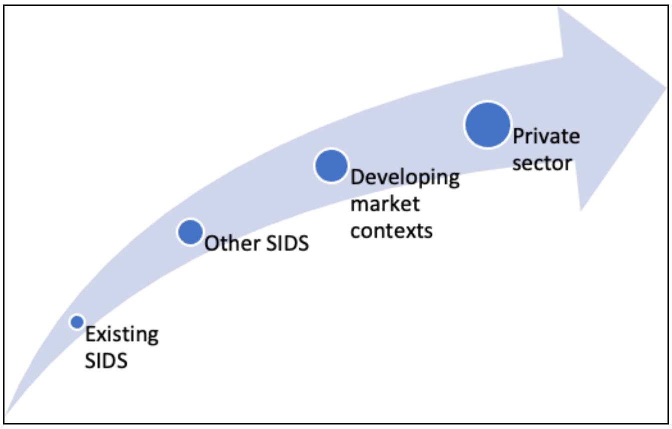


Figure 22: *RE-SAT commercial trajectory plans.*

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 Mauritius to contribute to their transition from fossil fuel electricity to renewables. The Renewable Energy target set by Mauritius at the start of the project (2018) was 35% RE penetration by 2025. A new, more ambitious target has now been submitted for the update to the NDCs in 2021, the target is now 60% by 2030.

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.

> *"An advantage we have in Mauritius is that we already had several installations in place, so we were able to calibrate the tool against real data to ensure the tool is working correctly. It is almost accurate to the real data."* Nirkita Seeburn, MEPU

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

> *"We had a very good collaboration with all stakeholders, in particular with the Met Services, we managed to get hold of CEB power generation also, as most of data was coming from them."* Doumeraj Jahajeeah, MEPU

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

> *"There was very good coordination and understanding with all the meetings we had and the Working Group sessions and the Task Group sessions. I think the way the meetings were held were very good, with [IEA] sending an agenda and actions which needed to be taken, like CEB needs to provide this... MARENA needs to provide this...* " Kajal Fowdar, MARENA

Relevance

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

> *"I think there was a really good coordination, and we were able to express what we expected from the platform and then you were able to discuss and improve on it. I think that was very good and that is what lead to success, you guys really listened."* Kajal Fowdar, MARENA

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

> *"RE-SAT plays an important role in identifying potential sites for development of renewable energy. In terms of resource plan and resource maps it's critical to make decision before proceeding. It's a starting point.* Rakesh Dhununjoy, CEB

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

> "*The roadmap has to be reviewed for the 60% so the development and research from the RE-SAT tool will supplement this roadmap. We will be able to simulate the different installations."* Nirkita Seeburn, MEPU
>
> [RE-SAT is] *"Very well aligned, especially with our with revised target of 60%. I think it is very relevant."* Kajal Fowdar, MEPU
>
> "*There is a project which is going forward where the intention is to reach 100% renewable by 2050. So, we will be able to use this tool to plan for future installations. I think the tool will be very helpful in order to plan and in writing the roadmap for Rodrigues."* Nirkita Seeburn, MEPU

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

> *"I will give an A+ to the IEA for what they have been doing in terms of training and capacity building and helping us in using the software."* Rakesh Dhununjoy, CEB

6.2. Impact evaluation

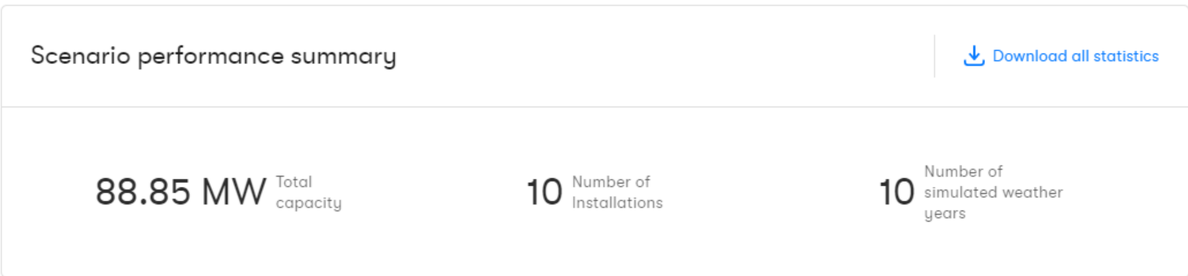
The RE-SAT projects has provided the Government of Mauritius with a new renewable energy platform that has been used to support their transition to renewables and a climate resilient future.

In August 2019, Mauritius defined a pathway for the development of RE technologies and diversifying the electricity mix to achieve the target of 35% RE by 2025 and maintain it until 2030 (Renewable Energy Roadmap 2030[8]) Since then, the country had submitted an update to that target through the updated National Determined Contributions (NDC)[9] with a pledge for the production of 60% of the energy needs by green sources by 2030. (NDC submitted on 10/05/2021). There is a gap between policy documents like the Road map and investment. For the Roadmap to be realised, the allocation of investment is needed. Mauritius saw the role of RE-SAT as a tool to provide the supporting information and evidence to investors to aid/ease the business case for investment.

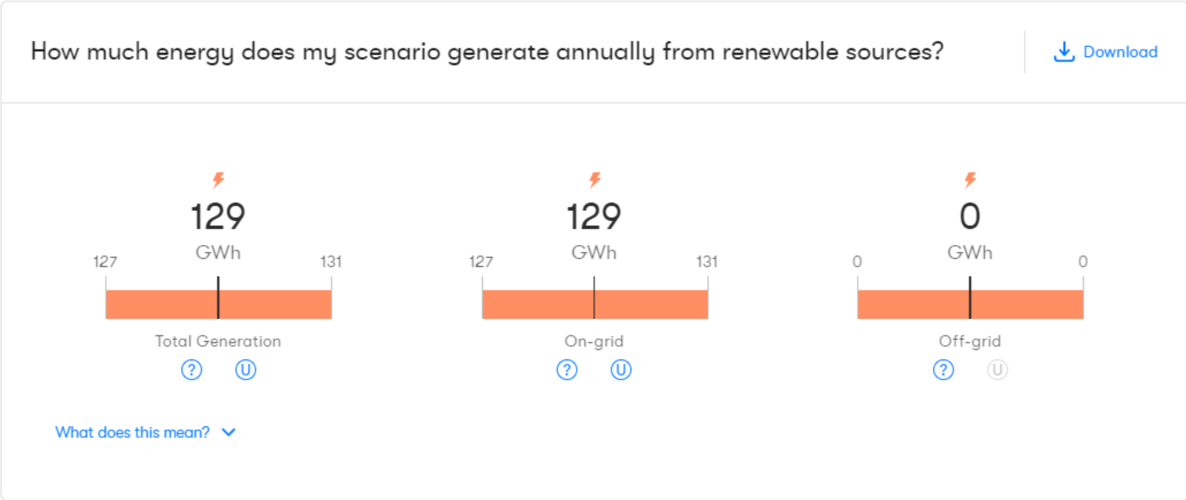
To support the government in achieving these targets RE-SAT has been used for some specific applications to test the performance of different combination of renewable energy installations. The IEA provided face-to-face training, assistance by video conference and practical workshops on how to use the RE-SAT platform to support Mauritius 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 with RE-SAT

The performance of RE-SAT was tested by creating a scenario of the current variable renewable energy installations in Mauritius (see Table 1 for the existing installations in Mauritius as of November 2021). The total installed capacity is 88.89 MW, generated by 9 solar PV installations and 1 on-shore wind farm. This configuration of installations was run through 10 simulated weather years to capture year on year variability. This scenario is the baseline for exploring future scenarios.



[8] https://www.climate-laws.org/geographies/mauritius/policies/renewable-energy-roadmap-2030-for-the-electricity-sector
[9] https://www.wri.org/insights/understanding-ndcs-paris-agreement-climate-pledges

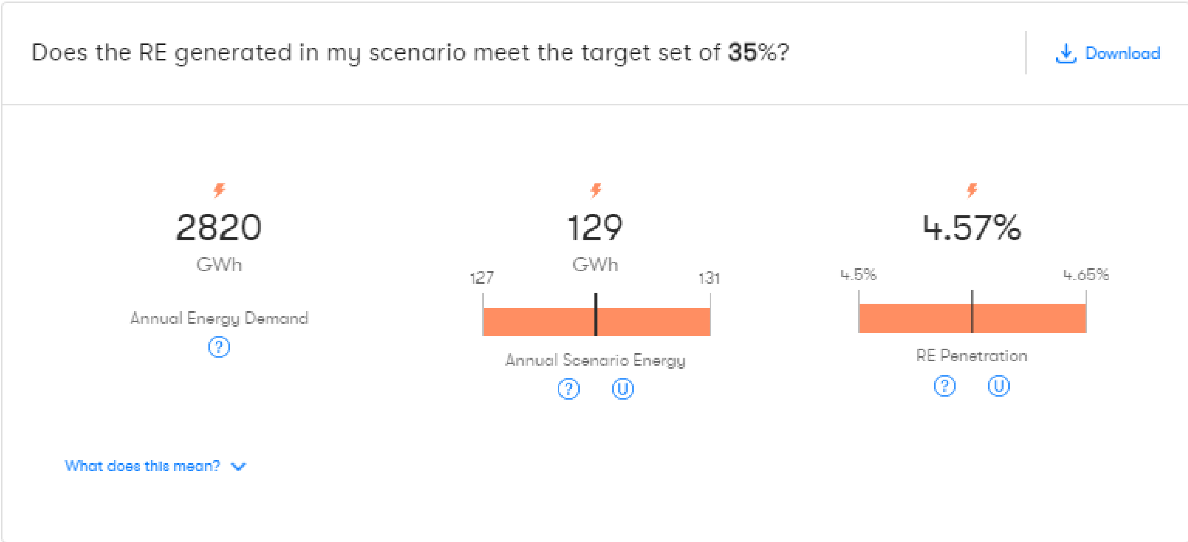


The scenario simulated by RE-SAT generated an annual energy average of 129 GWh [115 GWh generated by solar from a 79.5MW installed capacity and capacity factor of 16.7%), 14 GWh generated by wind (9.35MW installed capacity and 16.6% capacity factor. This performance compares well with the actual annual production from these installations (see Table 1 with statistics for energy generation in 2019 by IRENA). Please note that RE-SAT estimates are the average of our 10 year of simulated weather data and are not representative of any year in particular.

Generation in 2019	GWh	%
Non-renewable	**2 535**	**78**
Renewable	**702**	**22**
Hydro and marine	99	3
Solar	129	4
Wind	15	0
Bioenergy	460	14
Geothermal	0	0
Total	**3 237**	**100**

Table 1: Energy generated in 2019 by installation type in Mauritius. (Source: Energy Profile Mauritius, prepared by IRENA, https://www.irena.org/IRENADocuments/Statistical_Profiles/Africa/Mauritius_Africa_RE_SP.pdf

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 annual energy demand in Mauritius for 2021 in this scenario was set to 2820 GWh, therefore the generation from the exiting installations represents a 4.57% of renewables penetration.



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 27 kilitonnes of fuel and around 124 kilitonnes of CO2 emissions per year.

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

A. Testing the 2025 scenario proposed in the 2019 Roadmap

Mauritius stakeholders used RE-SAT to test some of the scenarios proposed in the Roadmap, aiming to find suitable location for the proposed new installation mix that would achieve the RE penetration targets by 2025. This took into account the exiting solar and wind generation (2021) (Solar PV = 79.5 MW and Wind = 9.35 MW) and assumed the forecasted energy demand for 2025 to be 3,354 GWh (Source: CEB, 2018; figure also included in the Roadmap).

The roadmap presented a scenario for 2025 with different % of share in the electricity mix for different energy sources. For wind, it projected 1.9%, and for solar 10.2%. The rest (22.9 % was to be generated through a combination of bagasse, landfill gas, Waste to Energy and hydro. The Roadmap took into consideration a number of PV and wind projects that CEB had in the pipeline to achieve these solar and wind targets and these were tested with RE-SAT. The planned project included:

- 3 Utility scale solar PV plants
- Small Scale Distributed Generation solar projects (residential) (rooftop)
- Medium Scale Distributed Generation solar projects (Commercial) (rooftop)
- Smart City
- Public Building rooftop solar
- A new wind farm

RE-SAT was used to create a scenario for 2025 aiming to achieve the 12.1% target, and following a location strategy based on the following criteria:

- Utility solar locations were selected based on maximum insolation and guided by the solar resource maps available at the platform.
- The smart city schemes were located at known sits and equally distributed
- MSDG – dispersed by 9 districts and located at mayor shopping malls
- Rooftop on Public buildings dispersed by 9 districts on schools and hospitals
- SSDC – distributed across the districts.

Stakeholders were satisfied with RE-SAT results and the annual values were comparable to the results calculated for the Roadmap. The advantage of using the application for this exercise was the ability to explore the best locations for these new installations.

B. Testing alternative RE configuration scenarios

Since the Roadmap was published in 2019, the finance minister in the 2020 and 2021 budget speeches announced more measures and projects to promote RE, these included:

- 2 MW floating solar PV plant at Tamarind Falls reservoir,
- Increasing the capacity of the solar PV farm at Henrietta from 2 MW to 10 MW,
- Installing 1,000 solar panels on houses of low-income families,
- Medium-Scale Distributed Generation Scheme for a maximum of 10 MW would be introduced to enable beneficiaries to produce electricity for their own consumption and sell the excess to CEB
- Up to 25 MW of rooftop solar for residential and public buildings would be opened
- Commissioning a battery energy storage system of 14 MW.
- CEB to request proposals to set up a 40MW wind farm

RE-SAT is well placed to support Mauritius in exploring all these projects and new ones. The platform allows the user to select best locations, and it calculated the performance of different configuration of installations, exploring the art of the possible.

C. Exploring hydropower generation with RE-SAT

Mauritius currently has 10 hydroelectric: Magenta, Champagne, Le Val, Réduit, La Ferme, Cascade Cécile, Ferney, Tamarind Falls, La Nicolière and Midlands. Production capacity for all 10 stations is approximately 58.4 MW.

The potential for hydropower in Mauritius has been almost fully tapped and RE-SAT can add the contribution of this source of energy by treating it as an installation with a fixed output or predetermined time-series of values provided by the user. In this way, RE-SAT is able to represent the contribution of this energy source as a *scheduled generator*, with a fixed generation profile that does not change with the weather.

Installation type / Unit	Installation year	Tags	AC Capacity kW	Capex per capacity USD per kW	Find on map
Hydroelectric			**58,400**		
Champagne	1984		30,000	1,760	
Cascade Cecile	1963		1,000	1,760	
Midlands	2013		350	2,230	
La Nicoliere	2010		350	1,760	
La Ferme	1988		1,200	1,760	
Reduit	1984		1,000	1,760	
Le Val	1961		4,000	1,760	
Magenta	1960		1,000	1,760	
Tamarind Falls	1987		9,500	1,760	
Ferney	1971		10,000	1,760	

Table 2: Hydroelectric installation in Mauritius (2021) from RE-SAT display.

D. Exploring distributed rooftop locations

In line with Government's objective to attain 35% of renewable energy in the energy mix by the year 2025, the CEB has a small-scale distributed generation (SSDG) scheme that allows allow residential customers who consume an average energy of up to 200 kWh per month to produce electricity from photovoltaic panels. CEB increases the capacity allowed for SSDG periodically.

The SSDG capacity is distributed across 1000's of rooftops across Mauritius. The capacity will reduce customer demand according to this distributed generation. As the capacity is distributed it will produce a smoother generation profile than the equivalent capacity installed in a single utility scale installation. RE-SAT allowed the planners to see the impact of this smoothed profile. The 1000s of individual installations are represented as three hundred "virtual" installations in RE-SAT distributed according to the population density of Mauritius (see Figure 23)

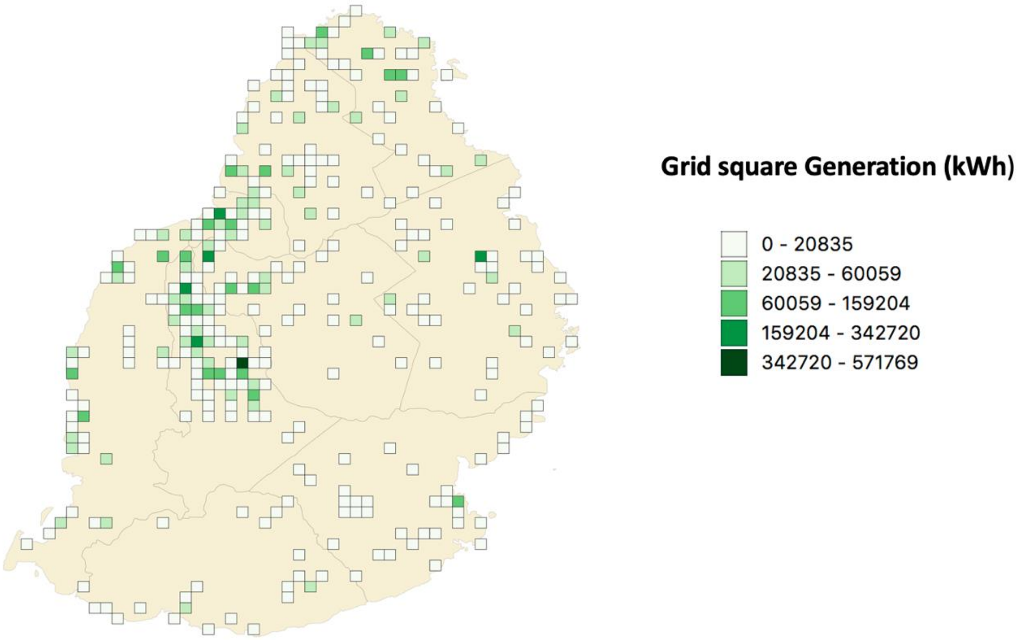


***Figure 23**: Small Scale Distributed Generation (SSDG) installations modelled as 300 virtual installations distributed according to population density in Mauritius*

Additionally, RE-SAT data was used to model the correlations between generation from a specific installations and other regions on the island (see Figure 24). In the figure, darker colours represent regions that are less correlated with the identified installation. This demonstrated to the CEB planners how RE-SAT data could be used to inform the planning of grid upgrades, and roll out of SSDG in a way that smooths the generation impact as renewable generation penetration increases. This assists in managing the need for increased power system flexibility as progress is made on the roadmap to national renewable energy targets .

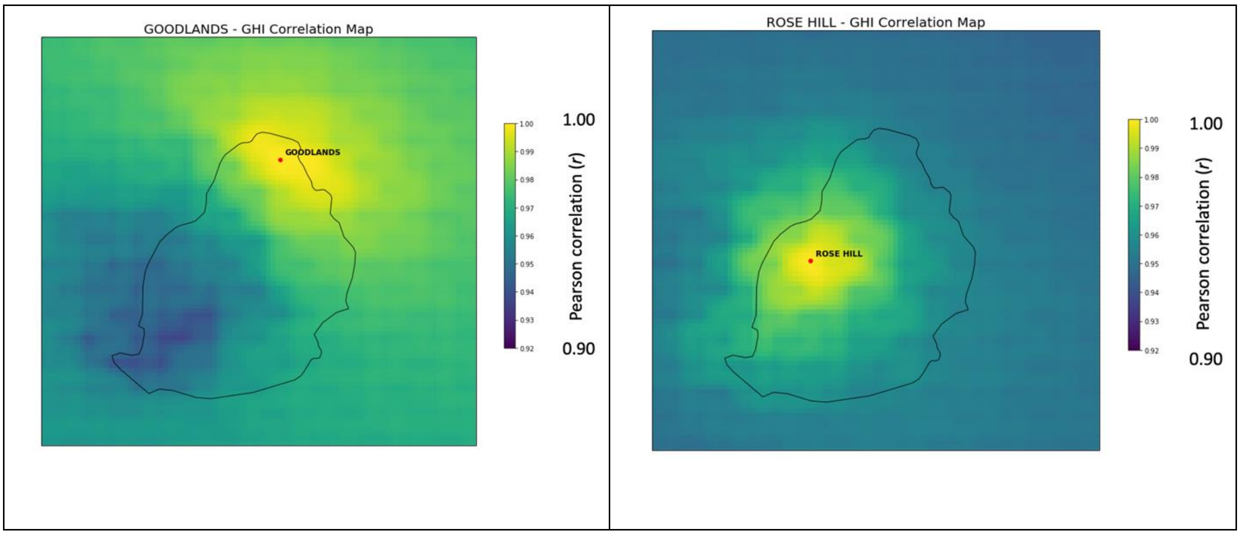


Figure 24: Global Horizontal Irradiance (GHI) correlation between a specific installation and other regions in Mauritius (left map for Goodlands and right map for Rose Hill)

Summary

Mauritius has now a common platform for officers in different department to use common data and analytics for efficient and effective collaboration and decision-making.

For the development of the Mauritius Renewable Energy Roadmap published in 2019, the portfolio of renewable energy technologies proposed by Maxwell Stam PLC[10] consultants, Carnegie[11] and Ryan Shea[12] were assessed. The Roadmap did not propose optimal locations for any of the scenarios proposed, and this is something that RE-SAT can support with.

> *"RE-SAT plays an important role in identifying potential sites for development of renewable energy. In terms of resource plan and resource maps it's critical to make decision before proceeding. It's a starting point.* Rakesh Dhununjoy, CEB
>
> *"The roadmap has to be reviewed for the 60% so the development and research from the RE-SAT tool will supplement this roadmap. We will be able to simulate the different installations."* Nirkita Seeburn, MEPU
>
> "*There is a project which is going forward where the intention is to reach 100% renewable by 2050. So, we will be able to use this tool to plan for future installations. I think the tool will be very helpful in order to plan and in writing the roadmap for Rodrigues."* Nirkita Seeburn, MEPU

[10] Maxwell Stamp PLC., (2016),Renewable Energy Management Master Plan and Action Plan
[11] Carnegie., (2017), High Penetration Renewable Energy Roadmap for the Republic of Mauritius
[12] Shea, R., (2017),Renewable Energy Roadmap for the Island Nation of Mauritius

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 Mauritius are also included.

In-country challenges:

- Timing and relevance are important for co-production: The RE-SAT project was well received by Mauritius 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 Mauritius, the Ministry of Energy and Public Utilities (MEPU), facilitated the engagement with other organisations. The inputs from the Central Electricity Board and MARENA were invaluable.
- There is a lot of competition for workshop time in the recipient SIDS: Many nations and suppliers are operating in Mauritius, and given the small size of the nation, 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 CEB, together with the weather data shared by the Met Service and geographical information shared by the Ministry of Lands were crucial for the validation and calibration of the tailored RE-SAT application in Mauritius.
- Local capacity to receive knowledge transfer varies across countries and therefore delivery methods need to adjust accordingly. For some of the organisations involved in Mauritius, learning about renewables was a new concept, but they reported gaining understanding and knowledge due to our project.

> *"The partnership is very symbiotic as both IEA and the local collaborators are benefiting from the regular discussions that we have during meetings and workshops."* V. Oree, University of Mauritius

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 the Working Group in Mauritius was welcome and crucial for the co-development of the platform that is fit-for-purpose. A Project Implementation Committee was also established to provided governance and ensure relevance of the project.

- 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 workshops that we held in Mauritius, reducing the impact of the project. Even though the 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. Mauritius 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. In particular for the island of Rodrigues, the scale of the island allowed the project to test the feasibility of creation of a 330m x 330m weather dataset. This is the highest resolution weather dataset successfully simulated by the RE-SAT project and confirm the feasibility of this scale for future applications.
- The addition of the contribution from other non-variable renewable energy generation (geothermal, hydro and biomass) in RE-SAT adds value to the platform. The Mauritius requirement to include hydro and biofuel production in some scenarios was the first example of the requirement of the addition of user specified power generation series and confirmed the feasibility of this capability in RE-SAT scenario planning.
- 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.

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