Increasing renewable contributions in island utility grids

Business case for island utilities

- Discover the outcomes that island utilities can achieve with solar photovoltaics, battery energy storage systems and the ABB e-mesh™ smart control solution.
- The island utility featured in this business case achieved an 18% reduction in the levelised cost of energy whilst sourcing 35% of the delivered energy from renewable sources.
1 Executive summary

Globally, island electricity systems are on a journey to reduce energy costs and break the singular reliance on imported diesel and heavy fuel oil for their electricity. As the costs for renewable generation and battery energy storage decline, island utilities can create increasingly resilient, lower-cost energy supplies whilst meeting domestic goals on the use of renewable energy.

Intelligent controls and smart automation are critical technologies for enabling island utilities to unlock the benefits of the low-cost solar photovoltaics (PV) and battery energy storage systems (BESS) available today. Island utilities can lower total costs whilst simultaneously increasing the use of renewable energy.

The island utility featured in this business case achieved an 18 percent reduction in the cost of generation whilst sourcing 35 percent of the delivered energy from renewable sources. These investments are viable under commercial terms. This investment had a 19 percent internal rate of return (IRR) and 5.3-year payback.

Figure 1 provides insight into the outcomes that island utilities can achieve with solar PV, BESS and the ABB e-mesh™ smart control solution. This island utility was able to deliver 35 percent of the energy to customers from renewable sources whilst minimising the life cycle cost of their electricity supply. The cumulative investment increased the use of domestic energy sources, increased energy security and reduced the island’s contribution to climate change.

The analysis also shows that the largest driver for high-energy costs in islands is the price of imported diesel fuel. Solar PV and BESS as part of the e-mesh solution provide a cost-effective hedge against diesel prices and volatility.

ACRONYMS IN THIS PAPER:

- BBL: barrels
- BESS: battery energy storage system
- CAPEX: capital expenditure
- CO₂: carbon dioxide
- IRR: internal rate of return
- kW: kilowatt
- kWh: kilowatt hour
- kWp: kilowatt peak
- L: liter
- LCOE: levelised cost of energy
- m²: square meter
- MUSD: million US dollars
- MW: megawatt
- MWh: megawatt hour
- MWp: megawatt peak
- NPC: net present cost
- PRP: peak renewable penetration
- PV: photovoltaic
- RC: renewable contribution
- RTU: remote terminal unit
- USD: US dollars
- Wp: watt peak
Three conclusions can be drawn from this business case:

1. Islands have a strong economic case for the use of solar PV and BESS to reduce their reliance on imported diesel fuel. This improves their resilience against volatile fuel prices.

2. Islands can make strong progress towards their renewable energy goals whilst lowering costs.

3. Smart controls and automation are key technologies necessary to unlock the benefits of low-cost solar PV and BESS.
2 Benefits of storage and renewables for island utilities

Island utilities are, traditionally, reliant on costly diesel and heavy fuel oil for their electricity. This singular reliance on an expensive resource has led island utilities to pay some of the highest and most volatile electricity costs in the world. It is not uncommon for island utility customers to pay between 0.20 and 0.50 USD/kWh for their electricity — two to five times what many customers of mainland utilities might pay.

Beyond the high cost, these fuels are toxic and contribute to climate changes that are eroding shorelines and affecting the environmental stability of many islands.

Recognising these challenges, many islands have committed to ambitious targets to reduce their dependence on imported fossil fuels. Figure 2 shows a selected list of islands and their publicly-stated renewable targets by (or before) 2030.

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Figure 2: Selected publicly announced island renewable targets by 2030

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To meet these goals, Islands will rely on renewable energy with support from BESS and smart control solutions. This island energy transition is technically viable and can economically reduce the risk and exposure to fossil fuels. As compared to mainland utility grids, island grids also have less diverse generation and demand, do not interconnect with larger networks and tend to lack secure and reliable network infrastructure.

One key economic driver is reduced technology costs: Installed solar PV prices have declined around 80 percent over the past eight years, whilst lithium-ion battery pack prices have dropped around 80-90 percent in the same timeframe. Cost declines for these technologies are projected to continue. In parallel, innovations in intelligent controls and integration technologies, like the e-mesh solution, have created a successful enabling environment for islands to unlock the economic benefits and decrease fossil fuel usage.

As renewable and storage prices fall, fossil fuel prices continue to spike and disrupt island economies. Renewable and storage investments can protect utility rate payers from fuel volatility, whilst supporting the islands in achieving their environmental and domestic energy goals. There is no technical limit to higher contribution of renewable energy; it is expected that the contribution of renewable energy possible at least cost will continue to improve as technological innovation continues.

The opportunity for BESS and smart controls with renewable energy in islands is immense. These technologies can increase fuel efficiency of the existing generation fleet, reduce wear and tear on the generation assets, stabilise frequency and voltage to improve power quality, all whilst improving renewable integration and use of renewable energy.

Each island is unique and has its own driving factors for using renewables. They can reduce energy volatility, increase use of local energy and limit contributions to climate change.

Key stakeholders in island energy systems include the utility, the island government, local renewable advocates and citizens, businesses and utility ratepayers. In addition to these domestic stakeholders, there is a diverse set of multilateral funding agencies, various political associations and investors that are working with island residents to influence their decision to transition to a lower-cost and less-volatile energy supply.

ABB has supported many islands in their goals to lower costs and increase the use of renewable energy. ABB has successfully supported over 170 microgrid and battery projects deployed globally, with a cumulative installed capacity exceeding 450 MW. This proven track record of renewable systems operating in all corners of the globe provides islands with certainty that they too can unlock these benefits.

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2 CIGRE 2018 C6-207, ‘Opportunities for interoperability between different energy networks for remote or island networks’

3 RMI. ‘Renewable Microgrids: Profiles from Islands and Remote Communities Across the Globe’. Rocky Mountain Institute, Nov 2015.
3 A pathway to high renewable contributions

This business case considers a base case and three renewable and BESS investment scenarios optimised using the HOMER Pro® microgrid modelling software. For each scenario, we assume an island with an 11.2 MW average load, with peaks up to 15 MW. The island has a 2.0 MW spinning reserve on top of the load, based on supporting a contingency event that causes an entire generator to drop offline.

The island electrical grid is managed by a local utility. The existing generators are fed with diesel fuel that has a fully-delivered price of 0.75 USD/L, inclusive of transport, taxes and other costs. This business case focuses on new (i.e., marginal) investment costs for the island utility, because those are the economics that affect the decision.

The total CAPEX of the installed solar PV system, including PV inverter, is 1.50 USD/Wp. The PV arrays receive an average 5.5 kWh/m²/day of solar irradiation. To account for intermittent cloud cover, 75 percent of the PV’s power output must be covered by spinning reserves from the diesel generators or the BESS. The BESS uses lithium-ion batteries and the round-trip efficiency is assumed to be 90 percent. The BESS and converter system have a capital cost of 300 USD/kWh combined with 500 USD/kW and a fixed 100K USD for delivery, controls and balance of plant. All cost assumptions are chosen to reflect higher construction costs in typical island locations but may be higher or lower for other locations. A 9 percent discount rate with 2 percent inflation rate was applied to future cash flows.

Figure 3 provides a summary of the incremental investments from the base case to the high renewable contribution scenario.
### Figure 3: Summary of the path to high renewable contribution in islands

<table>
<thead>
<tr>
<th>Base case: diesel only</th>
<th>Renewable ready</th>
<th>Medium renewable</th>
<th>High renewable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual, inefficient control</td>
<td>e-mesh™ +/− 4 MW (3 MWh)</td>
<td>e-mesh™ +/− 6 MW (5 MWh)</td>
<td>e-mesh™ +/− 14 MW (10 MWh)</td>
</tr>
<tr>
<td>Island load 15 MW</td>
<td>PowerStore™ BESS</td>
<td>PowerStore™ BESS</td>
<td>PowerStore™ BESS</td>
</tr>
<tr>
<td>Island load 15 MW</td>
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<td>Island load 15 MW</td>
<td>Island load 15 MW</td>
</tr>
</tbody>
</table>

- Nine-generator system is manually switched on and off
- One generator equivalent required as operating reserve at all times
- Generators share load
- Grid unable to accept significant contributions of renewables

- BESS supplies reserve so two generators can turn off
- Controls remove need to start up a generator during short-term peaks
- BESS improves power quality and reliability
- Grid is ready for renewables

- Larger BESS provides more reserve to turn off more generators
- BESS allows PV capacity to exceed transient and generator step loading limitations
- Controls maximise fuel savings and reduce generator hours

- Even larger BESS provides required reserve to turn most of the generators off
- Increased PV capacity to get more energy contributions from renewable sources
- During sunny daylight hours, all generators can be shut down

**Genset status**

- On
- On (for reserve)
- Off

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<table>
<thead>
<tr>
<th>On</th>
<th>Off</th>
</tr>
</thead>
<tbody>
<tr>
<td>On</td>
<td>Off</td>
</tr>
</tbody>
</table>
Transient and generator step loading constraints will limit the peak PV penetration to 15 percent of peak, which equates to a 4 percent annual energy contribution. The BESS helps overcome this limit whilst improving grid power quality and reliability.

Enables an island to get more than 4% of energy from solar

Mitigate problems with quality and reliability

Transient and generator step loading constraints will limit the peak PV penetration to 15 percent of peak, which equates to a 4 percent annual energy contribution. The BESS helps overcome this limit whilst improving grid power quality and reliability.

### CHALLENGES FOR RENEWABLES IN ISLAND UTILITIES WITHOUT STORAGE AND SMART CONTROLS

**Scale:**
'Small' amounts of renewable generation can cause instability and power quality issues

**Power quality:**
Renewables can exacerbate voltage and frequency issues in weaker grids

**Instability:**
Fluctuating renewables and dynamic loads may cause grid instability

**Penetration limits:**
Without smart controls and storage, renewable penetrations must be limited to prevent grid problems

### SMART CONTROLS AND STORAGE CAN OVERCOME LIMITS

| Enables an island to get more than 4% of energy from solar | Solar energy limit without BESS | Mitigate problems with quality and reliability | Transient and generator step loading constraints will limit the peak PV penetration to 15 percent of peak, which equates to a 4 percent annual energy contribution. The BESS help overcome this limit whilst improving grid power quality and reliability. |

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*The e-mesh PowerStore is a reliable containerised plug-and-play microgrid solution, available in various ratings with a standardised specification for installations including remote villages, islands, industry and utilities. Its ‘Virtual Generator’ capability can form a grid and integrate up to 100% of renewable energy.*

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### 3.1 Base case: diesel

Under the base case, the island utility continues to operate exclusively on diesel generation. The utility regularly uses nine 2-MW diesel generators that are each able to operate at a continuous minimum load of 600 kW. During times of peak power usage, eight gensets are necessary to serve the load directly, whilst the ninth is online to handle occasional load spikes. Without this ninth unit to supply spinning reserve, the utility would need to shed load during load spikes or risk blackouts. During off-peak times, fewer diesel generators are required to operate, but there typically remains an extra unit online to handle load spikes.

In terms of operations, in a traditional island utility, there is limited generation automation and the operators at the utility plant must manually control their diesel generators.

A portfolio based entirely on diesel leaves the utility and its ratepayer extremely exposed to the volatility of the petroleum markets. The utility consumes 446 barrels of oil a day to provide power to the island residents, and the levelised cost of energy (LCOE) for the generation passed through to utility customers is 0.223 USD/kWh, in addition to the utility’s administrative and distribution costs.

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Measuring renewables: renewable contribution versus renewable penetration

When describing percentages of renewable, both the energy contribution [kWh] and power penetration [kW] are important. Each metric is useful for describing a grid’s use of renewable generation.

<table>
<thead>
<tr>
<th>Renewable contribution</th>
<th>[Peak] renewable penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated based on energy [kWh]</td>
<td>Calculated based on power [kW]</td>
</tr>
<tr>
<td>Percentage of energy from renewables over a year</td>
<td>Percentage of power from renewables at a particular time</td>
</tr>
<tr>
<td>A cumulative (sum) value over time</td>
<td>Presented as peak (largest) value over time</td>
</tr>
<tr>
<td>Valuable metric for policy targets, in particular climate change mitigation</td>
<td>Valuable metric for technical operation</td>
</tr>
</tbody>
</table>

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### SMART CONTROLS AND STORAGE CAN OVERCOME LIMITS

| Enables an island to get more than 4% of energy from solar | Solar energy limit without BESS | Mitigate problems with quality and reliability | Transient and generator step loading constraints will limit the peak PV penetration to 15 percent of peak, which equates to a 4 percent annual energy contribution. The BESS help overcome this limit whilst improving grid power quality and reliability. |

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*The e-mesh PowerStore is a reliable containerised plug-and-play microgrid solution, available in various ratings with a standardised specification for installations including remote villages, islands, industry and utilities. Its ‘Virtual Generator’ capability can form a grid and integrate up to 100% of renewable energy.*
3.2 Scenario RR: renewable ready

An island utility can be made ready to use renewable with a battery energy storage system (BESS) paired with smart controls and automation. The BESS, an e-mesh PowerStore™, can displace the diesel generator that serves the fixed 2.0 MW spinning reserve requirement, as well as smooth demand peaks with battery storage, up to an additional 2.0 MW. Together, these BESS value streams enable the island utility to delay or avoid starting two generators during certain loading events. The BESS also enables the online generators to operate closer to their peak efficiency points.

The BESS improves the grid’s power quality and strengthens it against instability. These storage technologies are particularly valuable for island grids that support industry and other customers that use large, dynamic loads. It is also useful for avoiding these issues as the island adopts increasing amounts of variable renewable energy.

The total investment cost for a BESS solution to optimally improve the diesel generation efficiency whilst improving power quality is 3.0 MUSD. The selected BESS size is 4.0 MW / 3.0 MWh. Without the BESS, the solar PV capacity is limited by the minimum loading of the diesel generators in combination with their step load capabilities, as well as power quality limits in the distribution system.

The simulation output shows a fuel reduction of five barrels per day and an annual cost savings of 0.8 MUSD, leading to a payback period of 3.8 years and IRR of 27 percent. The LCOE is reduced from 233 to 227 USD/MWh, mainly due to a reduction in generator operation and maintenance costs.

Figure 4: Dispatch on a representative summer day for the renewable ready scenario

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1 The e-mesh PowerStore is a reliable containerised plug-and-play microgrid solution, available in various ratings with a standardised specification for installations including remote villages, islands, industry and utilities. Its ‘Virtual Generator’ capability can form a grid and integrate up to 100% of renewable energy.

10 Step load capacity is the maximum amount of power a generator can produce within a certain time to recover PV output lost due to cloud shading of the array.
3.3 Scenario MR: medium renewable

This scenario invests in solar PV with the e-mesh PowerStore BESS and e-mesh smart controls. Under a medium renewable scenario, the BESS continues to provide power quality and grid reliability support for loads, whilst enabling larger amounts of energy from solar PV and other variable renewable sources.

This allows the solar PV to displace diesel generation. The BESS provides reserve support to the grid, allowing reduced operation of the diesel generators. The PV and BESS interact not only with the diesel gensets, but also bolster and reinforce each other. There are modest amounts of PV shifting in which the PV charges the BESS during the day, coupled with charging from the diesel generators to ensure efficient fuel use.

This prepares the BESS to reduce generator fuel use and operation in the evening and night. Installing the 6 MW / 5 MWh BESS with 10 MW of PV requires a CAPEX of 19.6 MUSD. As a result, the annual operations and maintenance costs are reduced 20 percent, and the LCOE is reduced from 233 to 203 USD/MWh.

Fuel savings is the primary economic driver for this investment, with an average fuel usage reduction of 88 barrels per day (20 percent). Reduced generator operating hours provide cost savings as well. As a result, renewable sources on average contribute about 20 percent of the delivered electricity. The payback time is 4.1 years, and the internal rate of return (IRR) is 24 percent.

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Automatically turn generators off and on
Charge batteries with efficient diesel
Charge batteries with solar

Reduce diesel usage to save fuel
Manage spinning reserve

Battery power (MW) | Solar | Generator power (MW) | Load served (MW)

Figure 5: Dispatch on a representative summer day for the medium renewable scenario
### 3.4 Scenario HR: high renewable

In this scenario, significant amounts of solar PV and additional e-mesh PowerStore BESS capacity combine to maximise the value to the island. As in the medium renewable scenario, the two technologies still interact with and support the diesel genset. However, with the e-mesh controls, they bolster and reinforce each other to increase the impact.

An investment of 43.1 MUSD is required to add a solar PV system of 22.0 MW and a BESS of 14 MW / 10 MWh. The solar PV plus BESS investment reduces annual operating costs from 23.0 MUSD down to 14.8 MUSD, a savings of 8.2 MUSD annually. The savings are due to a combination of an average 159 barrels of fuel savings per day and maintenance savings due to the 45.5 percent reduction in genset usage.

The solution offers maximum value stacking from the storage component as it substitutes the diesel generator as operating reserve, smooths demand peaks and improves solar PV integration. An advanced BESS has the benefit of effectively managing the fluctuations caused by renewable energies, such as changing cloud cover, whilst continuing to deliver high-quality power. It also increases the ability of solar PV to reduce fuel usage by allowing spinning reserve generators to turn off, providing greater room for solar PV energy to contribute to load.

The results show that the investment has an IRR of 19 percent with a payback period of 5.3 years, and yields the greatest reduction in LCOE, reducing it by 18 percent to 190 USD/MWh. Under this scenario, the island would obtain a 35 percent renewable contribution, a measure of how much of the island utility’s electrical energy comes from renewable sources.

Renewable generation and BESS together help to yield the greatest reduction in price exposure, generation costs and diesel fuel usage.

![Figure 6: Dispatch on a representative summer day for the high renewable scenario](image-url)
3.5 Comparison of scenarios

Transforming an island to have a high renewable energy contribution can be achieved through incremental hybridisation investments in renewable generation and BESS. This approach is strongly supported by the modularity of solar PV and BESS; the investment can be undertaken in stages to lower investment risk and allow the utility to manage capital outlays.

Modern modular automation and controls, like those in the e-mesh solution, make it possible to customise the investment. The utility can focus on investments that maximise IRR, focus on achieving renewable targets, or take an approach that balances these goals.

Making the island renewable ready with a BESS investment can create a quick return. A solution that uses both batteries and solar PV will yield the greatest overall energy cost reductions.

Figure 7 compares the payback and yield for the three renewable scenarios. As the results indicate, the medium and high renewable scenarios have a slightly longer payback time but significantly higher savings.

Figure 7: Comparison of payback and yield for the three investment scenarios
A summary of the base case and investment scenario results are presented in Table 1. From this table, we can see that:

1. The high renewable scenario yields both the greatest savings and the greatest contribution of renewable energy. Although this scenario yields the greatest economic savings, even higher renewable contributions are possible with ABB e-mesh.

2. The renewable ready BESS investment provides value at a strong return.

3. The medium renewable scenario bridges the gap for islands that still want to use renewable energy but limit the capital outlay.

4. All three investment scenarios represent a step toward island goals of using more renewables, decreasing costs and reducing the reliance on volatile energy sources.

Regardless of the island and utility goals, there is a customised solution based on solar PV and BESS that will best meet those goals.

<table>
<thead>
<tr>
<th>Investment</th>
<th>Operations</th>
<th>Economics</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV (MW&lt;sub&gt;p&lt;/sub&gt;)</td>
<td>BESS (MWh)</td>
<td>Capital cost (MUSD)</td>
<td>Operating cost (MUSD)</td>
</tr>
<tr>
<td>Base case: diesel only</td>
<td>0.0</td>
<td>0.0</td>
<td>0</td>
</tr>
<tr>
<td>Renewable ready</td>
<td>0.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Medium renewable</td>
<td>10.0</td>
<td>5.0</td>
<td>19.6</td>
</tr>
<tr>
<td>High renewable</td>
<td>22.0</td>
<td>10.0</td>
<td>43.1</td>
</tr>
</tbody>
</table>

Table 1: Summary of the base case and island investment scenario results

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**RC** = \( \frac{\text{KWh}_{\text{renewable}}}{\text{KWh}_{\text{load}}} \)

**PRP** = \( \text{MAX} \left( \frac{\text{KWh}_{\text{renewable}}}{\text{KWh}_{\text{load}}} \right) \)
4 Evaluation of assumptions

To better understand the driving factors of LCOE savings, the high renewable scenario was analysed for a range of varying inputs. This sensitivity analysis includes diesel fuel price, installed solar PV price and battery price (excluding the converter).

Figure 8 shows the LCOE savings expected from the high renewable scenario as compared to the base case (diesel only). The chart indicates the change in LCOE as each of these prices vary 20 percent from the default.

At the default prices, indicated by ‘1’ in the horizontal axis, the savings for the high renewable scenario are just over 40 USD/MWh; at this set of prices, the island can expect to reduce the LCOE if it invests in solar PV and BESS with ABB e-mesh smart controls.

If the diesel price were to go up 20 percent, as indicated by 1.2 on the horizontal axis, the high renewable scenario saves more—almost 20 USD/MWh. This is due to the lower reliance on diesel fuel in the high renewable scenario. The diversification provided by renewable energy, BESS and smart controls insulates the island economy from diesel fuel price changes.

Even with the diversification that the solar PV and BESS offer, diesel costs still have the highest impact on LCOE savings. Diesel fuel price is the largest contributor to island system energy costs. Solar PV and battery technologies provide an economic technological solution to reduce the impact of diesel on island electric utility costs. If an island wants to make an investment to reduce its electricity costs, the most important choice they can make is in a hybrid solution that uses renewable energy, batteries and smart controls. This is true across the range of expected installed solar PV and installed battery prices.

The outcome of these sensitivity analyses is that investing in solar PV and BESS lowers the risk of increasing LCOE. It also demonstrates that a key driving factor to keep energy costs low on islands is to reduce dependence on expensive, polluting, imported diesel fuel.
5 Conclusions and next steps

Island utilities have more options for serving their customers than ever before. Previously, they were limited largely to diesel and heavy fuel oil-based generation. However, today there are options to diversify their supply with renewable energy and batteries energy storage. In addition to being less expensive and less volatile, these options help to meet renewable energy goals.

Investments in renewable generation, BESS and smart control technologies can make islands less vulnerable to market conditions, more resilient to environmental challenges and increase energy security using domestic energy sources.

Proven advanced integration technologies and controls create an opportunity for utilities to leapfrog the challenges of utilities in larger markets. ABB has expertise and experience in designing optimised microgrid and battery energy storage solutions with a proven track record of well over 170 global installations across a range of applications serving remote communities, islands, utilities and industrial customers. We are a leading provider of microgrid products and solutions that offer a complete end to end approach from initial consultancy through to remote monitoring.

ABB’s flagship solutions for island electrical grids are based on the e-mesh platform and offer flexibility and scalability to support power island power demands from hundreds of kilowatts to tens of megawatts.

6 ABB e-mesh

The e-mesh digital ecosystem of solutions and products enables the digitalisation of distributed energy resources.

The e-mesh portfolio offers end-to-end distributed energy solutions, combining advanced analytics, software technology and hardware systems. Our microgrids and battery energy storage solutions ensure the highest penetration of renewables share, increase grid stability and provide reliable power whilst minimising CO₂ emissions. The new age automation solution, built using ABB’s proven MicroSCADA and RTU platforms, helps to monitor and control distributed energy resources. The digital offering e-mesh Monitor and e-mesh Applications, based on IoT technology, helps to forecast trends, optimise performance and increase revenue streams.
Contact your local service and sales support team to discuss your requirements further.