NSTA SNS NUI Renewable Energy Package

Optioneering Study Report

NSTA

5204546-PM-REP-001-02

Notice

This document and its contents have been prepared and are intended solely as information for NSTA and use in relation to Optioneering study.

Atkins Limited assumes no responsibility to any other party in respect of or arising out of or in connection with this document and/or its contents.

This document has 93 pages including the cover.

Document history

Document title: Optioneering Study Report

Document reference: 5204546-PM-REP-001-02

Revision	Purpose description	Originated	Checked	Reviewed	Authorised	Date
Rev 0	Issued for information	EM	CM	OM/CD	JS	31/03//2021
Rev 1.0	Issued for client comment	EM	CM	OM/PH	JS	16/04/2021
Rev 2.0	Final Issue	EM	JS	EM	JS	25/05/2021

Client signoff

Client	NSTA
Project	NSTA SNS NUI Renewable Energy Package
Job number	5204546

Contents

Tables

Figures

Abbreviations

Term	Description
BEIS	Department for Business, Energy and Industrial Strategy
BESS	Battery Energy Storage System
CAPEX	Capital Expenditure
CNS	Central North Sea
CoP	Cessation of Production
EI	Energy Integration
ET	Energy Transition
GYOR	Green, Yellow, Orange, Red
HAWT	Horizonal Axis Wind Turbine
HPU	Hydraulic Power Unit
LOS	Line of Sight
MoSCoW	Must have, Should have, Could have, Won't have
NPAI	Not Permanently Attended Installation
NPV	Net Present Value
NUI	Normally Unmanned Installation
O&G	Oil and Gas
OEM	Original Equipment Manufacturer
NSTA	Oil and Gas Authority
OPEX	Operating Expenditure
P&A	Plug and Abandonment
PV	Photovoltaic
REP	Renewable Energy Package(s)
RFI	Request for Information
SNS	Southern North Sea
SWOT	Strengths, Weaknesses, Opportunities & Threats
ToR	Terms of Reference
TRL	Technology Readiness Level
UKCS	United Kingdom Continental Shelf
W2W	Walk to Work

Executive Summary

SNC Lavalin Atkins ("Atkins") was appointed by the Oil and Gas Authority (NSTA) UK, to undertake a study to explore the application of Renewable Energy Packages to Normally Unmanned Installations (NUIs) offshore. A Renewable Energy Package (REP) is one or more technologies, used to generate power without carbon combustion, and may involve additional elements such as energy storage devices, power management systems and electrical connection infrastructure.

Study Basis

The premise of the study was to consider how REPs may be used to offset all, or part of an individual NUI platform's electricity demand, which is currently met by hydrocarbon-based generation sources.

The study scope and requirements are listed in the Terms of Reference document provided by NSTA [1].

Objectives

The study aimed to describe the currently available and emerging REP technologies, set out proven operating envelopes, and provide analysis to highlight key factors to be considered if the REPs are deployed in an offshore environment. The work also sought to highlight, at a high level, the financial incentive to installing renewable energy generation on individual NUIs – while recognising that there are other incentives which may drive installation. The flexibility and adaptability of the REPs was considered to understand how to meet possible changes in future needs, such as scaling up the REP(s) originally installed, or redeploying an REP to another location following platform cessation of production (CoP) or decommissioning.

Platforms considered

The study considered 35 NUIs in the Southern North Sea (SNS) with installed power demands ranging from 20 to 300kWp and CoP dates from 2021 to 2037.

Findings

A range of different REPs was considered for the platforms. Summary findings for key REP technologies investigated are shown in Table 0-1.

Table 0-1 – Summary Study Findings – REP Deployment on Individual NUI

Technology	Picture	Details and Operating Envelope	Indicative £cost vs £benefit		Key Strengths / Weaknesses	Future Opportunities
			For small NUI 5 yrs to CoP	For large NUI 10+ yrs to CoP		
Small scale solar		10kWp; 1kW mean 26 panels 44m^2			Established technology. Offshore track record. Light weight. Low power generation. Large area needed, hence may be installable only at small scale	Can cover platform after CoP but power generated will be limited to few tens kW. Delicate nature may not suit redeployment but limited reason to do so anyway
Large scale solar		30kWp; 3kW mean 77 panels 130m^2	(Sufficient space unlikely)			
Small scale Wind		6kWp; 1.5kW mean one 6kW turbine			Established technology. Offshore track record. Light weight. Limited suitable sites if helideck and drilling on platform, hence installation may not be possible, or be limited. Modest power generation	Possible install more turbines post CoP, subject to generation proximity. Potential for few tens kW. May redeploy but limited reason to do so
Large scale Wind		18kWp; 4.5kW mean three 6kW turbines	(Sufficient space unlikely)			
Integrated Power container		10kWp solar + wind plus power mgt system in container			Engineered solution. Offshore track record. Low/modest power generation. Cost	Potential to hire to reduce costs? May scale if more space available May be redeployed if controls system adapted
Wave point buoy or Floating energy pontoon		20kW mean power	Larger than needed		High power potential. Redeployable. Scalable. Technology not yet ready. Cost, if deployed for powering just one NUI	Can install in numbers in area around or near platform Redeployable Economies of scale - install multiple units
Adding Energy Storage						
Battery Energy storage (in conjunction with energy generation)		Topsides: 220kWh; 6.7Te and footprint from 3.5m^2	Will add cost to renewable energy generation technologies without benefit for individual NUIs, except in isolated cases where platform has sufficient space to accommodate more generation capacity than it can use.		Facilitates greater % renewable power generation Unlikely to be worthwhile on NUI due to space limits for power generation. Increases cost of REP	Consider using as part of a future power hub platform, providing storage for surplus generated energy
Battery Energy storage (in conjunction with energy generation)		Subsea: 100kWh per unit; 6.7Te and footprint 6m^2			Facilitates greater % renewable power generation. Unlikely to be worthwhile on NUI due to space limits for power generation. Cost for subsea installation.	Consider using as part of a future power hub platform, providing storage for surplus generated energy. Installation costs per unit will be lower if multiple units installed.
On platform	*Off platform*					

A key study finding was the confirmation that the most viable energy generation devices are on-platform solar PV panels and micro wind turbines, which have an established offshore track record, but these technologies generate comparatively low levels of energy (which is also intermittent) for their required space, where space is very limited on most NUIs. Along with a high variability in a platform's energy consumption during the year, meeting the full NUI demands therefore presents a significant challenge for REPs, so the application of renewable generation on most operating NUIs is likely to be in a fuel offsetting mode (i.e.in conjunction with the existing power generator), rather than fully replacing hydrocarbon generation. In this mode there may be periods when the existing power generator is not required, which saves emissions in periods of low power demand when fuel burning generator efficiencies are lowest.

The assessment explored the balance of renewable generation contribution to diesel fuel offsetting; and concluded that meeting all of a NUI's power demand would be unlikely with 'on platform' technologies. Example cases were modelled for a 25kW average load platform demand (which is a common load in the SNS), with increasing contributions of renewables. It was shown that 30 to 50% diesel offsetting could theoretically be achieved, but the required footprint area of solar PV and wind turbines would be too large for all NUIs, except those with a combination of very low power demand and large areas of free space.

Deployment of 'on-platform' solar and micro wind power is therefore likely to be possible at a small scale only and best done on an energy offsetting basis with the REP running in parallel with the current hydrocarbon powered electricity generator. The addition of battery energy storage can enable REPs to provide a greater proportion of the platform's energy needs, but platform space limitations will typically limit the installable power generation capacity to levels below which worthwhile levels of surplus energy for storage are generated.

The 'on-platform' technologies are scalable, offering the opportunity of increasing energy generation capacity if more platform space is created by facilities simplification in late life or upon CoP. Re-deploying solar panels to another site (if required, to support post oil and gas energy needs) however their fragility may prove challenging.

For NUIs with higher power demands, 'off-platform' technologies such as wave point buoys or floating solar/wind/wave power skids offer potential, but these technologies are generally not yet ready for full scale commercial operation and are likely to be uneconomic for deployment to power individual NUIs. 'Off-platform' REPs are also scalable and their design gives them the option of re-deployment to other locations after CoP; possibly in support of Energy Transition developments. This is discussed further in Future Opportunities below.

While recognising that the installation of renewable energy generation on an offshore platform is not a purely financial decision, a preliminary estimate of life-cycle costs versus the value of renewable energy generated was made; to give an indication of the financial incentive to install REPs. This work showed that there may be isolated cases where REPs can provide a net positive financial benefit to an individual NUI platform, provided that there is sufficient space on the platform for large scale REP deployment and that the platform has a comparatively long remaining operational life (as indicated in Table 0-1). These examples involved on-platform solar panels (130m^2) or wind (three 6kW turbines) generation on NUIs with CoP dates on or after 2030.

The deployment of small-scale REPs specifically to provide power during an extended NUI Lighthouse mode (low power demand after well 'plug & abandonment' and topsides 'make safe and cold') was found to be financially negative. Retrofitting REPs on most NUIs for lighthouse mode alone is not likely to give a positive financial return; if the REPs are installed solely to support oil and gas operations.

Future Opportunities

Although the study found that the benefits of installing REPs on individual NUI platforms are limited, there is a wide range of possible opportunities to deploy renewable generation and energy storage in other, related contexts. Assessing the future energy REP opportunities (beyond immediate hydrocarbon production) can improve the economics of fitting REPs. Installations may undergo late life or post CoP 'platform simplification', to make space for a new REP and to reduce the required generation capacity provided.

Possible post Oil and Gas applications for REPs are numerous and larger energy generating devices could provide a significant opportunity to the wider Energy Transition; when these technologies are commercially available, meriting separate investigation. Potential development cases include:

- Powering neighbouring clusters of NUIs with off-platform REPs when the technology is sufficiently mature
- Energy hub concepts for Energy Transition initiatives, possibly converting large post CoP platforms, with uses including use for desalination, supporting hydrogen production, or supporting electrical transmission (e.g. an offshore substation).
- Large scale subsea storage options (e.g. flow batteries)
- Secondary uses for certain REP technologies after initial deployment on operating oil and gas platforms

A heat map of the SNS area (Figure 0-2) shows the potential for powering platforms in clusters where numerous installations are in relatively close proximity. This brings the possibilities of powering platforms with larger REP schemes, either installed locally to clusters, or from nearby wind farms.

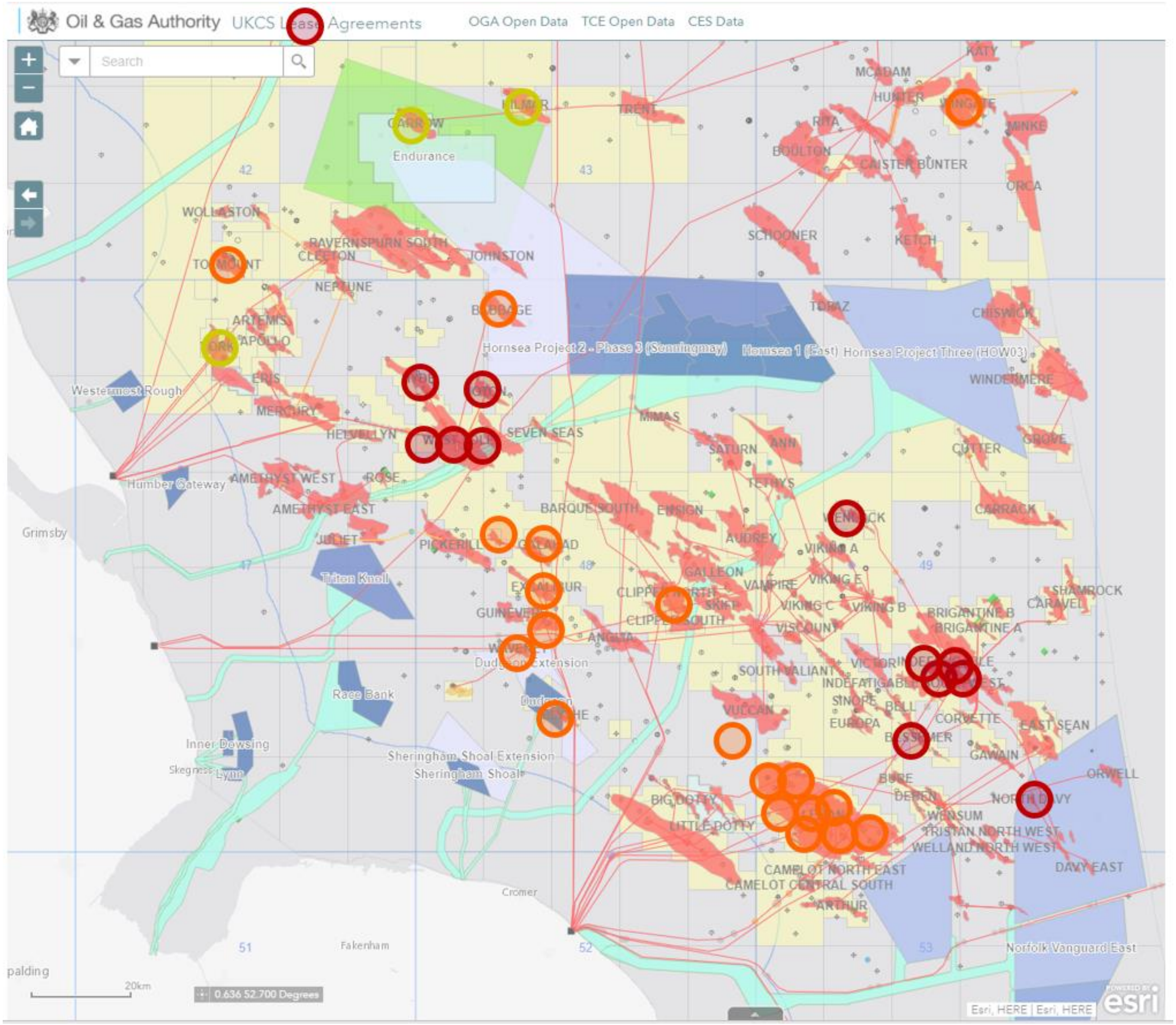


Figure 0-2 – NUI Location and Peak Power Demand Heat Map

Recommendations

Principal recommendations from the study are:

1. Seek feedback from operators of NUIs with existing REPs fitted, confirming how the technologies have performed, both technically and commercially.
2. Carry out a screening exercise to identify high potential NUIs for possible installation of REPs (those installations with a combination of long remaining lives and large available space) and assess whether installing REPs may be worthwhile.
3. Assess the feasibility of schemes which could power multiple NUIs in the same vicinity, with common off-platform renewable power schemes including locally to platforms and nearby wind farms.
4. Examine off-platform REP concepts in more detail for high demand NUIs to establish viability.
5. Refine the cost vs benefit assessment if greater accuracy is considered necessary
6. Assess the financial viability of installing a limited on-platform REP scheme (within the available space) during the platform operational phase and scaling up post CoP
7. Consider developing a dashboard style assessment a tool for NSTA or operators to assess usefulness of REPs to NUIs (by site location).
8. Confirm whether there is a requirement for ATEX or marine grade REP solutions on the NUIs to ensure that appropriate costs have been used in the estimate.
9. Explore a rental model for adopting REPs on NUIs as a potential economic way forward for operators

1. Introduction

1.1. Background

The Oil and Gas Authority (NSTA) is exploring decarbonisation strategies for the range of assets with the Southern North Sea (SNS). This technology scoping study forms part of this; and is part of wider area plan scoping.

Complimentary research areas have included data gathering and consultation with stakeholders. These discussions have considered how different offshore energy systems (oil and gas, renewables, hydrogen and carbon capture and storage) could be co-ordinated across the UK Continental Shelf (UKCS) for environmental and efficiency gains, including identifying technical, regulatory and economic hurdles.

Around the UKCS there are differences in the types of oil and gas installations and the energy generation methods on those installations. In the Northern and Central North Sea (CNS) there is a predominance of large production platforms in relatively deep water, powered by large gas turbines. In the SNS there are numerous small Normally Unmanned Installations (NUIs) with low energy demands, often powered by small engines such as diesel generators or mini gas turbines.

The NSTA is examining strategic approaches to reduce emissions, which may be followed in each region of the UKCS. This study and all findings relate to NUIs in the SNS, but the outcomes may be applicable to the wider UKCS.

1.2. Scope

The purpose of this technology scoping study is to identify and present a suite of REPs that may be installed on a NUI; and which could contribute to decarbonisation of the SNS assets.

The study undertakes a preliminary assessment of the REPs; exploring the technical limits, operating envelopes, advantages, disadvantages and limitations to applying the REPs offshore. A screening process was completed using defined selection criteria, developed with NSTA.

The work includes a preliminary indicative CapEx and OpEx assessment, and indicative payback calculations on the install cost against diesel fuel saved.

Consideration is given to the wider UK Energy Transition, and possible secondary life uses for the REPs on the NUIs. This review considers whether REP technical limits and operating envelopes may be compatible with secondary use energy generation roles beyond oil and gas and future opportunities identified from the study are captured.

1.3. Objectives

The primary objectives are outlined in the NSTA Terms of Reference [1]. The aims of the study are to:

- Assess the practical considerations for deploying renewable technology packages on NUIs, e.g. space, weight, redundancy, need for batteries or back-up generation.
- Confirm the operating envelope of the renewable technology packages.
- Give a preliminary view on reliability and availability of the technology.
- Indicate whether the renewable technologies could most effectively be deployed to eliminate all, or part of the NUI emissions.
- Give indicative system costs (CAPEX and OPEX) and whether this may deliver a net positive payback term to the NUI operator when savings (e.g. in fuel or maintenance costs) are considered.
- Investigate scalability of the renewable technologies for current and future changes and for larger installations.
- Assess whether the technologies may support future Energy Transition (ET) and Energy Integration (EI) objectives (e.g. for gas compression or powering desalination units). Consider this possible future use in conjunction with scalability of the renewable package technology.

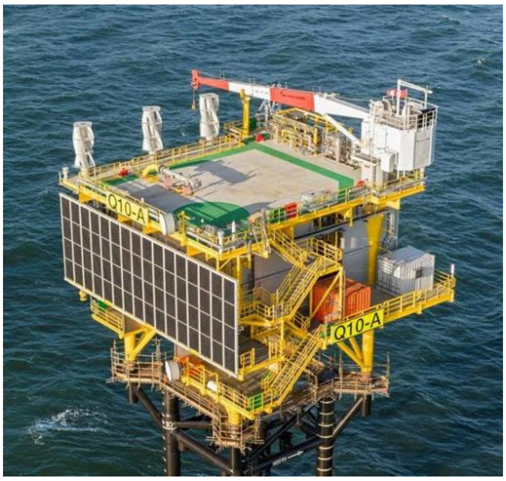
The advantages and limitations of the renewable technology packages are identified and noted as part of the work.

1.4. Existing NUI Examples (with REP)

Examples of NUI platforms with on-platform renewable energy technologies fitted are indicated in Table 1-1.

Table 1-1 – Installed renewable energy packages

Platform	Image	
Shell ONEGas – Leman Echo [2] Situated in UKCS SNS. Platform simplification works prior to REP installation completed in 2016.		
Shell – Cutter [3] Situated in UKCS SNS. Renewable technologies installed in 2006.		
Shell – Caravel [4] Situated in UKCS SNS.		

Platform	Image	
Ithaca Energy – Jacky [5] Situated in the Moray Firth Packaged solution installed in 2020.		
Tulip Oil – Q10-A [6] Situated in the Dutch North Sea Renewables installed in 2019.		

As is shown in Table 1-1 there are a number of renewable energy package concepts on-platform, based around Wind and Solar generation. The Jacky platform is currently using a containerised renewable solution to provide 100% of the platform's power demand whilst operating in lighthouse mode. The Caravel platform is also 100% powered by renewable technologies. Both of these solutions are reliant on batteries to ensure the energy requirement of the NUI is always met.

1.5. Input Data

The NSTA provided Atkins with a list of thirty-five NUI and Not Permanently Attended Installation (NPAI) facilities which were to be considered in the study (collectively referred to as "NUIs" henceforth) .

1.6. Study Key Assumptions

The following assumptions are made in the assessment:

1. The fitting of a REP is considered on an individual NUI platform basis only, i.e. no oversizing of a REP to provide power to multiple platforms.
2. Each NUI platform shall retain its current hydrocarbon-powered electricity generator to provide the operator with assurance of continuous power supply to vital platform systems, such as safety critical equipment and emergency back-up.
3. With respect to assumption 2, REPs have been considered to provide a level of 'diesel offsetting', where high availability is provided by the existing diesel/gas fuelled generator.

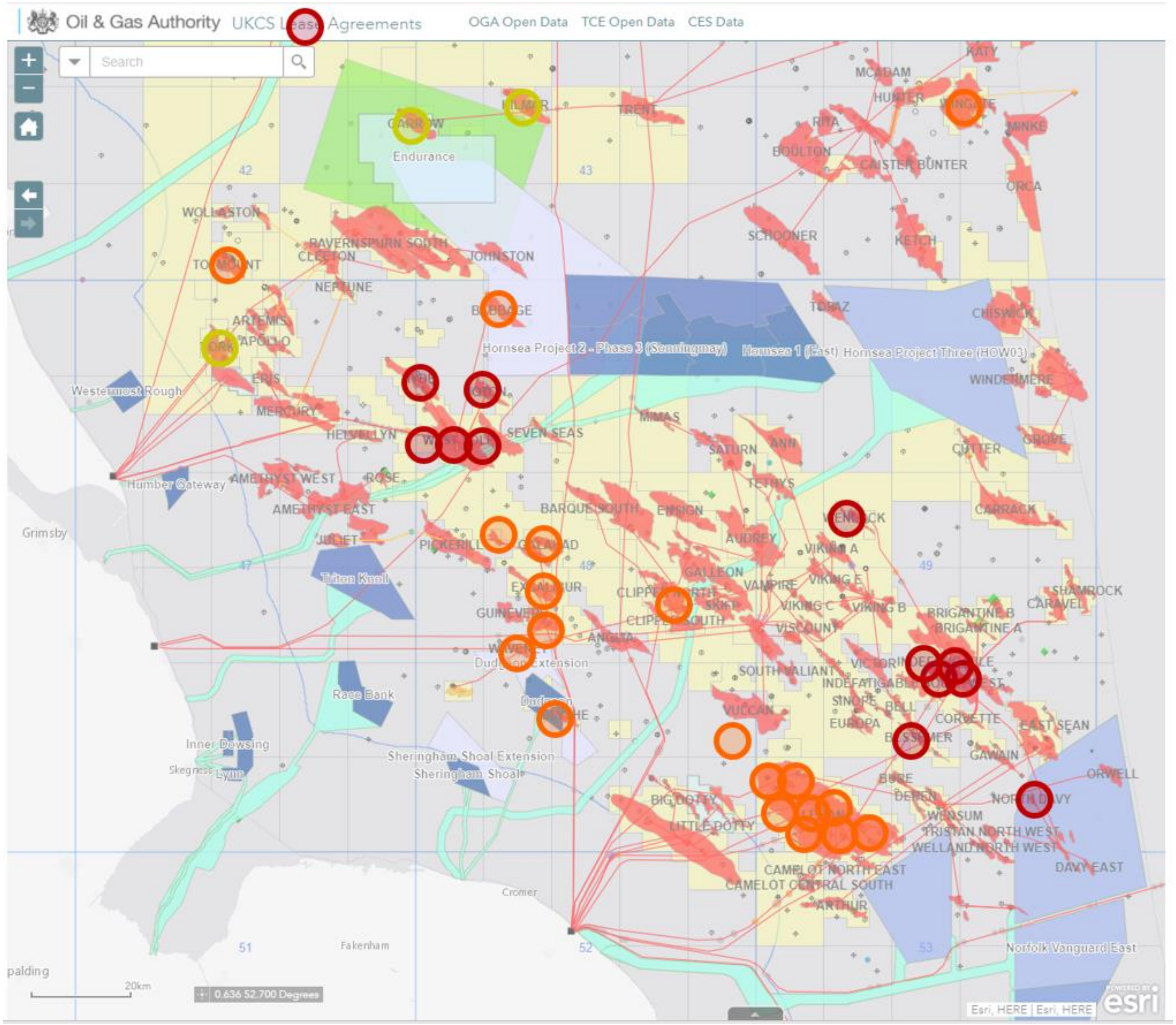


Figure 1-2 – NUI Location and Peak Power Demand Heat Map

2. Methodology

The approach followed in the study is summarised in Figure 2-1:

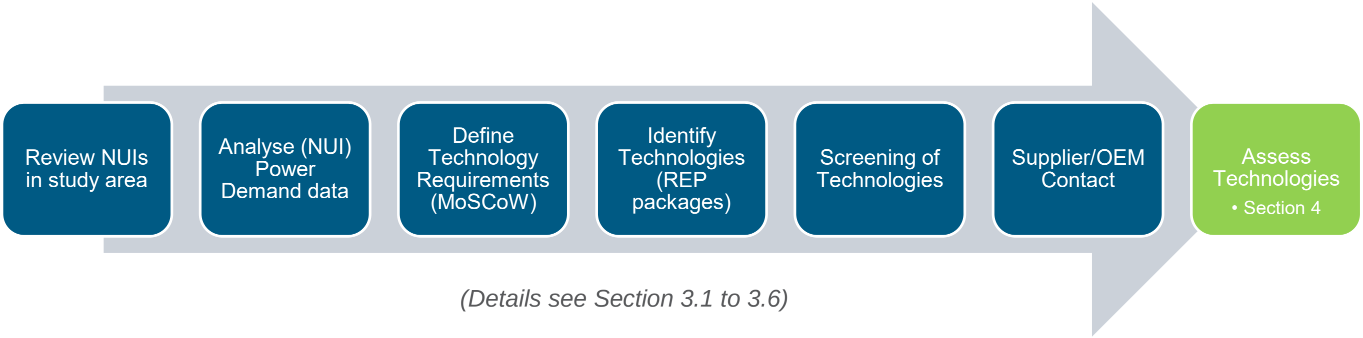


Figure 2-1 - Study Methodology

Review of NUIs in Study

The provided information on NUIs (given in Section 1.5) was first reviewed at a high level, with consideration of power generation installed, fuel type, location and Economic CoP. This information was used to better understand the range of power demands required, and any relationships that could be established, such as estimated fuel usage based on reported emissions.

Through discussions led by the NSTA with an operator, it was possible to obtain detailed information for the Babbage NUI to complement the original study information. This allowed a sensitivity verification of the data (see Section 3.2.4) to be completed.

Power Demand Data Review

The energy data provided for the study was interpreted and analysed by examining the power generation capacity installed and the demand information where the two differed. Based on industry issued carbon factors from the Department for Business, Energy and Industrial Strategy (BEIS), the emissions data was verified by fuel type to estimate the installed power generation capacity factor for each installation. This helped identify where power use may be intermittent, and to match NUI demand more closely with potential REP supply options.

Using this analysis, the NUIs were categorised by power demand, as shown in Figure 1-2. Further to this, the data was investigated to assess manned and unmanned use and energy demand variances. This aided the further discussions on the useful contribution of renewables and meeting the perceived ‘Must Have’ criteria (defined in Section 3.3).

Technology Requirements for NUIs

A MoSCoW analysis was carried out to generate a list of evaluation criteria to be used in the later screening phase of the study (Section 3.5) to compare and assess different REPs. The workshop was a collaborative session with access to a ‘virtual whiteboard’. This process was first completed internally by the Atkins team to generate potential assessment criteria, and then re-run live with NSTA to generate the final list of MoSCoW criteria (as shown in Section 3.3). During the internal workshop a long list of required criteria for the REPs was developed around ‘key word’ categories, which included those shown in Figure 2-2:

Figure 2-2 - Requirement category by 'key words'

The assessment was qualitative, with discussion based on the four main quadrants, as follows:

Must have

- Characteristics that are critically important, so if one 'Must have' requirement is not met, the REP concept is considered unsuitable.

Should have

- Important but not essential.
- Can be as important as 'Must have' but they are often not as time-critical or there may be another way to satisfy the requirement so that it can be held back until a future delivery timebox.

Could have

- Desirable but not considered essential. May be adopted as part of the scheme if cost is reasonable, hence these will typically be included if time and resources permit.

Won't have

- Characteristics or aspects of performance that are not accepted for the application

Won't have requirements are either dropped or reconsidered for inclusion in a later project phase

Once the 'virtual whiteboard' was completed, it was issued to attendees and served as the screening basis for confirming REPs that merited more detailed assessment. The full results of the MoSCoW workshop are presented in Section 3.3.

Identify Technologies

Referring to the MoSCoW workshop outcome criteria under 'Must Haves' to 'Won't Haves' criteria, the team then began an optioneering exercise to identify all qualifying technologies to be considered within this study.

Microsoft Teams was used as a central, open forum where the project team could collaborate and share any news, technology insights, study reports and supplier information.

A Microsoft Excel workbook was also set-up and used to record any potential technologies under key headings, e.g. Type, Technology, Description, Performance, Showstoppers, Link, Company info.

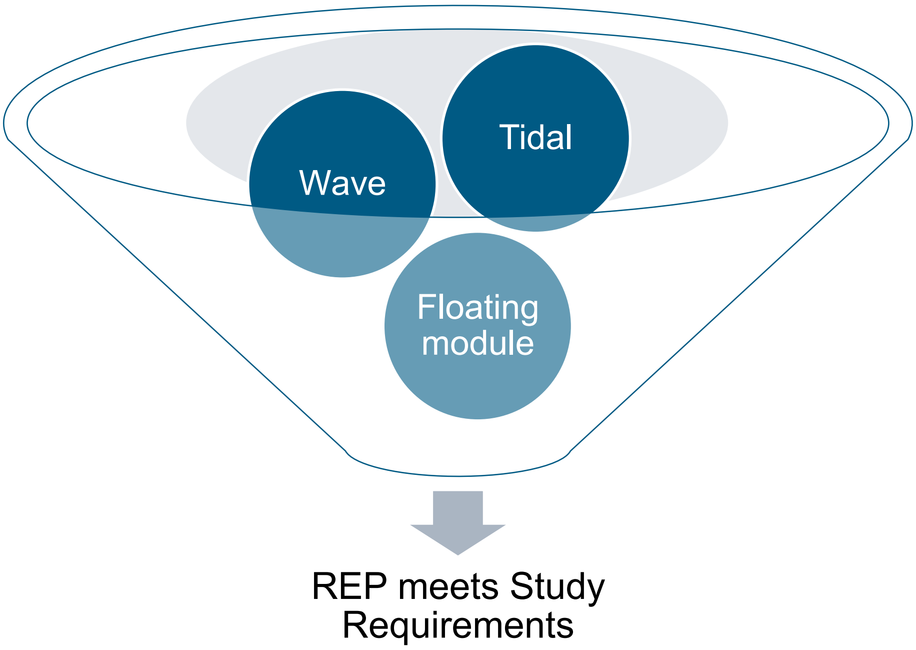
The workbook 'Type' grouped the technologies into 5 categories: On platform, Off platform, Packaged, Energy storage and Other.

An owner was assigned to each 'Technology' (e.g. tidal) to optimise research time and budget. Each owner updated their section of the workbook and identified potential suppliers of their technology. Where opportunities to host supplier discussion calls was available, these were shared with the wider team and client.

The results from this phase of the study are discussed in Section 3.5.

Screening of Options for Further Review

The long list of identified renewable energy packages was screened on a 'red flag' basis or pass fail, referring to the MoSCoW 'Must Have' and Won't Have' agreed criteria. The process is shown indicatively below by REP technology grouping.



The screened REP options that were retained from this 'red flag' assessment were then subject to more detailed review where the MoSCoW 'Should Have' and 'Could Have' criteria were considered. This helped identify technical and commercial risks to deployment, and where opportunities existed for wider Energy Transition scale up.

Some REP technologies were not considered suitable for application in the scope of the current study, which considers NUIs on an individual basis. Within this group were some examples where deployment of the REP technology in a different context may offer benefits, for example at a later date (when the TRL is more mature), deployment on a wider scale or deployment to support future Energy Transition objectives.

Supplier Contact

For the screened REP options, a short list of suppliers / Original Equipment Manufacturers (OEMs) able to deploy these technologies was developed. The project team then initiated contact through the stakeholder network, and through public contact information. The aim of the request to engage was to obtain more detailed cost, and technical information than was available online, and to allow the opportunity to discuss specific deliverability challenges to the NUIs considered in the study.

The results from the earlier MoSCoW workshop acted as a basis for these information requests and helped to identify information gaps.

Request for Information (RFI) process

A Supplier Questionnaire tab was set up in the project workbook to confirm the information needed, to enable further options assessment (Section 4). This process also ensured unbiased collation of data, and a standardised approach.

Assess Technologies

As part of the detailed assessment a further workshop was held. This revisited the MoSCoW criteria which were used to assess each option on a Green, Yellow, Orange, Red (GYOR) basis. The GYOR assessment criteria were used on the following basis:

Table 2-1 - GYOR SWOT legend

G	No issues, or meets criteria
Y	Some issues, expect to be resolved
O	Fails criteria, but not showstopper. Can overcome issue
R	Fails essential criteria (only in Must or Wont's)

As the screened REP technologies had already been assessed on a 'Must Have' and 'Won't Have' basis this workshop assessment focused on the 'Should Haves' and 'Could Haves'.

The REP packages considered were reviewed on a supplier agnostic basis. The research for the study indicates that renewable technologies can be grouped into three main categories of service providers, as listed in Table 2-2.

Table 2-2 - REP service provider categories

System Integrator	A System Integrator is a company that does not manufacture any specific technology but integrates several technologies into one tailor-made solution. These companies generally design bespoke solutions for individual platforms.
Technology Manufacturer / Original Equipment Manufacturer (OEM)	A Technology Manufacturer / OEM is a company who manufactures and sells their own renewable technology. They may interact directly with the operator or liaise with a System Integrator to install their product.
Hybrid Companies	A Hybrid Company provides a mixture of the services detailed above. They manufacture their own technology but also collaborate with other manufacturers to design an overall solution to the platform's energy demand.

Using the results of the MoSCoW assessment, the screened REPs were then subject to a Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis, which was used to capture the key points from the assessment.

3. Preliminary Review and Screening

3.1. Review of NUIs in Study

OGA provided high level data for 35 installations. The data comprised asset name, operator, installation type, fuel type, installed power generation, power demand and economic CoP. In some cases, the annual carbon emissions were also provided.

The data has been used to help understand the challenge in terms of the power load to be supplied and potential carbon emission savings. A review of the power data is summarised in the following sections. The information shown in Figure 1-1 has been used to develop the chart in Figure 3-1, which presents the remaining economic CoP years against the number of installations. This shows that most of the installations in this study have a remaining economic CoP of more than 5 years.

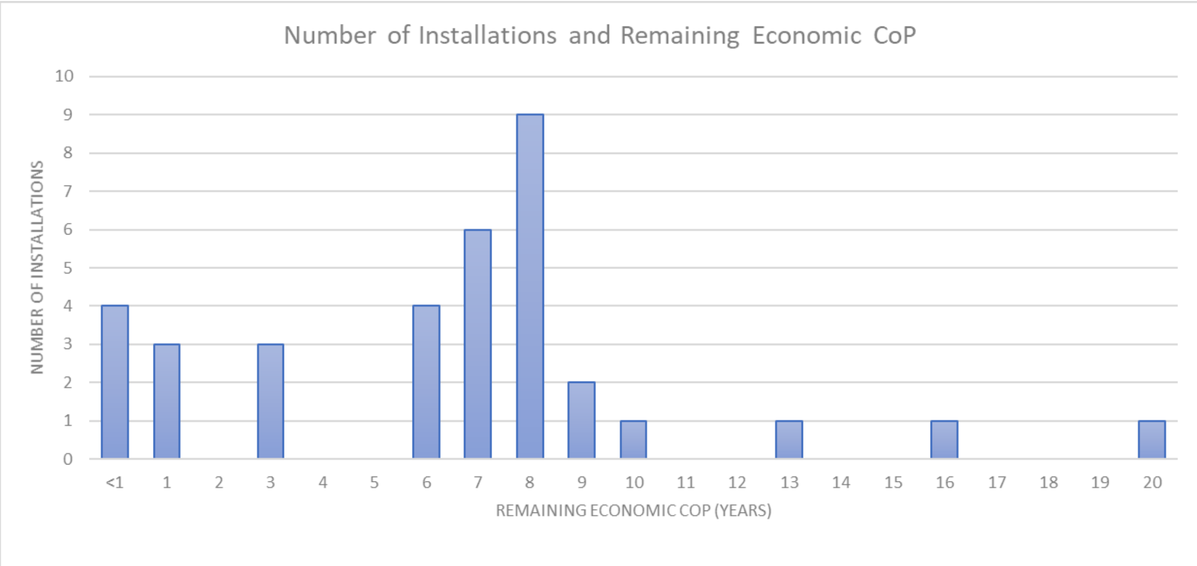


Figure 3-1 - Number of installations and remaining economic CoP

Table 3-1 –Study Scope NUI Remaining CoP

Years remaining to CoP	Number of NUIs
0-3 years	10
6-10 years	22
13+ years	3

3.1.1. Platform CoP and Lighthouse Mode power requirements

Reaching CoP brings the installation to the early stages of decommissioning. The wells will cease production and an intervention rig will temporarily isolate the reservoir. The NUI is at Phase 1 of well decommissioning, has been suspended and is now a Warm Stack. At this point the export facilities are likely to be isolated, so no hydrocarbons can enter the pipeline and enabling the pipeline to be safely decommissioned. The platform may be in this state for several years. In warm stack that the NUI is in a similar state to as if it was operating and the power requirements are therefore similar to those during unmanned operations. The duration of warm stack may be several years.

Once the decision has been made by the operator to Plug & Abandon (P&A) the wells, a rig will permanently isolate the reservoir from using cements plugs, bringing the NUI to at Phase 2 of decommissioning in Figure 3-2. As part of this operation the onboard facilities will be made hydrocarbon free, so the platform is ready to be removed and dismantled. This leads to a condition referred to as a Cold Stack[1], which again may last for several years until eventual platform removal. Cold Stack brings the platform to Lighthouse mode where the installation's power demands are normally much reduced as it needs power only for minimal services such as maritime navigational aids and basic lighting. Power demands will remain generally at this level until removal.

The decommissioning phases highlight the need to provide for a varying power demand beyond CoP for sometimes lengthy periods of time until the installation is eventually removed. REPs may therefore be designed to support either production and/or Lighthouse modes of operation, giving potentially different scales of installed renewable energy equipment, which will vary between platforms. Platform power demand is explored further in Section 3.2.

Figure 3-2 - Decommissioning workflow

3.2. Power Demand Data Review

From the information provided as part of the study, the installations were identified as having installed power generating capacity in the range of 30kW to 300kW. The current power demand of each installation was also provided, however in most cases this was quoted as the same figure as the installed power capacity and had a range of 20kW to 300kW. Figure 3-3 presents the number of installations with a particular power demand. It can be observed that most installations have stated power demands of 100kW and 200kW.

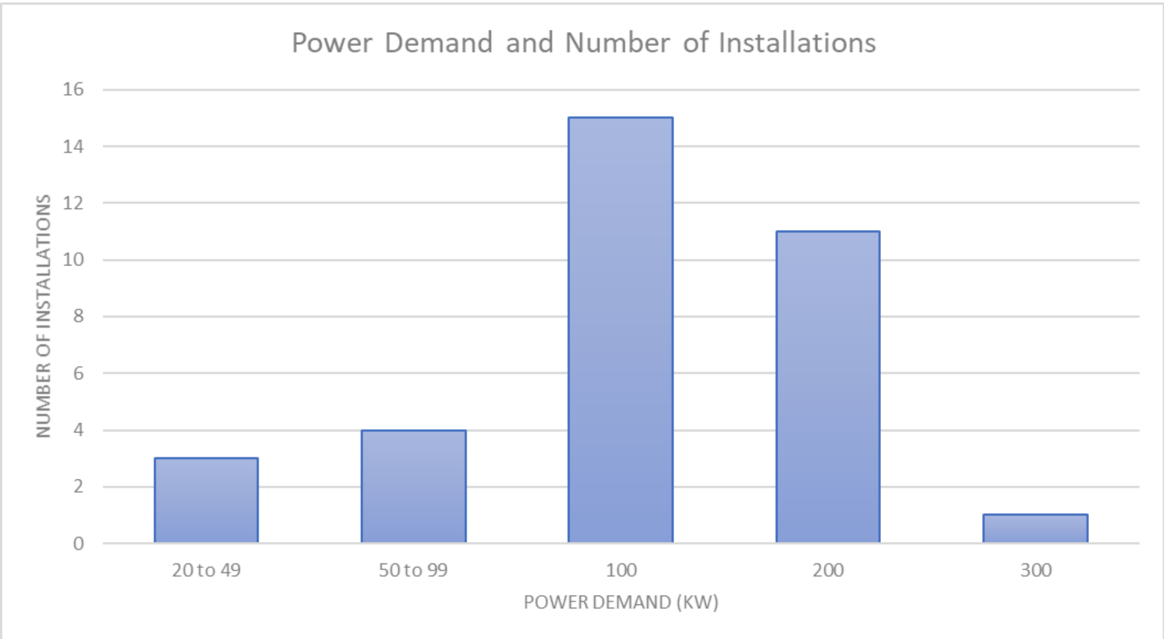


Figure 3-3 - Range of NUI power demands

Generally, the installed power generation capacity (e.g. Diesel genset) would be sized to meet the peak load requirements of the installation expected during its operating life. Depending on how the power demand

[1] Cold stack means that the NUI required crew is greatly reduced but power demand for the NUI utilities have not changed significantly, as it is still required for UPS, HPU, Nav Aids, and LOS Communications.

fluctuates, peak demand may only be needed for a smaller percentage of time and the average power demand over a year is likely to be less than the installed capacity; by how much will depend on a specific installation setup and operation.

The benefit of a controllable power source, e.g. a diesel engine, is that it can react to the changing power demand and ramp up or ramp down so that supply matches demand. However, the downside is that the diesel engine produces carbon emissions and its efficiency changes with load, having lower efficiency at a lower load. A new modern 100KVA diesel engine would typically have an efficiency of up to 40% at 100% rated power and less than 30% efficiency at 25% of the rated power. This means that fuel consumption per kWh and hence carbon emissions per kWh increase when the generator is operating at lower loads. A power profile is important when considering REP's as the renewable source is not controllable i.e. supply does not always match demand and needs to be considered when designing a REP.

Example of differences between Installed, Peak and Average Load

To demonstrate this an example, illustrative daily load profile has been plotted in Figure 3-4 for an installation with 100kW of installed power generation capacity. This figure represents the power generation that has been defined to meet the peak demands, however the peak demands only occur for a relatively low percentage of time and over the duration of a day this results in an average that is less than the installed generation capacity. In this example, the peak demand is 98kW, the minimum demand is 30kW and the average demand is 54.5kW. Each installation is likely to be unique, unless of the same design and operation.

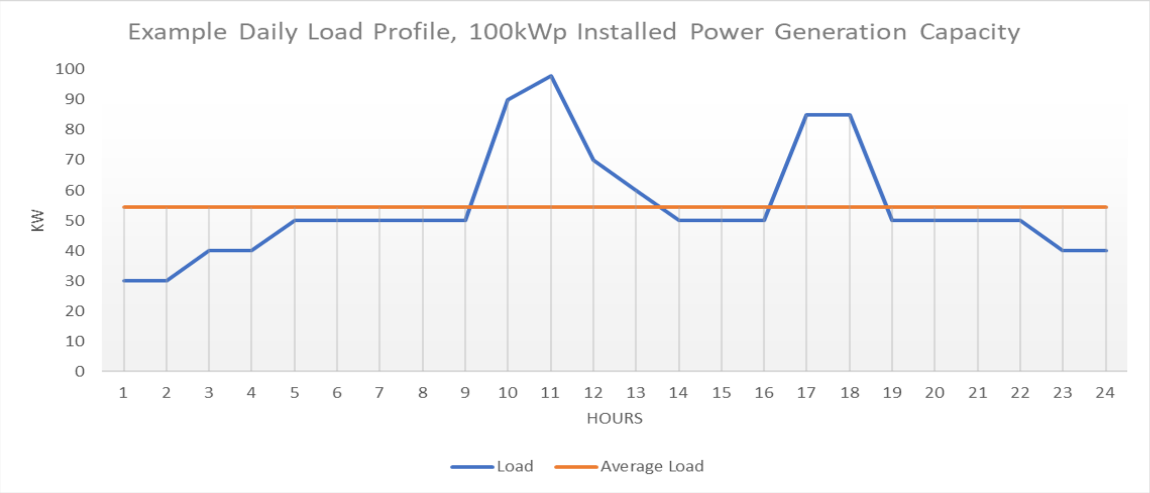


Figure 3-4 - Example daily load profile, 100kW installed power generation capacity

3.2.1. Fuel type

The power generation fuel source for each installation was provided, this was identified as diesel only, gas only or a mix of gas and diesel. From a total of 35 installations, Figure 3-5 shows the percentage split of fuel sources and it can be observed that diesel is the dominant fuel. For installations which were identified as Gas and Diesel, no information was provided on the proportion of the fuel split.

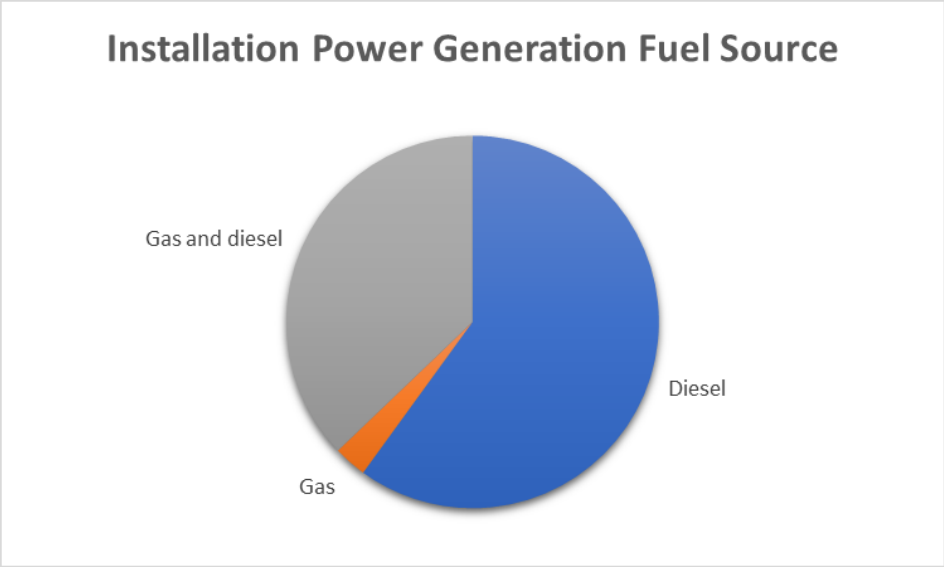


Figure 3-5 - Installation power generation fuel source

3.2.2. Carbon Emissions & Average Load

The current fuel source is an important factor when determining carbon emissions as typically power generation from diesel emits around 0.27kg CO_2 / kWh whereas gas emits 0.20kg CO_2 / kWh (based on thermal input and on a net CV basis) [7]. Diesel also has the associated transport cost and emissions to refuel the installation

Carbon emissions data has been provided for some of the 35 installations. Assuming all the emissions are associated with power generation and assuming a conversion efficiency, it is possible to use the data to estimate an annual average power load. Based on the below assumptions, the average annual power load for diesel only powered installations, where annual carbon emissions have been made available is presented in Table 3-2.

Assumptions for diesel power generation:

- kg of CO_2 produced per litre of fuel: 2.652kg CO_2 / L [7]
- kg of CO_2 produced per kWh of fuel: 0.265 kg CO_2 / kWh (Net CV)
- Power generation efficiency: 30%

Table 3-2 - Estimation of average power load based on annual carbon emissions

Asset	Power Generation Installed (kW), *actual*	Stated Power Demand (kW), *actual*	Emissions CO_2 (t) *actual*	Diesel(l/ year) *estimate*	Diesel(kWh/ year) *estimate*	Average Load (kW) *estimate*	Average Load Factor (%) *estimate*
	96	36	169	63,600	190,722	21.8	23%
	200	100	487	183,600	550,471	62.8	31%
	80	60	506	190,600	571,601	65.3	82%
	47	20	253	95,300	285,800	32.6	69%
	100	100	293	110,500	331,248	37.8	38%
	100	100	158	59,600	178,625	20.4	20%
	100	100	164	61,800	185,409	21.2	21%
	100	100	112	42,200	126,620	14.5	15%
	100	100	204	76,900	230,630	26.3	26%
	30	30	82	30,700	92,207	10.5	35%

The estimated average load shown in Table 3-2 is below the installed power generation capacity and in all but one case, is below the stated power demand. This links back to the earlier discussion and Figure 3-4 where an example daily demand profile is provided. The daily demand profile is important to identify the time of use as this information needs to be considered when designing and sizing a REP, as renewable power is not dispatchable as with a diesel engine or micro gas turbine i.e. you can only take renewable energy when it is available.

Table 3-2 also shows the average load factor of the installed power generation; this is the average load divided by the installed power generation capacity. Lower load factors tend to indicate that the installed power generation capacity is higher than required, however this does not consider peak loads. Lower load factors also indicate a larger proportion of time operating at a lower efficiency, hence resulting in higher carbon emissions per kWh of electrical output.

3.2.3. Platform Simplification

Platform simplification is the process of reducing, simplifying and deferring energy demands of a NUI platform while maintaining the operational functions needed. This process is an essential first step towards overall carbon reduction of the platform as it follows the core principals of environmental management:

- ➢ REDUCE, REUSE, RECYCLE, in this context these could be considered as:

Reduce (energy demands), Reuse (dual function, end of life or simplification), Recycle (Switching to low carbon fuels, but also decommissioning of materials and wider environmental impact).

The value in prioritising simplification at the start of any carbon reduction project includes:

- Reduced CAPEX of proposed REP, reduced ongoing OPEX of the platform
- Simplifies facilities maintenance
- Can reduce operational risk to personnel
- Reduces power demand and therefore REP sizing
- Better understanding of critical loads; efficiency of operation
- Creates additional space for installing REP solutions and simplifies installation

Platform simplification was a key stage in retrofitting a REP to the Shell Leman Echo platform. Figure 3-6 shows the platform before and after the simplification campaign was carried out.

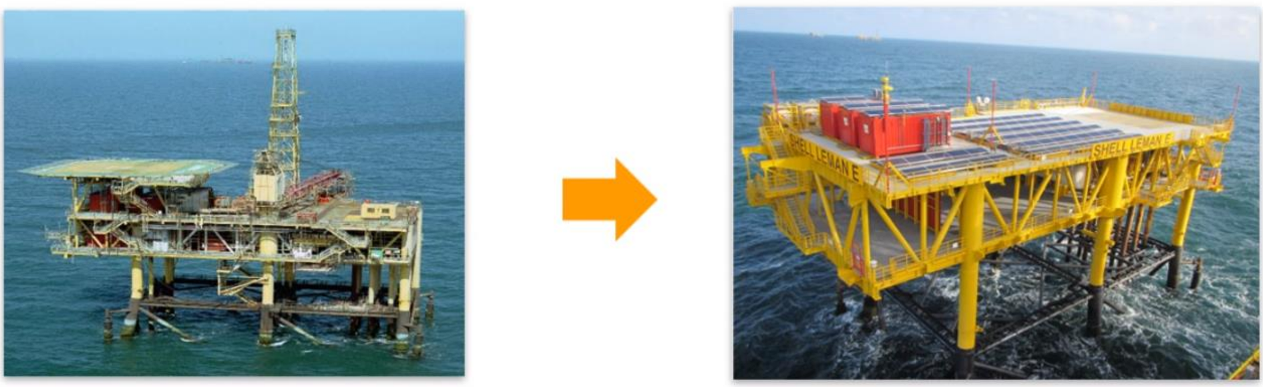


Figure 3-6 - Leman Echo platform simplification

3.3. Technology Requirements for SNS NUIs

A MoSCoW analysis was carried out to identify the REP requirements for installation on SNS NUIs. The results of the workshop are presented in Figure 3-8.

MUST HAVE

- Safety – manageable installation and maintenance risks
- Safety – compatible with NUI hydrocarbon operation
- Reliability no less than current
- Can be integrated in platform systems (non safety critical items)
- Operational NUI asset life met by REP, until decom

SHOULD HAVE

- Small physical footprint / remote from NUI
- Location does not significantly impact NUI access
- High availability
- Power supply able to meet (High/Medium/Low) demand bands
- Low impact on NUI operations during installation
- Low impact on NUI operations during well and other NUI operations
- Can provide NUI lighthouse power requirements
- Meet ATEX/DSEAR specifications, if required
- Economics neutral as minimum*

COULD HAVE

- Can be re-purposed or re-deployed
- Manufactured / assembled in the UK
- Complete package solution
- TRL – Commercially off the shelf
- Reduce maintenance visits to NUI
- Low weight of renewable energy package
- Modular design
- Scalable design
- Ability to meet 100% NUI power demand (space limit, use of diesel)*

WON'T HAVE

- Net positive carbon footprint over intended life
- Technology Readiness Level (TRL) < 7
- Increase in current NUI maintenance requirements
- High environmental impact d
- Decommissioning legacy issues

*MoSCoW quadrant selection was changed (for this criteria) post-workshop through further client discussion.

Figure 3-8 - MoSCoW defined evaluation criteria for NUI platforms

3.4. Technology Identification

Once the MoSCoW analysis had been carried out, the next stage was to identify the potential technologies that should be considered as part of this study. To achieve a comprehensive and unrestricted technology identification phase, an open workbook was used with the team to record all technology options. The template was set up to record technology options in the following sequential process:

I. Products
II. Integration
III. Solutions

As shown in Figure 3-9, the initial list of PRODUCTS was split down by INTEGRATION categories and further suppliers/OEMs were researched to explore developments within that technology grouping. Finally, through supplier engagement and better understanding of the REPs available on the market, SOLUTIONS were recorded to form the assessment part of this study (Section 4).

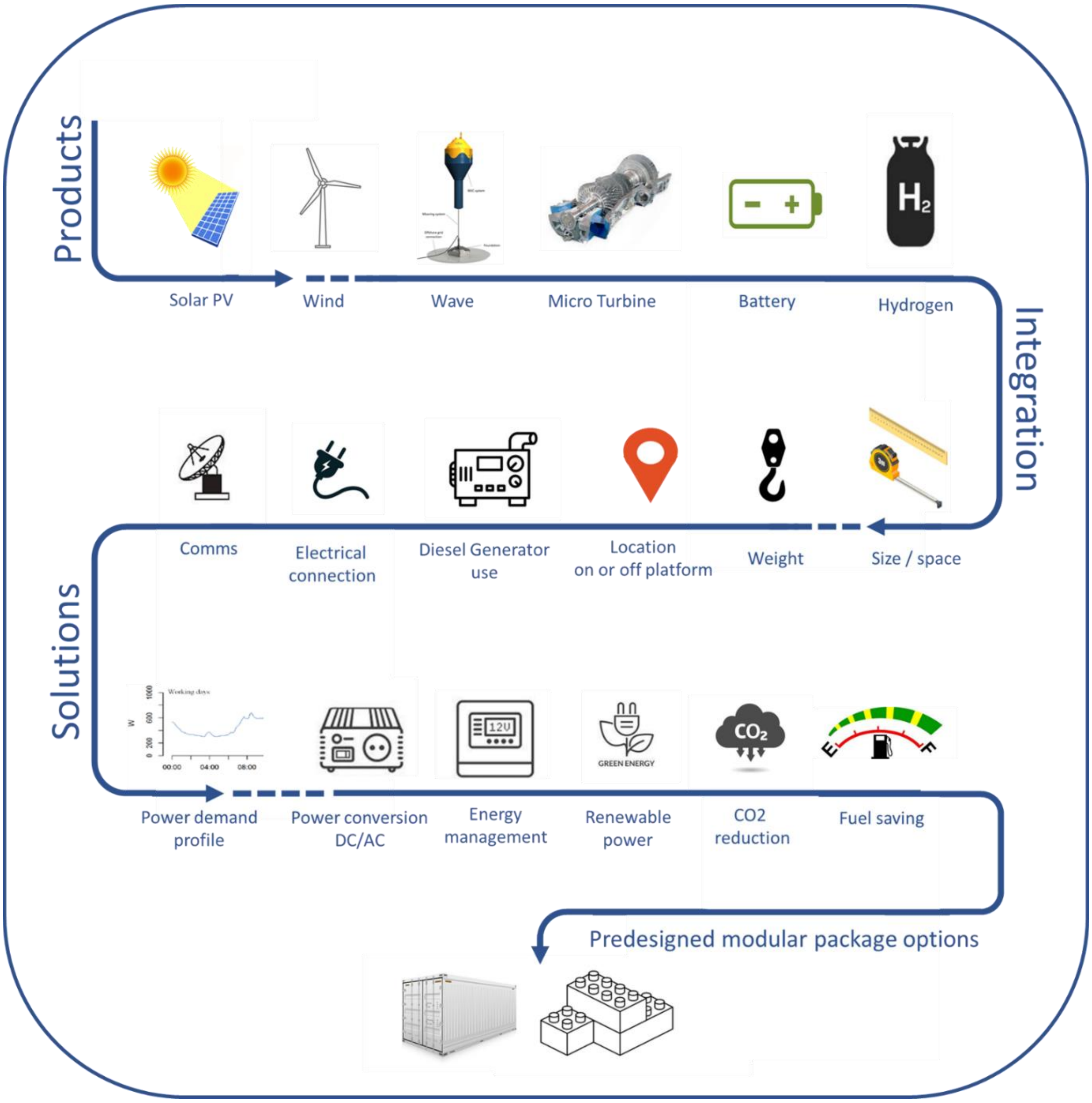


Figure 3-9 - Technology identification and application process

Table 3-3 lists the generic technology types that were identified for preliminary assessment and screening. For the full list of renewable technologies please refer to Appendix B.

Table 3-3 - Identified technologies by category

Renewable Energy Package or Technology	Description	Image
Tidal Image Reference: [8]	Tidal energy is created from the movement of tides and oceans. These technologies include underwater turbines and submerged tidal rigs. Turbines are typically 100kWp+ rated and arranged in clusters.	
Wave Image Reference: [9]	Wave energy is captured from ocean surface waves. There are multiple different technologies used for wave energy (e.g. Corpower half scale demonstrator point absorber shown, 50-100kWp models)	
Floating Module Image Reference: [10]	Floating module with a variety of wind, solar and wave technologies incorporated. (e.g. Sinn Power concept shown, typically 100kWp+)	
Solar photovoltaics (PV) Image Reference: [2]	Solar PVs capture the sun's energy and convert it into electricity. Solar PV would be mounted on-platform. Individual panels 250-400 W (per panel of 1.7x1m) and can be scaled to 10's kW range, given sufficient space.	
Micro Gas Turbine Image Reference: [11]	Micro gas turbine using hydrogen / hydrogen blend. Up to 200kW range is typical unit size.	

Micro Wind Image Reference: [12]	Horizonal axis wind turbine (HAWT) mounted on the platform. Typically, 3 – 10kWp range, on 4 to 27m masts. Platform helidecks and cranes restrict feasible locations of wind turbines. Proximity distances for siting wind turbines on NUIs with helidecks are discussed further in Appendix G.	
Containerised REP Solution Image Reference: [5]	All-in-one transportable container with wind and solar energy plus battery storage. Typical packaged solutions are <10kWp and can offer 1-2kW continuous power. Scalability is possible, subject to platform space and deck weight capacity limitations.	
Electro-Chemical Batteries Image Reference: [13]	Battery energy storage system (BESS) to combine with the diesel generator and / or renewables. Considering different types of battery (e.g. lead acid, Li-ion, Flow battery etc.) Modular by design so can range from 3kW to 100's kW range. Different types offer advantages depending on scale and application.	

Suppliers by Category

As noted earlier (Table 2-2), providers of renewable technologies can be grouped into three main categories: System Integrators, Technology Manufacturers and Hybrid companies who provide both services. Example companies in the different categories are listed in Table 3-4.

Table 3-4 - Service provider categories

Category	Contacted Companies	
System Integrator	Vonk TSS	
Technology Manufacturer / OEMs[2]	Airlight Energy Amphibious Energy CorPower Ocean Eco Marine Power Moss Maritime SD Wind SINN Power	SMA Solar Technology AG SmartFlower Sungold SunWare Marlec Tesla Tocardo
Hybrid Companies	Ryse Energy Motive Offshore	

3.5. Technology Screening

Once all potentially relevant technologies were identified, they were then carried forward to the screening process where their feasibility for deployment on the NUIs was assessed.

The criteria identified in the MoSCoW workshop (see Section 3.3) were used as the basis for this screening. Table 3-5 shows the results of the process, including reasoning for the screening decision. The full screening assessment worksheet is in Appendix D and a list of the identified and screened technologies is shown in Appendix B.

In Table 3-5 an **Amber category** ("ET/Cluster") was also introduced to the screening to show REP technologies, which fail the screening criteria for this particular study (for REPs which may be applied to individual NUIs), but which have potential to support the wider Energy Transition objectives or which could be more suited to a scaled-up solution, potentially offering power to a cluster of NUIs. The wider Energy Transition opportunities have been identified in Section 6.

Table 3-5 - Technology Screening Results

Technology	Screening Result (Pass / Fail)	Reasoning
Off-Platform		
Wave point generator	Pass	Pilot scale demonstrators in operation, with development timeline to full scale. Technology has no impact on NUI operation and can be scaled to fit demand.
Floating module (Solar/Wind/Wave)	Pass	Examples currently in testing phase. Potential to provide supply to higher demand NUIs (>100kW range).
Tidal	ET/Cluster	Currently lower TRL. Solution more suitable for higher power range or clustered solutions. Currently development barriers to deploying in the kW power range (i.e. high cost).
Geothermal heat pump	Fail	Currently low TRL and not applicable to all NUIs. High CAPEX to install for individual NUI.
On-Platform		

[2] engaged as part of study

Technology	Screening Result (Pass / Fail)	Reasoning
Micro wind (<10kW)	Pass	Installed and proven technology in offshore environments.
Solar PV	Pass	Installed and proven technology in offshore environments.
Containerised Solutions	Pass	All in one package providing 100% renewable energy. Currently installed and operating on offshore platforms.
Small wind (<500kW) - off Platform	ET/Cluster	A small number of off platform wind turbines will be expensive due to the need to mobilise large plant to install them. Fixed turbines required large/deep foundations. Floating turbines require large mooring lines and are unlikely to be practical in the shallow SNS water.
Other - Energy Storage		
Batteries (i.e. Li-ion)	Pass	Batteries to be combined with other options as part of a package solution. Installed and proven technology in offshore environments.
Flow battery	Pass	Batteries to be combined with other options as part of a package solution. However not proven technology in offshore environments.
Hydrogen bi-directional storage unit	Pass	Four units in trial phase with no issues at present. Containerised solution with low installation and maintenance risks.
Compressed air energy storage	Fail	Small scale applications low TRL. Subsea storage not best suited for shallow water, generally need depths of >100m.
Liquid air energy storage	Fail	Small scale applications low TRL. High CAPEX for single NUI solution.
Other Technologies		
Micro gas turbine	Pass	Installed and proven technology in offshore environments. High fuel flexibility and fuel efficiency. Skid-mounted solutions offer packaged/containerised option for simplicity. Immediate carbon savings vs diesel use.
Fuel cell	ET/Cluster	Fuel cell is only one component of overall system. Low lifecycle efficiencies, and potential dependence on desalination plant. Would require further infrastructure and CAPEX to create full solution.
H_2 gas turbine	ET/Cluster	Some NUIs don't have existing gas turbine. Source of hydrogen provides additional complexity and cost (incl. need for storage and desalinated water).
Turbo expander	ET/Cluster	Additional infrastructure may be required for solution to operate. May be in conflict to production operations.
Direct air capture technology	Fail	Small scale applications low TRL. High CAPEX for single NUI solution.
Gas turbine improvements	Fail	GTs are only applicable to a small proportion of NUIs at present. Optimising efficiency/fuel use is only expected to bring modest savings and is not a pathway to carbon free power generation.

Technology	Screening Result (Pass / Fail)	Reasoning
Subsea electrical power distribution	Fail	High CAPEX required to install subsea cables. Would be required to operate at a higher voltage to minimise losses and hence an on-platform transformer would be required

3.6. Supplier Contact Findings (for REP Data Gathering)

A range of suppliers were contacted to provide information to support the further options assessment which followed Screening. A Supplier Questionnaire work sheet (in Appendix F) was developed to help identify areas where information was required and to provide a consistent basis for the information gathering and focus discussions with the suppliers. Table 3-4 lists the companies that were contacted as part of this study.

After the initial round of engagement with suppliers, a gap analysis was completed to identify consistency of received information across suppliers. Once gaps were identified, required outstanding information from suppliers was followed up. The gap analysis identified a lack of CAPEX information across the technologies considered. The impact of this on the CAPEX / OPEX analysis work is discussed in section 5.1.

The received supplier information collated as part of this study will be made available as a Zip folder to the NSTA.

4. Assessment of Screened Options

The screened options remaining from the process outlined in Section 3.5 were taken forward for further assessment as described below.

4.1. Screened Options Summary

Based on the research work and supplier discussions, the REPs were investigated in closer detail by market offering, technology type and application. The process of assessment is discussed in Section 3.4 and Figure 3-9. Table 4-1 provides some further details of the options which were refined and taken forward, including space and weight requirements.

Table 4-1 – Screened Options Summary including Space and Weight

Application	Technology	Description	Power rating (kWp)	Space requirement	Indicative Weight Loading
Off platform (in close proximity to NUI)	Wave energy generation device	Inertial Sea Wave Energy Converter (ISWEC) tethered to seabed, e.g. buoy.	Indicative 50-100kW per device	Off platform, rigidly moored to seabed. Half scale pilot of approx. 16m x 4m	Connection equipment only on platform, hence negligible
	Floating module; could be ship-shaped design or pontoon.	Floating platform with various; wind, wave and / or solar in the 100's kW range.	100's kW	Off platform, tethered Modular design in 10 x 20m blocks.	Connection equipment only on platform, hence negligible
On platform; (individual or as part of integrated package)	Solar PV	Platform mounted options - with/without modifications e.g. rigid, flexible, or tracking type	Panels 250-400W range per panel (1.7x 1m).	~150-230 W/m^2	Negligible compared to NUI deck capacity (approx. 17kg per panel)
	Micro Wind (<10kW)	Platform mounted HAWT	Turbines 3kW, 6kW	4-27m mast. Rotor dia. 3.9m or 5.6m (see also Appendix G)	Negligible compared to NUI deck capacity (for sub 10kW)
	Micro Gas turbine	Using gas available on platform	Up to 200kW is typical	1.7 x 3.7 x 2.5m (skid mounted)	Approx. 2000kg for 200kW unit
On platform; pre-packaged container	Amphibious Energy, Motive Offshore	all-in-one, transportable package (incl. Wind, solar, BESS)	8kW rated for 20ft container, to provide 1kW continuous power	2.3(W) x 2.5 (H) x 6m or 12m (L) (20 or 40ft, L) containers	10 to 20Te typical per container (around 700-1500 kg/m^2)
	Motive Offshore; Renewable Hybrid Power Container		6.4kW typical, scalable	2.3(W) x 2.5 (H) x 6m or 12m (L) (20 or 40ft, L) containers	10 to 20Te typical per container

Application	Technology	Description	Power rating (kWp)	Space requirement	Indicative Weight Loading
On platform - engineered package	e.g. VONK, Rhys Energy, TSS	system integrator designs system to fit specific installation (typically incl. Solar + battery + diesel back up)	3 to 7.5kW (offering 500W to 1kW continuous power)	2.3(W) x 2.5 (H) x 6m or 12m (L) (20 or 40ft, L) containers	10 to 20Te typical per container
On platform – energy storage ONLY	Hydrogen bi-directional storage unit	Containerised package that can store surplus renewably generated energy as H_2 and generate electrical power from the H_2 to avoid need for diesel as back up	8kW (current quoted rated power)	Not available, but expected to be container mounted	TBC
On platform – energy storage ONLY	Electro chemical battery	Battery energy storage to combine with the diesel generator and / or renewables.	3kW Scalable (up to 130kW),	1.3 x 1 x 2.2m (for 130kW module)	2,199kg for 232kWh module (Li-ion) 238kg per ~10kWh module (lead acid)
On platform – energy storage ONLY	Flow battery	Packaged flow battery; anode/cathode tank store (possible subsea install)	28kW min size, and scalable	6m x 2.5m x 2.4m per module	25Te for 28kW module (224kWh)

4.2. REP Power Generation Categorisation

Figure 3-3 shows that many of the NUIs in the study have an installed power rating of 100kW or more. For the ten example platforms (for which full data was available) listed in Table 3-2, the mean current annual power demand varies between around 10-60kW , and Figure 3-7 shows that the peak power may be significantly higher than the annual mean.

The platform demands present a challenge for REPs, which for the proven concepts are mostly relatively low power generation devices or systems fitted to the topsides and requiring more space than is generally available. In most platform cases it is therefore probable that an REP will be used in a fuel offsetting mode (i.e.in conjunction with the operating power generator), rather than fully replacing hydrocarbon generation. This approach aligns with the premise that the installations should retain their current generators for powering safety critical equipment (started in Section 1.6), so the study progressed on this basis.

To assess the REPs that may be applied for different NUI power demands, three REP power supply banding categories were defined. These are as shown in Table 4-2.

Table 4-2 - REP power demand contribution categories

Category	Power demand (rated power, peak) of REP
Low	<10kWp
Medium	>10 to <50kWp
High	>50kWp

Examples of the renewable technologies needed to meet these power demands are shown in Table 4-3. The REP scheme may be a combination of multiple technologies, to suit the characteristics of the platform.

Table 4-3 - REP details by demand category

Category	REP Power (peak)	Example REP requirements for peak power demand
Low	<10kWp	25 solar PV panels (1.7m x 1m =43m^2), or 4 x 3kW micro wind turbines, or 1-3 containerised power packages* + associated solar panels and wind turbines
Medium	>10 to <50kWp	For 50kWp: 125 solar PV panels, or 9 x 6kW micro wind turbines, or 4 large, containerised power packages + associated generation devices 1-2 x wave point buoys or floating energy units
High	>50kWp	For 100kWp: 250 solar PV panels, or 17 x 6kW micro wind turbines, or 2-4 x wave point buoys or floating energy units

* Containerised packages comprise the power generation and controls & management elements in an integrated REP solution.

In Table 4-3 the example packages are sized to provide the stated power at peak periods and may be matched with a NUI with a power demand of not less than that value. However, the highly intermittent nature of renewable energy generation results in the REP providing this power for only a small proportion of the time, so a platform with an average load demand of ~10kW will need around ~87,600kWh of energy each year, but will require 'oversized' renewable power generation capacity to meet this need, with energy storage (e.g. battery).

Table 4-3 shows that, for the example packages, the listed on-platform fitted technologies require a relatively large amount of space. This may not be available on small, congested installations such as NUIs that are the subject of this study, and hence it appears that on-platform technologies are unlikely to be able to provide more than a small proportion of most individual NUI platform operational energy needs. There may be opportunities to optimise the configuration by using a mixture of technologies but it will be challenging to meet higher power demands. Other opportunities may exist for off platform options for elements (subject to technology readiness) of the provided renewable package, or a dedicated power generation platform configuration for clustering which may warrant further review on an asset specific basis.

In this section the applicability of different REPs to meet different energy requirements is investigated. Technology costs are examined in Section 5. On a platform-by-platform basis, the balance between useful contribution of clean energy from renewables and diesel genset reliance will vary as a function of the platform power demand and the available space to fit the new generation technologies. The benefit of fitting the REPs will also be strongly influenced by the NUI remaining operational life and anticipated time in Lighthouse Mode.

The REP power demand contributions to the NUI will be in one of the following categories:

i. Diesel as baseload (REP as peaks)
ii. Diesel as peaks (REP as baseload)
iii. 100% renewables, no diesel[3] (applicable only to low demand installations)

Energy may be provided to the NUIs in the following NUI operational modes:

i. Producing (Operational),
   Manned (% of time)
   Unmanned (% of time)
ii. CoP (late life to CoP)
iii. Decommissioning mode (warm stack and cold stack), including during any facilities simplification

[3] Except for emergency back-up supply for safety critical systems

iv. Lighthouse mode
v. Post Oil & Gas life (e.g. to support Energy Transition), if relevant

Figure 4-1 presents the NUI operating modes graphically against the REPs technologies screened for the study. The above-defined power demand categories, have been overlaid to show which REPs are applicable for these categories.

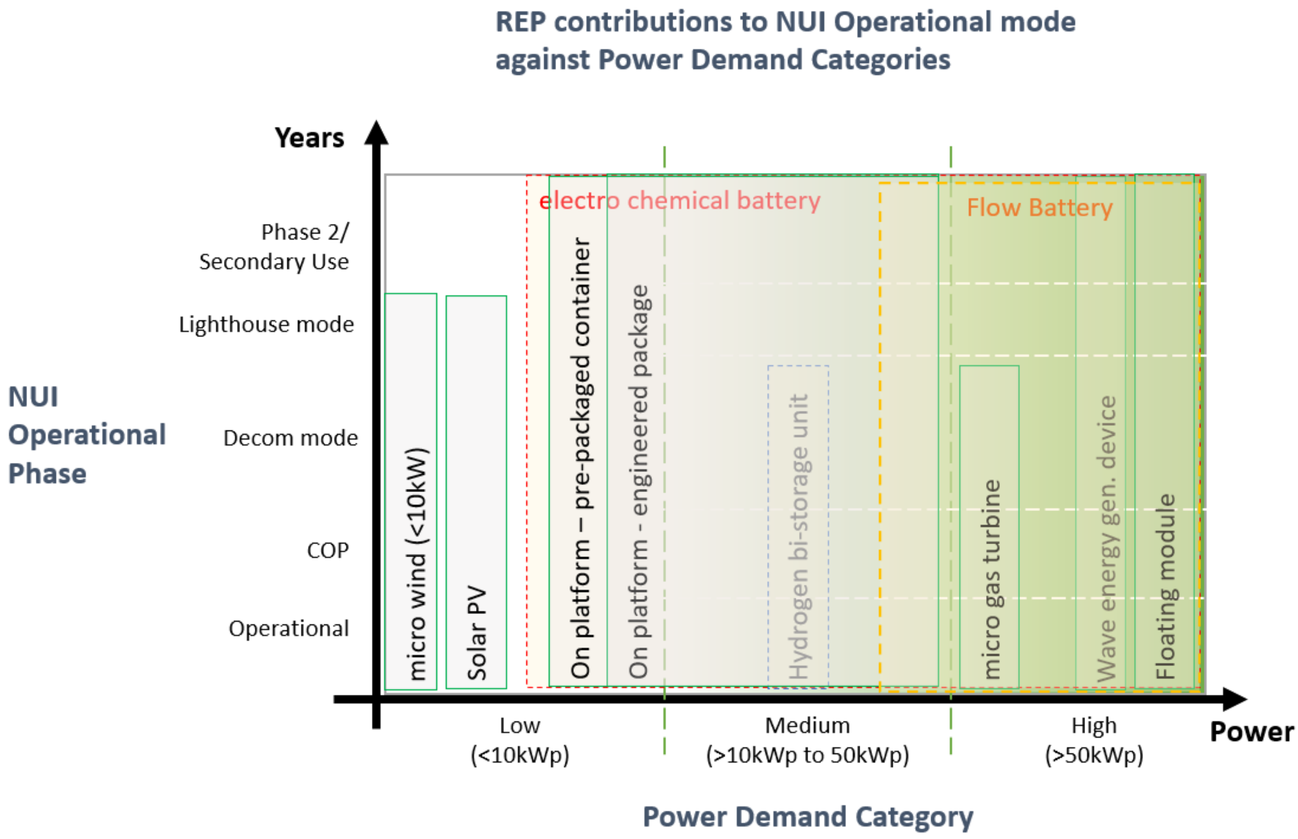


Figure 4-1 - REP contributions to NUI Operational mode against Power Demand Categories

Figure 4-1 shows that solar PV and wind are low power demand contributors, but are applicable to all stages of NUI life. The packaged options (both pre-designed and bespoke engineered) are low to medium power demand solutions, with wide application to NUI operational modes. Finally, the off-platform wave and floating technologies potentially offer larger power generation (by rated power). The 'off-platform' technologies are however not fully mature and are likely to be better suited to NUI clusters or to meet a larger power demand to reduce average cost (per kWh). The energy storage options are overlaid on this chart in blue, green and yellow outlines (with dashed outlines). The storage solutions considered have wide applicability and can be scaled accordingly, however the flow battery has some constraints on size and suits larger applications.

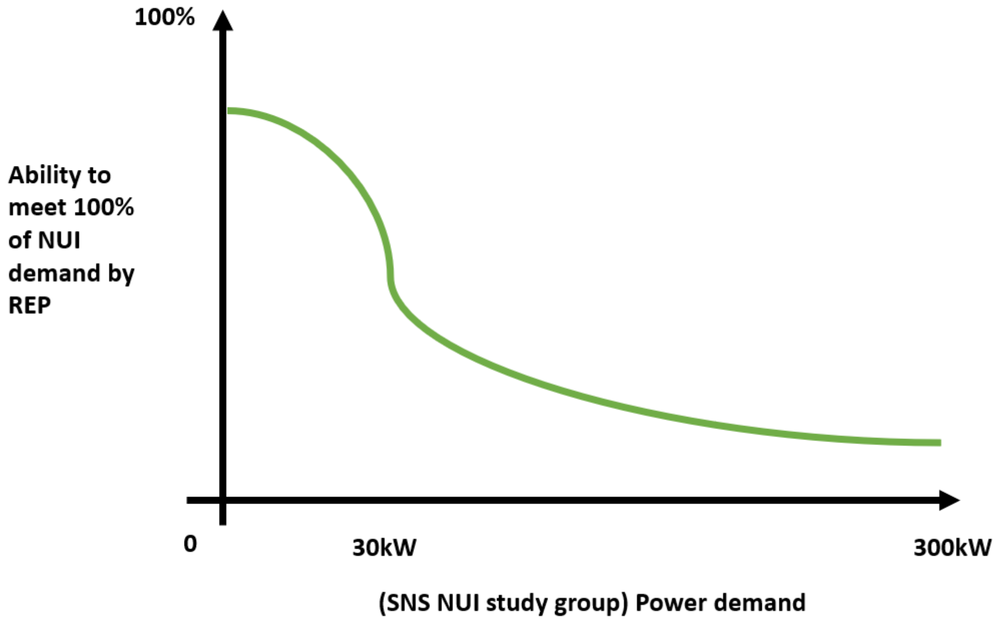


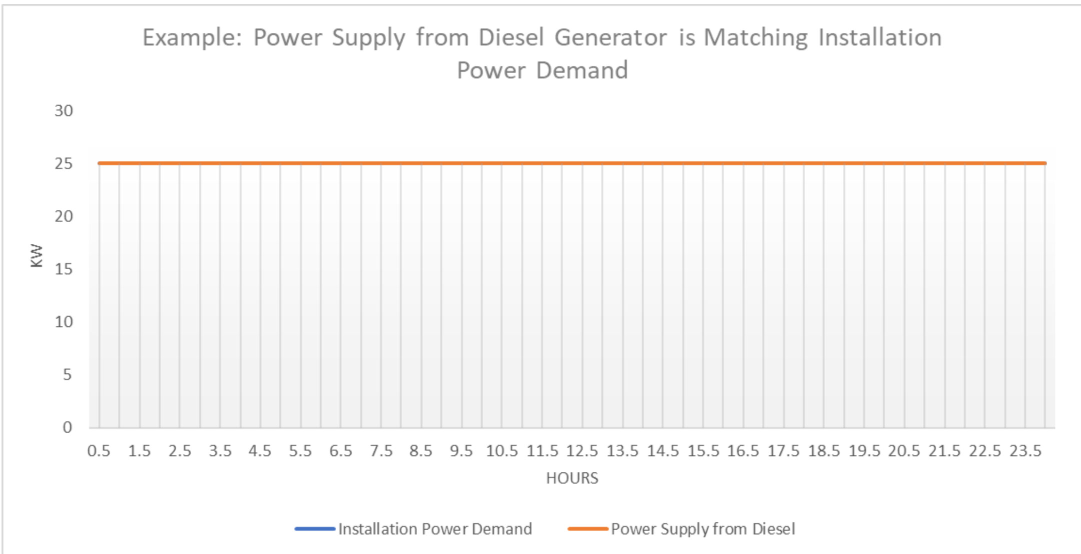
Figure 4-2 - Potential Contribution of REPs by Rated Power to diesel offsetting

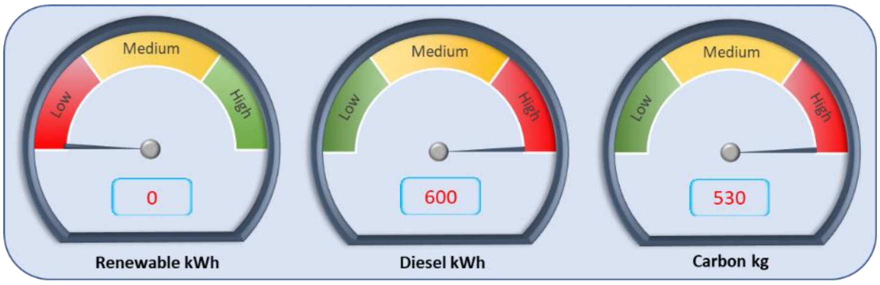
From the earlier discussion of NUI Power categorisation (see Table 4-2) the challenge to meet NUI demands of greater than around 25kW is significant and limits REP options considered in this study to just a handful of off-platform ideas. Figure 4-2 presents (indicatively) the level of REP contribution possible across the NUI study group by power demand. This shows that for smaller power demands (less than around 25kW) it is theoretically possible to provide 100% of the demand profile at peak renewable energy generation times (e.g when the sun and/or wind is strong). The influence of intermittency of renewable energy generation, and potential build up of packaged REP solutions to best meet a platform's energy needs is explored further in Section 4.3.

4.3. Packaged Options - Case Study Example

To understand how a REP could contribute to the power demand of a NUI installation, the power demand and supply need to be compared. This is explored in the example set out below.

For simplification, if we assume an installation has a diesel generator rated at 100kW and a constant load of 25kW over a given day, the supply and demand profile would be that shown in Figure 4-3, i.e. the diesel generator supply always matches demand and hence it is only possible to see one single line in the figure.





Diesel: 600kWh, Renewable:0kWh, Carbon emissions: 530kg

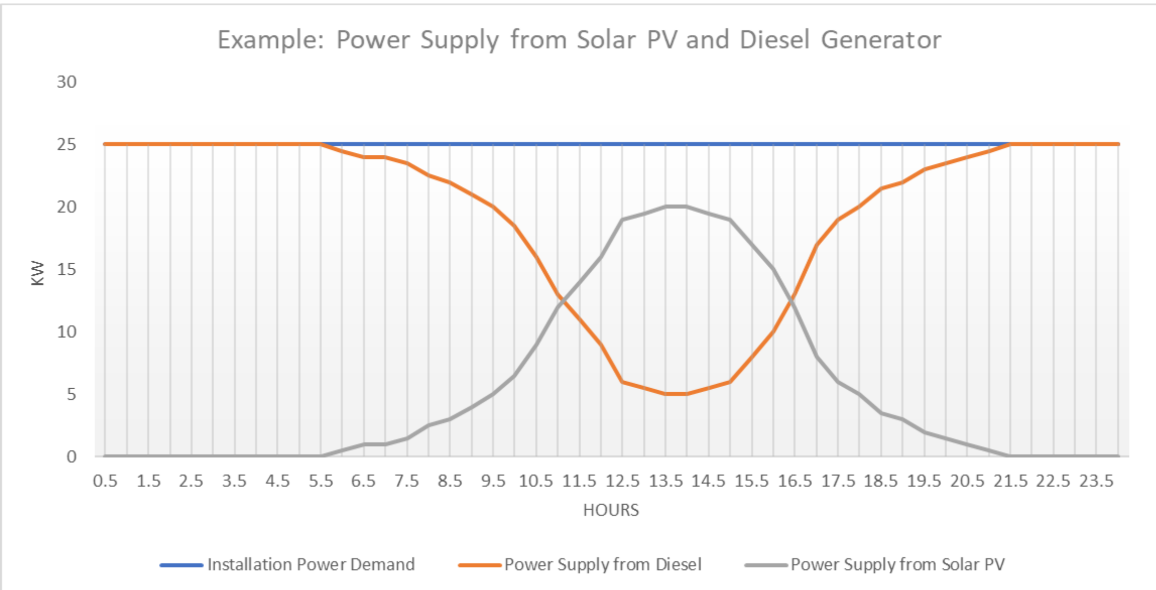
Figure 4-3 - Power supply from diesel generator matching installation power demand

If, for example a 20kWp solar PV system is now connected in tandem with the diesel power supply, when the solar PV system is producing power, the diesel generator would effectively see a reduced load and therefore reduce its output proportionally by the contribution from the solar PV system. A solar PV system only produces power in daylight hours and its power output is proportional to the received solar (direct and diffuse) irradiance, therefore the resulting daily power output profile from a solar PV system is a bell-shaped curve with the peak around mid-day / early afternoon. For the example 20kW solar PV system, assuming sufficient solar irradiance is received (summertime), this would result in a peak of 20kW power output at the top of the bell curve, declining to zero output at either side based on sunrise and sunset times.

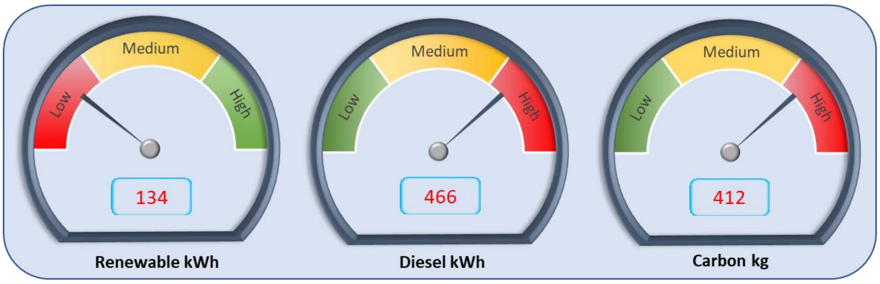
Figure 4-4 shows the solar PV power supply curve. As the solar PV power output increases within the day it can be observed that the required power output from the diesel generator decreases if the overall power supplied (solar and diesel) remains constant at the 25kW demand.

1kWp of solar PV would require a minimum of circa 7m^2/kWp . Adjacent banks of panels need little space around them, however the installed angle and aspect (due south being best) may result in less than optimum energy yield influencing the required area take up. Examples of inclined solar PV panels on installations can be seen in Table 3-3. It should be noted that on space constrained NUIs the siting of solar PV may need to be adapted to suit available space, e.g. vertical, side or curved surface mounting.

The required area therefore becomes a trade-off between installed kWp and resulting energy yield. For 20kWp of solar PV a minimum panel area of 140m^2 is needed, and possibly more to optimise energy yield and working within installation constraints. The weight of solar PV is circa 67kg/kWp excluding any mounting frame / fixings, resulting in circa 9.6kg/m^2. This is negligible compared with platform deck loading capacity (typically around 1500kg/m^2)



Case 2: NUI with (20kWp) Solar PV



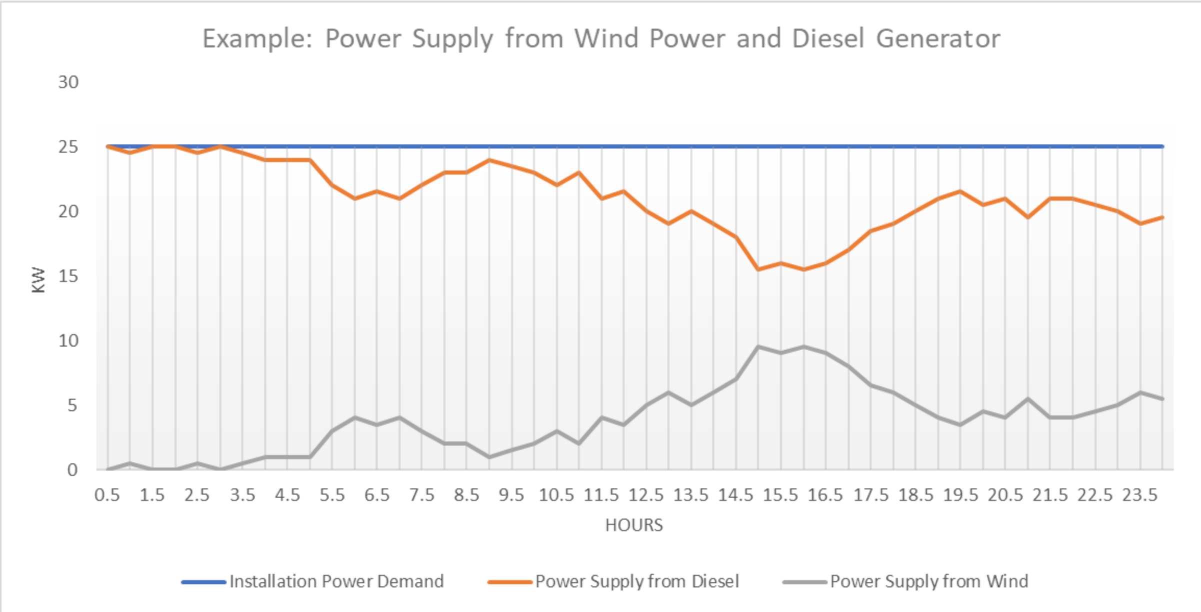
22% reduction in diesel fuel and carbon emissions

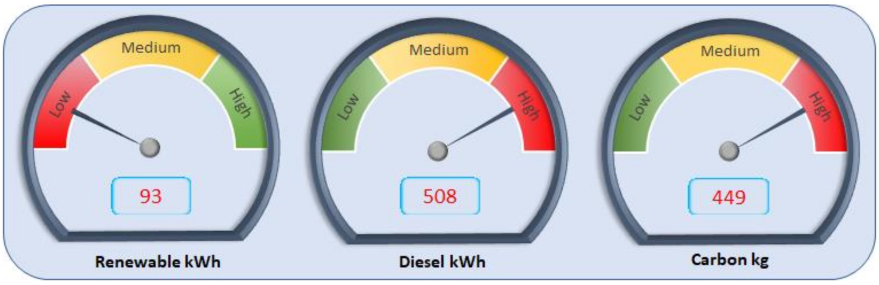
Figure 4-4 - Power supply from 20kWp Solar PV and diesel generator

In wintertime, the solar PV contribution would be less as the bell shape curve would be narrower (less daylight hours) and flatter (less solar irradiance).

A similar example can be examined for wind power. The power output from a wind turbine is proportional to the cube of the wind speed and turbines typically have a minimum cut in wind speed of 2 m/s and maximum operational wind speed of 25 to 30 m/s. The maximum power output of a wind turbine typically occurs around 9 m/s [14], but varies by design / supplier. Figure 4-5 demonstrates a power output from an example 10kWp wind turbine and the resulting power output from the diesel generator to meet the demand requirement of 25kW.

A 10kWp wind turbine typically has a rotor diameter of circa 10m, which would mean each blade is 5m long and would thus have a 5m overhang at either side of its nacelle / installation point. Clearance distances would also need to be considered with surroundings. The tower height is also an important factor that would affect the overall energy yield as the higher the tower height, the higher the windspeed is likely to be at any given time. A 10kWp wind turbine rotor and nacelle would have a weight of circa 1,000kg, in additional to this would be the tower weight. For the platform structure, a wind turbine would be considered to be a point load with applied bending moment as the base of the tower is relatively small.

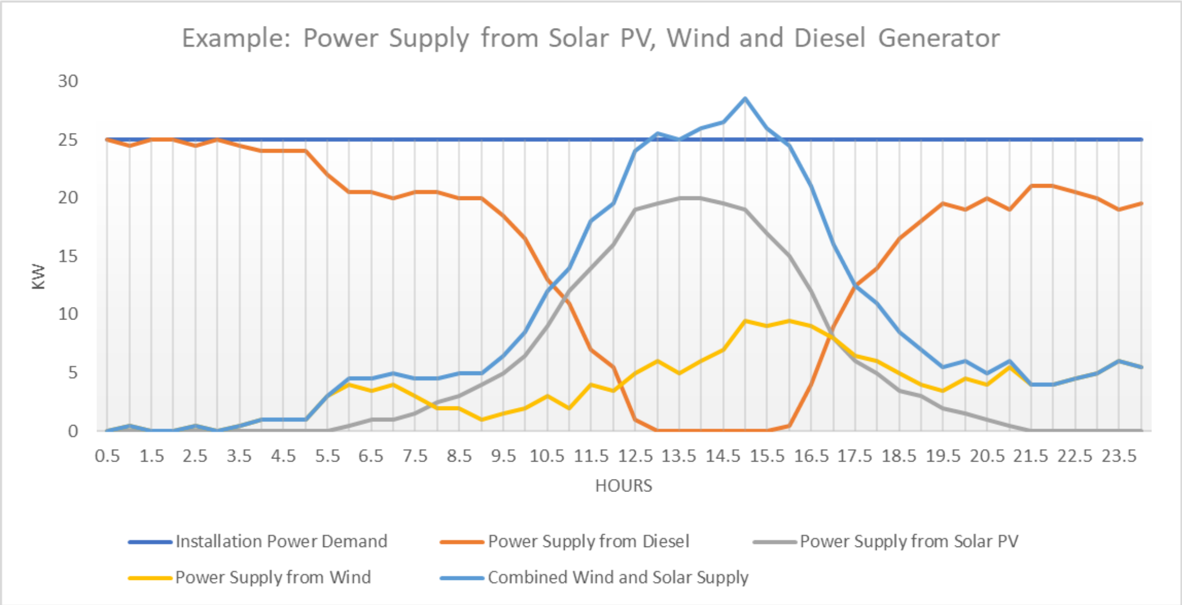


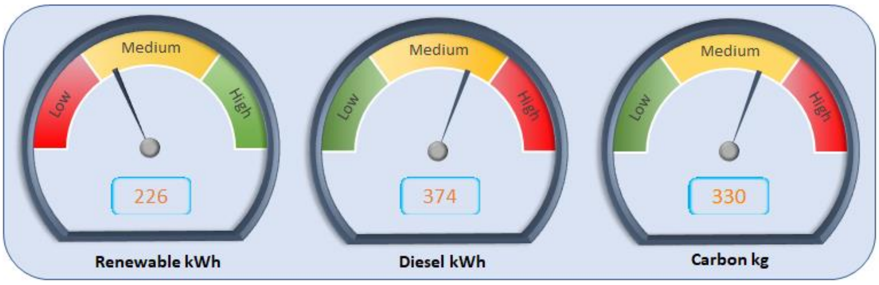


15% reduction in diesel fuel and carbon emissions

Figure 4-5 - Power supply from 10kWp Wind and diesel generator

Assuming sufficient space, it is possible to combine multiple different types of renewable power generation so that the generation profiles become amalgamated. Taking the 20kWp solar and 10kWp wind example above, the resulting amalgamated supply profile is shown in Figure 4-6. It can now be seen that for a small proportion of time, the combined wind and solar supply exceeds the demand and the required output from the diesel power generator drops to zero.



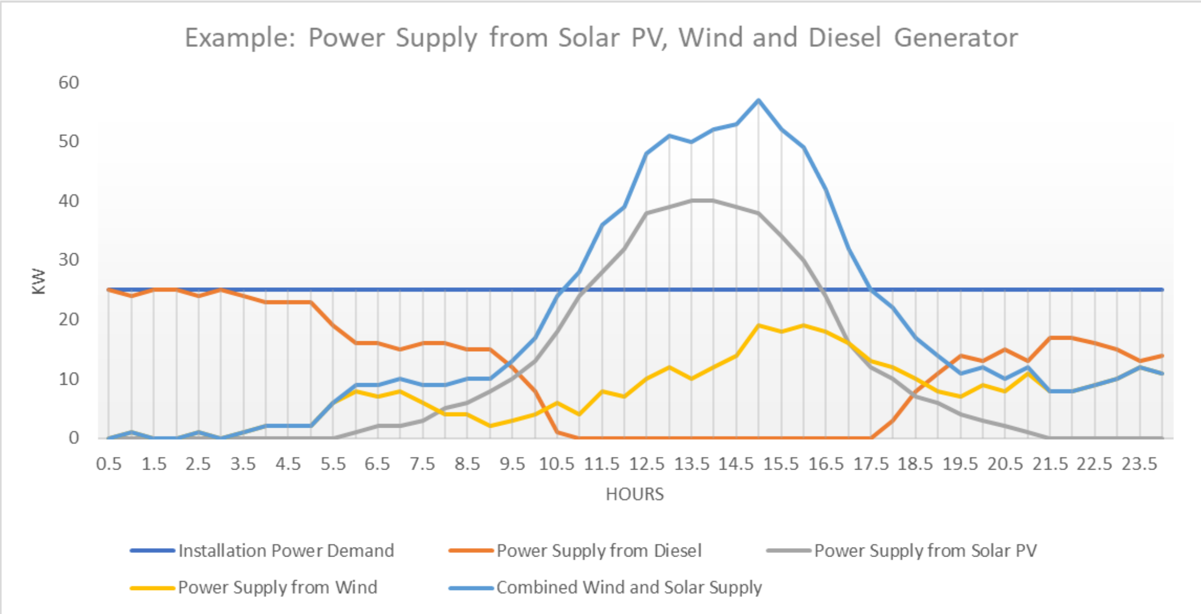


38% reduction in diesel fuel and carbon emissions

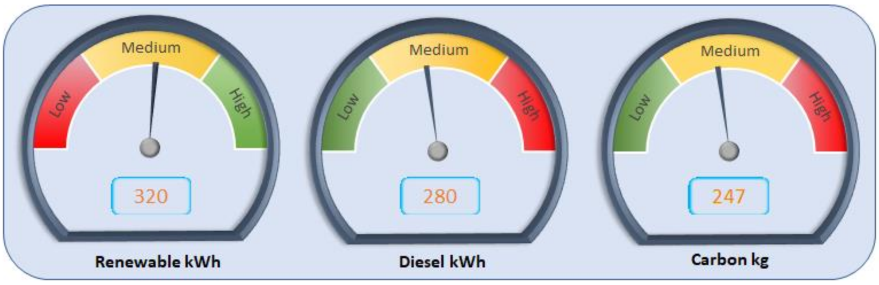
Figure 4-6 - Power supply from 20kWp Solar, 10kWp Wind and diesel generator

Power supply greater than demand starts to indicate that not all available renewable power generated from the installed renewable energy system size is being captured. When this is the case, any wind power generation may need curtailment, possibly in the form of a resistive heat dump load (for an off-grid system), the system payback is reduced and there are possible power supply stability issues with operating a diesel generator at such a low load where carbon emissions from the diesel generator on a per kWh basis will be highest.

If the installation size of the solar PV system and number of wind turbines is increased e.g. 40kWp of Solar PV and 2 x 10kWp wind turbines, with the same power demand of 25kW, the amount of excess power would further increase as shown in Figure 4-7.



Case 5: NUI with Solar F + Wind (larg install)



Renewable Utilised:320kWh, Renewable Unutilised:132kWh

53% reduction in diesel fuel and carbon emissions

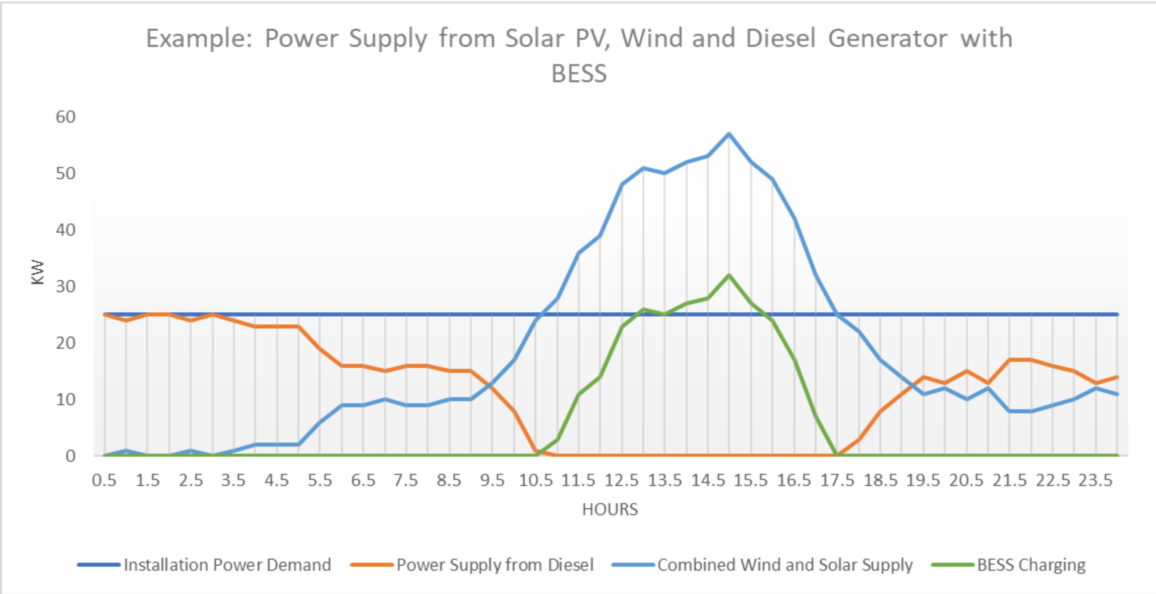
Figure 4-7 – Hybrid power supply with increased solar and wind capacity

It now becomes clearer that in a particular time period there is excess power supplied and this would be unharnessed, unless energy storage is introduced. Energy storage would capture excess renewable power at times when supply is higher than demand and release energy when supply is lower than demand.

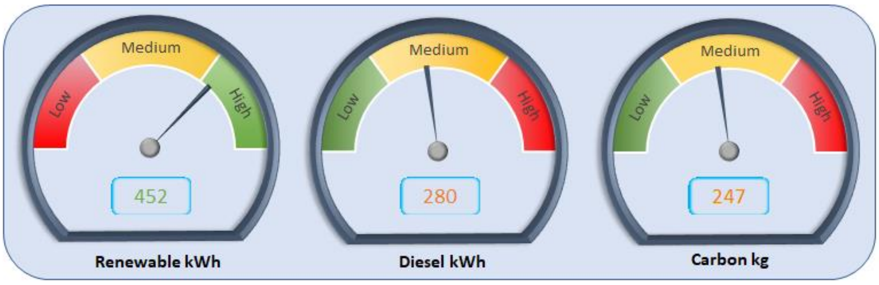
In the examples above, the diesel generator would still be operating at no load and hence would still consume diesel and produce carbon emissions, albeit at a reduced rate. The generator in these examples, is ‘idling’ but not doing useful work, to avoid the need for stop-start and swings in performance.

To address this, remote/automated energy management can be introduced with a suitably sized energy storage device such as a Battery Energy Storage System (BESS) to capture all available renewable power and to start / stop the diesel generator when required so that the diesel generator is operating for a shorter time but at a higher load factor resulting in lower overall carbon emissions and improved emissions per kWh. While providing a benefit in terms of reducing platform carbon emissions, the addition of the BESS elements to the renewable package solution adds CAPEX and OPEX, altering the economic viability of the scheme.

Figure 4-8 shows a simplified version of Figure 4-7 showing the combined wind and solar power supply and demonstrates that energy storage would be triggered at times of excess supply.



Case 6: NUI with Solar P + Wind + BE (large install



53% reduction in diesel fuel and carbon emissions

Figure 4-8 – Renewable energy power supply with diesel generator and energy storage

Once the combined wind and solar power supply falls below the demand, instead of utilising the diesel engine, the battery can be discharged to meet the required power demand up to a point when the BESS becomes exhausted and all the accumulated energy from earlier in the day has been discharged. At this point the diesel generator would need to supplement the power supply.

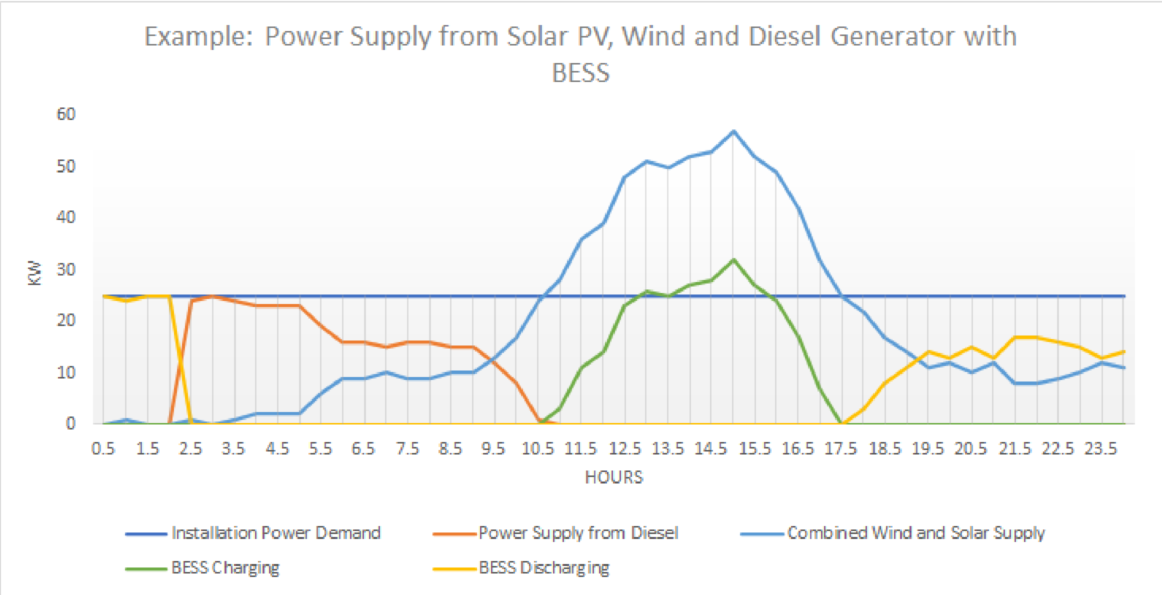
It should be noted that this is a simplified example case and the installed capacity of renewable power generation and energy storage system would need to take into account factors such as:

- Power demand profile
- Renewable power source size, seasonal variance, and power generation probability
- BESS technology and charge / discharge rate
- BESS capacity for daily and seasonal variance
- BESS charge / discharge efficiency
- Overall energy management system

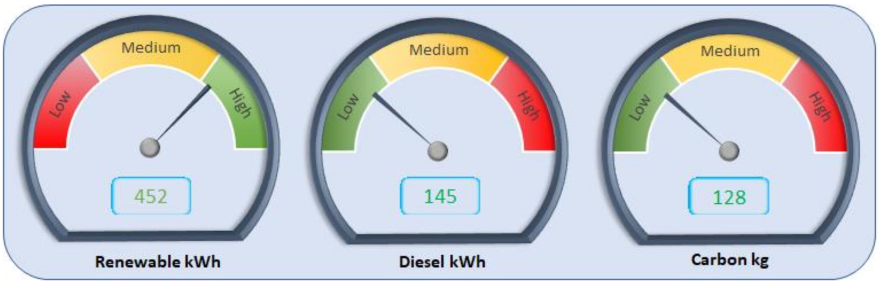
To capture the excess renewable power generation of 132kWh, the battery package would typically need to have a capacity larger than this figure due to the charge / discharge rate, range of depth of discharge, resulting number of cycles and the effect that this has on its life. These factors also vary by battery technology. If we assume a depth of discharge of 60%, this would mean a battery package with a capacity of 220kWh. For Valve Regulated Lead Acid (VRLA) batteries, this would result in a weight of circa 6,700kg and minimum area of 3.5m^2, resulting in 1,924 kg/m^2 not considering spacing and racking / fixings. Typically, batteries would be installed within a container and hence the weight would be more distributed and probably load the platform by less than the typical NUI deck capacity of 1500kg/m^2. If there are space or weight limitations, it may be possible to install several large battery storage units subsea[4], however this would incur the probably large expense of subsea works which includes seabed preparation, unit placement and cable installation work.

It can be seen in Figure 4-9 that power from the diesel generator is still matching the difference between demand and the supply from wind and solar renewable generation. Assuming a suitably sized and capable BESS, it would be possible to operate the diesel generator for a shorter period at a higher fixed load. For the example in Figure 4-9, the total energy supplied from the diesel generator is 146kWh; the same could be achieved by operating the diesel engine at a load of 50kW for 3 hours (150kWh) or other variations depending on the BESS specification. This is likely to lead to greater engine operating efficiency and thus lower emissions.

It is emphasized that the REP and BESS package shown in Figure 4-9 is sized for high environmental energy yield conditions and that daily and seasonal variations will result in less energy being generated and stored.



Case 7: NUI with Solar P + Wind + BE (large + optimised)



76% reduction in diesel fuel and carbon emissions

Figure 4-9 - Renewable power supply with diesel generator and storage

The above generation analogy can be applied to other renewable generating technologies such as wave energy converters.

In conclusion to the above, for an installation currently in production it is possible to meet a proportion of the platform electrical energy demand by installing renewable generating technologies on the installation itself, however to meet a higher proportion or 100% of the demand, more space would be required and, in all except a small number of low demand/ high available space platform cases, would prompt the need to consider off-platform installation options such as floating solar / wind and wave energy. These are however generally not currently yet mature enough to be deployed at scale. Alternatively, an energy 'hub and spoke' model where there is a central repurposed platform for energy generation and feeding a cluster of NUIs, also has potential.

[4] See example at https://oceanpowertechnologies.com/subsea-battery/, accessed 24/05/21

Example REP to meet full 25kW Power Demand

Building on the above examples, an estimate of the REP installed power to meet the full power needs of the platform was made. This case is illustrative and shares the similarity with the above examples, that the REP is sized based on the optimum conditions for energy generation and not those experienced over a whole year. This is because determination of the energy generation and storage concept to meet a platform's complete needs throughout the year requires assessment which is more detailed than is achievable in this study.

In this case the installed capacity of the solar PV, wind turbines and energy storage would need to be increased from those cases presented above, to provide a system that could be capable of providing 25kW from 100% renewable supply for a day. This would require 50kWp of solar PV, 3 x 10kWp wind turbines and energy storage with a usable capacity of around 250kWh.The power profile for this arrangement is shown in Figure 4-10.

As identified earlier in Section 4.3, 1kWp of solar PV would require a minimum of circa 7m^2/kWp (if flat mounted), however this would not result in the optimum energy yield and hence the area required can be greater and is a trade-off between installed kWp and resulting energy yield. Therefore, 50kWp of solar PV would require a minimum area of 350m^2, and possibly up to 500m^2 depending on angle and orientation to maximise the ideal yield in the example. Even with a platform simplified to accept the maximum possible renewable energy generation, this typically indicates that an 'off platform' solution would be required, such as floating solar or wave.

Assuming a battery with a 60% depth of discharge would mean a battery capacity of 395kWh; this would equate to approximately 12,000kg and require a minimum deck area of circa 8m^2 (for acceptable deck loading).

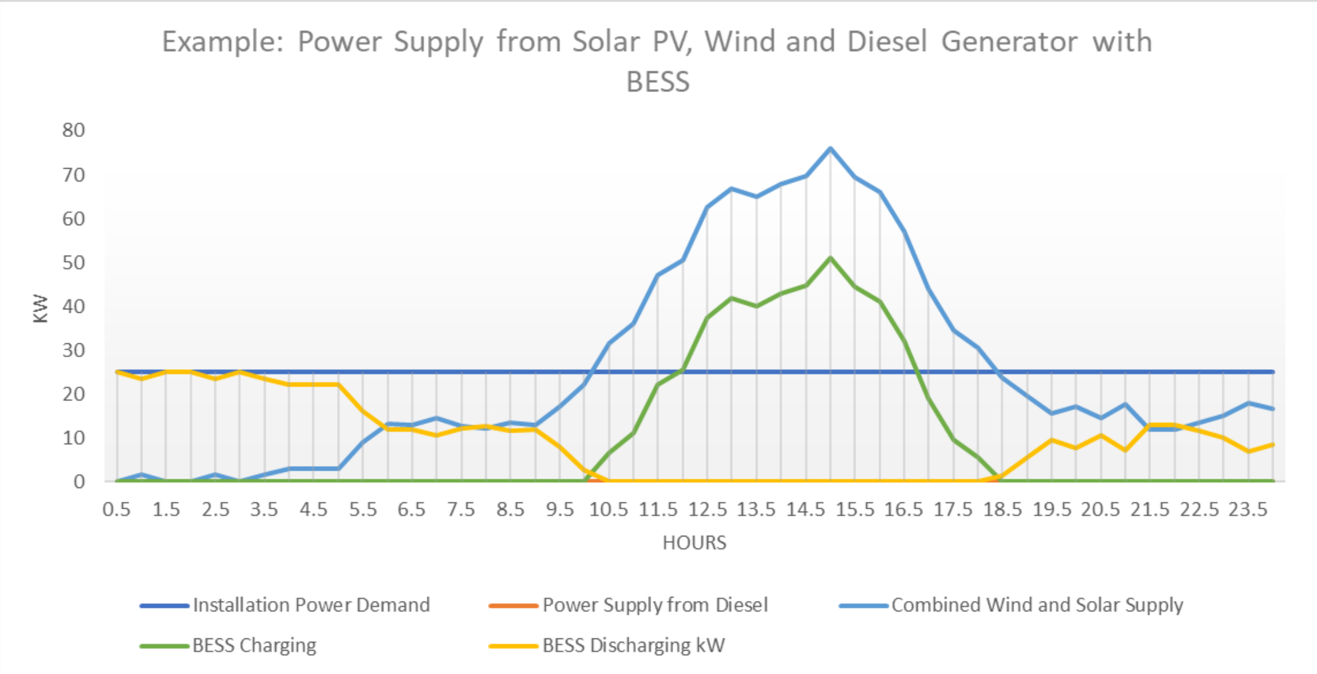


Figure 4-10 – 25kW with 100% Renewables (50kWp Solar PV, 30kWp Wind, 237kWh BESS)

Seasonal variation needs to be considered when designing a 100% REP system and this would require a probability and statistical analysis of energy yields to effectively produce Figure 4-10 for each day of the year and take account of various scenarios used for REP design such as the number of days without wind, more cloudy days in a year etc. to refine the REP system size. Therefore, the above example would need the installed REP capacity increased further to account for seasonal variations i.e. wintertime when day light hours are shorter, and the solar irradiance is less compared to summer.

Seasonal variations would be dealt with by increasing the REP installed capacity, however at times of higher energy yield this will lead to oversupply which would potentially be wasted. Energy storage can be utilised to help with seasonal variation. Battery energy storage is useful for a number of days storage, however for seasonal storage it would require technology that can store energy over a number of months e.g. where energy could be stored in the summer and released in the winter, in particular if that energy is generated by solar PV.

Green hydrogen generation is a potentially viable option for seasonal storage, as excess renewable power can be used to generate green hydrogen which can then be stored for many months. The green hydrogen can then be used as required within a fuel cell to produce electricity. The round-trip efficiency of the seasonal storage and the additional CAPEX would need to be reviewed against oversizing of renewable generation when considering the options. In the study, however there were limited hydrogen-based technologies found to be commercially ready, and typically these are offered at larger scales (MW ranges). As included in the Technology screening, the hydrogen bi-directional unit offers a possible future alternative to diesel back-up systems.

4.4. Strengths/Weaknesses of Individual Technologies

In conjunction with the MoSCoW matrix assessment of the REPs, a Strengths, Weaknesses, Opportunities and Threats (SWOT) assessment was also carried out, to provide a summary of the key points emerging from the assessment. A summary of the SWOT analysis is given in Table 4-4. The full SWOT analysis as well as MoSCoW GYOR matrix are shown in Appendix E.

Table 4-4 - Summary of SWOT analysis

Technology	On/Off Platform	SWOT Summary
Wave Point Buoy	Off-platform	Scalable solution. Low impact to NUI. Low TRL means unlikely to be mature enough for commercial use at present, Suited to large scale deployment (>50kW) or for NUI clustering. Can move/redeploy for secondary life use.
Floating module (Wind/Solar/Wave)	Off-platform	Scalable solution. Low impact to NUI. Lower TRL, potentially high OPEX, Suited to large scale deployment (>50kW) or for NUI clustering. Unclear on survival design, and sea state suitability.
Solar PV	On-platform	Established and proven technology. Space constraints limit scaling. Good flexibility to pair with other technologies, good reliability. Opportunity for novel product types to mould to NUI platform, on increase generation per m^2 (e.g. tracking).
Micro wind turbine (<10kW)	On-platform	Established and proven technology. Some limitations on siting and tower height. The need for ATEX rating would limit supplier selection and add CAPEX. The presence of a helideck, platform cranes and drill rig access limits the installed size and placement.
Micro gas turbine	On-platform	Technology can be sized to meet platform energy requirements. High fuel flexibility, but typically fuelled by natural gas so cannot offset all carbon emissions. If turbines are hydrogen ready, this solution can be used as a post O&G generation option. Packaged solution, simplifies installation.
Pre-packaged container, e.g. Amphibious Energy, Motive Offshore	On-platform	Containerised solution with operational track record. High availability due to combination of wind, solar and battery. Leasing option may also be attractive. Scaling could be limited by space constraints.

Technology	On/Off Platform	SWOT Summary
Engineered container package, E.g. VONK, Rhys, TSS	On-platform	Engineered to NUI platform, so optimises sizing. Typically, containerised solution with operational track record. High availability due to combination of wind, solar and battery. Leasing option may also be attractive. Scaling could be limited by space constraints.
Hydrogen bi-directional storage unit	On-platform	Low perceived TRL, but component parts all individually 'off-the-shelf'. Offers clean energy storage solution and avoids the need for a backup diesel generator. Small scale units at present, with large scale under development. Needs appropriately sized renewable power, which may be space constrained. Demineralised water refill requirement is a potential bottleneck, resulting in increased OPEX.
Electro-chemical battery	On-platform	Established and proven technology. Hardware is dense, and could reach upper limits of platform permissible deck loading. However, modular and can be designed to suit available space. Requires pairing with renewables but can be used standalone with diesel to offer modest carbon savings. Cycles use vs change out and OPEX/ crane requirements are key considerations. Scale up options include siting subsea, or on floating platforms.
Flow battery	On-platform	Established and proven technology. Suited to larger scale, but can offer low cost, reliable energy storage. Cycles use vs change out and OPEX/ crane requirements are key considerations.

For information, guidance on the scale of technology readiness level (TRL) is provided below [15]:

- TRL 1 – basic principles observed
- TRL 2 – technology concept formulated
- TRL 3 – experimental proof of concept
- TRL 4 – technology validated in lab
- TRL 5 – technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- TRL 6 – technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- TRL 7 – system prototype demonstration in operational environment
- TRL 8 – system complete and qualified
- TRL 9 – actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

5. REP Preliminary Cost Assessment

This section summarises a preliminary assessment of the financial incentive to install REPs on the NUIs. The assessment first estimated the current cost of running the existing platform hydrocarbon fuel system and then compared this with the costs of installing and operating REPs; assuming the financial benefits of the renewable energy produced as ‘diesel offsetting’.

The assessment focused primarily on proven technologies, hence most of the REP cases considered involved on-platform solar PV, micro wind turbines and containerised energy solutions. ‘Off platform’ generators were considered as a sensitivity case. Given the earlier conclusion that it will not be possible to meet 100% of the energy needs of most NUIs, the assessment considered the benefit of ‘diesel offsetting’ different amounts of the existing platform hydrocarbon power generation with REPs. This requires the current generator to be maintained and, where applicable, fuel still delivered (albeit at less frequent intervals, due to the lower consumption).

5.2. Supplier REP purchase costs

Suppliers were approached for purchase costs and these are shown in Table 5-5. There are some gaps in supplier information (indicating no data given or in some cases due to data sharing sensitivity).

It is noted that Table 5-5 presents both standalone REP solutions and complete packages, so direct cost comparisons cannot be made from the table. Further work is presented later to enable comparison.

Table 5-5 - Summary of CAPEX for screened technologies

	Indicative CAPEX from Suppliers (£)	£/kW Equivalent (Purchase)
On Platform Technologies		
Solar PV	Price range per panel: Around £720 (marine grade)	Approx. 1,800 £/kW
Micro Wind (<10kW)	20kW non-ATEX ~ £66k 5kW non-ATEX ~ £14k 3kW non-ATEX ~ £10k 3kW ATEX ~ £24k	3,300 £/kW 2,800 £/kW 3,333 £/kW 8,000 £/kW
Micro Gas Turbine	Approx. £250k for a 200kW unit (£1 = $1.36 April 2021)	700 – 1,250 £/kW [16] (£1 = $1.36 April 2021)
Containerised Packages (incl. energy storage)	Price ranges from £120k - £250k (9kW to 11kW ATEX rated). On larger scale, ~ £500k (65kW)	7,700 – 22,700 £/kW
Engineered REP System Integrator (incl. energy storage)	Price ranges from £650k - £950k (10kW to 20kW) *These costs include design, assembly, testing & project management*	47,500 – 78,000 £/kW
Off Platform Technologies		
Wave Point Buoy	Not available; as data only available at pilot scale	Not available
Floating Solar/Wind Module	Not available. Pilot technology	Not available
Energy Storage and Conversion Technologies		
Battery: Li-ion	Approx. £9,000 for 7kW [17]	1,300 £/kWh
Battery: Lead Acid	Approx. £1,600 for ~10kW	210 £/kWh
Battery: Subsea Li-ion	Cost would include subsea installation campaign. Size up to 100kWh usable charge	
Battery: Flow Battery	TBC - costs sensitive to pilot scale demonstrators	
Hydrogen bi-directional storage unit	N/A	N/A

5.3. REP Life Cycle Costs

The life cycle costs are made up of:

- Purchase costs for the REP hardware – as noted in Table 5-5, or estimated where information was not provided.
- *Costs of purchase and/or fabrication of associated equipment*, e.g. mounting frames, fixings and coating for solar panels or cabling and electrical hardware to connect and integrate the REP into the platform's power supply system. For the different technologies these costs are expected to be between

£50k (for a fully engineered, containerised 10kW REP) to £200k (for the structures needed for a 5kW mean containerised system with 80 solar panels and two wind turbines) to £600k (for the cable pull-in structure for an assumed 20kW mean power provision, off-platform device).

- *Engineering, procurement, installation and commissioning cost*. This is the platform operator's cost to design, specify, buy, transport, fit and connect the REP to the platform. This will typically involve a project team of between 2-3 people over several months, with additional expense from an engineering design company and the physical costs from delivery to start-up. Estimated costs in this category vary from £70k (for a single wind turbine and battery pack) to £200k (for a basic containerised REP needing integration and commissioning) to £800k (for an off platform device needing subsea installation work).
- *Operation and maintenance* – this cost covers scheduled offshore visits to the NUI to inspect and maintain the REP and to purchase and replace worn components. Estimated costs over the life of the installation vary from £2k to £80k to £170k.

5.3.1. REP Life Cycle Cost Estimate Approach

The assessment of REP lifecycle costs requires estimates for items and works across a wide range of categories. Within the scope of this study, the aim of the life cycle estimate is only to provide an indication of whether there is a strongly positive or negative financial case for installing REPs on individual NUIs. Many of the figures in the estimate are therefore based on experience and judgement. No discounting of cashflows (for Net Present Value determination) has been made in the estimate , as the estimate approach taken does not justify this.

Estimates of REP life cycle costs for the different NUIs in Table 5-4 were made for the following cases given in Table 5-6. Lighthouse mode of 2 years was assumed in all cases except where noted otherwise. Some cases also consider the removal of the diesel generator at the start of the Lighthouse mode, to examine the sensitivity of the results to ongoing generator maintenance costs.

Table 5-6 – REP Lifecycle cost estimation cases

Case	REP installed	Peak power generation	Average Load power generation (continuous)	Battery storage	Lighthouse mode	Existing diesel generator
1	26 solar panels (44m²)	10kWp	1kW	-	2 years	Retained
2	77 solar panels (130m²)	30kWp	3kW	-	2 years	Retained
3	3x6kW wind turbines	18kWp	5kW	-	2 years	Retained
4	Medium container 52 solar panels 2x6kW wind turbines	32kWp	5kW	-	2 years	Retained
5	Large integrated container 103 solar panels (175m²) 4x6 wind turbines	64kWp	10kW	-	2 years	Retained
6	1x wave point buoy	60kWp	20kW	-	2 years	Retained
7	1x6kW wind turbine	6kWp	1.5kW	**Yes**	**5 years**	**Removed**
8	77 solar panels (130m²)	30kWp	3kW	**Yes**	**5 years**	**Removed**
9	3x6kW wind turbines	18kWp	5kW	**Yes**	**5 years**	**Removed**
10	Large integrated container 103 solar panels (175m²) 4x6 wind turbines	64kWp	10kW	**Yes**	**5 years**	**Removed**

5.4. REP Preliminary Cost Estimate Conclusions

The preliminary cost estimates show that there are some isolated cases (cells with bold border) where the installation of REPs on individual NUIs may offer a positive return. These relate to platforms with CoP dates of at least 2030 combined with the application of large scale on-platform solar and wind REPs.

The following points are noted in considering these findings, and those shown earlier in this section:

1. The estimated costs have large uncertainties and should be considered indicative. The positive values are marginal (in relation to the calculated costs and benefits) and may become negative (or vice versa) with further analysis.
2. The REPs which give positive financial results (Cases 2, 3, 8 and 9) require significant space or access. Earlier discussions in this report indicate that it is unlikely that many NUIs will be able to accommodate 130m^2 of solar panels or three wind turbines.
3. Cases 8 and 9 assume 5 years in Lighthouse mode and the decommissioning of the existing diesel generator. This may not be the case.
4. The retrofitting of small-scale REPs specifically to meet the low power demands of platforms in lighthouse mode is not financially supported.

6. Post Oil and Gas Opportunities

While the preliminary cost assessment does not support installing REPs on individual operating NUIs, there is the possibility that the value of renewable technologies fitted to platforms may be enhanced by generating or storing energy after cessation of hydrocarbon production, to support Energy Transition and Energy Integration.

The study has shown that limited space on NUIs means that established on-platform technologies will generate modest and intermittent amounts of power (few kWs). Available space on the platforms may be increased in late operational life or post CoP by simplification of the platform facilities (as illustrated in Figure 3-6 for Leman Echo), resulting in an increase in the space and access to install banks of solar panels and also possibly several micro wind turbines and energy storage.

For a large platform with space available these schemes may give perhaps 10-20kW of average load over a year and the economics may indicate that this is worthwhile if the REPs are installed early enough, the energy can be used productively, and the post Oil and Gas operating period is sufficiently long. If the NUI has a long remaining period of operating life until CoP, there may be a benefit in installing some of the REPs in the available space now; and extending the deployment after platform simplification to support later Energy Transition requirements. Solar panels, wind turbines and containerised REPs are all scalable, enabling this approach, provided that the platform's electrical power distribution system is modified if needed.

It is therefore recommended that further assessment is carried out on one or more selected, example NUI's to confirm whether this approach may be viable.

As part of the screening optioneering workshop performed during this study, the screened options were discussed in the context of wider Energy Transition and Energy Integration opportunities. Table 6-1 records the outcome of the assessment, presenting a summary of the REP opportunities and NUI infrastructure.

Table 6-1 - Energy Transition Opportunities

Category	Type	Future Opportunities
Wave point buoy device, Floating module (wind+ solar + wave)	Off platform	Large scale energy generation possible, particularly if deployed in numbers. Space for deployment of technologies is not constrained beyond platform vessel access. Off platform REP concepts require only their mooring lines and electrical cable to the NUI to be detached before being transported to another location to be used again. Technologies are maturing and viable concepts may be available at scale in next 2-4 years.
Packaged solutions - pre-designed, engineered to fit or system integrators	On platform	On platform REP solutions that are housed in/on a container are more flexible for use in another location (than individual technologies) e.g. on a NUI or onshore.
Storage options (H_2 or Electro-chemical)	On platform	Deploy to support wider energy generation, and increase capacity factors, large scale energy storage could be installed (e.g. Chemical or H_2). This could possibly be done subsea (when developed) in containers with umbilical / power cable to the NUI.
REP technologies	On/Off	Economies of scale may improve payback calculations, or when considering roll out of REPs across multiple sites.
Secondary platform use	On Platform	The platform itself could become attractive to a range of larger scale energy solutions which support the wider renewables generation. For instance: Battery storage, H_2 production, H_2 storage, Maintenance / Construction laydown platform (supporting offshore wind sector), Desalination plant, Accommodation, Commercial applications (e.g. tourism or training). If topsides weight is removed as a result of platform simplification or post oi and gas conversion, the installation may be able to accept significant new equipment, e.g. heavy battery units.

Hydrogen Production	On Platform	If the wider application of hydrogen grows as predicted, the NUIs could provide a valuable space for hydrogen production, storage or power generation via fuel cells.
Offshore substation	On Platform	The NUI could be used to support electricity transmission, by siting transformers or as a central hub of 'hub and wheel' power island concepts.

7. Conclusions

Referring to the Terms of Reference document which described the requirements for the study, the objectives of the work were as follows:

1. Assess the practical considerations for deploying renewables technology packages on NUIs, e.g. space, weight, redundancy, need for batteries or back-up generation
2. Confirm the operating envelope of the renewables technology packages
3. Preliminary view on reliability and availability of the technology
4. Indication of whether the renewables technologies would most effectively be deployed to eliminate all, or part of the NUI emissions
5. Indication of system cost (CAPEX and OPEX) and whether this may deliver a net positive change to the NUI operator when any savings (e.g. in fuel or maintenance costs) are considered
6. Investigate scalability of the renewables technologies for current and future changes and for larger installations
7. Assess whether the technologies may support future Energy Transition (ET) and Energy Integration (EI) objectives (e.g. for gas compression or powering desalination units). Consider this possible future use in conjunction with scalability of the renewable package technology
8. The advantages and limitations of the renewables technology packages are to be identified and noted

The study findings and recommendations relating to these points are summarised below.

1. Practical considerations

On-platform technologies are generally off-the-shelf solutions, whereas off-platform technologies are typically at earlier TRL phases. This precludes their current use on operating platforms but their future deployment is a possibility. Offshore industry or government may need to sponsor the development to accelerate development or mitigate risk; this is already happening with some technology examples.

Wind and solar REP options are well established on offshore platforms (at <10kW scale), and are proven solutions particularly for (modest) 'diesel offsetting' mode. They are light weight and relatively inobtrusive, but there are significant installation limitations, given space requirements. REP solutions typically require a much larger area for the same installed kW capacity compared to fossil fuel-based power generation. Platform helidecks, cranes, laydown requirements and drill rig access limit the suitable sites for these technologies and therefore the renewable power that can be generated. Horizontal Axis Wind Turbines were shown to be preferred to vertical axis turbines in sea trials and by case study operating hours.

Due to space constraints, in the majority of cases it is unlikely that NUI power demands can be met with on platform wind and/or solar generation alone, e.g. 25x solar panels = 10kWpeak (requiring 45m^2). As the mean power provision of solar panels is around 10% of their rated peak power, the 25 panels would provide around 8500kWh per year; this is equivalent to a mean supply of just 1kW. By comparison, in this study the mean NUI power demands vary from 11 to around 60kW.

Few manufacturers yet offer ATEX rated REP solutions. ATEX rating of wind turbines increases basic cost by 300-400%. At this stage of study it is however not yet confirmed whether platform-mounted turbines need to be ATEX rated as the units are relatively remote from potential hydrocarbon leak paths and may thus be considered Zone 2 equipment (an area in which an explosive gas atmosphere is not likely to occur in normal operation and, if it occurs, will only exist for a short time). This should be confirmed.

The packaged (containerised) nature of hybrid energy generation solutions is footprint space-efficient and offers several benefits to a standalone technology, but these units are also low power generators, are relatively expensive and many rely on the addition of large areas of solar panels.

When the technology is sufficiently mature, off-platform REP technologies may provide meaningful power contributions to suit the energy needs of clustered installations, but may face CAPEX challenges due to the need for routing the cable up the platform from the seabed, and for marine-based maintenance regimes. The effectiveness and survivability of some of these systems in an offshore environment has also not yet been proven at scale and longevity, which presents a current risk.

The low power demands of operation in 'Lighthouse mode' mean that it may be possible to develop a small number of off-the-shelf style REP solutions for operators to select from, to fast track the process of adoption. Financial considerations alone do not support this approach, unless the REP is used to generate worthwhile power after platform CoP.

2. Operating Envelope

Renewable power is inherently intermittent, yet this is not a barrier if a diesel offsetting approach is taken, which is the recommended approach if on-platform technologies are to be fitted. The optimising of renewable loads against diesel use requires detailed modelling on a case-by-case basis. The REP should be sized to maximise useful clean energy generation, which may be a solution with, or without storage.

Multiple REP technologies can be combined by system integrators to provide a more comprehensive power supply, which is closer to the NUI demand profile, however there will remain lengthy periods where little, if any renewable energy will be generated (e.g. still nights, still foggy days or stormy conditions). Providing a package which gives a smoother energy supply requires a significantly larger and more complex REP system which includes over-sized generation, large-scale energy storage and a more complex power management system. This will be more costly and there is likely to be insufficient space on NUI's to install these systems. As noted above, off platform systems may offer benefits to multiple installations when the technology is sufficiently mature.

3. Reliability and Availability

Through supplier discussions and review of data sheets, the available REPs are found to have high reliability and are supplied with manufacturer guarantees. The target of being 'better than diesel genset' is a benchmark that some of the package OEMs design to. There is good system reliability in some REP solutions, e.g. solar array, as a single point of failure is minimised. In addition, there is an archive of good case study examples of the screened REP solutions on NUIs in multiple locations.

Availability assessment for renewables requires consideration of the system as a whole. Where REP technologies are layered, they can provide better overall capacity factors. However, as noted above, to replace diesel gensets does not offer a financial benefit and space limitations (if deployed on individual NUIs) are likely to make such schemes unfeasible on most platforms.

If back up and redundancy is a key design requirement, some providers of packaged solutions include new, right-sized modern back-up diesel genset and power management technology in containerised units to complement REP systems. For platforms with a low power demand, it has been shown in experience of operation that these units may not be required operationally if the REP includes suitable battery storage.

4. Meeting NUI power demands

As noted above; proven on-platform REPs may provide only a small proportion of most NUIs' demands on a diesel offsetting basis; the exception would be a platform with low energy demand and significant available space for solar panels and/or wind turbines.

REP's may fully provide the low energy needed by a platform operating in 'Lighthouse mode, but the platform operator may choose to continue maintaining the existing hydrocarbon electricity generator (and hence continue to pay associated maintenance and fuel costs) to give confidence in the security of power to safety critical equipment on the installation. The need for ongoing maintenance of the generator may have an impact on the incentive to install the REP.

Energy storage (e.g. batteries) are not explicitly required for operational needs but can complement a system to provide continuous clean power. Locating battery storage on board the NUI would be preferable to subsea units (because of the installation costs) if topsides space and weight considerations allow. However, the standalone REP systems (e.g. wind/solar) can offer better payback periods when complimenting a diesel system only (without battery) by offsetting fuel use.

6. Scalability of REPs

Installing REPs during platform operational life may enhance economics if the package can be increased in size to meet Energy Transition needs when more space or weight capacity becomes available after cessation of hydrocarbon production. The study found that there were no REPs where there was a clear barrier to upscaling, but the physical nature of the small NUI platforms would present limits as to how much new generation equipment could be added to the platform.

NUIs vary in size and layout and have differing power demands and profiles and operating lives. Standardisation (e.g. for scaling) of REP solutions is therefore unlikely to meet performance outcomes, unless it is only a low level of diesel offsetting that is targeted. Energy optimising therefore needs to be considered on a case-by-case basis with operators.

7. Energy Transition Opportunities

A large platform with significant deck space may offer the opportunity for generating worthwhile amounts of energy (10-20kW average load) using proven solar and wind generation, but there are few NUI examples where this is expected to be the case as most of these platforms are small.

The main opportunities therefore lie with off-platform energy generation where there is space for large generation units. Wave point buoys, seabed-mounted wind turbines or floating energy generation units may offer several hundred kWs which can be used either on one installation (e.g. to generate hydrogen or power CO_2 injection pumps), or on multiple nearby installations. The off-platform REPs are also scalable so the generation capacity can be sized to suit. Many of these technologies are not yet mature enough for full scale commercial deployment, but this is expected to change in the next few years.

Large subsea battery units may be part of a future Energy Transition renewable generation scheme, adding operational flexibility to power provision.

While currently small scale, the ongoing development of hydrogen generation and fuel cell devices also presents a possible future opportunity to deploy energy storage with seasonal longevity offshore to support Energy Transition objectives.

8. Advantages & Limitations of REPs

The strengths and weaknesses of each REP option considered in the study are presented in Table 3-5, Table 4-1 and Table 4-4. Key points are:

‘On-platform’ technologies are proven but generate little energy and require significant space which is at a premium on a small platform.

The pre-packaged or system integration (also on-platform) solutions have an advantage over individual technology options, as they can be custom designed to suit NUIs, and where space allows, several units can be combined as modules. This lends itself to ease of deconstruction, or secondary life uses. These units however provide only limited energy and are relatively expensive.

Off platform technologies can provide significantly more energy but are generally less proven and appear to be too expensive to deploy for individual NUIs but have the potential to be used at scale more economically and are re-deployable for future, post oil and gas energy generation.

Every REP provides intermittent power, which may be at least partially addressed by installing hybrid packages with suitably sized energy storage, where these add value to the scheme.

8. Recommendations

The following recommendations are made from the study:

1. Seek feedback from operators of NUIs with existing REPs fitted, confirming how the technologies have performed, both technically and commercially.

2. Carry out a screening exercise to identify high potential NUIs for possible installation of REPs (those installations with a combination of long remaining lives and large available space). For those installations, revisit the assessments carried out in this study to confirm whether there is a case for installing REPs. This work should include examining the power demands for the NUI considered, to match with REP capabilities. Confirm actual available space and potential REP capacity that may be installed. Update the cost estimate with site specific data.

3. Assess the feasibility of schemes which could power multiple NUIs in the same vicinity, with common off-platform renewable power. NUI cluster/ simplification opportunities should be explored, with mapping of offshore wind farm proximity and their planning application phase, and confirmation of appetite to discuss a shared project vision.

4. Examine off-platform REP concepts in more detail for high demand NUIs to establish technology maturity and development schedule, expected energy yield in the SNS region, and costs. An additional objective of this work would be to examine the technical and economic case for developing off-platform renewable technologies to be scaled up to meet post oil and gas Energy Transition needs.

5. If greater accuracy is considered necessary in the cost vs benefit assessment, examine and refine the estimates of its components (e.g. CAPEX of large items, engineering, procurement, installation, integration, commissioning, OPEX), with operator input if possible. Consider savings associated with procuring elements at scale. When more accurate information is available, re-develop the assessment according to Net Present Values of the REP concept cases.

6. Assess the financial viability of installing a limited on-platform REP (within the available space) during the platform operational phase and scaling the REP up to support future Energy Transition objectives at CoP, post platform simplification when more space becomes available

7. Consider developing the dashboard style assessment approach presented in Section 4.2 as a tool for OGA or operators to assess usefulness of REPs to NUIs (by site location) as it could be a helpful, unbiased resource to encourage operators to adopt the most suitable selection of REPs. (Challenges to be addressed in achieving this include: data sharing, security and sensitivity, quality (recent) operator data, consortium of stakeholders, knowledge sharing of key deliverables).

8. The requirement for ATEX or marine grade REP solutions on the NUIs should be established to ensure that appropriate costs have been used in the estimate.

9. A rental model or OPEX approach to adopting REPs on NUIs could be an economic way forward for operators. Further investigation to confirm potential application and benefits is recommended.

9. References

[1] NSTA, “SNS-NUI Renewable Power Packages Study ToR,” Rev1, 2021.

[2] Vonk, “Training NAM and Shell UK,” [Online]. Available: https://iivonk.com/training-nam-shell-uk/. [Accessed 29 March 2021].

[3] J. Beckman, “Shell duplicates minimal platforms to cut cost of UK/Dutch projects,” Offshore Mag, 1 August 2005. [Online]. Available: https://www.offshore-mag.com/home/article/16762969/shell-duplicates-minimal-platforms-to-cut-cost-of-ukdutch-projects. [Accessed 29 March 2021].

[4] TSS, “Oil & Gas,” 2021. [Online]. Available: https://www.tss4u.com/oil-gas/. [Accessed 8 March 2021].

[5] Amphibious Energy, “Ithaca Energy,” 2020. [Online]. Available: https://onshore.amphibiousenergy.com/wood-ithaca-energy/. [Accessed 8 March 2021].

[6] Tulip Oil, “Q10-A Project,” 2019. [Online]. Available: https://tulipoil.com/q10a/. [Accessed 12 March 2021].

[7] UK Government (BEIS), “GHG Conversion Factors for Company Reporting,” 2020.

[8] T. Singh, “100-Foot Subsea Turbine Successfully Installed at World’s First Tidal Farm Off the Coast of Scotland,” Inhabitat, 19 May 2012. [Online]. Available: 100-Foot Subsea Turbine Successfully Installed at World’s First Tidal Farm Off the Coast of Scotland. [Accessed 29 March 2021].

[9] CorPower Ocean, “Clean Energy from our Oceans,” 2019. [Online]. Available: https://www.corpowerocean.com/. [Accessed 29 March 2021].

[10] SINN Power, “Ocean Hybrid Platform,” 2021. [Online]. Available: https://www.sinnpower.com/platform. [Accessed 29 March 2021].

[11] Power Mag, “Microturbine Technology Matures,” 1 November 2010. [Online]. Available: https://www.powermag.com/microturbine-technology-matures/. [Accessed 29 March 2021].

[12] J. Rosebro, “Fossil-Fuel Platform Runs on Renewable Energy,” Green Car Congress, 20 April 2006. [Online]. Available: https://www.greencarcongress.com/2006/04/fossilfuel_plat.html. [Accessed 31 March 2021].

[13] EST-Floattech, “Our Modules,” [Online]. Available: https://www.est-floattech.com/est-technology/our-modules/. [Accessed 29 March 2021].

[14] Ryse Energy, “E-10 HAWT Overview,” 2020. [Online]. Available: https://www.ryse.energy/10kw-wind-turbines/. [Accessed 26 March 2021].

[15] EU europa, “"Technology readiness levels (TRL); Extract from Part 19 - Commission Decision C(2014)4995",” Retrieved 10/05/2021.

[16] U.S. Department of Energy, “Using Distributed Energy Resources,” [Online]. Available: https://www.nrel.gov/docs/fy02osti/31570.pdf. [Accessed 08 April 2021].

[17] Tesla, “Powerwall,” [Online]. Available: https://www.tesla.com/en_gb/powerwall. [Accessed 08 April 2021].

[18] Civil Aviation Authority, , “CAP 437, Standards for Offshore Helicopter Landing Areas,,” 2018.

[19] M. v. Grieken, “Wind Turbines and Landscape, Beatrice Dower,,” Wind Energy Engineering, , 2017.

[20] Energypedia , [Online]. Available: https://energypedia.info/wiki/Layout_of_Wind_Projects. [Accessed 2021 04 09].

[21] Ryse Energy,, “E-5 Data Sheet, Version 1,,” 2021.

[22] copters, [Online]. Available: http://www.copters.com/aero/hovering.html. [Accessed 09 04 2021].

[23] Ember Climate, “Daily EU ETS Carbon Market Price,” 2021. [Online]. Available: https://ember-climate.org/data/carbon-price-viewer/. [Accessed 19 March 2021].

[24] Office for National Statistics, “Average Sterling exchange rate: US Dollar,” [Online]. Available: https://www.ons.gov.uk/economy/nationalaccounts/balanceofpayments/timeseries/auss/mret. [Accessed 08 April 2021].

[25] ORE Catapult, “Tidal Stream and Wave Energy Cost Reduction and Industrial Benefit,” [Online]. Available: https://www.marineenergywales.co.uk/wp-content/uploads/2018/05/ORE-Catapult-Tidal-Stream-and-Wave-Energy-Cost-Reduction-and-Ind-Benefit-FINAL-v03.02.pdf. [Accessed 08 April 2021].

[26] BloombergNEF, “Battery Pack Prices Cited Below $100/kWh for the First Time in 2020, While Market Average Sits at $137/kWh,” 16 December 2020. [Online]. Available: https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/. [Accessed 08 April 2021].

[27] Lazard, “Lazard’s Levelized Cost of Energy Analysis — Version 14.0,” October 2020. [Online]. Available: https://www.lazard.com/media/451419/lazards-levelized-cost-of-energy-version-140.pdf. [Accessed 08 April 2021].

[28] BEIS, “Updated Short term traded Carbon Values (available; https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/794186/2018-short-term-traded-carbon-values-for-appraisal-purposes.pdf),” Gov. Uk, April 2019.

Appendices

Appendix B. Identified and Screened Technologies

REP technology	Screened REPs for further assessment
Tidal **Wave** **Floating module** **(Deep) Geothermal/ heat pump** **Small wind (<500kW)** **Floating energy island** **Airborne wind technology** **Aquatic turbine** **Solar PV** **Micro wind (<10kW)** **H2 gas turbine** **Turbo expander** **GT improvements** **Direct air capture tech.** **Micro gas turbine** **Fuel cell** **Hydrogen bi-directional storage unit** **Subsea electrical power distribution** **Desalination** **Amphibious Energy - Energy Pods** **Motive Offshore - Renewable Hybrid Power Container** **Battery ; li-ion** **Battery flow battery** **Hydrogen Electrolyser** **Compressed Air Energy Storage (CAES) technology** **Liquid Air Energy Storage (LAES) technology** **Gravity Energy Storage**	Wave Floating module Solar PV Micro wind (<10kW) Micro gas turbine Hydrogen bi-directional storage unit Amphibious Energy - Energy Pods Motive Offshore - Renewable Hybrid Power Container Battery ; li-ion Battery flow battery

Appendix C. Operator RFI questions template

1	Can you provide an energy load profile for the platform (in kW and KWh if possible)? Where available, please also provide: • Metered electricity data • Fuel type (diesel/gas) and rated power • If diesel used, please indicate storage size (Litres or physical tank size) • Seasonal daily profiles, or demand profile variation annually • Indication if provided load profile will be representative of future profile
2	What are the largest energy consumers on the platform and approximately how often are they operated? • How and where electricity is used • If future loads may change • Is there any potential for energy savings/ fuel switch outs or improvements in efficiency which may be made to reduce energy consumption or peak load?
3	Approximately how often is the platform visited? • Refill the generator diesel tanks (if diesel powered)? • Perform other operations requiring access to the platform? • How is the platform accessed? Walk to work, helideck?
4	Approximately how many days per typical year is the platform manned?
5	Can you provide a photograph or basic layout of your platform? If available please also provide: • Single line diagram showing how power system is configured • Please confirm the highest voltage & frequency
6	Is there any unused platform space for the siting of a renewable energy package, e.g. 20 or 40ft container? • Does the platform already have any renewable energy generation or storage equipment?
7	What power generation availability do you require? E.g. do you have systems that are dependent on power 24/7 or flexible?
8	Can any large or heavy items be removed from the platform (either completely or transferred to another nearby facility)?
9	Are the current power generators operating below optimum conditions or requiring significant maintenance? • Any other maintenance issues noted?
10	If known, does the platform have capacity to carry additional weight (from new renewables equipment)?
11	When is the platform COP date?
12	If Known, what are the platform's annual emissions?

Appendix D. REP Screening Worksheet

Type	Renewable Energy Package (REP) or Technology	REP Description	Performance/capability (kW or kWh)	Screening phase (Pass / Fail)	Showstoppers	Company
off platform	Wave	Wave energy is the capture of energy from ocean surface waves. There are multiple different technologies used for wave energy (e.g. CorPower point absorber)	50 - 100kW (CorPower Point Absorber - based on pilot version)	G	The loading would require the wave tech to be a distance from the NUI.	CorPower Ocean
off platform	Floating module	Floating module with a variety of wind, solar and wave technologies incorporated.	Variable depending on technology	G	Will depend on the solution - would need to consider the environment (big waves) and any risk to NUI structure. If it can be located a suitable distance away, this provides a good opportunity as it requires minimal modification to the NUI and would be outside of any atex zoning requirement.	Sinn Power
on platform	Solar PV	Solar photovoltaics (PV) capture the suns energy and converts it into electricity. Platform mounted solar panels.	On platform solar panels average power rating of 250-400W per m2.	G	Potential to be shadowed by existing infrastructure (e.g. helideck, cranes). Examples of panels being lowered or raised hydraulically to reduce wind load.	TSS, Marlec
on platform	Micro wind (<10kW)	Small wind turbine (generally 3 - 10kW range) - platform mounted.	SD Wind Energy 3kW (ATEX rated) & SD6 - 6kW RyseEnergy E-range wind turbines (E5, E10, E20 and E60)	G	Potential to impact helicopter access. Structural loading of existing (20-40 year old) NUI jacket.	SD Wind Energy / Ryse Energy
on platform	Micro gas turbine	Micro gas turbines already installed on some existing NUIs. Reduced CO2 emissions in comparison to diesel generator.	Standard generating capacity up to 200kW	G	Strong option if using production gas. Also has the potential to mix with clean fuels / biofuel.	Capstone Turbine Corporation, Ansaldo Energia
on platform	Hydrogen bi-directional storage unit	Containerised H2 package that can store or generate power to avoid need for diesel as back up	8kWp electrical power output.	G	These are very promising as replacements to diesel back up (<500hrs) otherwise require desal water which is a bottleneck	Vonk

Type	Renewable Energy Package (REP) or Technology	REP Description	Performance/capability (kW or kWh)	Screening phase (Pass / Fail)	Showstoppers	Company
packaged	Amphibious Energy - Energy Pods	The Energy Pod provides an all-in-one, transportable package of wind and solar energy and battery storage. Currently installed and operating on the Ithaca Jacky platform.	MonoPod - 8.5kWp (7.5m^2) TwinPod - 17kWp (15m^2) QuadPod - 31.5kWp (28.3m^2)	G	May only meet a small portion of the overall NUI demand (1-10kW range). Able to link multiple units but potential space constraints may limit this.	Amphibious Energy
packaged	Motive Offshore - Renewable Hybrid Power Container	With renewable technologies, including small-scale wind turbines and solar photovoltaics (PV), the power container also combines all control systems, battery bank and remote monitoring within the fully integrated system.	20ft container - 8kWp 40ft container - 16kWp	G	May only meet a small portion of the overall NUI demand (1-10kW range). Able to link multiple units but potential space constraints may limit this.	Motive Offshore
storage	battery ; li-ion	Battery energy storage to combine with the diesel generator and / or renewables.	Various	G	Generally for fast charge and discharge cycles. May still be possible to use but a deep cycle battery maybe better - it would depend on the specific energy requirements.	EST, Tesla
storage	Battery flow battery	Packaged flow battery	78kW min size, and scalable	G	Generally the technology is only just being used in early stage commercial projects, but there are not many and it has not been used offshore. Potentially good for longer term storage (compared to lithium ion)	Invinity Energy
off platform	Tidal	Tidal energy is created using the movement of tides and oceans. These technologies include underwater turbines and submerged tidal rigs.		R	Unsuitable for individual NUIs, but could be more suitable for clustered NUIs due to large generation.	
off platform	(Deep) Geothermal/ heat pump	Drill a geothermal well whereby the 1°C increase in temperature supply with a heat pump could generate sufficient power		R	Not applicable to all NUIs. May require significant topside infrastructure.	
off platform	Small wind (<500kW)	Wind turbines to provide 00's kW. Solution to be off platform due to space and weight requirements of larger scale turbine.		R	High CAPEX requirement to install single off platform turbine. Solution more suited to installing cluster to power multiple NUIs.	

Type	Renewable Energy Package (REP) or Technology	REP Description	Performance/capability (kW or kWh)	Screening phase (Pass / Fail)	Showstoppers	Company
off platform	Floating energy island	Large scale offshore renewable energy hub. Ability to generate GW of electricity. Transmission centre for surrounding wind turbines.	Various - GW range	R	TRL level 5-6	
off platform	Airborne wind technology	Wind turbines attached to kite / drone to utilise high altitude winds.	100's kW range	R	TRL level 4-5	
off platform	Aquatic turbine	Submerged turbine to utilise currents in seas and rivers		R	Solution is very location specific. Currents may not be strong enough in the SNS. Capex would suit larger scale project.	
on platform	H2 gas turbine	Hydrogen fuelled gas turbine. Can also run with blended hydrogen fuel.		R	Not all NUIs currently powered by gas turbine. Potential challenge with sourcing hydrogen.	
on platform	Turbo expander	Extracts energy from pressure reduction of gas	Large power range currently in operation (750 W - 7.5 MW)	R	Additional topside infrastructure would be required to operate.	
on platform	GT improvements	Improvement and optimisation of current gas turbine installed on NUI. Using methods such as increased compressed air through flow through turbine to lower fuel use. Use of alternative fuel such as biofuel.		R	Solution does not apply to many NUIs as majority are powered by diesel generator rather than micro gas turbine.	
on platform	Direct air capture tech.	Direct Air Capture (DAC) units or CCS type technology on existing gas turbines to capture released CO2.		R	Technology works best in heavily polluted atmosphere, limited development on drawing a waste stream through it, e.g. GT or engine exhaust. However, still a good phase 2 second life option.	
on platform	Fuel cell	Fuel cell technology using methane or hydrogen. Potential to use gas available on platform.		R	Fuel cell only one component of a system and would require further infrastructure to generate power. More likely a phase 2 scale up option	TECO - Marine fuel cell
other	Subsea electrical power distribution	Long power cables connecting NUI to shore or local offshore renewable cluster (e.g. wind farm).	15-20MW proportional to 200km distance	R	Technology limitations against distance from shore. Also depends remaining asset life of the NUI. Unlikely to provide an economic solution due to the relatively low power demands of the NUI's.	ABB

Type	Renewable Energy Package (REP) or Technology	REP Description	Performance/capability (kW or kWh)	Screening phase (Pass / Fail)	Showstoppers	Company
other	Desalination	Process of removing salts from seawater to produce freshwater. Freshwater can then be fed into an electrolyser to produce Hydrogen. Not a direct power supply method.		R	More a consideration for phase 2 of the study looking at NUI use post operation. Potential to power desal station renewably to generate green Hydrogen.	
storage	Hydrogen Electrolyser	Containerised electrolyser package	Often larger than required for these NUI	R	Existing off the shelf packages appear too large and are very expensive. Also a very energy intensive process in comparison to alternative battery storage solutions.	ITM / H-Tec
storage	Compressed Air Energy Storage (CAES) technology	Process of storing energy as compressed air in a similar philosophy to pumped hydro. Current plants store compressed air in underground salt caverns. Compressed air then fed into existing gas power stations, tripling the efficiency.	Example existing CAES plants - Huntorf, Lower Saxony, Germany & McIntosh, Alabama, USA. Both store compressed air in underground salt caverns and feed into existing gas-fired power stations. Tripling efficiency of the plant	R	Large storage typically needed. Subsea storage benefits from constant pressure by depth of water, however in SNS this is limited due to shallower water depths .e.g. 20m depth would be approx 2bar.. need 100m+. Estimated 3kWh requires 65m3 of storage (e.g. 2.5m dia x 14m cylindrical vessel).	
storage	Liquid Air Energy Storage (LAES) technology	LAES uses low temperature liquid air to store energy. Liquid air is pumped into a boiler to convert the air back to gas. This massive increase in volume and pressure is then used to drive a turbine.	Highview power CRYOBattery technology - looks to be operating at the 50MW range with scale up potential	R	Currently large scale generation. Not applied to lower demand situations.	Highview Power
storage	Gravity Energy Storage	Energy storage that uses gravitational potential energy. Mass suspended and when released, electricity can be generated through an electric generator.	1 - 20MW	R	Large scale energy storage. Would require large amount of excess energy to raise mass.	Gravitricity

Appendix E. Technology GYOR Summary and SWOT Analysis

ID	Application	Technology Name	**Power banding** High >50kWp Medium 10 to 50 Low <10kWp	Strengths	Weaknesses	Opportunities	Threats
1	Off platform in close proximity to NUI	Wave energy generation device	High	Has no impact on NUI operations, technology is scalable to fit demand; not space constrained by deck area	Currently has lower TRL level than desired. Cost/kWh likely to be high for small number of units deployed for individual NUI	Designed for larger scale deployment so economics will be better suited to providing supply for cluster of NUIs. Secondary use for floating module possible after NUI CoP. Availability could be improved by pairing with energy storage, if economic	Intended for 20m water - is the technology suitable for 50+m? Unknown operational life Effectiveness unknown in SNS environment (not ocean waves)
2	Off platform in close proximity to NUI	Floating module; could be ship like design or towable structure	High	Has no impact on NUI operations, technology is scalable to fit demand; not space constrained by deck area	Currently has lower TRL level than desired. Potentially high OPEX and maintenance cost due to floating installation and access issues for cleaning of solar panels or WTG interventions	Able to provide larger scale generation with more units - power multiple NUIs from one cluster? Leasing opportunity to avoid operator dealing with maintenance? Secondary use for floating module possible after NUI CoP. Availability could be improved by pairing with energy storage, if economic	Uncertainty of robustness of these concepts in the rough waters of SNS - unmooring (hence also risk to NUI), breakages

ID	Application	Technology Name	**Power banding** High >50kWp Medium 10 to 50 Low <10kWp	Strengths	Weaknesses	Opportunities	Threats
3	On platform; top, side or integrated options	Solar PV	Low	Proven and deployed technology. Lightweight. Low OPEX and maintenance requirements	Space limitations on NUIs and low generation capacity mean this tech provides only small % of most NUIs' energy needs. Also has known continuity generation limitations (e.g. no generation at night, variable during time of day and weather).	Potential to deploy emerging technologies (flexible, rolling, load bearing panels) to optimise NUI coverage. Availability could be improved pairing with energy storage (for v low power demand NUIs only where installed generation > demand)	Potential installation challenges on NUIs with no crane access. Impairment of ops (e.g. well interventions) if poorly sited.
4	On platform	micro wind (<10kW)	Low	Proven and deployed technology. Lightweight. Relatively small physical footprint	Limited to size (particularly if helideck) and number of units per NUI, hence may provide only small % of demand. Technology has known generation limitations (e.g. no wind). Need to ATEX rate significantly increases cost	Availability could be improved pairing with energy storage (for low power demand NUIs only where installed generation > demand)	Potential installation challenges on NUIs with no crane access. Overhaul work carried out as part of preventative maintenance.
5	On platform-packaged	micro gas turbine	High	Simple, proven technology with high power capacity	Not a 100% green solution, it is a reducing CO_2 option	Fuel flexibility, could lend to H_2 blending or fuelling	Fuel source may go when platform operations end
6	On platform - pre-packaged container	Amphibious Energy - Energy Pods;	Medium	Containerised solution with operational track record. High availability due to combination of wind, solar and battery. Amphibious control power management system of the platform	Potential generation limitations (8kWp)	Opportunity to lease technology from Amphibious. Due to storage, able to provide 100% platform demand in lighthouse mode	Space constraints may limit potential to link multiple units. Crane needed for installation

ID	Application	Technology Name	**Power banding** High >50kWp Medium 10 to 50 Low <10kWp	Strengths	Weaknesses	Opportunities	Threats
7	On platform - pre-packaged container	Motive Offshore; Renewable Hybrid Power Container	Medium	Containerised solution combining industry proven technologies into one package	Potential generation limitations (~10kWp)	Due to storage, able to provide 100% platform demand in lighthouse mode	Space constraints may limit potential to link multiple units. Crane needed for installation
8	On platform - engineered package	VONK	Medium	Able to provide bespoke renewable solutions for a range of NUI configurations and requirements	Potential generation limitations (~10kWp)	Due to storage, able to provide 100% platform demand in lighthouse mode	Crane needed for installation of renewable technologies. Increased cost due to design of bespoke solutions.
9	On platform - engineered package	TSS	Low	Able to provide bespoke renewable solutions for a range of NUI configurations and requirements	Potential generation limitations (~10kWp)	Due to storage, able to provide 100% platform demand in lighthouse mode	Crane needed for installation of renewable technologies. Increased cost due to design of bespoke solutions.
10	On platform - engineered package	Ryse Energy	Low	Able to provide bespoke renewable solutions for a range of NUI configurations and requirements	Potential generation limitations (~10kWp)	Due to storage, able to provide 100% platform demand in lighthouse mode	Crane needed for installation of renewable technologies. Increased cost due to design of bespoke solutions.
11	On platform - storage ONLY	Hydrogen bi-directional storage unit	Low	On platform containerised solution. Potential to act as replacement to diesel generator as back up generation source.	Lower TRL level, unsure if currently installed or just prototype	Potential to offset diesel as backup generation source. Potential to act as an energy storage source for excess renewable power (stored hydrogen). Plans to make system much bigger	Limited information available on product

ID	Application	Technology Name	**Power banding** High >50kWp Medium 10 to 50 Low <10kWp	Strengths	Weaknesses	Opportunities	Threats
12	On platform - storage ONLY	electro chemical battery	Medium	Proven technology	Heavy and space intensive - may not fit on platform. Require many units to meet high energy needs If li-ion has poor end of life recycling, lead acid much better. Creation of waste when replaced	Li-ion or lead acid can be modularised to suit REP design Seabed install for large scale?	Cycles vs changeout is key consideration in regards to payback period/ Opex Large loads to lift (up to 50 Te/unit) - need for big vessel to install?

	MUST HAVES							SHOULD HAVES								COULD HAVES						WON'T HAVES			
Technology Name	Safety compatible with NUI hydrocarbon operation	Safety - manageable installation risks & maintenance risks	Will be suitable for offshore use	Reliability not less than current.	Ecomomics at least neutral	Can be integrated in platform systems (non Safety Critical items)	Operational life not less than NUI's	Small physical footprint / remote from NUI	Limited Opex (e.g. redundancy provision)	Location does not significantly impact NUI access	High availability	Ability to meet 100% NUI power demand (space limit, use of diesel)	Low impact on NUI ops during installation	Low impact on NUI ops during well ops and other NUI ops	Can provide lighthouse power requirements after NUI H/C ops	Scalable to enable future change, eg post NUI H/C ops	Can be re-purposed or re-deployed	Complete package solution	Modular design	Low weight of REP	UK suppliers	Net positive carbon footprint over intended life	TRL<7	Increase in current NUI maintenance requirements	High environmental impact or decomm legacy issues
Wave energy generation device	G	Y	G	A	A	G	A	G	G	G	A	G	G	G	Y	G	G	A	G	G	A	Y	A	G	Y
Floating module; could be ship like design or towable structure	G	Y	G	A	A	G	A	G	Y	Y	Y	G	G	G	Y	G	G	Y	G	G	A	A	A	G	Y
Solar PV	G	Y	G	G	Y	G	G	A	G	G	A	A	Y	Y	Y	A	Y	A	G	G	Y	Y	G	G	Y
Micro wind (<10kW)	Y	Y	G	G	Y	G	G	G	Y	G	A	Y	Y	Y	Y	A	Y	A	G	G	G	G	G	G	G
Micro gas turbine	G	Y	G	G	Y	G	G	G	Y	G	A	G	G	G	G	A	G	G	G	G	G	A	G	G	Y
Amphibious Energy - Energy Pods	G	G	G	G	Y	G	Y	Y	Y	G	G	Y	Y	G	G	G	G	G	G	Y	A	Y	G	G	Y

	MUST HAVES							SHOULD HAVES								COULD HAVES						WON'T HAVES			
Technology Name	Safety compatible with NUI hydrocarbon operation	Safety - manageable installation risks & maintenance risks	Will be suitable for offshore use	Reliability not less than current.	Ecomomics at least neutral	Can be integrated in platform systems (non Safety Critical items)	Operational life not less than NUI's	Small physical footprint / remote from NUI	Limited Opex (e.g. redundancy provision)	Location does not significantly impact NUI access	High availability	Ability to meet 100% NUI power demand (space limit, use of diesel)	Low impact on NUI ops during installation	Low impact on NUI ops during well ops and other NUI ops	Can provide lighthouse power requirements after NUI H/C ops	Scalable to enable future change, eg post NUI H/C ops	Can be re-purposed or re-deployed	Complete package solution	Modular design	Low weight of REP	UK suppliers	Net positive carbon footprint over intended life	TRL<7	Increase in current NUI maintenance requirements	High environmental impact or decomm legacy issues
Motive Offshore - Renewable Hybrid Power Container	G	G	G	G	Y	G	Y	Y	Y	G	G	Y	Y	G	G	G	G	G	G	Y	A	Y	Y	G	Y
VONK	G	G	G	G	A	G	Y	Y	Y	G	G	Y	A	G	G	G	Y	G	G	Y	A	Y	G	G	Y
TSS	G	G	G	G	A	G	Y	Y	Y	G	G	Y	A	G	G	G	Y	G	G	Y	A	Y	G	G	Y
Ryse Energy	G	G	G	G	A	G	Y	Y	Y	G	G	Y	A	G	G	G	Y	G	G	Y	A	Y	G	G	Y
Hydrogen bi-directional storage unit	G	G	G	Y		G	G	G	A	G	G		G	G	G	G	G		G	Y	Y		G	G	G
Electro chemcial battery	Y	G	G	G		G	Y	Y	Y	G	G		Y	G	y	G	G		G	A	A		G	G	G
Battery flow battery	Y	G	G	G		G	Y	A	G	Y	G		Y	G	y	G	G		G	A	A		G	G	G

Appendix F. Supplier/OEM Info

This work would not be possible without contributions from technology suppliers. Data received by Suppliers/OEMs of the REP will be provided on request as a ZIP file. This includes data from:

- Amphibious Energy
- CorPower Ocean
- Eco Marine Power
- Motive Offshore
- Ryse Energy
- SD Wind
- SINN Power
- SMA
- TESLA
- TSS
- Vonk

Appendix G. Wind Turbine Siting

Sitting wind turbines on NUIs is presenting unique access and operation challenges. Given the expected frequency of helicopter visits, the wind turbines must be sited in proper position to ensure that the overall risks remain at a tolerable level.

The purpose of this memo is to confirm and reference the acceptance criteria Atkins have applied for the layout of wind turbines on NUIs with helidecks.

G.1. Distance between wind turbine and helideck

The following limitations are considered for sitting any obstacles on NUIs with helidecks according to CAP 437 [18]:

- OFS: Obstacle Free Sector. The 210° sector, extending outwards to a distance that will allow for an unobstructed departure path appropriate to the helicopter the helideck is intended to serve, within which no obstacles above helideck level area permitted. For helicopters operated in Performance Class 1 or 2, the horizontal extent of this distance will be compatible with the one-engine inoperative capability of the helicopter type to be used.
- LOS: Limited Obstacle Sector. The 150° sector within which obstacles may be permitted, provided the height of the obstacles is limited. The LOS sector extends out to 0.83D from the centre of the D-circle, where D is the largest overall dimension of the helicopter when rotors are turning.

Figure 9-1 lists the key parameters of various helicopters [18]. For instance, if a small helicopter is used, e.g. Agusta A109, its D-value is 13.05m.Then obstacles should sit away from the OFS 210° sector and LOS 150° sector with limit of 10.83m (i.e. 0.83D), so that the obstacles should be sit at least 4.31m (10.83m-13.05m/2) away from the edge of the helideck as shown in Figure 9-2 [18] . The LOS and OFS should already have been defined for any NUIs under consideration as part of the helideck and installation design.

Note CAP 437 only provides guidance for sitting generic obstacles, a further study is recommended to confirm the distance between helideck and wind turbines.

Type	D-value (m)	Perimeter 'D' marking	Rotor diameter (m)	Max weight (kg)	't' value	Landing net size
Bolkow Bo 105D	12.00	12	9.90	2400	2.4	Not recommended
EC 135 T2+	12.20	12	10.20	2910	2.9	Not recommended
Bolkow 117	13.00	13	11.00	3200	3.2	Not recommended
Agusta A109	13.05	13	11.00	2600	2.6	Small
Dauphin AS365 N2	13.68	14	11.93	4250	4.3	Small
Dauphin AS365 N3	13.73	14	11.94	4300	4.3	Small
EC 155B1	14.30	14	12.60	4850	4.9	Medium
Agusta/Westland AW 169	14.65	15	12.12	4800	4.8	Medium
Sikorsky S76	16.00	16	13.40	5307	5.3	Medium
Agusta/Westland AW 139	16.63	17	13.80	6800	6.8	Medium
Agusta/Westland AW 189	17.60	18	14.60	8600	8.6t	Medium
Airbus H175	18.06	18	14.80	7500	7.5	Medium
Super Puma AS332L	18.70	19	15.60	8599	8.6t	Medium
Bell 214ST	18.95	19	15.85	7938	7.9t	Medium
Super Puma AS332L2	19.50	20	16.20	9300	9.3t	Medium
EC 225 (H225)	19.50	20	16.20	11000	11.0t	Medium
Sikorsky S92A	20.88	21	17.17	12565	12.6t	Large
Sikorsky S61N	22.20	22	18.90	9298	9.3t	Large
AW101	22.80	23	18.90	14600	14.6t	Large

Figure 9-1 - D-value, t-value and other helicopter type criteria

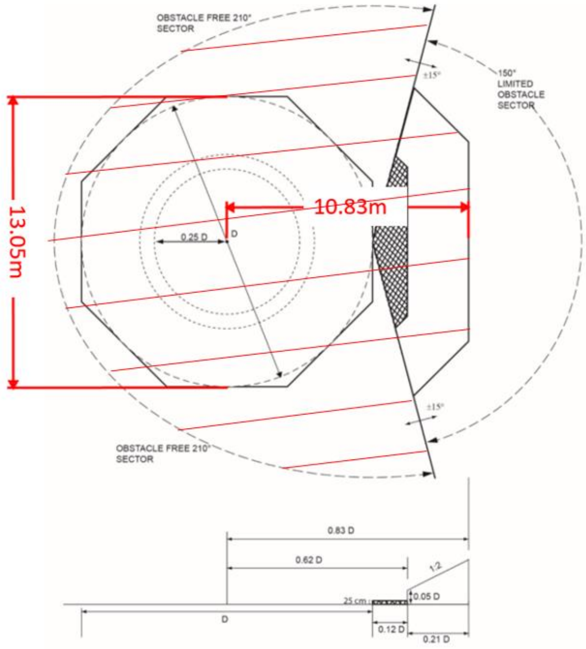


Figure 9-2 **- Obstacle limitations for helicopter Agusta A109**

G.2. Turbine Layout

For the micro-siting certain minimum distances between the individual wind turbines must be observed to minimize the wake effects. A common rule of thumb specifies 3~5 rotor diameters in cross wind directions (less than three is possible under some circumstances), and 6~8 rotor diameters in main wind direction as shown in Figure 9-3 [19] . The minimum distance of three times or less the rotor diameter in cross wind direction is only feasible in case the wind direction is strictly perpendicular to the row of wind turbines. The wind turbines need to be sit in proper positions so that the wake losses do not cause decrease in energy output below 85% for the following wind turbines [20]

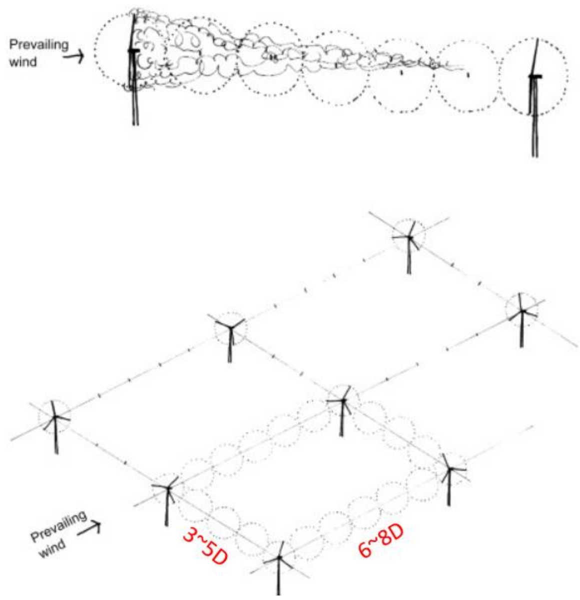


Figure 9-3 - Turbine Separation Requirements Taking Account of Wake

Furthermore, it is critical to keep the availability of lay down space to ensure the service requirement. Therefore, the turbine distance must be larger than the total height of one turbine. For instance, the rotor diameter of SD3EX wind turbine is 3.9m, tower height is 6m and distance between these two turbines is 9m which is sufficient for laying down one turbine (total height~7.95m).

G.3. Tower Height

The wind turbine suppliers can provide flexible tower heights. For example, Ryse Energy can provide tower with flexible height 6-27m for their 5kW wind turbine (see Table 8-1) [21]. Typically, higher towers can access to faster wind so that the annual energy production can be increased correspondingly. However, the tower cost increases with tower height. It's recommended to fit red lights on the hub if the wind turbine is 15m higher than the landing area [18]

Table 9-1 - Ryse Energy E5 Turbine Datasheet

Annual Mean Wind Speed (m/s)	Estimated Annual Output (kWh)
2	290
3	1,900
4	3,900
5	6,900
6	10,000
7	14,300
8	17,700
9	20,000
10	22,500

The helicopter will introduce additional wind flow during hover, and the air velocity under the helicopter may reach 30m/s~50m/s [22]. Even though these micro wind turbines are designed to Class 1 marine standard and their survival wind speed is up to 70m/s [21], It is recommended to further investigate the effects of turbulent air flow on the wind turbines.

G.4. Conclusions

Except for the factors discussed in this appendix, other limiting factors such as structural integrity and platform operations etc. are also necessary to be considered for selecting the most viable locations of wind turbine installations.

In summary, the following factors are essential with regards to the successful sitting of wind turbines on NUIs with helidecks:

- Clear wind regime
- Minimum distance between helideck and general obstacles is ~4.03m for small helicopters. However, a further study is recommended for turbine-relevant distance.
- Sufficient distance between wind turbines, 3~5 rotor diameters in cross wind directions and 6~8 rotor diameters in main wind direction.
- Minimise obstacles in prevailing wind direction, e.g. crane
- Serviceability of turbines – availability of lay down space
- Load bearing capacity of foundation connection – structural integrity of substructure

Ewan Murray
Atkins Limited
8 Mallard Way
Strathclyde Business Park
Bellshill
North Lanarkshire
ML4 3BF

ewan.murray@atkinsglobal.com