Energy Report and Modelling Summary

BRINK! – Community Garden Project
Kent Street, Belfast, BT1 2JG

Examined Areas & Technologies:

- Site Electricity Consumption
- Solar PV Potential
- LiFePO4 Battery System
- Electric Vehicle V2L application
- Financial & Emission analysis

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Executive Summary

The energy modelling completed for the BRINK! project highlighted several scenarios that have the potential to minimize generated CO_2 emissions, whilst offering significant economic benefits when compared to the baseline use of just a diesel generator. Project lifetime costs were reduced by at least **50%** for all models explored, with project savings of up to **64%** being achieved when compared to baseline generator use.

Notably modelling showed that the adoption of biodiesel generators coupled with solar photovoltaic (PV) systems and battery energy storage had the possibility of reducing emissions by up to **99%**. When integrating an electric vehicle with vehicle-to-load (V2L) technology instead of using a conventional diesel generator, emission reductions of **98%** were possible, with **53%** financial savings were achievable.

As society begins to transition to a more renewable powered world, energy systems are likely to get more complex to meet future requirements. In this regard it is important to demonstrate now that a range of hybrid energy systems are feasible and can be deployed in a wide range of locations. The BRINK! project is located in a dense urban environment in the heart of Belfast City centre, which would not initially seem like an ideal location for a hybrid renewable energy system. Nevertheless, this project and associated energy modelling shows how even the most unlikely of locations can reduce their environmental impact with the right design approach and philosophy.

The BRINK! project serves as a practical example of how green spaces can be brought into city centres sustainably and economically, aligning with long term goals for a net zero future. The project emphasizes the environmental benefits from utilising renewable energy sources, even in challenging environments, and the benefits of incorporating biofuels over conventional ones.

The modelling results and actuality of the project on the ground demonstrates that with the right strategies and long-term vision, achieving net-zero emissions is not only possible, but it is now within reach.

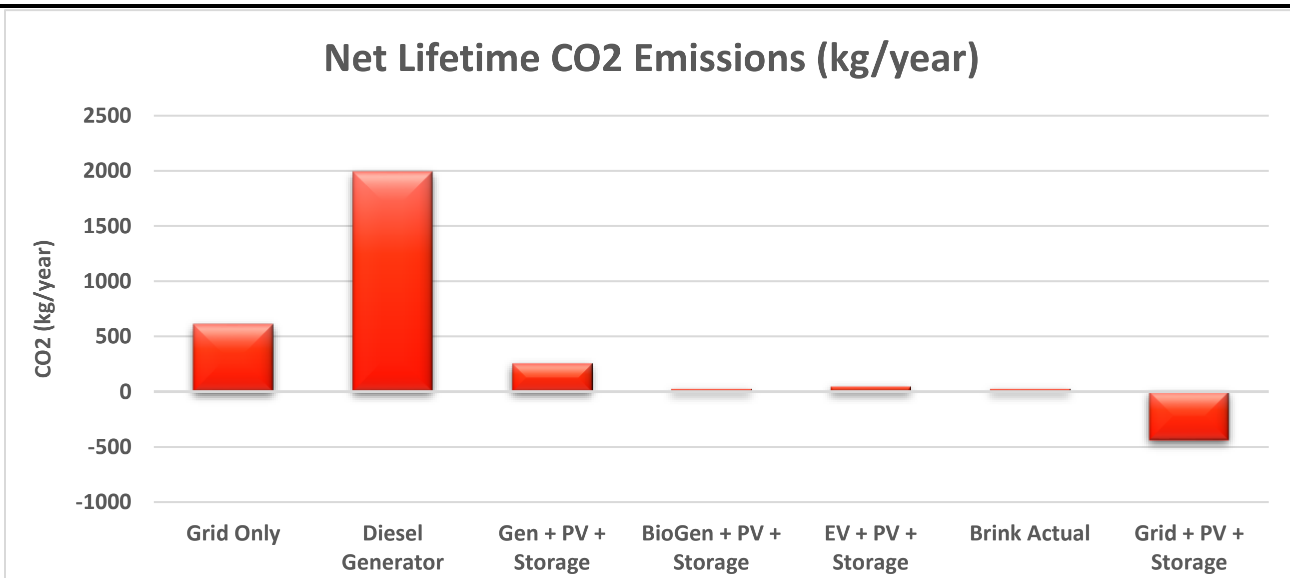

Chart Showing net CO2 emissions for all modelled scenarios.

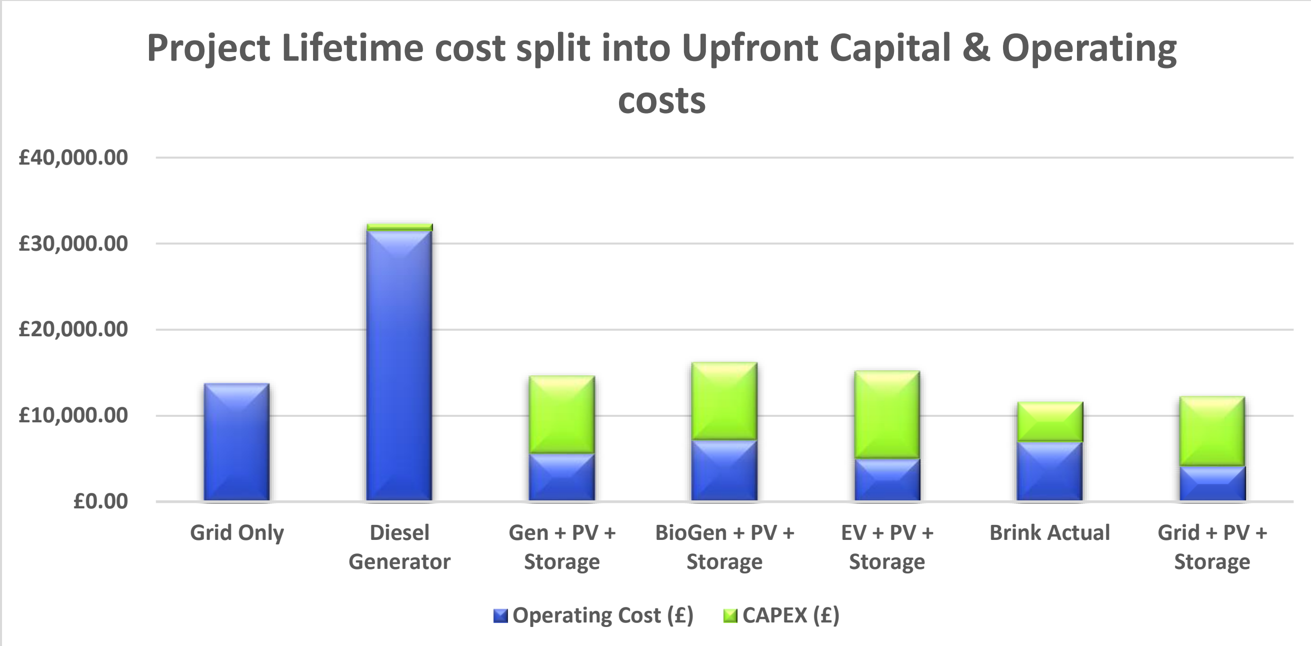

Chart showing Project Lifetime Costs broken down into upfront capital + total operating costs.

***Summary of Modelling Results*:**

Name	Lifetime Cost (£)	COE (£/kWh)	Operating Cost (£/yr)	CAPEX (£)	Ren Frac (%)	CO2 (kg/year)	Energy Generated (% of demand)
Baseline 1	£13,681	£0.30	£547	***£0***	***0***	610.9	0%
Baseline 2	***£32,352***	***£0.70***	***£1,262***	£812	***0***	***1992.4***	102%
Scenario 1	£14,590	£0.32	£223	£9,006	83	255.7	204%
Scenario 2	£16,145	£0.35	£286	£9,006	83	25.2	204%
Scenario 3	£15,186	£0.33	£200	***£10,194***	92.4	46.5	187%
Scenario 4	***£11,596***	£0.25	£280	£4,606	83	25.2	204%
Scenario 5	£12,158	***£0.14***	***£165***	£8,029	***93.6***	***-440.4***	187%

- ***Baseline 1** – Grid Only*
- ***Baseline 2** – Generator Only*
- ***Scenario 1** – Generator + Solar PV + Battery*
- ***Scenario 2** – Biodiesel Generator + Solar PV + Battery*
- ***Scenario 3** – Electric Vehicle V2L + Solar PV + Battery*
- ***Scenario 4** – (Brink Actual) - Biodiesel Generator + Solar PV + Battery*
- ***Scenario 5** – Grid + Solar PV + Battery*

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Project Description

Location:

BRINK! is a platform designed to foster dialogue, education, and action on the critical issues surrounding climate change. In alignment with its objectives, a proposal has been put forward to repurpose the currently underutilized space known as Belfast Stories into a vibrant community garden and event park.

This project aims to enhance the availability of green spaces within the local vicinity, while also showcasing the effective integration of renewable technologies in an urban setting. The envisioned transformation seeks not only to beautify the area but to serve as a practical demonstration of sustainable practices within the heart of the city. This project will address the concerns of using mainly off-grid renewable technologies within a heavily developed built environment.

Located between Royal Avenue and North Street in Belfast, the proposed site is conveniently situated just a 5-minute walk from the city centre. Spanning an area of approximately **909m2** (**14.6 acres**) and enclosed by a perimeter of approximately **125 metres**, this space presents a prime opportunity for revitalization that can contribute significantly to the community's environmental and social well-being.

Figure 1 - Google maps view of approximate location/perimeter of site.

Projected Site Electricity Consumption:

To facilitate the development of the proposed site, a preliminary assessment of the energy requirements was conducted. Due to the lack of an available grid connection on site it is an important step before any modelling can be completed. This to help predict any shortfall in energy generation from renewable resources used on site, which will allow for mitigating any potential demand issues before they arise. Understanding the site's energy needs will also allow for more accurate forecasting of system performance, as well as enabling optimization of any proposed system.

The anticipated equipment necessary for the site's operation includes:

- A kettle or water heater for preparing hot beverages for staff on site.
- Festoon lighting to illuminate the outdoor areas.
- Strip lighting within containers to provide adequate visibility inside the utilized spaces.
- Auxiliary power for a workshop, supporting the use of various devices such as laptop and phone chargers, speakers, and other event-related equipment.

Equipment	*Max Power (kW)*	*Avg. Hours / Day*	*kWh / Day*	*kWh / Week*	*kWh / Year*	*Avg. Power (kW)*
Kettle	1.85	1	1.85	9.3	481.0	0.23
Workshop Lighting	0.18	8	1.44	7.2	374.4	0.18
Workshop Appliances	0.25	8	2	10.0	520.0	0.25
Festoon Lighting	0.22	8	1.76	8.8	457.6	0.22

Figure 2 - Table showing estimation of energy and power demands used to model consumption on site.

To project the site's energy consumption, several assumptions were made. It was estimated that the site would operate for 8 hours daily, from 10 AM to 6 PM, and remain open 5 days a week (Tuesday through Saturday). It should be noted that there is no historical data as the site has not been in operation yet, and as such estimates are based on the specifications of equipment expected to be on site. The total site electricity consumption was estimated to be ***1,840 kWh/year***, which is approximately ***5.04 kWh/day***.

These estimates are conservative and designed to account for year-round operation with a constant demand. It is expected that the site will only operate for a couple of days a week, with intermittent increases in activity throughout holiday or event periods. This is most likely an overestimation of what the actual demand on site will be but will ensure that the planning process remains adaptable and scalable, accommodating both current needs and expansion of the site.

Due to uncertainty around when the site would specifically operate, and what a "normal" day would look like, consumption was modelled as if it would be the same every day throughout the year. This means that we did not remove days to account for holiday periods, nor did we increase consumption around peak event times. It is to be expected that there will be increased activity and consumption around holiday periods, however it is difficult to predict what, if any, extra appliances would be utilized on site to accommodate this.

This issue is part of the reasoning behind why the decision was made to overestimate the energy usage throughout the year by assuming a full working week on site, when it is not expected to operate as many hours and/or days of the week. This will hopefully allow some room for error if future energy consumption increases around peak activity times.

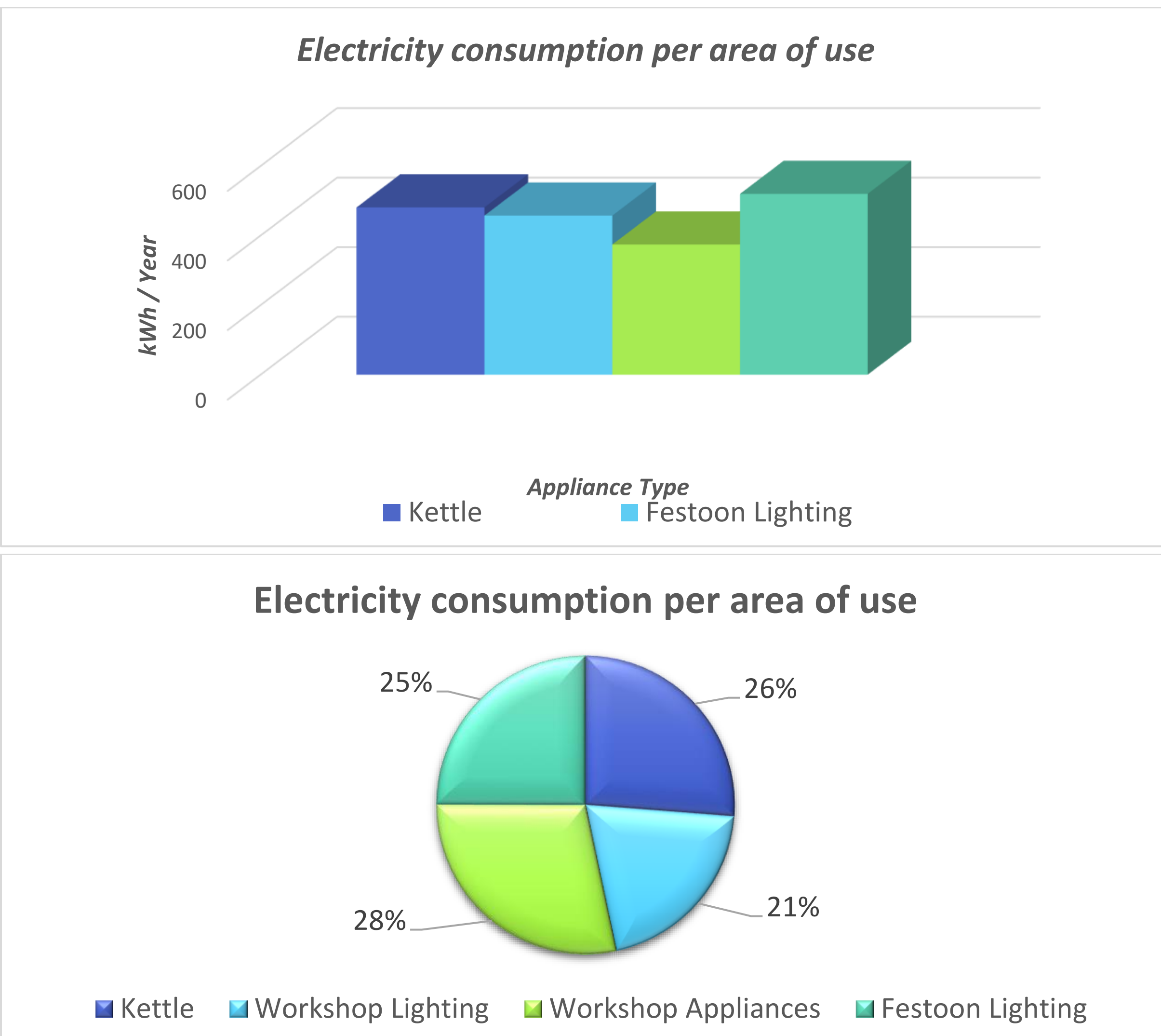

Figure 3 - Charts showing estimated electricity consumption per appliance used.

Baseline Electricity Generation and Emissions:

Given the undeveloped state of the site, which lacks established energy infrastructure, evaluating the environmental impact and benefits of renewable energy integration is challenging, as there is no existing baseline. To address this, baseline models representing either a diesel generator or a grid connection were developed for each scenario to mimic conventional energy solutions typically used in the absence of renewables.

The establishment of these baselines is crucial for identifying potential shifts in both the economic and emissions profiles for each simulated scenario. While the option of establishing a grid connection exists, it would require thorough planning, obtaining necessary permissions, and possibly incurring substantial extra costs. This is particularly relevant given the project's short-term nature, lasting approximately ***18 months***, with the complexities associated with securing a grid connection within such a timeframe.

Consequently, a scenario was modelled assuming the absence of an on-site grid connection, necessitating the inclusion of a generator. Diesel was selected as the fuel for the generator due to its common usage already for off grid generation in industry. To calculate impacts on emissions, a carbon intensity of approximately ***2.51 kgCO2 per litre*** consumed was used, with financial modelling based on the current pump price of ***£1.444 per litre*** at the time of writing.

This baseline model plays an important role in evaluating the environmental footprint associated with conventional energy sources. In scenarios where a grid connection is unavailable or on-site renewables cannot fully meet the site's power needs, the reliance on a generator becomes inevitable. Therefore, incorporating such considerations into the modelling process is essential to truly understanding any potential impacts from implementing a hybrid/renewable energy system.

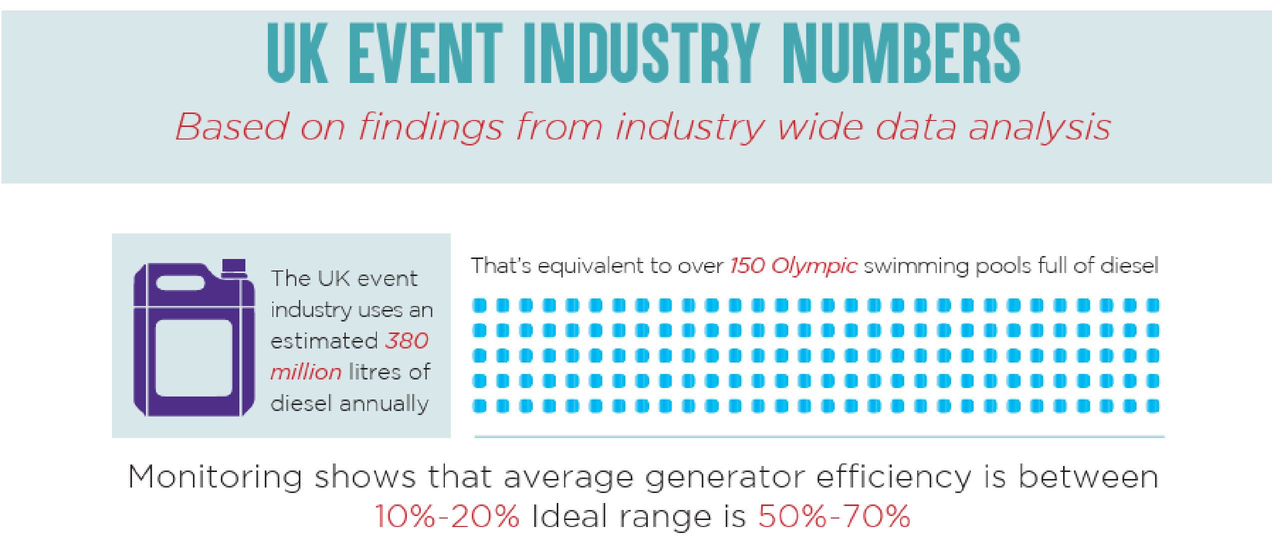

Figure 4 - Infographic showing volume of diesel consumed by UK events industry.

Biodiesel Fuel:

Given the constraints present at the site with obtaining a grid connection, biodiesel has been selected as the alternative fuel of choice to replace diesel for use in generators. While Solar PV is the main source of energy for the site, the lack of generation during the winter months requires an additional generation source. As such if a generator is to be considered, it seems appropriate to explore renewable fuel sources, in this case **HVO** Biodiesel.

Biodiesel offers a significant reduction in carbon emissions, with net carbon emissions being up to **90%** lower than compared to conventional diesel. Moreover, biodiesel's compatibility with existing diesel engines allows for it to be used in any existing equipment without any modifications. This helps reduce the costs sometimes associated with incorporating renewable fuels and makes HVO a better alternative to some other biofuels that are not as easy to work with.

Biodiesel's environmental benefits extend beyond just lower carbon emissions as it also produces fewer particulates, contributing to cleaner air quality and an overall healthier environment. Additionally, the use of biodiesels could support a circular economy by utilizing waste and other non-food-grade oils as feedstock. As such determining the viability of HVO biodiesel is an important aspect of the modelling process.

To calculate impacts on emissions, a carbon intensity of approximately ***0.251 kgCO2 per litre*** consumed was used, which represents a 90% reduction compared to the conventional diesel fuel also modelled. For financial modelling metrics a price ***£2.09 per litre*** of HVO fuel was used, as this was the current pump price available in Northern Ireland at the time of writing this report.

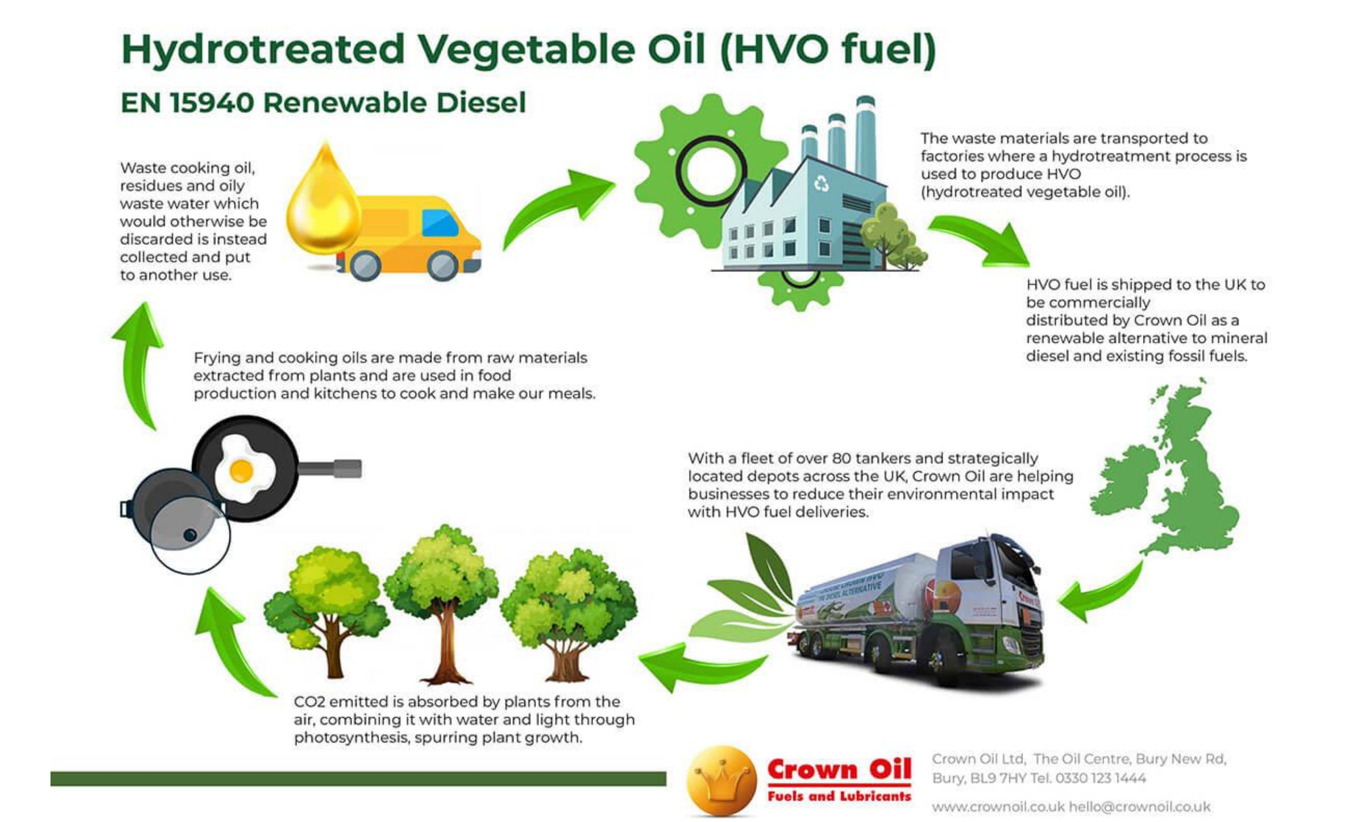

Figure 5 - Infographic showing production cycle for HVO biodiesel.

Solar Photovoltaic (PV):

Due to the limited development possible on site, Solar Photovoltaic (PV) technology has been selected as the foremost renewable energy solution for the site. This choice is due to the technology's cost efficiency, and the practicality of its integration into a hybrid energy system. Detailed analysis using PVGIS (Photovoltaic Geographical Information System) data has underscored the viability of Solar PV, projecting an annual electricity generation capacity of approximately ***894 kWh*** per installed kilowatt peak (***kWh/kWp***).

Sixteen **250W** panels have been allocated for the system installation, initially providing a total installed solar power of **4kWp**. There is also the potential for the solar allocation to increase to **6.5kWp** from more panels being installed at a later date. Due to uncertainty around the specific performance specifications of the panels used, a performance value of ***88%*** of rated output after ***25 years*** of service was selected. When modelling the financial aspects of a solar installation, associated costs of ***£1,250/kWp*** installed were used. A system array of **4kWp** was selected for the modelling process as this reflects the guaranteed installation planned for the site.

It should be noted that the physical layout and operational dynamics of the site necessitate careful consideration of panel placement to avoid interference with daily activities. Additionally, the panels will initially be limited to being located on top of shipping containers and as such there is a definitive limit on how much solar PV can be installed without making changes to the overall project design.

It is also essential to recognize that although Solar PV provides a reliable and sustainable energy source, its output can fluctuate significantly throughout the year. Therefore, to ensure a reliable and consistent power supply, it is advisable to consider integrating additional energy generation and/or storage solutions alongside Solar PV to meet demand when solar generation alone cannot.

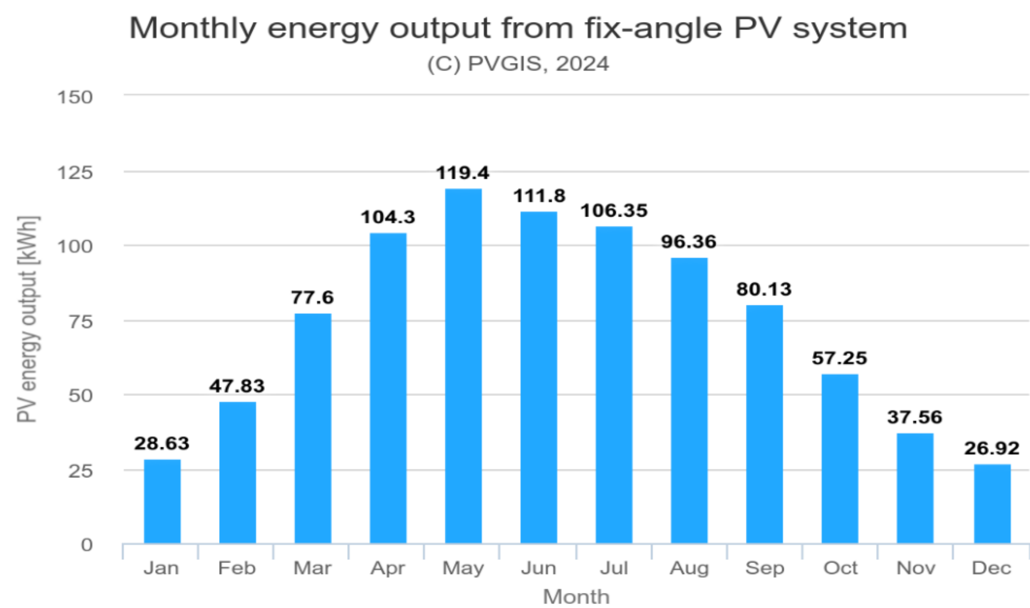

Figure 6 - Bar chart showing monthly electricity production per kW of installed solar PV at Belfast Stories site.

$LiFePO_4$ Battery & Distribution System:

The integration of a renewable energy system introduces complexities due to the variable nature of photovoltaic (PV) power generation. Even though the Belfast Stories site is expected to have a relatively modest and stable power demand, it is anticipated that during the winter months, this demand may surpass what the ***4kW*** solar array can generate.

To mitigate this anticipated shortfall, the implementation of *a* ***280Ah****,* ***48V*** battery storage system is proposed as part of the energy solution. This system will bridge the gap during periods when solar output is insufficient, provided there is adequate charge. Additionally, it facilitates the storage of surplus solar energy during periods of low demand, enhancing the site's overall efficiency in utilizing generated renewable energy.

The selected battery offers a usable capacity of ***14.4kWh*** at a total cost of ***£2,204.84 (£153.11)***. This was the actual cost to procure the battery being used and is not an estimate. It should also be noted that this battery was procured in ***2023***, with the prices having decreased even more since this time. The inverter being used cost ***£850*** with this cost also being included in during the modelling process.

When defining the battery characteristics an ***80%*** depth of discharge (DoD) was selected to strike an optimal balance between maximizing energy availability and prolonging battery life, with the batteries projected to have a lifespan of ***5,000*** cycles. This DoD is essential for maintaining steady battery performance and extending its useful life.

Given the low expected usage over a ***25-year*** project lifespan, the batteries and inverter system are anticipated to require replacement after approximately ***12.5 years***. While this replacement timeline extends beyond the 18-month duration of the current project, detailing these parameters is crucial for accurately predicting battery economics, performance, and degradation, particularly if the project is extended or relocated.

Figure 7 - Image showing testing of LiFePO4 battery with hybrid inverter system.

Electric Vehicle to Load (V2L):

The integration of Vehicle-to-Load (V2L) technology into the energy system introduces an interesting approach to managing energy demand and supply, leveraging the battery storage of electric vehicles (EVs) as a dynamic component of the site's energy infrastructure. This system capitalizes on the potential of EVs to act as mobile energy storage units, providing additional flexibility and resilience to the site's energy profile. This is of particular importance when considering meeting the shortfall in energy generation that occurs due to variability of solar PV.

By incorporating V2L technology, EVs connected to the site could discharge stored energy back into the system during peak demand periods or when solar generation is insufficient. This not only enhances the site's ability to meet its energy needs with renewable sources but also promotes the efficient use of EV battery capacity, contributing to a more integrated and sustainable energy ecosystem. If managed correctly, this would also facilitate the removal of the requirement to have either a grid connection or diesel generator on site, as the EV storage capacity far exceeds any potential energy demands for a given day on site.

The feasibility and impact of V2L technology depend on various factors, including the availability of EVs and their battery sizes, which are subject to change with future technology adoption and advancements. Despite these variables, exploring the use of V2L signifies a commitment to enhancing the site's energy self-sufficiency. As this technology continues to develop, its integration is key to adopting more flexible and sustainable energy management practices, particularly in situations where conventional energy solutions are either impractical or insufficient.

When modelling EVs and V2L technology an assumption was made that an EV would not need to be purchased, and as such there was no additional cost for acquiring an EV. This was done to reflect the potential future where transport is electrified, where electric vehicles are the norm. The additional cost of the required V2L equipment was included in the modelling process, with a 6kW inverter (see image below) costing approximately ***£2000*.**

Figure 8 - Image showing testing of V2L technology using Nissan Leaf as part of previous case study.

Modelled Energy Systems – Model Summary:

To thoroughly evaluate the Belfast Stories site's energy strategy, detailed modelling exercises were conducted for a range of scenarios. These models were aimed at examining both the financial implications and environmental impact associated with various energy configurations possible given limitations of the chosen site.

The objective was to ensure that the initial project planning stages fully explored all possibilities, potentially uncovering advantageous strategies that might otherwise be overlooked. All scenarios that included solar PV and a battery had the same size in all scenarios, which was 4kWp and 11.5kWh for solar PV and battery capacity respectively. The scenarios explored include:

- ***Baseline 1*** **–** Grid Only: Baseline model if only a grid connection is utilized on site.
- ***Baseline 2*** **–** Generator Only: Baseline model if only a generator is utilized on site.
- ***Scenario 1*** **–** Diesel Generator + Solar PV + Battery: Conventional 3kW diesel generator, 4kWp solar PV & 11.5 kWh useful battery capacity.
- ***Scenario 2*** **–** Biodiesel Generator + Solar PV + Battery: 3kW Biodiesel generator, 4kWp solar PV & 11.5 kWh useful battery capacity.
- ***Scenario 3*** **–** EV/Grid + Solar PV + Battery: Grid charging + Electric Vehicle V2L, 4kWp solar PV & 11.5 kWh useful battery capacity.
- ***Scenario 4*** **–** Brink Actual - Biodiesel Generator + Solar PV + Battery: Identical to scenario 2 with biodiesel generator, but uses actual financial details associated with BRINK! project.
- ***Scenario 5*** **–** Grid + Solar PV + Battery: Grid connection with exports enabled, 4kWp solar PV & 11.5kWh useful battery capacity.

For each scenario analysed, a projected lifespan of ***25 years*** was selected. Despite the project's actual duration being only ***18 months***, the purpose of the analysis is to assess the viability of implementing such an energy system on a more permanent basis across similar initiatives. This approach aligns with the project's goals to explore and extend the limits of current technological capabilities, warranting a comprehensive assessment of the project's full lifecycle within the analysis.

It is important to highlight that the distinctive characteristics of this project have led to the procurement of energy equipment in a manner that could be described as "ad-hoc," resulting in cost implications that are unusually lower than those typically encountered with broader adoption of similar systems. To accommodate this Scenario 4 was selected to specifically represent the reality of the BRINK! Project rather than a representative system as was done in the other scenarios.

In this regard, to mitigate any potential inaccuracy of the modelling results due to the unique financial aspects of the BRINK! project, it was decided to incorporate broader industry data that more accurately reflects the costs associated with standard installations for most of the scenarios. This adjustment impacts only the financial aspects of the analysis and does not influence the system's performance metrics. This was done so that the modelling can be applied to similar project ideas that would be procuring equipment with more typical costs.

Modelling Results

Baseline 1 – Grid Only:

Scenario Description:

This baseline model only measures the system economics and emissions produced from having a conventional grid supply for the modelled energy use. Grid purchase price of ***£0.2974/kWh*** used.

Total Cost (£)	COE (£/kWh)	Operating Cost (£/yr)	CAPEX (£)	Ren Frac (%)	CO2 (kg/yr)	Grid Purchases (kWh)	Grid Sales (kWh)
£13,680.77	£0.30	£547.23	£0.00	0	610.90	1840.1	0

Baseline 2 – Generator Only:

Scenario Description:

This baseline model only measures the system economics and emissions produced from having a 3.6kW diesel generator supply the modelled energy use. Diesel purchase price of ***£1.44/L*** used.

Total Cost (£)	COE (£/kWh)	Operating Cost (£/yr)	CAPEX (£)	Ren Frac (%)	CO2 (kg/yr)	Energy Produced (kWh)	Fuel Consumed (L)
£32,351.57	£0.70	£1,261.58	£812.15	0	1992.40	1879.2	761.1

Scenario 1 – Diesel Generator + Solar PV + Battery:

Scenario Description:

This scenario models the system performance if a hybrid PV-Battery-Generator system was adopted with the following equipment:

- ***4kWp*** Solar PV System
- ***5kW*** Hybrid Inverter Charge Controller
- ***14.4kWh*** LiFePO$_4$ Battery at **80%** DoD
- ***3.6kW*** Diesel generator with a diesel price of ***£1.44/L***

Total Cost (£)	COE (£/kWh)	Operating Cost (£/yr)	CAPEX (£)	Ren Frac (%)	CO2 (kg/yr)	Solar PV Output (kWh/yr)	Battery Throughput (kWh/yr)	Generator Output (kWh)	Fuel Consumed (L)
£14,590.23	£0.32	£223.37	£9,005.99	83.0	255.67	3441.1	663.8	312.9	97.7

Scenario 2 – Biodiesel Generator + Solar PV + Battery:

Scenario Description:

This scenario models the system performance if a hybrid PV-Battery-BioGenerator system was adopted with the following equipment:

- **4kWp** Solar PV System
- **5kW** Hybrid Inverter Charge Controller
- ***14.4kWh*** LiFePO$_4$ Battery at **80%** DoD
- ***3.6kW*** Diesel generator with a biodiesel price of ***£2.09/L***

Total Cost (£)	COE (£/kWh)	Operating Cost (£/yr)	CAPEX (£)	Ren Frac (%)	CO2 (kg/yr)	Solar PV Output (kWh/yr)	Battery Throughput (kWh/yr)	Generator Output (kWh)	Fuel Consumed (L)
£16,144.83	£0.35	£285.55	£9,005.99	83.0	25.20	3441.1	663.8	312.9	97.7

Scenario 3 – EV + Solar PV + Battery:

Scenario Description:
This scenario models the system performance if a hybrid PV-Battery-EV system was adopted with the following equipment:

- **4kWp** Solar PV System
- **5kW** Hybrid Inverter Charge Controller
- ***14.4kWh*** $LiFePO_4$ Battery at **80%** DoD
- **6kW** V2L (Vehicle-to-load) inverter price at **£2000**

Total Cost (£)	COE (£/kWh)	Operating Cost (£/yr)	CAPEX (£)	Ren Frac (%)	CO2 (kg/yr)	Solar PV Output (kWh/yr)	Battery Throughput (kWh/yr)	Grid Purchases (kWh)	Grid/Energy Sold (kWh)
£15,185.73	£0.33	£199.68	£10,193.84	92.4	46.53	3441.1	590.6	140.1	0

Scenario 4 – BRINK! - Biodiesel Generator + Solar PV + Battery:

Scenario Description:
This scenario models the system performance using the actual metrics from the BRINK! Project, if a hybrid PV-Battery-BioGenerator system was adopted with the following equipment:

- ***4kWp*** Solar PV System
- ***5kW*** Hybrid Inverter Charge Controller
- ***14.4kWh*** $LiFePO_4$ Battery at **80%** DoD
- ***3.6kW*** Diesel generator with a biodiesel price of ***£2.09/L***

Total Cost (£)	COE (£/kWh)	Operating Cost (£/yr)	CAPEX (£)	Ren Frac (%)	CO2 (kg/yr)	Solar PV Output (kWh/yr)	Battery Throughput (kWh/yr)	Generator Output (kWh)	Fuel Consumed (L)
£11,595.52	£0.25	£279.58	£4,605.99	83.0	25.20	3441.1	663.8	312.9	97.7

Scenario 5 – Grid + Solar PV + Battery:

Scenario Description:

This scenario models the system performance if a PV-Battery-Grid system was adopted with the following equipment:

- ***4kWp*** Solar PV System
- ***5kW*** Hybrid Inverter Charge Controller
- ***14.4kWh*** $LiFePO_4$ Battery at **80%** DoD
- National ***Grid*** connection with grid sales enabled, Import Price - ***£0.2974/kWh***, Export Price - ***£0.1422/kWh***

Total Cost (£)	COE (£/kWh)	Operating Cost (£/yr)	CAPEX (£)	Ren Frac (%)	CO2 (kg/yr)	Solar PV Output (kWh/yr)	Battery Throughput (kWh/yr)	Grid Purchases (kWh)	Grid/Energy Sold (kWh)
£12,157.73	£0.14	£165.15	£8,029.01	93.6	-440.35	3441.1	504.9	218.2	1544.5

Summary of Modelling Results:

Name	Lifetime Cost (£)	COE (£/kWh)	Operating Cost (£/yr)	CAPEX (£)	Ren Frac (%)	CO2 (kg/year)	Energy Generated (kWh)	Energy Generated (% of demand)	Grid Purchases (kWh/year)	Fuel Consumed (L/year)
Baseline 1	£13,681	£0.30	£547	***£0***	***0***	610.9	0	0%	1840.1	-
Baseline 2	***£32,352***	***£0.70***	***£1,262***	£812	***0***	***1992.4***	1879	102%	-	761.1
Scenario 1	£14,590	£0.32	£223	£9,006	83	255.7	3754	204%	-	97.7
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- ***Baseline 1*** *– Grid Only*
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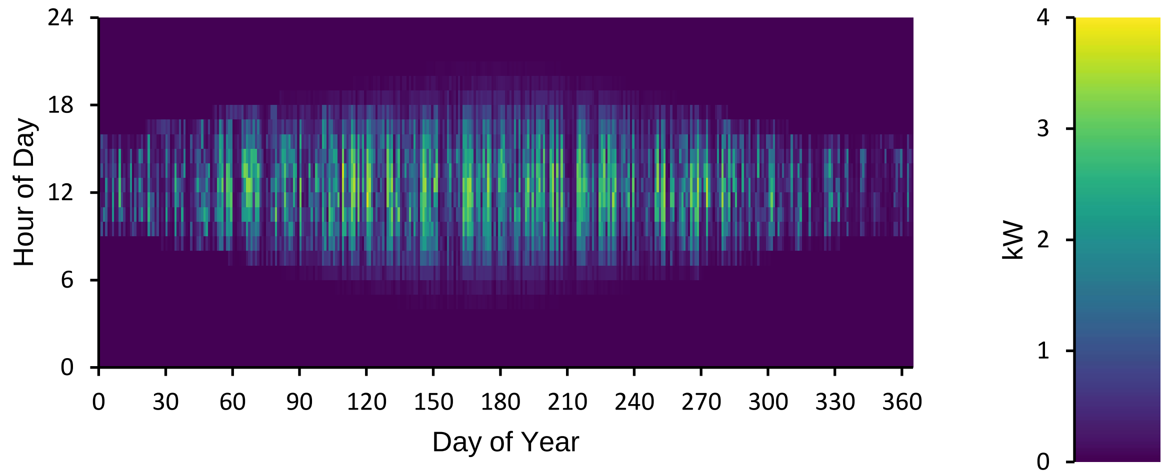
- ***Scenario 5*** *– Grid + Solar PV + Battery*

System Performance Results

4kWp Solar PV System Performance:

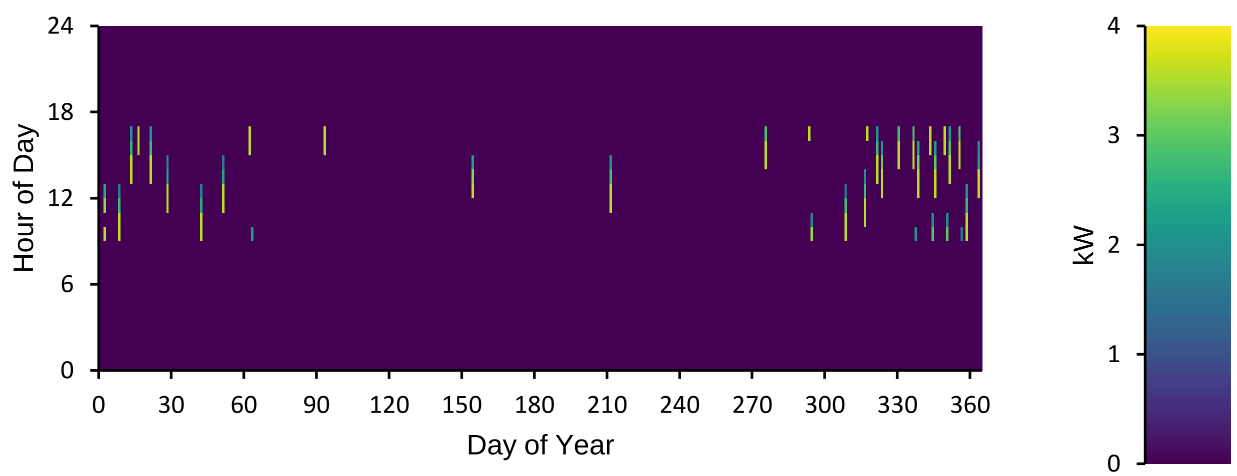
PV Performance:

Rated Capacity	4.00 kWp	Total Production	3,441 kW
Capital Cost	£5,000	Specific Yield	860 kWh/kW
COE	0.0581 £/kWh	PV Penetration	187 %



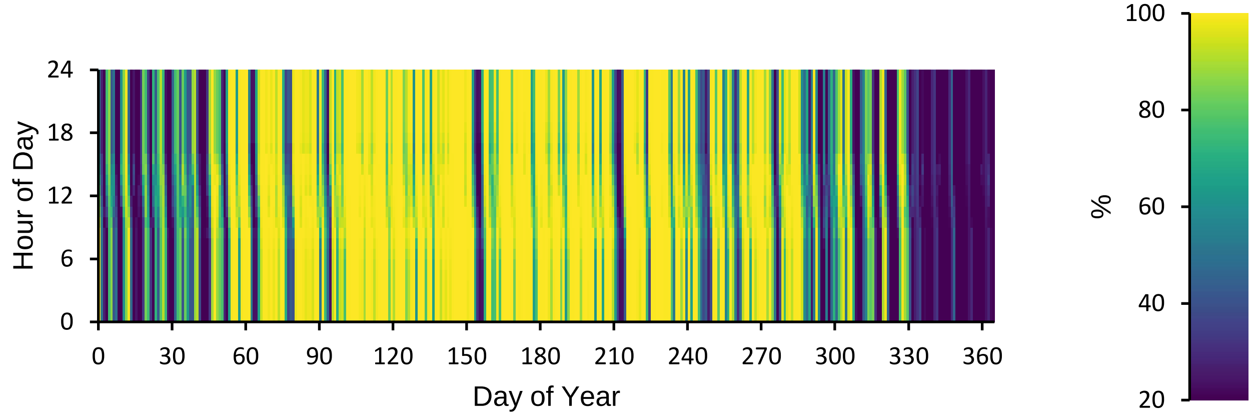
Generator Performance:

Generator Size	3.6 kW	Generation Cost	0.388 £/hour
Fuel Consumption	97.7 L	Generation Cost	0.571 £/kWh
Hours of Operation	103 hours/year	Electrical Production	313 kWh/year



Battery Performance:

Useful Capacity	11.5 kWh	Expected Life	12.5 years
Annual Throughput	505 kWh/year	Capital Costs	£2,205
Losses	10.1 kWh/year	Autonomy	51.2 hours



Overall Demand:

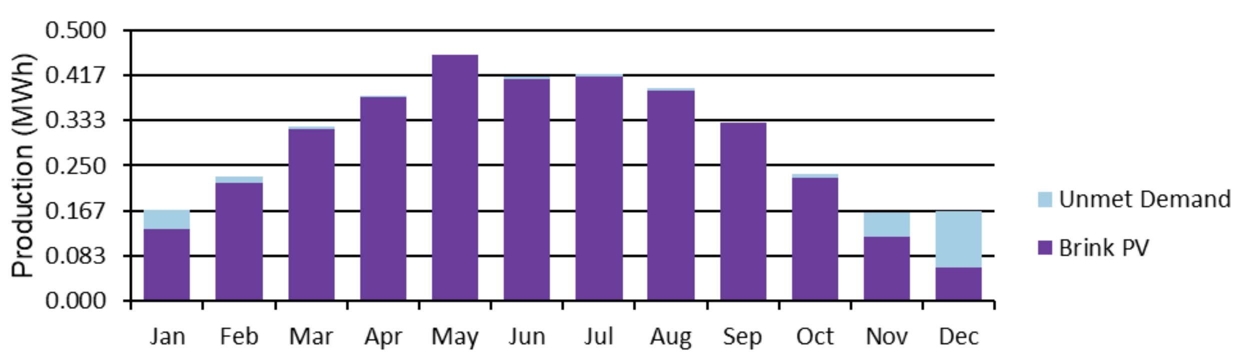


Figure 9 - Bar chart showing monthly electricity of solar VS unmet demand that needs to be supplemented.

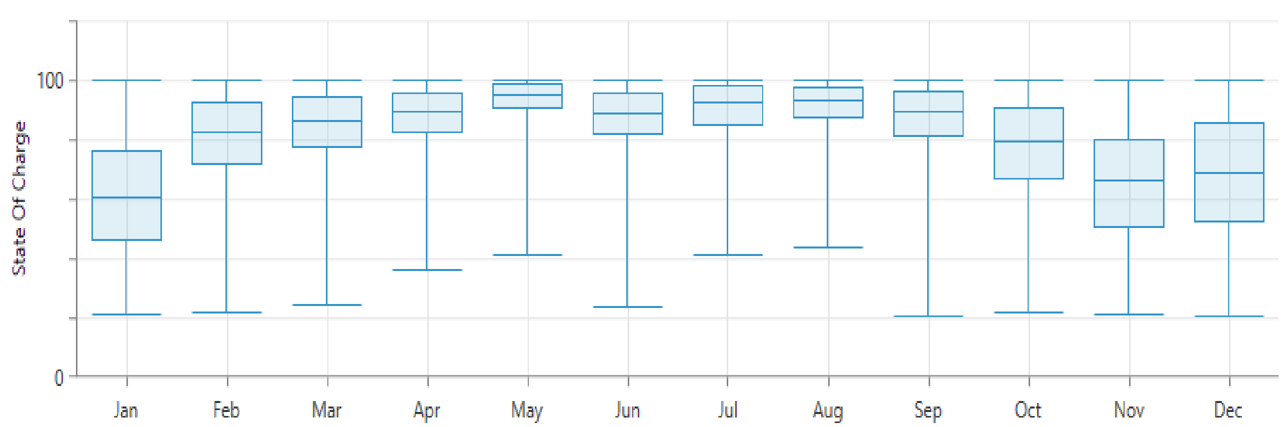


Figure 10 - Box plot showing range of battery capacities during each month.

Modelling Analysis

Modelling analysis:

The modelling completed showed great potential for all the explored scenarios, with reductions in net emissions and financial savings being achievable when compared to Baseline 2 of only using a diesel generator.

As discussed previously it is unlikely that a grid connection will be available on site making Baseline 2 the most appropriate scenario for comparing any results, as this is the most likely scenario without any renewables being implemented. As such results from the Grid only model in Baseline 1 will be shown in charts but will not be used when identifying the most optimal results across different metrics in the analysis below.

Lifetime Cost (£):

The project lifetime cost is the sum of all revenues and costs over the project lifetime, and includes all aspects of installing, maintaining, and decommissioning the project.

The model with the most optimal NPC was Scenario 4 coming in at £11,596 with this model being the actual BRINK! project scenario using a biodiesel generator, solar PV, and battery storage. There are numerous reasons for this result, but the main factor has been the smart procurement seen by the project managers when getting equipment for this project. They have been able to obtain solar PV panels and other equipment at a more favourable rate than would be typically expected.

The next most optimal result for NPC is Scenario 5 with an NPC of £12,158. This was the system utilizing a grid connection with exports enabled, a 4kWp solar PV system, and battery storage. This was mainly due to the additional revenues generated by enabling grid exports improving the overall economics.

It should be noted however that all of the scenarios explored had very similar economics when looking at the lifetime project cost, with significant improvements being made compared to baseline scenarios.

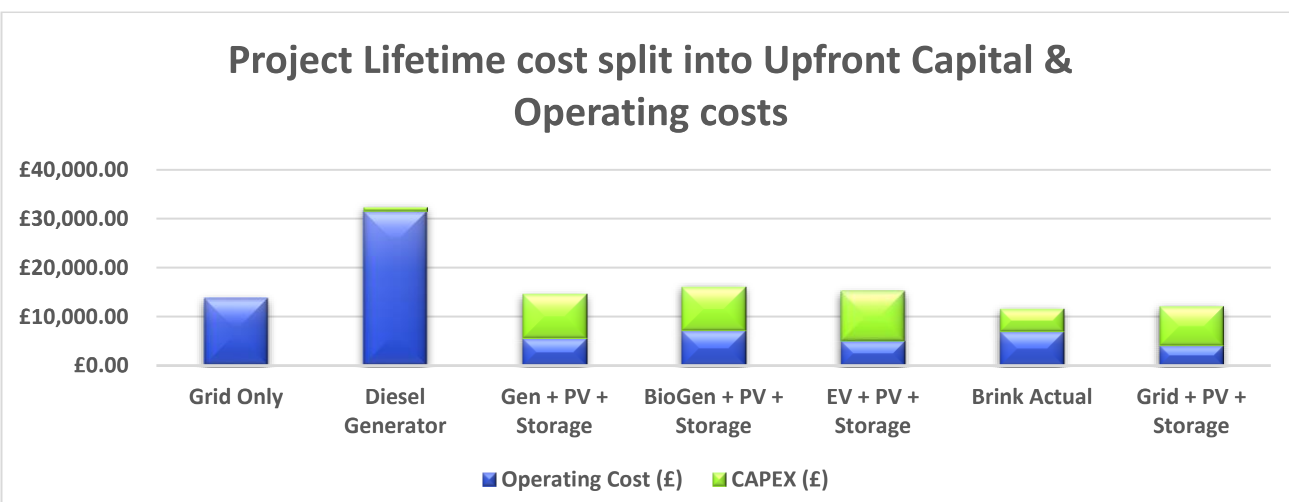


Figure 11 - Chart showing Project Lifetime Costs broken down into upfront capital + total operating costs.

Cost of Electricity (COE £/kWh):

The cost of electricity is calculated by first taking the total lifetime project cost and dividing it by the total amount of useful energy generated on site. Any excess generation that is not used or exported is not considered when calculating the COE value, and as such it reflects the average cost incurred per kWh of electricity used.

The model with the most optimal COE was **Scenario 5** with an average energy cost of **£0.14/kWh**. This was the system utilizing 4kWp solar PV, and battery energy storage and a grid connection with exports enabled. This scenario benefited from having an abundance of relatively cheap energy from solar PV, combined with the low energy cost of purchasing electricity from the grid relative to using a diesel generator. This can be directly seen when comparing the two baseline scenarios, as using a generator alone is **238%** more expensive than buying from the grid alone.

It should be noted that each of the modelled scenarios offered significant improvements when compared to the baseline COE of £0.70/kWh. All the modelled scenarios would be advantageous when compared to the baseline, with **the worst scenario still offering financial savings of 51%** compared to just using a diesel generator.

Yearly Operating Cost:

The yearly operating cost is the total amount of money required on an annual basis to ensure operation of any given system and is often representative of fuel and maintenance costs. In models where equipment was required to be replaced, the replacement costs were factored into the yearly operating costs. This was to represent consistent contributions to the project overheads in the model rather than a lump sum cash amount being allocated at the start of the project.

Like the previous metrics all the scenarios represented an improvement to the annual running costs, as any additional generation added to site directly displaces fuel consumed by the generator. As such although some scenarios did indeed have lower running costs, all scenarios had such significant reductions that there is little value to be gained selecting a system purely from this metric alone. This may not be the case in projects which have significant energy bills, however that does not apply so much for this project.

Upfront Capital Expenditure Required (CAPEX):

Often the biggest barrier to any project is the upfront capital required to initialize any scenario. This is the sum of money required to purchase all the equipment necessary to begin operations of the proposed system. This is often a barrier due as it often represents a large capital requirement relative to the business cash flows and can be a deal breaker without adequate financing options. It also represents a large risk when compared to only paying ongoing fuel costs, as there is the perception of losing value in system equipment in the event the business or project fails.

Regarding the required upfront capital, the optimal scenario was Baseline 2. This is of course due to the only upfront purchase being the generator, with the rest of the costs mainly accounted for in fuel purchases over the project lifetime. Excluding this the optimal model was Scenario 2 with a CAPEX requirement of **£4,606.61**, which was the 4kWp solar PV, biodiesel generator, and battery storage system. This scenario offered the lowest CAPEX requirements of the hybrid energy systems, and had the lowest NPC compared to other systems.

Renewable Fraction (Ren Frac %) and CO_2 emission reductions:

The renewable fraction represents how much of the total energy consumed on site is provided by the renewable resources being modelled, with the difference being provided by the grid or alternative generation source, in this case a generator. This value also directly correlates to the emission reductions when compared to the baseline, as any renewable percentage above 0% results in an almost linear reduction in fuel consumption.

In this regard the most optimal scenarios were Scenarios 3 and 5, with both scenarios achieving renewable fractions above 90%. Scenario 3 had access to a large volume of energy storage through utilising an EV, and scenario 5 enabled a grid connection which helped balance the overall system. These factors appear to be the biggest influence as to why the renewable fraction was higher, as they were able to better utilise otherwise excess solar PV generation. This would not only represent savings for the site but would also reduce emissions for the wider network. These scenarios however necessitate either a grid connection, and/or an available electric vehicle. As such although these options were the most ideal, they may not be viable for this project.

The next best systems were in Scenarios 2 & 4, which both achieved a renewable fraction of 83% and emission reductions of 98.8%. These systems were a 4kWp solar PV array, biodiesel generator, and battery energy storage system. They were both identical, with scenario 4 represented the actual BRINK! project model. Due to the use of biodiesel in the generators both scenarios were able to almost achieve a net zero carbon footprint, with only 1% of emissions remaining when compared to conventional diesel generator use.

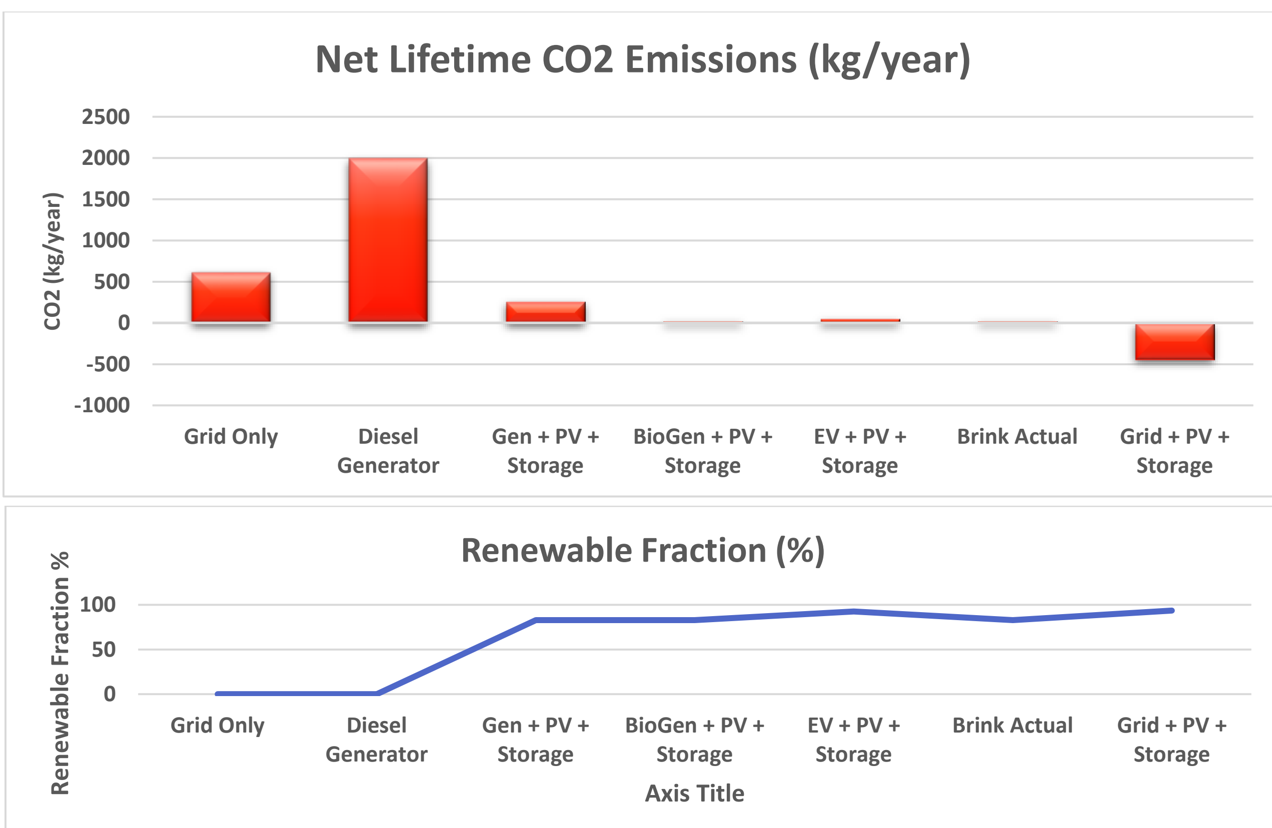


Figure 12 - Chart Showing net CO2 emissions and renewable fraction for modelled scenarios.

Other:

When conducting the modelling process, it was decided to include some scenarios with a hybrid renewable system that had access to the grid. This was to explore the possibilities for the site to expand later, and to also increase the usefulness of the results if used in scenarios later where this may be possible. When this is an option the potential for exporting power the grid should be considered.

Indeed, in Scenario 5 it was possible for 1545 kWh of electricity to be exported to the grid, which is comparable to the total energy demand on site. In this scenario the net emissions of the site would not only have been reduced and at a cheaper rate, but additional benefits could also have been added to the wider network. This was also true in other scenarios with grid connections albeit to a lesser extent. Although not a current possibility, this highlights the potential for projects like the one at the Belfast stories site to not only add value to their local economy through adding services, but also by fundamentally adding value to the local networks and economy.

Conclusion:

In conclusion, it can be said that all the proposed systems are beneficial when compared to the baseline generator usage. When deciding which scenario would be ideal, it just depends on the long-term goals of the project in general. For cost and emission reductions Scenarios 2 & 4 are clear winners when compared to the baseline. These scenarios not only achieve financial savings of 50% & 65% respectively, but they also achieve a net reduction in CO_2 emissions of 99% when compared to baseline. These are the scenarios that incorporate Biodiesel, Solar PV and Battery energy storage.

The modelling did highlight however the potential for EV technologies to be utilised on site, which may be a better alternative if the noise from a generator would prevent its use. Scenario 3 achieved financial savings of 53% and emission reductions of 98%. This makes it have slightly better economics compared to Scenario 2 when using a biodiesel generator, however it does add much complexity to the system. There is also the necessity for an electric vehicle to be provided, and the requirement for it to be on site to deliver power. As such it should be considered if the resources involved with procuring an EV for this is worth the marginal economic improvement.

Although a grid connection is not currently and probably will not be possible at the site, it should be noted that in all circumstances combing the hybrid energy system with a grid connection was always more favourable than using a diesel generator, not only for the consumer on site but also for the wider network as well. Excess solar PV energy generation occurred in all scenarios, and as such there would have been economic and environmental benefits if this energy was not wasted.

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