A modelling solution for solar PV, battery storage and grid connection constraints

New simulation software offers an engineered solution for the connection of renewable energy systems with battery storage in areas with poor grid connection

Obtaining grid approval for the connection of a renewable energy systems is becoming increasingly challenging in the face of significant connection charges and long lead times for reinforcement works.

Over the past 3 years LHW Partnership LLP has developed Yieldworks; a methodology that **maximises generation** and **consumption** of renewable electricity, both with or without **battery storage**.

The model works to minimise a system's impact on the local distribution network, resulting in lower upgrade costs and delays as well as providing import offset savings.

Yieldworks assesses a number of key system requirements:

1. On-site demand
2. Generation profile
3. Export capacity
4. Battery storage
5. Export constraint

Background

Generally, the micro-generation industry looks at solar generation on a monthly basis, and the reports of all the proprietary web based or PC based packages present the information over the period of one year, as illustrated in Figure 1.

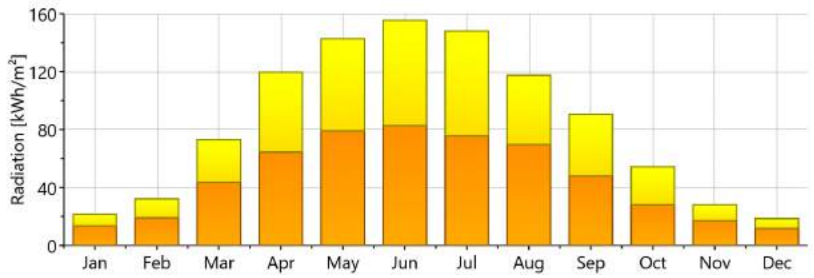

Figure 1: Monthly radiation (kWh/m^2)
(Yellow: Global radiation, Orange: Diffuse Radiation)

In the case of a location with no grid constraints, monthly generation profiles are adequate to estimate the optimal system size, the predicted system yields, financial returns on investment and CO_2 off-set.

However, in the case of site that is subject to an export constraint, monthly generation profiles are less meaningful and a more granular approach is required.

Over the course of a year the output of a solar PV system will vary, with periods of peak generation (midday during the summer) where the inverter outputs are at their highest to periods of low generation (mornings, evenings or dark, cloudy days) where the inverter outputs are at a minimum. Figure 2 illustrates the typical output profile of a solar PV inverter over the course of day.

The same data shown in Figure 2 can also be reproduced to illustrate the hours of operation as a percentage of the maximum inverter output as shown in Figure 3.

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The output of a solar PV inverter typically peaks at around midday, with minimum outputs seen during early mornings and late evenings.

The resulting bell shaped curve is produced for all times of the year, with a varying time distribution a peaks.

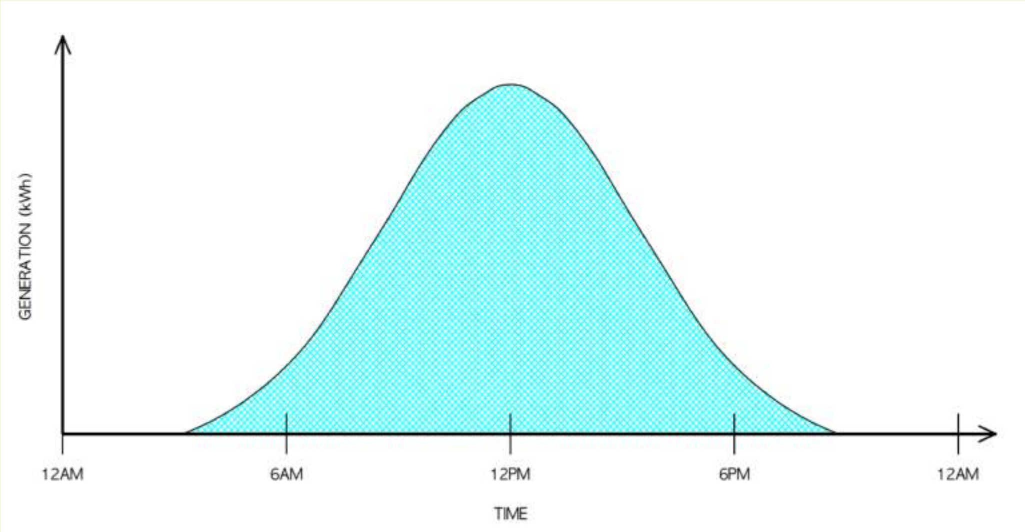

Figure 2: Daily profile for the output of a solar PV inverter on a summer's day

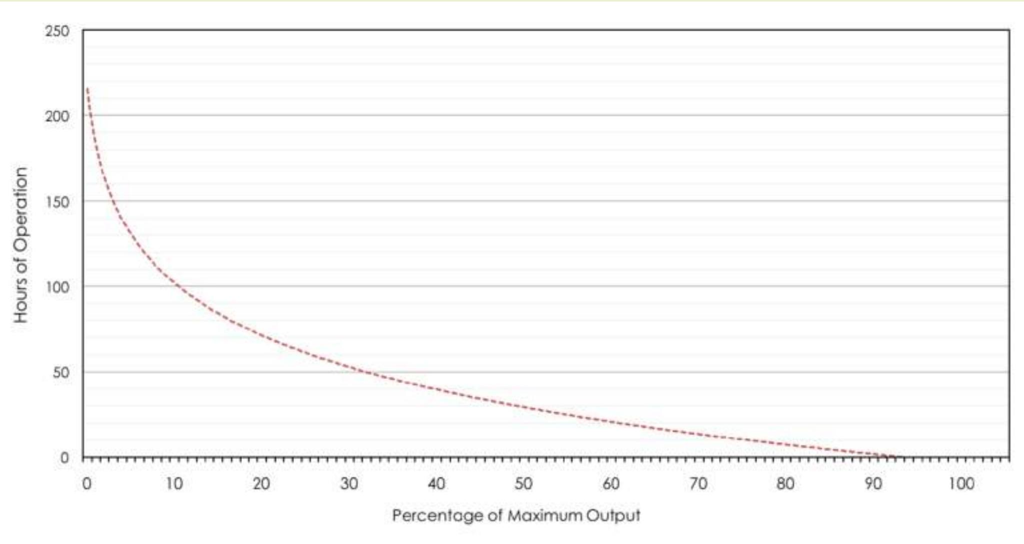

Figure 3: Output of a solar PV inverter expressed as the hours of operation as a percentage of the maximum inverter output

By collating the daily inverter output data over a period of one year, it is possible to see the hours of operation as a percentage of the maximum inverter output.

Fig 3. shows that a domestic solar PV system, the inverter rarely operates at maximum outputs.

There are 8760 hours in one year; 50% of the time a solar PV array will be in darkness and 3% of the time there is insufficient sunlight for the array to start generating energy. Therefore, a solar PV inverter will be operational for 4090 hours per year.

In the example shown in Figure 3, we can see that for 230 hours of the year, the inverter will operate at 3% of maximum output and the inverter very rarely, if ever, operates at 100% of maximum output.

Implications of Limited Export

It is often assumed that if the DNO provides a grid connection offer with a limited export, the size of the solar PV system must also be limited to meet the export constraints of the site, but this is not the case.

As can be seen from Figure 3, inverters very rarely operate at maximum output therefore it is possible to install a larger system size than is often thought, particularly if there is on-site demand.

Yieldworks models the outputs of a solar PV system against on-site demands and export constraints to enable customers to select the most suitable system size.

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Project Example 2.2kWp Solar PV System

The Project - Domestic Property Specification

System Size:	2.2 kWp
Orientation:	South
Pitch:	35 degrees
Shading:	None
Inverter Size:	2.2 kVA
Baseload:	250 W
% of Year Operational:	47%
Hours of Operation:	4090 hours

The Problem

A domestic property with a 24/7 base load of 250 Watts comprising of fridges, freezers and technology on standby wants to install a 2.2 kWp Solar PV system with a 2.2 kVA inverter.

Enquiries with the local DNO has established that the local grid cannot sustain an export greater than 292 W at any time. The customer wishes to understand what impact the export constraint will have on the system.

Undertaking a Yieldworks assessment of the project will allow the customer to understand the impacts.

Figure 4 shows that when the system is operating the average output is at 25% of peak output (yellow lines), which equates to 542 W and by including darkness hours the average output is 253 W. This equates to an annualised capacity factor of 11%.

Assuming a 24/7 baseload demand of 250 W with no other loads, the Yieldworks model indicates that the system would export an average of 292 W. Given the 292 W export limitation imposed by the local DNO, the impacts of the constraint can be seen in Figure 5.

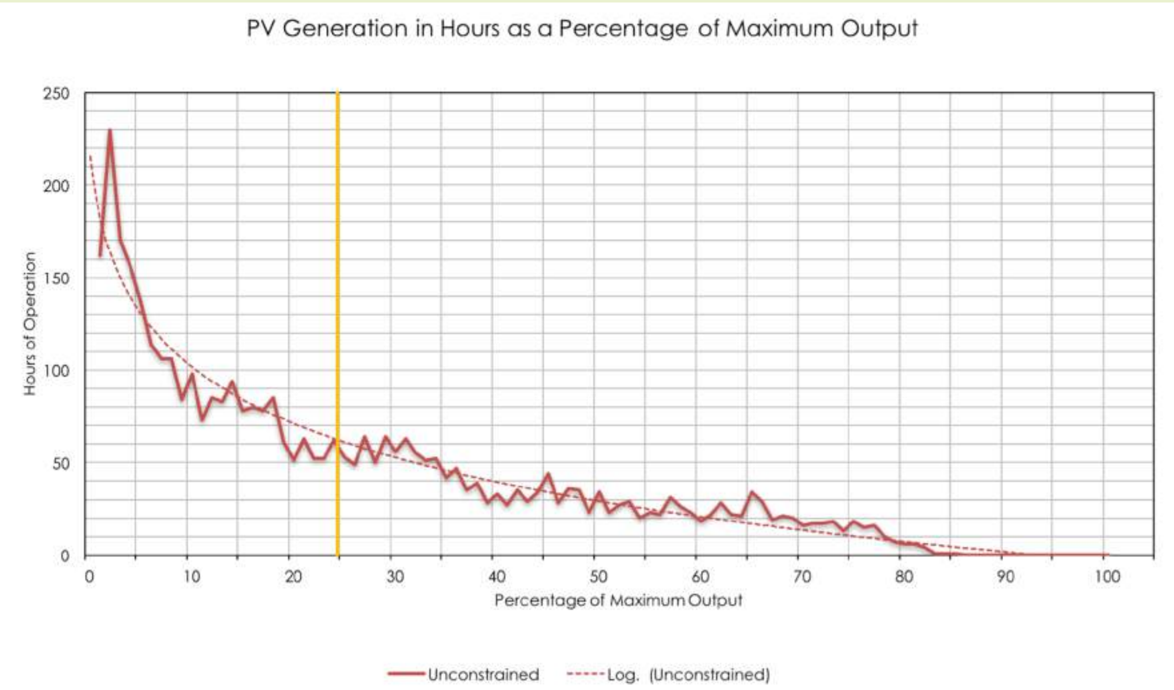

Figure 4: Hours of operation as a percentage of maximum inverter output for an unconstrained system. Average output at 25% (yellow line)

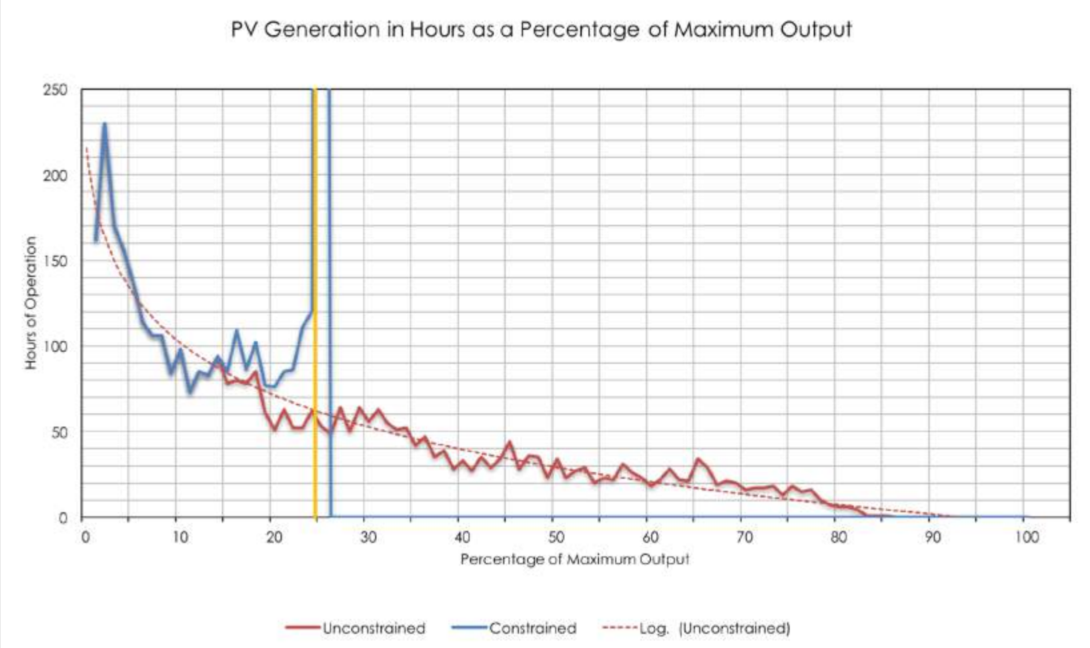

Figure 5: Hours of operation as a percentage of maximum inverter output for an unconstrained and constrained system. Average output at 25% (yellow line)

Maximum Non Constrained Annual Output	2,215 kWh
Constrained Export (at average output)	1,399 kWh
Constrained Generation as a % of Maximum	63%

Table 1: Maximum non-constrained and constrained annual outputs for a 2.2kWp solar PV with a 292 W limited export

Table 1 and Figure 5 illustrates that despite heavily constraining the outputs to its average levels, the impact on the annual generation is markedly less than maybe have originally been anticipated.

Yieldworks also allows the most optimal system size to be modelled given a level of constraint. The impact of a 16A export constraint was modelled for a range of system sizes (2.2 to 25kWp).

In the absence of on-site demand, the results (Table 2) indicate that a domestic property can connect a 10 kWp system with an export constraint of 16A, and continue to generate 82% of peak generation. In reality, each property will have significant additional loads, therefore the impact of export constraint will impact be minimal.

ENA ER G83/2
16A per Phase

Current ENA ER G83/2 regulations state that a customer can connect a system with an export capacity of up to 16A per phase without prior notification.

An ENA document (G100) will be released for consultation in the coming months and the document is expected to include the use of export limiting devices.

System Size (kWp)	Percentage of Maximum Output	Percentage of Constraint
2.2	100	0
3	100	0
4	100	0
5	100	0
6	98	2
7	94	6
8	90	10
9	86	14
10	82	18
15	66	34
17	61	39
20	54	46
25	46	54

Table 2: Impact of 16A per phase export constraint

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Case Study Rye Harbour

LHW Partnership LLP was engaged by Topbond Group plc to prepare a preliminary system design as part of a tender submission for a 25kWp solar PV project for the Environment Agency. Topbond Group plc was successful in its submission and LHW Partnership was instructed to provide detailed system design and grid connection services.

A site survey identified that the site had a split phase 20kVA transformer with a 10kVA feed to the campus however, discussions with the local DNO (UKPN) established that upgrading to a 3 phase supply was uneconomical. LHW therefore undertook export constraint modelling and a 10kVA export limited system with 90% non-constrained generation output was agreed upon.

The adoption of on-site energy storage is envisaged in the near future and the technology selected facilitated future developments for the 100% use of generated power. Located on the river Rother, the site was known to be prone to flooding and a ballast-free mounting system suitable for securing in shingle was required. LHW Partnership proposed the use of Tree System's innovative anchoring system which was successfully installed by Topbond Group plc. The system was commissioned by LHW Partnership in April 2015 and the system's operation is monitored at a module level using SolarEdge's web monitoring portal

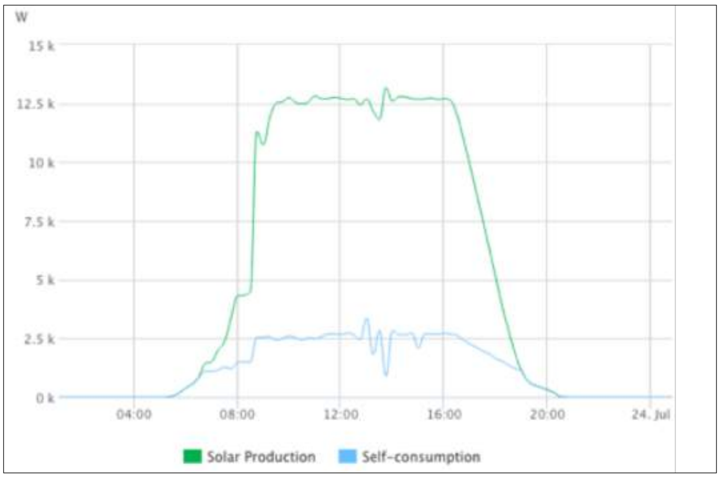

Figure 6: Solar production and amount of self-consumption for Rye Harbour's solar PV system.

Date	April 2015 - March 2016
Energy Exported	15.17 MWh
On-site Consumption	8.61 MWh
Total Generation	23.78 MWh

Table 3: Generation, export and consumption data for Rye Harbour from April 2015 to March 2016

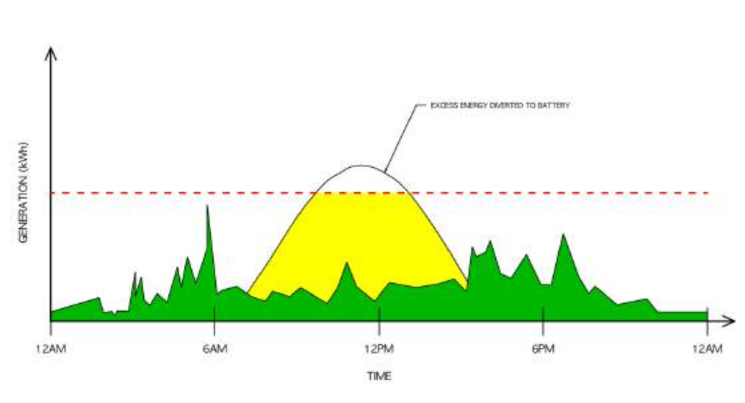

Figure 7: Profile of a solar PV system with excess energy diverted to battery

The current advancement of energy storage technology adds another facet to export limiting. When the inverters are constrained, they run inefficiently and collect the energy off the PV at a sub-optimal power point, resulting in "lost energy".

Battery storage will allow the battery to take the surplus energy reducing the level of constraint, using the stored energy in the evening when the system is not generating.

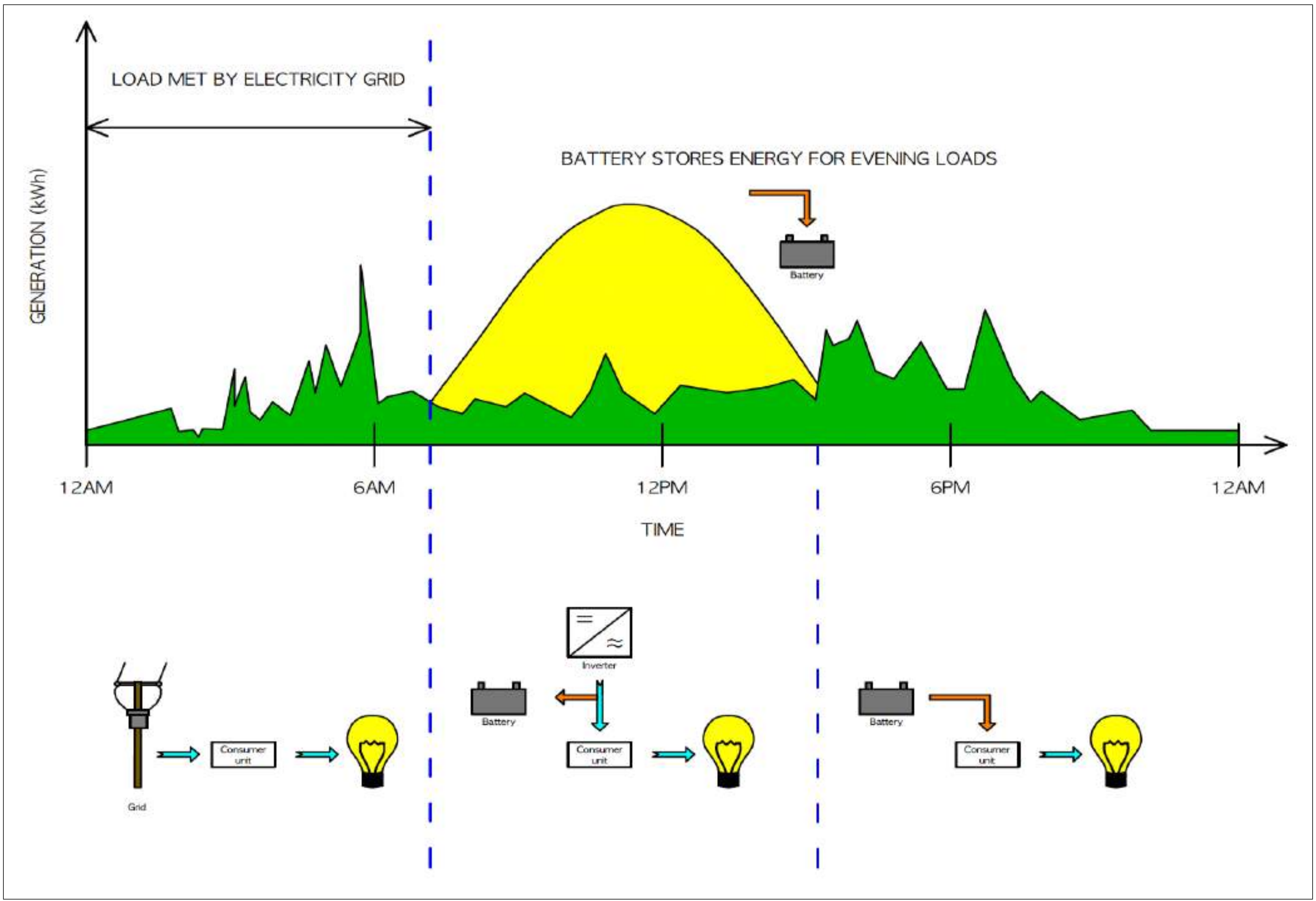

Figure 8: Profile of a solar PV system with excess energy diverted to battery and consumed during evening periods

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Energy Storage

Yieldworks models the impact of battery storage technologies on a half hourly basis and the model incorporates a number of factors including:

1. Range of battery sizes
2. Charge & discharge rates (nom and max)
3. Depth of discharge
4. Year of operation
5. Efficiency
6. Losses

The simulation can be undertaken for a wide range of scenarios and provides a like for like comparison of systems with or without battery storage.

In addition to providing a granular assessment of energy generation, demand and storage, the model can also estimate the resulting revenues and cost savings as a consequence of adopting battery storage technologies.

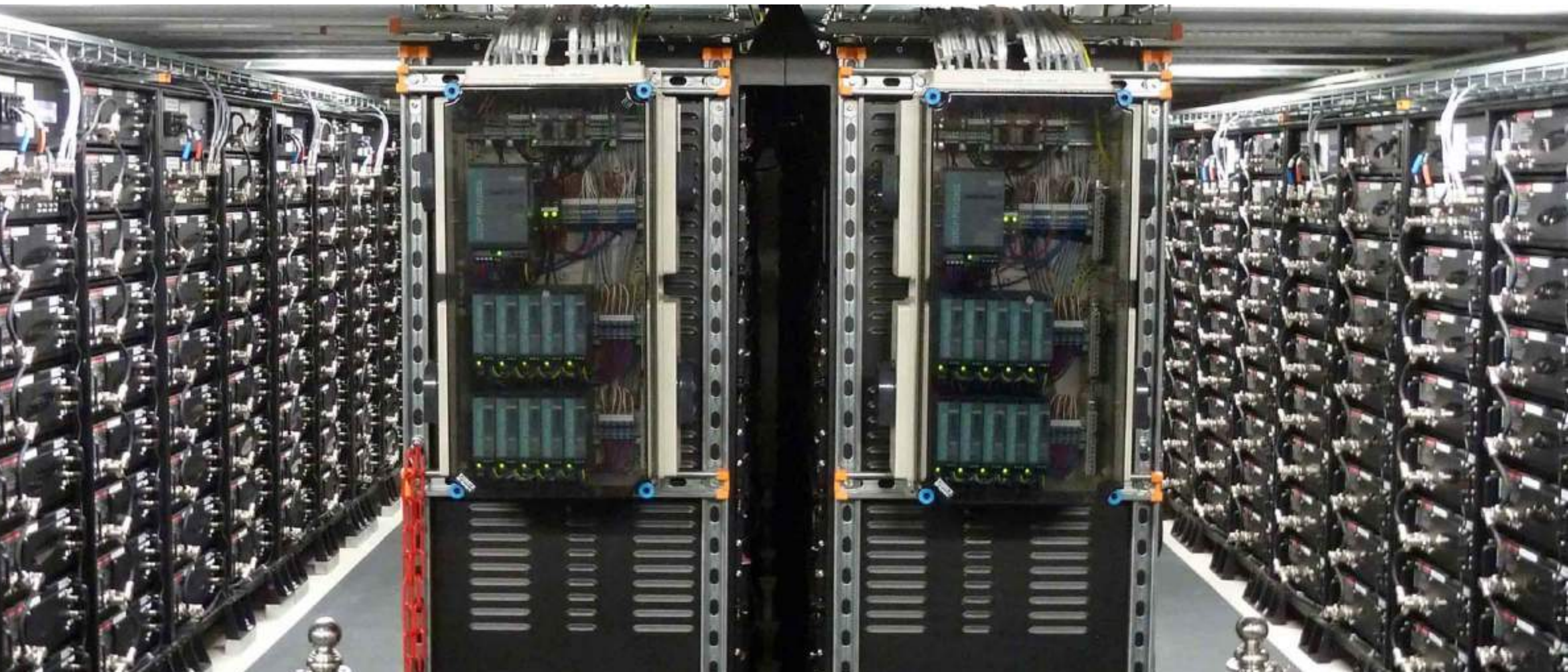
Financial Appraisals with / without energy storage

1. Feed-in Tariff Revenues
2. Export Revenues
3. Metered Billing Savings
4. DUoS Savings
5. TNUoS Charges
6. TRIAD Charges
7. Climate Change Levy Charges
8. IRR Estimates

Yieldworks can model on a half hourly basis (or down to 1 minute intervals) which helps significantly with managing the uncertainty of variable generating and demand profiles. We use bankable, world leading PV simulation software for the generating profile, including parasitic losses and charging / discharging losses for both the battery and charging technology.

Yieldworks can assess different solar PV and **battery sizes** without the need to remodel each scenario allowing the optimal system size to be identified at an early stage.

In addition, the model can easily provide sensitivity analysis based on future demand reductions (e.g. adoption of energy efficiency measures).



Yieldworks How can it help?

Yieldworks is a modelling system developed by LHW Partnership LLP to assess and optimise the most effective solar PV system array size. The software accommodates a combination of export constraint limitation, on-site half hourly consumption (historical or estimated), predicted solar PV yields as well as battery storage technology.

The Yieldworks software can incorporate meteorological data form any location in the works from a wide range of sources including Meteornorm, SolarGIS and Soda.

We use industry leading solar PV modelling software and shade analysis technology to enable a solar PV project to be modelled from total export to constrained export scenarios, allowing for shading, on-site demands, private wire and the adoption of future peak generation storage systems.

The software can model single or multi-facial arrays down to by-pass diode string level and it can be used for any system sizes, from domestic to utility scale with any combination of solar PV module, inverter, DC, and AC cable rating and route length.

What information do we require?

1. On-site half-hourly demand profile (historic or estimated)
2. Proposed system size
3. Geographic location and orientations
4. DNO export constraints
5. Battery storage technology
6. Other on site generation (e.g. STOR)
7. Demand technology age profile (energy efficiency)

What will we do and what will we provide?

We are offering a service not a software package, as it requires a level of engineering modelling with assumptions based on experience.

We will model the solar PV system based on site specific system parameters (orientation, pitch, equipment, stringing design etc.).

The Yieldworks software will produce a generation profile, based on our algorithms, transposed to a simulated half-hourly generation profile over the whole year.

Making agreed assumptions about future demand profiling, solar generation and battery technology, we will match the HH or estimated demand against the HH generation profile, incorporating export limitations, to compute the usable energy and level of energy loss (constraint).

The results will be summarised in a tabular report, allowing the system size and costs to be appraised and modelled against yields, revenues and constraints, facilitating the decision making process.

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Yieldworks What are the benefits?

Yieldworks offers a range of benefits including:

- Following an assessment it is likely that the installation of a larger system will be possible, with a limited level of constraint. Larger systems are more efficient to install with a higher level of imported electricity offset, the financial and economic appraisal may favour a larger system with some constraint compared to a smaller system with no constraint.
- The benefits of the adoption of energy storage technologies can be analysed on a granular level.
- It may initiate a review of on-site energy consumption practice in order to maximise on-site demand at times of energy generation.
- The modelling is undertaken by experienced Energy Engineers with no commercial interests in selling a solar PV system thus providing unbiased advice based experience gained from years of experience in the installation sector.

What are the limitations?

Uncertainties include those associated with matching an uncertain generation profiles against an demand profiles based on historic data. Solar PV simulations have been proven to be accurate historically, and similarly historic energy demands may decrease with improving technology (e.g. LED).

Over a year or longer, there is a level of statistical balancing of the uncertainty and this can be accommodated. P90 exceedance solar data can be adopted, showing lower yields.

Demand reduction factors can also be incorporated as part of the sensitivity analysis in order to overcome an optimistic appraisal, providing the caution that many investors expect.

Who have we worked for?

We have Yieldworks services to a large number of customers including land agents, a major haulage company for London Southend Airport, water utilities and commercial property developers as well as private clients.

The Yieldworks methodology has been adopted to model the feasibility of a private wire supply from the UK's tallest wind turbine to an international aggregates organisation. The simulation modelled the adoption of solar PV to supplement the wind technology and maximise grid connection efficiency.

How much does it cost?

The cost of an appraisal will depend on the system size and the level of complexity.

Please refer to our pricing sheet for guideline costs.

We look forward to discussing your project.

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