Potential benefits of deploying hybrid generation with smart-grid controls and power distribution systems for electrification at off-grid temporary outdoor events.

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ABSTRACT.

The thesis considers the issues of oversizing and inefficient operation of generation assets, associated with off-grid electrification of temporary events and the overall potential for deployment of hybrid systems in conjunction with smart grid control philosophy for power management and distribution. The underline hypothesis is that the use of battery storage together with power management and distribution controls will yield a potential reduction of Green House Gas emissions, with additional benefits for fuel reduction in generation assets. Set thesis builds on the research previously conducted by Professor Paul Fleming of De Montfort University into the GHG impacts associated with music festival style temporary events. During the course of current research it has been identified that power management and quality can play a vital part toward achieving the necessary reductions in GHG emissions and fuel consumption.

Set discovery follows the preliminary analysis of telemetry data from generation assets deployed at Latitude music festival over a number of years. Analysis of 2013 data was identified as the most viable option for theoretical profiling of power consumption, which can then be utilised to provide a base line for future power consumption. Telemetry data indicates that Power Factor directly correlates to power quality. Power Factor correction is an in-depth subject of its own, which will only be briefly evaluated in the following project as part of an overall picture.

It has been identified that there is a significant knowledge gap in the understanding of how to appropriately size/estimate and deploy hybrid systems. It is often the role of the organisers of the event to estimate their power requirements, which are then met by the power providing contractor. A degree of conflicting priorities are often in action at such events, as there is no accurate estimation of the potential power demands and a number of health and safety constraints, as well as contractual obligation, which coincide in over compensation in sizing of generation equipment. Since reliability of supply is key a “better safe than sorry” mentality is employed, throughout majority of reviewed events.

Analysis of telemetry data in conjunction with interviews and surveys demonstrate the need for greater degree of education on the subject in question. Findings in this research support the hypothesis of set thesis, by confirming that significant reductions in GHG and fuel consumption could be achieved, by deploying appropriately sized hybrid systems with sufficient storage and generation capacity for appropriate loads. Based on the conducted research, a fundamental understanding can be achieved for developing research into subfields associated with the problems outlined in this thesis.

CONTENTS PAGES.

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ABBREVIATIONS.

GHG Green house gases
I/O Input output
kWh Kilowatt hours
VA Volt amps
PV Photovoltaic
PF Power Factor
Li-Ion Lithium Ion

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INTRODUCTION.

The following thesis consists of both qualitative and quantitative research methodologies. Qualitative portion of the research will focus primarily on interpretation of observations in a form of questioners and informal interviews for the purpose of obtaining the necessary knowledge to meet aims and objectives. While a more logical and mathematically centred approach will be implemented to review statistical data to provide the numerical validation to the underlined theories, thus aiding in theoretical modelling.

Research outlined in this thesis will build on the previous research conducted by Ben Marchini and Professor Paul Fleming of De Montfort University, on the issues associated with Green House Gas emissions at outdoor off-grid events. Previous research in this area considered the emissions produced by music festivals in the UK, from electrification, transportation and waste management points of view. A number of different areas for improvement were identified, with some novel approaches for GHG reductions that could be utilised in other GHG emitting sectors, to aid the achievement of CO2 reduction targets which UK has committed to.

A key area of exploration for the following thesis is the potential integration of hybrid power generation systems for use at off-grid temporary events. This field of enquiry is novel in many ways, thus the following thesis should form a solid foundation for further research into this specific subject. One of the main hypothesis prior to embarking on the following research, is that a performance of a conventional off-grid power generation system can be improved significantly by introducing battery storage (i.e. hybrid component) with a novel smart grid power management system. Based on the existing knowledge obtained from relevant literature and previous research, it is important to consider demand management, power quality, energy security, regulations, user philosophy, equipment capabilities and human factors when conducting set enquiry.

AIMS AND OBJECTIVES.

2.1.Research Aims.

To achieve reductions of Green House Gases and fuel consumption of off-grid temporary outdoor event power generation equipment, through the appropriate sizing of generators and deployment of appropriate hybrid systems with a smart-grid and energy distribution systems.

2.2.Research Objectives.

1. To generate and analyse a theoretical energy load profile for off-grid outdoor event:

    This compiling historic minute by minute data from previous off-grid outdoor events, which have been monitored by the Institute of Energy and Sustainable Development, Faculty of Technology, De Montfort University between 2009-2014.

2. To generate a recommendation template for appropriate sizing of generators to work in tandem with hybrid systems:

    The template can be utilised by event organisers/energy suppliers to provide energy security and quality supply to the event; while simultaneously providing the capacity to switch non-priority generators off to allow hybrid systems to provide off-peak power, with sole purpose of fuel and GHG reductions.

3. To survey the potential energy requirements of connected users:

    By carrying out the survey, non-priority dispatchable loads can be identified and evaluation of the potential limitations of current portable/ temporary electric generation and grid systems, as well as energy storage systems can be highlighted.

4. To evaluate and comment on the existing energy control/management philosophies:

   Set evaluation will identify the potential of a smart-grid control system for demand management, in order to match the supply needs and storage capabilities for specific uses.

5. To estimate energy, cost and GHG savings at this year's event, which could be achieved as a result of the above efficiency recommendations.

6. To make a set of recommendations for future studies on potential 'optimal' technologies available today, which could be deployed to generate, store and manage/distribute energy at future off-grid outdoor events.

BACKGROUND.

The UK has committed itself to an overall reduction of 80% in CO2 emissions, compared to 1990 by 2050, as outlined in Climate Change Act 2008 (*DECC, 2009*). This is a significant undertaking by any measure and in order for set target to be met, all industries must take an active role by reducing their own carbon footprint. Many industries are heavily regulated and targeted with government incentives, however the off-grid temporary event industry is often neglected.

At 2012 there were over 1,000 regular festival types of off-grid events in the UK (*Efestival, 2012*), with steady increase experienced year on year. Such temporary events are responsible for 77,000 tonnes of CO2 equivalent in 2008 (*Bottrill, 2008*). Although this figure only amounts for 0.012% of the UK's emissions in 2008 (*DECC, 2010*), the under-lining issue of oversized generators and unmanaged power generation/distribution systems can be found in other industry sectors, such as construction. The term 'oversized' refers to the selection of a generator, which produces more power than can be consumed at peak demand (a simple analogy of a 10 kW generator powering a 2W LED light bulb). Such mismatch of resources is evident throughout the industry. One of the contributing factors to such mismatch, is the lack of understanding on the part of the consumer.

In the past, there has been no significant incentive to improve the efficiency of off-grid power generation/distribution systems, as often, consumers demanded energy security at any cost. Moreover, since the suppliers of the generators sold the fuel for set systems, there were financial incentives for deploying oversized generators, so that more fuel could be consumed. As a direct result of a number of academic projects in respect of efficiency and impact of temporary off-grid events, a significant number of organisers have been educated on the potential saving and GHG reductions, which could be achieved from smarter approach to off-grid power generation and management.

Thus, it is logical to speculate that the market place of off-grid temporary events (i.e. festivals, live shows, construction projects, etc.) would be inclined to pay per unit of energy consumed rather then generating capacity, as majority of end users are concerned with having the energy and not how it is produced. Such philosophical change would then require suppliers to reconsider the overall business model for electrification of off-grid events.

Below are the two major areas of consideration, associated with off-grid electrification:

- **Power Factor** is the product of Real Power divided by Apparent Power (*Turchi, 2014*). Real power is the actual power used to do work (i.e. light a lightbulb) and is measured in Watts (i.e. volts x amps). Apparent power is the power which can be produced by a generator in theory, which is measure in VA.

  Turchi (*2014*), emphasises the importance of maintaining a Power Factor as close to 1 as possible. When Power Factor is near perfect, that means each unit of energy produced is of adequate quality to be transformed to do useful work.

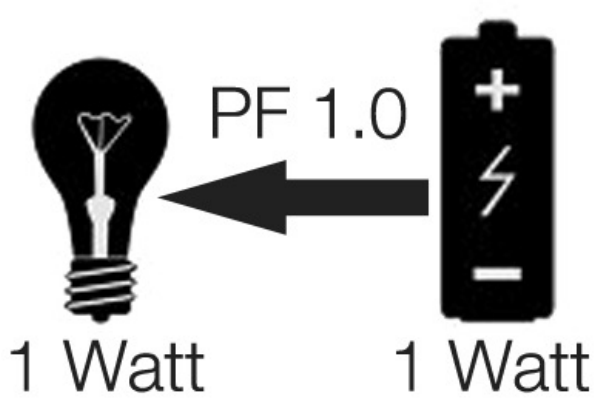


Diagram 1 (*Robert Yates, 2015*)

Basically, the above figure demonstrates the importance of Power Factor. Think of a light bulb which needs power of 1 watt to light up; if the Power Factor is perfect it would require a power source of 1 watt to light the bulb.

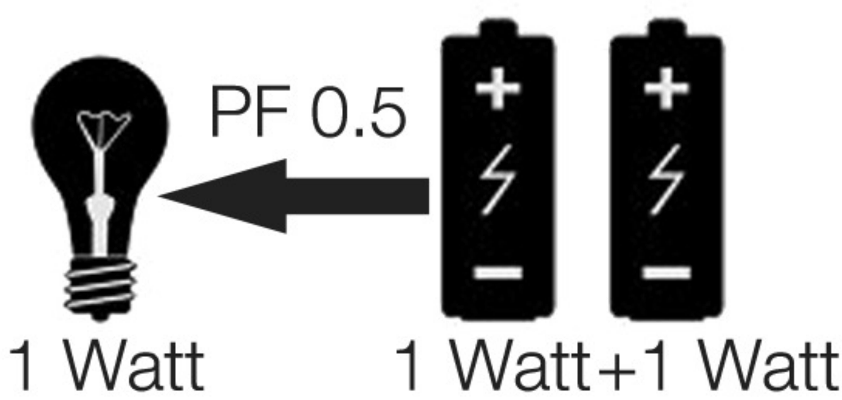


Diagram 2 (*Robert Yates, 2015*)

However, if the Power Factor is poor, for example 0.5, then two 1 watt power sources would be required to power the same bulb.

The Power Factor can be effected by a number of things such as harmonics (*Turchi, 2014*), which can be caused by none linear load (i.e. a poor resister, for example L.E.D). Turchi (*2014*) states that current/voltage waveform is directly related to the harmonics number of current. The following figure gives an example of poor Power Factor and high harmonics.

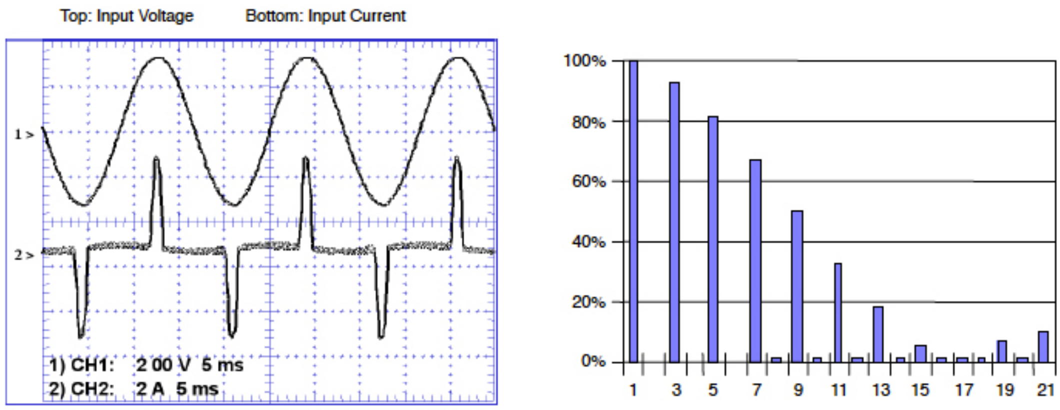


Diagram 3 (*Turchi, 2014*)

On the left hand side is the current and voltage waveforms completely out of phase, causing a low Power Factor which results in high harmonics number on the right.

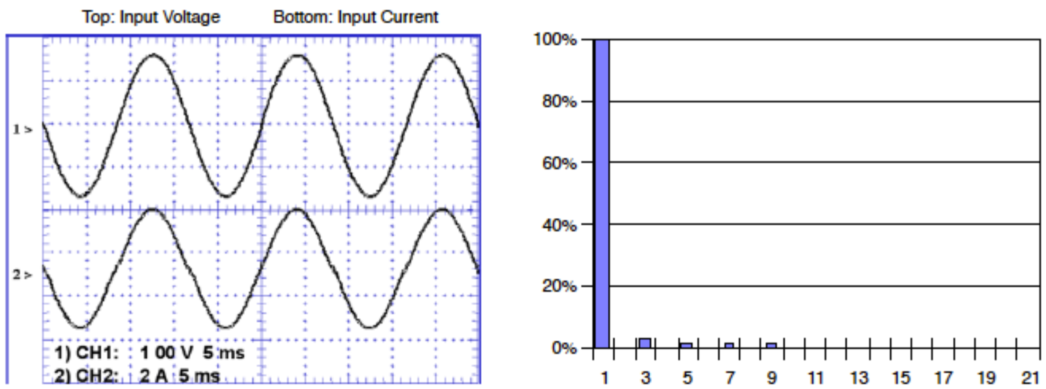


Diagram 4 (*Turchi, 2014*)

The following figure is an example of perfect Power Factor and low harmonics.
On the left the current and voltage waveforms are in phase, resulting in low harmonics on the right.
When the waveforms are in phase there is no pollution in the power supply, thus the power quality is at it's highest, which means more useful work can be done using this power, compared to the previous example. Since the harmonics are directly related to Power Factor, there is a strong case by Turchi (*2014*) for Power Factor rectification through harmonics manipulation and control.

- **Generator Functionality**, an overwhelming majority of generation assets deployed for off-grid electrification, are internal combustion Alternating Current units. Although there are a number of fuel options available (i.e. petrol, gas) diesel remains the industry standard, due to ability to be converted to run on bio-diesel and higher torque output (*Ibrahim, 2011*) than other counterparts.

  The following figure demonstrates internal arrangement of an internal combustion generator.

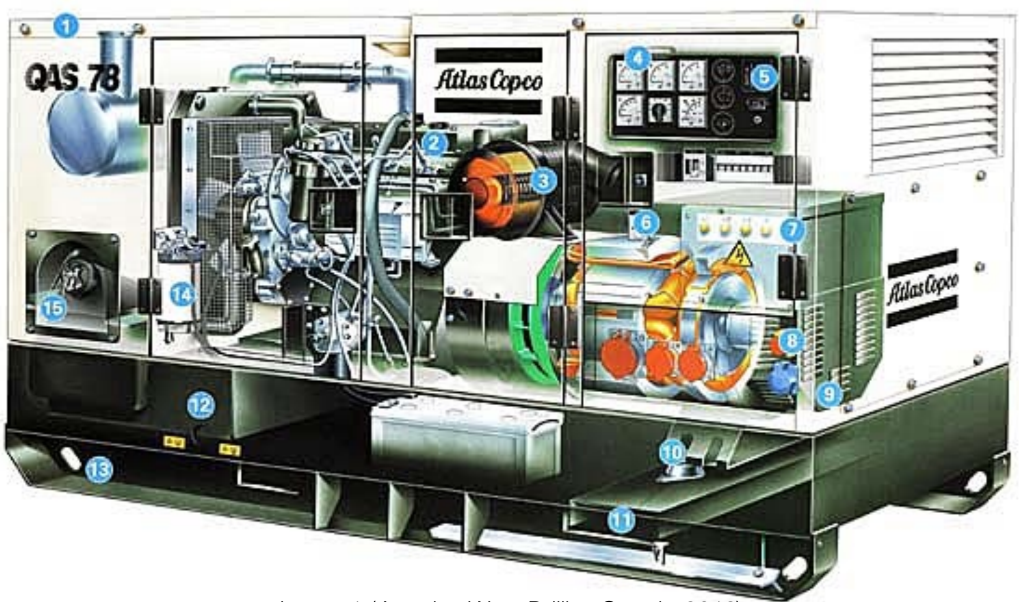


Image 1 (*America West Drilling Supply, 2013*)

Number 2, identifies an internal combustion engine which drives number 6, the alternator. Generally, a generator will operate around 1,500-3,800 rpm range depending on the manufacturer and specification (*Ibrahim, 2011*). The reason an engine with high torque output is preferable for AC generator application, is the design of the alternator.

As can be seen on the right, the alternator contains a large solid core rotor, which needs to be rotated to create magnetic field to generate electricity. The rotor is proportional to the size of the alternator and to achieve greater electric output the size of the alternator needs to be increased.

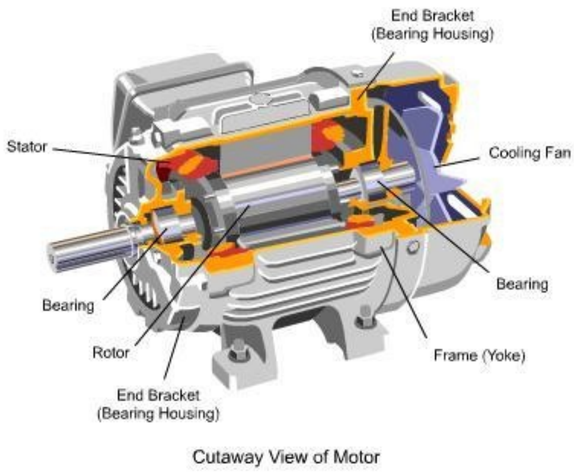


Image 2 (*Admired, 2015*)

It must be noted, according to Ibrahim (*2011*), the generator will consume the same amount of fuel regardless of the load (i.e. how many units of energy are produced). Thus, to increase the work efficiency (i.e. kWh per litre of fuel), the generator should be operated at above 75% load. The load percentage is calculated based on the rating of the generator (i.e. kVA), which is determined by alternator output, engine and internal electrical circuit capabilities.
Furthermore, to maintain a steady electrical frequency of 50 or 60 Hz, which is associated with the previously mentioned waveform in the Power Factor section, the engine rpm must remain constant. Therefore, as the load increases, engine will need to apply more torque to maintain the rpm, otherwise the frequency cannot be maintained and power quality will degrade (*Ibrahim, 2011*).

A number of opportunities arise for improvements in fuel consumption and reduced GHG emissions. This could be achieved by:

1. Analysing past load profiles to estimate future demand.
2. Appropriately sizing generation assets and deploying hybrid systems, utilised to cope with off-peak and sudden surges in demand.
3. Identifying dispatchable loads.
4. Implementing Smart-grid frame work for power management and distribution.

At present time there are a number of potential technological solutions available on the market which have proven to provide a number of the above solutions.

Currently, generation solutions can be obtained in sizes ranging from 30 kVA to 10MVA (*OffGrid Energy, 2013*). These systems are capable of providing energy security and continuous operation.

Conventional diesel generator Pros and Cons.	
Pros	**Cons**
Supply Security.	Non-variable output.
Off-grid deployability.	Requires continues maintenance.
Large power capacity.	Relatively inefficient.
Continues operation.	Significant CO2 output.

Such traditional systems are unable to variate their output. Thus, when demand drops, the generator asset still produces the same amount of power, which is often significantly above the requirements.
This is one of the key drivers behind the need to understand and analyse the load profile/energy requirements of a project, in order to select the appropriate size generation assets to reduce over production/consumption.

The drawbacks of traditional systems can now be mitigated by introducing a Hybrid components into the electrification grid. Systems such as Grid to Go™, can offer energy storage solutions, which can provide energy for off-peak demand and provide a boost to the system during sudden demand spikes. Such systems are available in sizes of 5kVA to 300 kVA and would compliment a traditional generator as well as renewable sources (i.e. Wind turbine, Solar PV) (*OffGrid Energy ,2013*).

Hybrid system Pros and Cons.	
Pros	**Cons**
Supply Security.	Requires charging.
Off-grid deployability.	Higher Costs.
Large power capacity.	End of Life Disposal.
Continues operation.	
Variable output.	
Very low maintenance.	
Silent operation.	
Smart grid controllable.	
Reduces CO2 and fuel consumption.	

These systems can produce potential savings of **£87** per 24 hours (fuel and maintenance cost reduction) and **228 kg** of CO2 per 24 hours (savings based on 16 kVA grid-to-go and 40kVA generator example) (*OffGrid Energy, 2013*). Such savings are obtained by switching off the conventional generator when Grid to Go™ reaches full charge and provides sufficient power for off-peak operations. Furthermore, by integrating a Hybrid system, the overall generator sizing can be potentially halved.

On this final note, by analysing load profile/demand patterns of a system, Smart-grid controls can be implemented, which can manage the energy production/storage and proactively respond to any demand spikes/anomalies. As part of proactive response, non essential loads can be dispatched during peak demand to maximise stability of the system (*Gellings, 2009*).

LITERATURE SURVEY.

The following literature survey will consist of detailed evaluation of essential literature, which is most suited to act as a complimentary source of knowledge to support key arguments and underlined assumptions of set thesis.

The following is the survey structure:

I. Core context literature: This section will consist of previously undertaken research by reputable academics and experts in the field of temporary off-grid electrification and power management. The common theme of set literature is the review of methods of GHG and fuel consumption-reduction associated with off-grid electrification.

II. Qualitative & Quantitative Research Literature: This section considers the implications associated with carrying out research, from data gathering through to data analysis. A useful feature of set literature is the understanding of mechanisms associated with inquiries for a successful gathering of information in a structured and ethical manner.

III. Power Factor Literature: This section will endeavour to take stock of literature available on the concept of Power Factor rectification. The complexity surrounding the issues associated with Power Factor is pivotal to the development of set thesis. The knowledge which can be obtained in set literature is vital for making appropriate recommendations and formulation of hypothesis.

IV. Electric power generation literature: This section will consist of a recent publications that can be utilised as a reference guide for conventional electricity generation/ transmission and potential capabilities of hybrid-diesel-renewable systems. Although primarily the literature focuses on large scale grid based applications, a significant part of underlined knowledge can be extrapolated for off-grid utilisation.

V. Battery storage literature: This section will be centred around recent publication which considers the storage capabilities of a variety of battery systems, that will aid with matching load profiles to the most suitable system, based on their charge/discharge cycles and longevity.

VI. Smart grid controls: This section will consists of recent publication, in regard to smart grid infrastructure, power management and distribution. Which considers the potential of dispatchable loads and demand management through intelligent deployment of generation assets.

The above stated literature will be evaluated for their relevance to the thesis and any knowledge gaps, hence, a better understanding can be achieved in regard to the risks associated with the project.

4.1.Core context literature.

Festivals and Sustainability: Reducing energy related greenhouse gas emissions at music festivals (Marchin, 2013).
Electricity-related GHG emissions at off-grid, outdoor events (Fleming, 2014).
The Power Behind Festivals: A guide to sustainable power at outdoor events (Green Festival Alliance, 2012).

The above literature is the starting point for this research thesis. The findings of set literature, clearly identify the need for GHG and fuel reduction associated with off-grid temporary events in the UK. One of the key aspects associated with this problem is appropriate sizing of generator equipment, which can provide quality and secure power supply to an off-grid event. Previous research has raised the awareness amongst organisers for the need to address energy waste/inefficiency, in order to reduce Green House Gases and fuel consumption at temporary off-grid events. Although it is highlighted that off-grid temporary events account for almost a negligible part of the overall GHG emissions in the UK, the knowledge that is and can be obtained in future research, would be translatable into other areas of power generation.

A potential solution proposed within the past research is monitoring and prediction of load profile, to aid with sizing appropriate equipment and actively managing energy distribution. This forms the baseline premisses for the following thesis. From this starting point, further solutions can be explored.

Past research underlines vital area for improvement, which is the monitoring of live data output by the energy provider, in order to actively manage the supply and demand based on load profiles. By implementing an active smart grid control system, non-priority loads can be identified and dispatched to avoid over production of energy and excessive fuel consumption. Therefore, this thesis focuses on predicting future load profiles based on past data and monitoring data outputs at live events, to measure the potential of GHG and fuel reductions.

4.2.Qualitative and Quantitative research.

Qualitative-quantitative Research Methodology: Exploring the Interactive Continuum (Benz,1998).

The above book considers both qualitative and quantitate research in significant detail, with case studies and examples throughout. The authors present a straight-forward description of the two methodologies of research and provide significant insight to how both methods can compliment one another. One of the key underpinnings of the book, is an explanation of how to assure research validity for any field of study. Core audience for this literature, is both research designers and consumers. The book does not make any attempted to teach qualitative and quantitative methods, but instead, it attempts to provide an understanding of how the research questions and assumptions shape the design of the enquiry. The book is aimed at masters and doctorate level individuals, who wish to use this literature as supplementary guide to execution of higher quality research, with underlined assumption that there is an understanding of statistical and other analytical methods. A number of case studies are presented within the context to provide a better understanding of the concepts one must consider, when designing and carrying out research.

The book begins by contrasting on both research styles in order to produce an understanding of the differentiation between the two. A significant portion of the book is dedicated to chapters on validity and legitimacy of any giving research, which is of great importance to any research undertaking in order to withstand peer review and other validation procedures. Emphasis is placed on a number of key strategies that can be utilised by the researcher, in order to enhance the legitimacy and validity of their enquiry. The book concludes by demonstration of potential application of qualitative and quantitative methods to varied field of studies.

Overall, this is a useful piece of literature, which builds on existing knowledge of a researcher, who has completed previous enquiries throughout their professional or academic career. Thus, it compliments this thesis as both qualitative and quantitative research are employed throughout set research paper.

4.3.Power factor.

Power Factor Correction (PFC) Handbook, Choosing the right Power Factor Controller Solution. (Turchi, 2014).

This handbook is aimed at a semiconductor and consumer electronics industry, which utilises highly delicate components and is especially concerned with power quality/efficiency. Fundamental definition of what a Power Factor is, is identified from the first chapter, i.e. Power Factor is a product of Real Power (Watts) divided by Apparent Power (VA). A detailed description is given of how the relationship between the two powers influences power quality. Set chapter explores the link of Power Factor to Harmonics. It is highlighted that high Power Factor results in low Harmonics and vice versa. This forms the introductions to a variety of different methods of controlling power quality, the understanding of which is pivotal for set thesis and further research. Variety of methods for Power Factor correction are outlined in the further chapters of the book, such as active and passive, with pros and cons analysed in some detail.

Around ten different methods of Power Factor correction are outlined, which demonstrates the potential of real world application of set methods. It is important to note that not all methods are suited to off-grid applications, as some of the methods are suited for Direct Current circuit application only. Correction systems in the book range from simple resister circuits to advanced algorithm controlled electromechanical devices, with a number of potential design suggestions for Power Factor correction circuits. A significant degree of transferable knowledge has been presented and with a list of comparable components the handbook provides an in-depth guide to the readers. In the further chapters, a detailed review of the most complex Power Factor correction systems is presented to the reader, with essential comparison and analysis of set systems.

Overall, the handbook contains a significant degree of transferable knowledge for both this thesis and any reader who is interested in Power Factor correction. Although the information contained within the handbook is not primarily aimed at large electrification applications, a number of potential correction systems can be utilised for off-grid application.

4.4.Electric power generation.

Electric Power: Generation, Transmission and Efficiency (Lefebre, 2007). Potential of a Hybrid Wind-Diesel-Compressed air system for Nordic Remote Canadian Areas (Ibrahim, 2011).

The above literature presents up to-date research on electric power and how it is generated, transmitted and what efficiency controls are utilised. The knowledge obtained from the literature can be implemented on a smaller scale energy generation/electrification project, as the fundamental concepts and issues remain the same for systems running on AC current. Some of the more relevant sections make direct references to the problems associated with hybrid generation systems, which utilise the combination of diesel/ renewable generation and battery storage. These chapters will prove to be the most crucial to the practical development of set thesis, as the core technology suggested within the scope of the project are hybrid diesel systems. The comprehension of the functionality of a diesel generator presented the necessary understanding to issues of demand response and issues associated with sudden peaks of demand. It is outlined in this literature, that a significant consideration is to be placed on the methods of inverting and converting power within a hybrid system, as the batteries must be charged and discharged at a sufficient rate to meet the demand placed upon the system.

The power generation literature contains a great deal of information, regarding high-voltage long distance transmission of energy, which has no benefit to the thesis as the systems in question will be a small scale close proximity power distribution arrangement. Although the concepts of dispatchable generation assets is not the aim of the thesis, the understanding of demand management and concept of demand dispatchability are the novel attributes of set thesis.

Some of the issues associated with compatibility of hybrid systems, are clearly outlined in the above literature. This in turn, will provide sufficient reference point during the thesis for suggesting and reviewing suitable energy generation/storage methods. Most importantly, a clear understanding of the limitations of available systems can be achieved, which in turn should minimise the margin of error during the thesis, as the literature provides relevant knowledge of the real world functionality of hybrid energy generation systems.

4.5.Battery storage.

Modern Batteries, An Introduction to Electrochemical Power Sources (Vincent, 1997).

As can be seen from the direction of the thesis thus far, the success or failure of the project hinges on the use of hybrid energy systems. The current hybrid systems all utilities battery cell technology of one type or the other. The above book provided an up-to-date understanding into the different battery cells that may be utilised. It is of great importance, to both select and understand the performance characteristics of the technology, as there are a great number of different batteries. They all vary in their performance characteristics. The most important characteristic for this thesis, is the charge/discharge cycle and the overall service life expectancy.

The literature identifies key limitations, which will aid with formulating of theoretical load profiles that can be met by the appropriately sized hybrid systems. This information can also form the bases of core knowledge for the readers of the thesis, who are interested in matching battery storage with their energy generation equipment. The knowledge of battery cell technology provided the necessary understanding for interpretation of commercial literature/specification associated with equipment that may be deployed for real world use.

One area of potential concern, is that the above book doesn't consider the need of a high-power electrification project and although the functionality of battery technology could be extrapolated and scaled up, there may be unexpected complications with interfacing the generation and storage technologies. Based on the outlined information, the area of focus should be charging equipment (i.e. inverters), as at this stage there is the potential for failure and efficiency losses.

4.6.Smart grid controls.

The Smart Grid: Enabling Energy Efficiency and Demand Response (Gellings, 2009).

The above book provides a clear definition of the concept of a Smart grid system and how it is conceptualised within the industry by government departments and companies/ organisations. Overwhelming movement towards the need for the implementation of set systems, is the inherited efficiency which can be achieved during production and distribution of energy, as a direct result of Smart techniques. However, the literature stresses the importance of end-use efficiency, due to it being regarded as a crucial link in the chain, without which any efficiency improvements in generation and distribution would be of little benefit. One of the key benefits associated with Smart grid is a dynamic demand response, which means that a greater result may be achieved with fewer assets by analysing past demand and predicting the future profile. The importance of demand side planning is emphasised across multiple chapter of set book, as it is fundamental to understand the actual demand and plan for the delivery without shortages in supply capacity. An age old discussion of DC vs AC is evaluated, since in the modern world more and more systems run on DC current, which is converted from the supplied AC. It is argued that, by utilising DC current within a small Smart grid setup, it could provide significant efficiency saving that would otherwise be losses of the AC to DC conversion process.

Finally, the book describes a potential architecture of "*The Perfect Power System"* (*Gellings, 2009*), which could be utilised as base reference for a small scale Smart mini grid, which is essential for this thesis of off-grid temporary event electrification.

Overall, the above literature offers the depth of knowledge that is essential to the success of set project. A concise list of alternative technologies, which could be of use, are clearly outlined within the book. However, some concerns arise in regard to the complexity of a Smart grid system, which is largely associated with demand, planning and response. The question of operators competence comes into mind, as the book clearly identifies the limitation of the equipment and the overwhelming need for the human counterpart.

4.7.Survey conclusion.

The above literature survey forms the foundation of academic knowledge, which combined with candidates expertise shall provide a sufficient comprehension into the field of query. Some of the issues outlined in the literature can aid in further understanding of the problems relevant to the thesis goals of GHG and fuel reduction at off-grid temporary events. That being said, there is a significant amount of first hand experience of both the project supervisor and cooperating industry professionals that will need to be incorporated into the project. As the above literature forms a clear direction of the thesis and the appropriate methodology which can be implemented, to ensure a successful completion.

It must be noted that the literature collection in the above survey are reputable sources of information, based on the authors expertise in their respective fields and validity of the publishers, as outlined in the literature legitimacy of the research is a crucial step towards validation of theories obtained during the process.

One area of concern, is that the above literature may contradict some of the findings of set thesis, as the subject area explored within this thesis is novel to a degree. Thus the thesis it self may be utilised as a literature source for further research.

METHODOLOGY JUSTIFICATION.

5.1.Recap.

This thesis is aiming to assess the potential deployment of hybrid power generation systems, with smart-grid like energy and distribution control philosophy, as a means of reducing fuel consumption and consequently Green House Gas emissions at off-grid temporary events. The view of the research was to gain sufficient understanding of problem factors, which can hinder achievement of the above aim, such as:

- Assessing the state of technological readiness, is a consideration of available technologies and solutions, that can be applied in order to achieve necessary results. Furthermore, it is a review of developing solutions which may produce more sufficient results than is currently possible with todays technological limitations.

- Power generation, transmission and distribution are the three key steps of electrification of any electrical grid system. Understanding the principles behind set processes provide the relevant knowledge for assessment of capabilities and limitations.

- Power quality is of great importance to any electrification based research. Understanding the role of Power Factor issues and how they effect generation capacity, is a fundamental step towards potential problem solving.

The following is a series of logical steps which can be repeated for the purposes of validation of the thesis and further research into the field of off-grid electrification.

5.2.Approach.

First step was to conduct a relevant literature survey covering relevant research approaches, power generation, power distribution, battery cell technologies, hybrid systems and smart energy distribution. The literature survey provided the necessary understanding of technological concepts and implementation, as well as reinforcement of underlined hypothesis.

Literature survey consists of published journals, books and academic papers published for the most part in the past ten years. The reasoning behind this, is the provision of diverse and up to date concepts surrounding the vital themes of set research. Chosen literature reinforces the researches existing knowledge on how to conduct set research and how to address the technological challenges.

Second step was to select a real world case study, in the form of Latitude Music Festival, for which historical data could be obtained. The main reason for this selection, is the relationship the organisers of set event have with Professor Paul Fleming (supervisor of set thesis) and the issues which they wish to address, as part of creating a more environmentally sustainable event. As a part of ongoing research, the electrification equipment utilised at Latitude Festival has been monitored for a number of years, thus sufficient historical data could be obtained in regard to I/O readings, which could then be analysed.

Third step was quantitative data acquisition. Set data was supplied under authorisation of the event organisers, by power providers who are a contractor responsible for electrification and provision of power at set event. Data readings were obtained from the generators onboard telemetry system, which monitored key readings at regular intervals and then transmitted them to a remote recording station via GSM network. The data sets chosen for analysis were obtained at 2013 event. The reason this data set was chosen for analysis, is due to it being the latest data set available, which represents the current power requirements. The following assumption on data reliability can be made: since the telemetry system is embedded directly into the generator by the original equipment manufacturer, it provides accurate readings with little or no interference.

However, the data handling system is an area of concern, as according to Professor Fleming the readings are transmuted via the GSM network, which can become congested during the event, with guests operating their mobile phones. In which case, the data

transmitted by on board telemetry systems can be lost due to the lack of GSM signal strength, that in turn creates entry gaps in the data sets.
During the analysis of recorded telemetry data, the use of complex software packages such as MatLab was considered, as it would be able to provide a powerful graphical statistical and calculation tools. However, due to the previously mentioned entry gaps, the collected data required manual sorting and handling. The data was sorted in the following manner:

Out of all telemetry readings available, a set of readings most relevant to the aims of the thesis were chosen:

- kWh to identify the total units of energy consumed.
- Power Factor to understand the power quality and assess the load type.
- kW and kVA reading to verify the Power Factor readings and to identify demand peaks.

The reasoning behind focusing on kW and kWh is that this reading provides actual power measurement, which is useful power consumed to do work and is a standard unit of measurement of energy.

Available data was organised into 30 minute intervals based on the associated date and time stamp. Starting from 00:00 to 23:30 whenever permitted by available data. If a number of readings had a similar time stamp i.e. within +/-10 minutes, the highest reading was kept and the lower reading was discarded, so that to avoid false sense of accuracy and to provide a worst case scenario. Since the readings were orientated around demand for the purposes of generator sizing, the worst case scenario was a safety factor to prevent underestimation of demand.

The available telemetry data was analysed using Apple Numbers statistical tools to identify the lowest, average, highest readings of demand (i.e. kW and kWh) and Power Factor values.

Due to the above factors, Microsoft Excel and Apple Numbers were chosen as software of choice for data analysis, as the original data file was recorded in Excel to avoid any data errors. It was imported into Numbers via copy and paste function. Numbers were chosen due to the simplicity of the software and graphically superior presentation tools.

Fourth step was theoretical profiling of potential energy demand for comparable events, based on the telemetry data mentioned in the above steps. The purpose of theoretical profiling is to consider the possibility of utilising historical data, to make predictions for future demand and as a means of aiding the potential generator or hybrid sizing. As mentioned in step three, there were a number of data gaps over the monitoring period and as a result non of the generation assets had a complete 24 hour cycle. A key piece of telemetry which identified the meter readings in the beginning of the operation and at the end of operation of the generator, provided an accurate idea of how much power was consumed. Since the number of operational hours were also recorded and average power production per hour could then be calculated.

At this point, it was reasonable to assume that a theoretical 24 hour profile could be created by combining all the available telemetry readings for each generator into a single cycle. Data selection followed similar logic as in the above step, where by the highest readings for a specific time stamp were retained and the lowest were discarded, thus assuming worst case scenario as a means of adding a safety factor to the estimations. After a theoretical 24 hour profile was created, the data was analysed using Apple Numbers statistical to identify the lowest, average, highest readings of demand (i.e. kW and kWh), Power Factor values and total energy consumed. As a way of verifying the theoretical data, the total energy consumed in this 24 hour period was compared to the average energy consumed which was extrapolated from consistent meter reading and machine hours. The theoretical data was within +/-5%, which provided a fairly accurate assumption when considering data gaps. Final step was to take a single 24 hour profile and modify it to reflect the condition over all of the three operational days. This was achieved by assuming:

- First day would consume the least energy and would have the lowest demand, due to visitors only beginning to arrive and no main acts performing till the following days.
- Second day would experience the highest consumption and demand peaks as all of the visitors would be at the event with main stage performances performing at regular intervals.
- Third day would show the second highest consumption and demand peaks only due the fact that the event would be coming to an end, thus guests would begin to depart.

One of the main challenges of predicting a demand at such events, when compared to national grid demand, is the near 24 hour operation of acts and performances with food and lighting remaining available around the clock.

Fifth step was generation of qualitative data gathering tools in a form of traders and production questioner (*ref:Appendices 2*), to access the understanding of energy users and the cataloging of the types of power consuming equipment to be deployed.
By understanding the type of the equipment which will be consuming power, a more detailed and accurate estimation can be made to the power requirements of the event. By knowing which equipment places the highest strain on the electrification system, an educated decision can be made as to appropriateness of set equipment and wether it should be replaced for more energy efficient or alternative options. Furthermore, the users willingness to adopt changes could also be reviewed in order to identify potential ways of embedding change in future events.Academic peer educator briefing material has been generated, for the purpose of sharing the knowledge obtained thus far, in the course of the research and to identify the role peer educators have in gathering further data. The findings were combined into the form of posters, which were to be displayed at Face your Elephants project facilities at Latitude 2015 and a document outlining the background, aims and hypothesis of this thesis, was disseminated to all peer educators prior to the event. As a final step of peer education, during the event the author made a presentation to the peer educators as a way of reinforcing the knowledge summed up in previously mentioned materials. Key part of set presentation was the Q&A session during which, peer educators asked questions relating to the research which is being undertaken and what their role entailed. The purpose of this was so that they were able to grasp the complexities and comprehend key issues associated with set field of research.

Sixth step was conducting first hand qualitative data gathering, which was divided into two stages:

- Stage one consisted of the author approaching power provider's staff on site at Latitude festival to conduct interviews, which were at first designed to be a structured interview aimed at obtaining relevant knowledge regarding the functionality of the equipment, control methods, generator sizing, deployment philosophy, view point on deployment of hybrid systems and issues associated with processes. It should be noted that after an on-site assessment into the appropriateness of structured interview style, as advised by Benz *(1998)*, it was decided to conduct a more proactive interview in a form of general conversation as not to irritate the staff and increase the willingness to participate. The method has proven to be successful, as all staff members were inclined to participate in general conversation while carrying out their daily duties. Set conversations were recorded in note and video form for later analysis.

- Stage two was conducted by peer educators who carried out the questioner survey on traders at the event. As per briefing, the educators were advised to first gauge the understanding the interviewees had in regard to energy consumption and the equipment they utilise. To avoid inconsistencies and to improve quality of technical data, the educators were encouraged to assess the equipment personally by asking to view documentation such as, rating plates that display energy specification of electrical equipment.

Finally, an analysis of qualitative data obtained at Latitude 2015 was undertaken. It was important to isolate the understanding the staff had in regard to the technological readiness of hybrid generation systems and what are the limitations associated with the power generation technology as a whole. The data was interpreted by the author, based on the responses provided to the questions that were asked and a value was assigned to the responses at a scale “low or no understanding”, “sufficient understanding”, “expert understanding”. As highlighted by Benz *(1998)* qualitative data can be challenging to quantify at times, thus the researcher should not attempted to obtain false sense of accuracy by attempting to assign numerical value to every response.

Seventh Step was to generate a conclusion based on the findings of set research throughout the above steps. The findings of the research were discussed and evaluated in length, to attain whether the aim of the thesis was achieved. A set of recommendations was generated to encourage future research based on the findings of the thesis and how the obtained knowledge could be implemented at present by any interested parties.

Eighth step was to present the findings of the project as a thesis, with a comparison and reflection on the differences between the theoretical demand profiles and actual demand. Moreover, degree of GHG and fuel reduction will be evaluated based on the manufactures specification of the equipment and output generation data.
The final report shall form the bases for further research opportunities, as well as highlighting the limitation of the equipment and methodology employed. This thesis is presented in the form of an academic report, as outlined in the handbook for module ENGT 5304. The handbook defined restrictions in regard to fonts, spacing, margins and length of the report, which were adhered to by the author. The layout deployed in this thesis, adequately follows the specifications outlined in the module handbook.

5.3.Reproducibility.

The above methodology provides a sufficiently in-depth description of quantitative aspect of the research such as, data gathering and analysis, which any individual should be able to repeat or reproduce in their own comparable research into set themes. Qualitative aspect of the methodology in large part was tailored to this specific situation, which considered the time restriction and complexity requirements of the project. In addition, the work environment in which some of the qualitative data was gathered in i.e. a live event had to take a less formal approach, as the researcher/author had to work around the schedule of the interviewees. As identified by Benz (*1998*) it is important to adopt and design appropriate research methodology, thus the qualitative aspect of this methodology may not be suitable to others, as it was tailored to this situation and no two situations can be identical.

5.4.Precedence.

A significant portion of the above methodology was similar to Marchini's *(2013)* PhD thesis, which considered the sustainability aspect of music festivals and potential reduction of green house gas emissions. Although Marchini chose to review the same event i.e. Latitude music festival, his thesis considered implication of GHG emissions from all aspects of the event, transport, waste and energy production, where as the following thesis concentrates solely on GHG emissions associated with energy production. Thus, only some portions of the methodology could be comparable.

5.5.Rationale.

One of main reason of combining both qualitative and quantitative research methods in this thesis, is the nature of the aim. To simply identify technological feasibility of hybrid system deployment would be insufficient, as it is essential to gauge the state of cultural readiness and awareness by the end users and operators of potential technology. Quantitative aspect of this research provided the fundamental understanding into the technical capabilities and guided the direction of interviews and surveys. As the result a complete picture of the underlining issues and concerns were obtained, which assisted in meeting the aim of the thesis.

5.6.Reliability and validity.

As part of this research, the reliability and validity of quantitative data was considered throughout. The telemetry data from embedded monitoring equipment is of sufficient accuracy, as it is utilised by power providers to monitor condition of the equipment to prevent any failure or loss of services. A significant portion of telemetry data could be verified through simple extrapolations and calculations, for example the Power Factor reading could be double checked by actual power (kW) reading being divided by apparent power (kVA) reading at any of the data samples. It should be noted that short term interval telemetry data monitoring is not a novel approach, it has been previously utilised by Marchini in the course of his PhD and it has been a standard practice by power providers for a number of years. Theoretical modelling data could also be verified to within an acceptable tolerance by statistically analysing telemetry data to obtain the average consumption per timed interval.

The only data which should be treated with a degree of scepticism is the qualitative data, as some of the questions may not have received an honest answer due to commercial sensitivity or lack of engagement, throughout the interviews and questioner fillings. It should be noted that it is the researches professional opinion, that during the interview, the participants did cooperate and provided reasonable answers, that should be regarded as truthful, due to there being little to suggest otherwise.

5.7.Sampling.

Quantitative data was collected from over thirty power generators deployed at various locations throughout Latitude 2013 festival. Set generators ranged in size from 30kVA to 320kVA, which provided a sufficiently diverse data set, to be analysed to consider the implications of load, Power Factor, supply and demand response of the equipment. Such great sample size provided a reliable data set for statistical analysis, that in turn provided greater validity to the theoretical modelling.

Qualitative data consisted of interviews of a number of individuals holding various roles, from equipment operators to managers and organisers of the event. This level of participation provided a unique view of how the end user and operator views the same issues in different ways, and how the resources are prioritised to address the underlining issues.

5.8.Ethical constraints.

One of the key constrains of this thesis is the handling and presentation of proprietary data provided by the organisers of the Latitude festival and their respective contractors power providers and Off-Grid Energy. Set telemetry data is not available to general public and thus cannot be presented in its original form. Thus any data represented in this thesis, is extrapolated from original source file and is presented in a manner which shall not jeopardise commercially sensitive information.
Furthermore, the interview notes and recordings are presented anonymously as not to highlight the identities of the interviewees, who shared their expert knowledge and opinions throughout the research project. All proprietary data shall be returned to original source or deleted, insuring compliance with data protection laws.

5.9.Generalisation.

Data obtained throughout the course of research for set thesis, can have a general application as a demonstration tool for event organiser and equipment operators, for appropriately estimating demand and sizing of generator equipment, as well as provide significant guidance on issues of control philosophies and how these are effected by various factors.
The information contained in set thesis can be extrapolated and utilised as a reference point for further in-depth research, or can provide general guidance for all other off-grid applications.

RESEARCH ACTIVITY.

Research activities of set thesis consisted of both quantitative and qualitative components. Quantitative data which underwent the review process was gathered from eighteen events over a four-year period. Set events ranged in size from small to major, with a capacity of 2,300 to 70,000 people. Both urban and rural settings hosted the venues. Such an extensive data set has provided a significant overview of the energy demands associated with a temporary music/festival events, for the purposes of theoretical data analysis, the Latitude 2013 festival was chosen. This event represents a middle of the capacity range of all the reviewed data sets, with a capacity of 35,000 (*eFestivals, 2015*). One of the fundamental reasons for selecting Latitude festival is the willingness of the organisers to improve the green credentials of set festival. Thus an abundance of the telemetry data is available for set event.

As a direct result of selecting Latitude festival as a sample event, majority of qualitative data acquisition was conducted at or in the relation to set festival. Data in question was gathered through a number of unstructured informal interviews as suggested by Benz *(1998)* as a means of insuring cooperation. It should be noted that interview data is treated with a degree of anonymity, due to commercial sensitivity, as outlined in ethical constraints section of above methodology.

6.1.Quantitative data.

The following data analysis is from telemetry data of energy production and consumption at Latitude music festival. Set data has been recorded across a number of generator assets from 17-22/07/13 by power provider's telemetry monitoring system.
For the purpose of theoretical energy profiling, readings from non-essential assets were reviewed.

Asset ID	Data Time Stamp	Desegnation	Sizing	Duty of Asset	Total Energy Count
XCKW009	19-22/07/13	Crew Bunkcabins / Caravans	200 kVA	22%	951 kWh
XAZX143 (aka XAZX134)	17-22/07/13	Traders / Coffee Cake Shop	30 kVA	127%	649 kWh
XAED007	17-22/07/13	The Village	350 kVA	9%	1791 kWh
XCBA004	17-22/07/13	The Village	350 kVA	10%	1118 kWh

Table 1 (Sample of Generation Assets)

The data from the above mentioned assets, was analysed based on the available telemetry data, from set data the following key components were isolated:

kWh	This component was isolated as it is a standard unit of measurement for energy/power consumed over time. Large majority of consumer equipment is rated for energy efficiency and power consumption in kWh.
kVA	This component was isolated as it is a standard unit used for sizing industrial power generation equipment.
Power Factor	This component was isolated as it is vital for identifying power quality issues, by understanding the causes of PF fluctuation can insure a smarter energy generation system. Furthermore, when sizing equipment the PF will indicate the appropriate generation asset required based on demand estimations.
kW Demand **kW Supply**	These components were isolated to demonstrate peaks and lows essential for producing an energy profile and to reflect on the quality of supply response to demand spikes.

Telemetry data contains a number of gaps and inconsistencies, most probably due to communication issues between the assets and recording/control stations. Thus, for the purpose of set analysis, all available data of each asset was combined into a three respective theoretical profiles, to portray the energy demand of each area of deployment.

Theoretical profiles that were produced, are as close to 24 hour cycle as telemetry data permitted. Please note that only the highest readings from available data sets of each assets were chosen for a particular 30 minute interval. By choosing only the highest readings, the theoretical profile indicates the potential demand profile, which takes into account a safety factor for error correction. Finally, since XAED007 and XCBA004 powered the same area of deployment, they were modelled as a single asset in a combined theoretical profile.

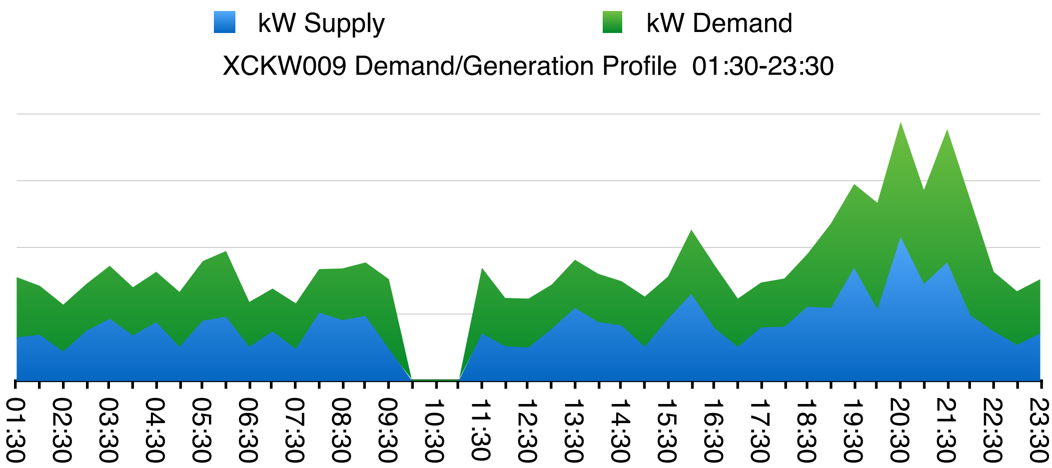
First asset to be analysed is XCKW009. The original data was captured in 30 minute intervals using onboard telemetry system. Raw data was then presented as Excel spread sheets. Due to minor data gaps in the samples obtained by equipment, raw data was condensed to extrapolate the following analysis, the combination of peak readings in regard to relevant sample intervals were compiled to produce complete data set.
It has been recorded that over a period of four days, approximately 895 kWh were consumed; thus working under the assumption that the demand profiles would remain similar. Over set period the combined samples may be utilised to produce a theoretical profile. Set assumption is further reinforced by the 208 kWh combined consumption figure shown in the table below, which if viewed in the context of 895 kWh ÷ 4 days = 223.75 kWh per day, which would justify the above assumption.

XCKW009 01:30-23:30 Demand/Generation.

	kWh Consumed	System PF	System kW	kW Demand	Peak Hold kW Demand
Maximum	11	0.9	21.5	19.9	20.4
Average	4.6	0.72	8.7	9.1	18
Minimum	1	0.6	4.4	6.3	17.7
kWh Consumed	**208**				
Total kWh Consumed 19-22/07/13	**895**				

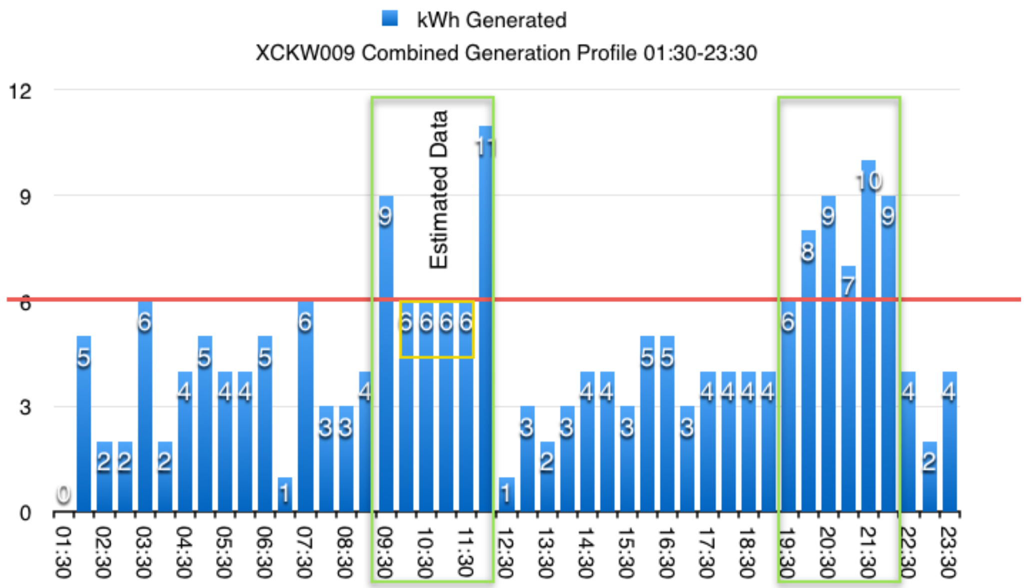
Table 2 (statistic of asset)

Graph1 shows the Demand vs Supply response profile of XCK009, as it is clearly visible, there is a significant response gap between the demand and the systems capability to respond in time. This gap can be attributed to the type of generation equipment utilised, as automatic voltage regulator installed, may have a slower rate of response than the demand load. This gap can cause significant issues in power quality and if a demand would to spike suddenly the system may not be able to respond quick enough, causing loss in supply and unnecessary strain on connected equipment. The portion of missing data in the chart can be attributed to data corruption or communication error between recorder and telemetry system.



Graph 1 (Demand vs Supply)

Graph 2 shows the energy which has been generated by XCKW009, set profile contains the same missing data as Graph 1. However, as the kWh units have been recorded before and after the laps, the missing data can be averaged out and accounted for. It must be noted that demand between the hours of 19:30-22:00 spikes in a similar fashion to demand estimates between 09:30-11:30. Hence, it is safe to assume that Graph 1 would show similar pattens if the data was not missing.



Graph 2 (Generation Profile)

Second asset to be analysed is XAZX134 (aka XAZX143). The original data was captured in 30 minute intervals using on-board telemetry system. Raw data was then presented as Excel spread sheets. Due to minor data gaps in the samples obtained by equipment, raw data was condensed to extrapolate the following analysis. The combination of peak readings in regard to relevant sample intervals was compiled to produce complete data set.

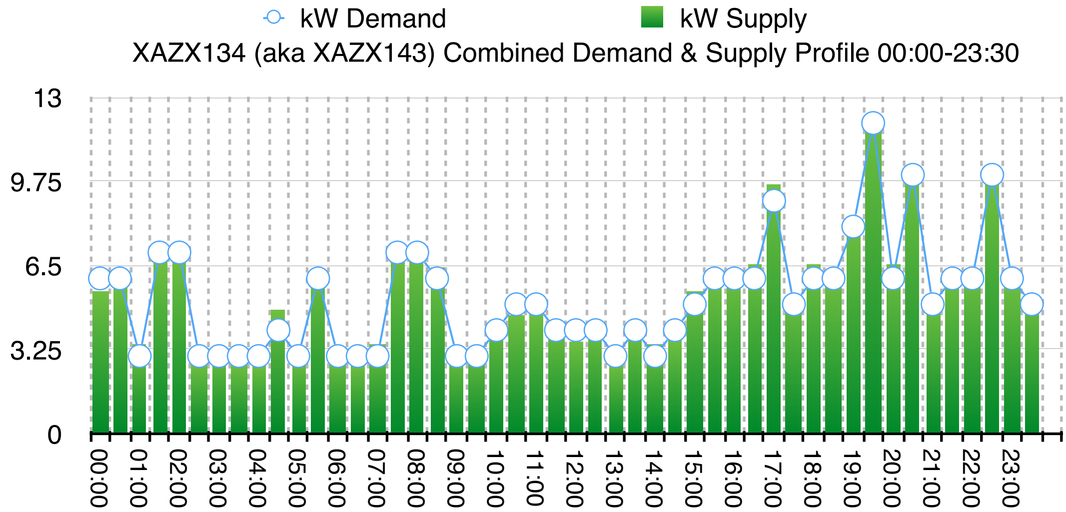
It has been recorded that over a period of five days, approximately 649 kWh were consumed, thus working under the assumption that the demand profiles would remain similar over set period. The combined samples may be utilised to produce a theoretical profile. Set assumption is further reinforced by the 119 kWh combined consumption figure shown in the table below, which if viewed in the context of 649 kWh ÷ 5 days = 129.8 kWh per day, therefore justifying the above assumption.

XAZX134 (aka XAZX143) Combined profile (00:00-23:30)
Demand/Generation.

	kWh Generated	System PF		kW Demand	System kW
Maximum	5	1		12	12.12
Average	2.48	0.99		5.23	5.27
Minimum	1	0.94		3	2.7
kWh Consumed	**119**				
Total kWh Consumed 17-22/07/13	**649**				

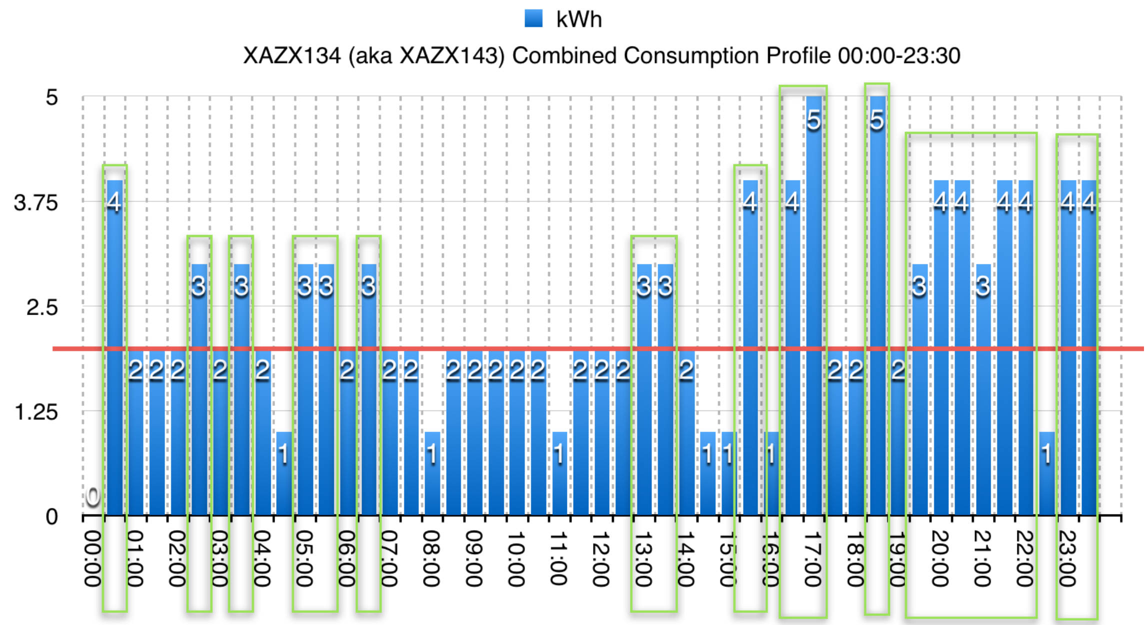
Table 3 (statistic of asset)

Graph 3 shows the Demand vs Supply response profile of XAZX134 (aka XAZX143). It is clearly visible that demand often exceeds the supply. Based on the asset duty percentage of 127%, it should be noted that this asset is significantly undersized for the intended deployment area.



Graph 3 (Demand vs Supply)

Graph 4 shows the energy which has been generated by XAZX134 (aka XAZX143). It must be noted that this data does not correlate to demand data in Graph 3. This can be attributed to offset in the sample rate and the duration of demand. The below data indicates significant energy consumption over prolonged period of time: 00:30, 02:30, 03:30, 05:00-05:30, 06:30, 13:00-13:30, 15:00, 16:30-17:00, 18:30, 19:30-22:00, 23:00-23:30.



Graph 4 (Generation Profile)

Third asset to be analysed is XAED007 & XCBA004. The original data was captured in 30 minute intervals using onboard telemetry system. Raw data was then presented as Excel spread sheets. Due to minor data gaps in the samples obtained by equipment. Raw data was condensed to extrapolate the following analysis. The combination of peak readings in regard to relevant sample intervals was compiled to produce complete data set.

XAED007 & XCBA004 Combined profile (00:30-00:00)
Demand/Generation.

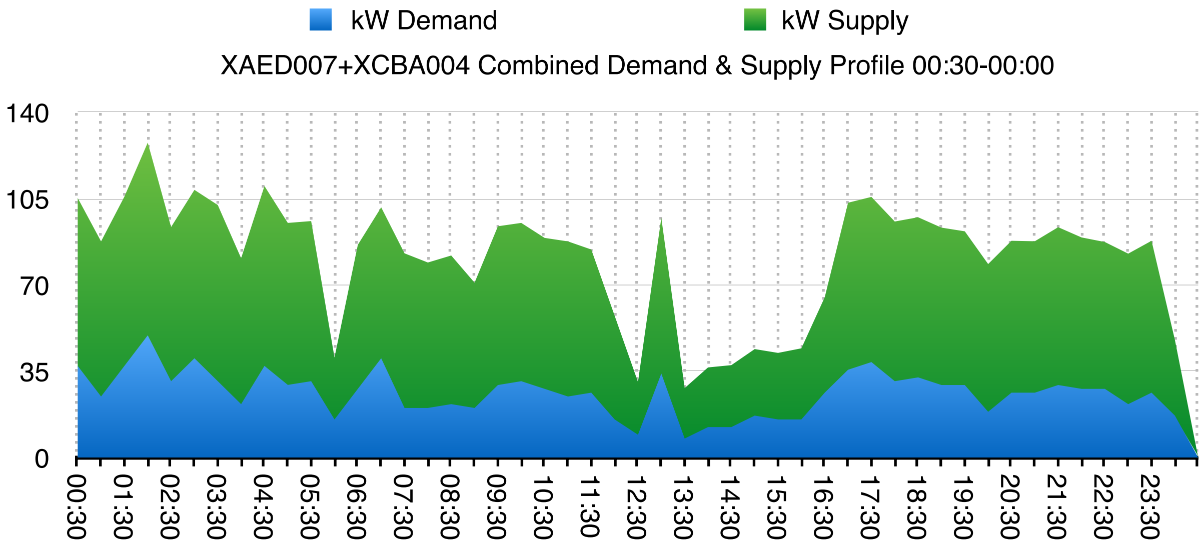
	kWh Generated	System PF		kW Demand	System kW
Maximum	26.35	0.68		49.6	78.12
Average	12.11	0.48		26.25	55.41
Minimum	1	0.31		7.75	20.46
kWh Consumed	**581.25**				
Total kWh Consumed 17-22/07/13	**2,909**				

Table 4 (statistic of asset)

It has been recorded that over a period of five days, approximately 2,909 kWh were consumed. If 2,909 kWh ÷ 5 days = 581.8 kWh per day. Working under the assumption in the previous section would be incorrect, since the combined profile only produced 375kWh per day based on the available data. When considering the deficit between actual 581.8 kWh/day and theoretically profiled 375 kWh/day, it can be assumed that all the data in the theoretical profile can be increased by 1.55 (obtained by 581.8÷375).

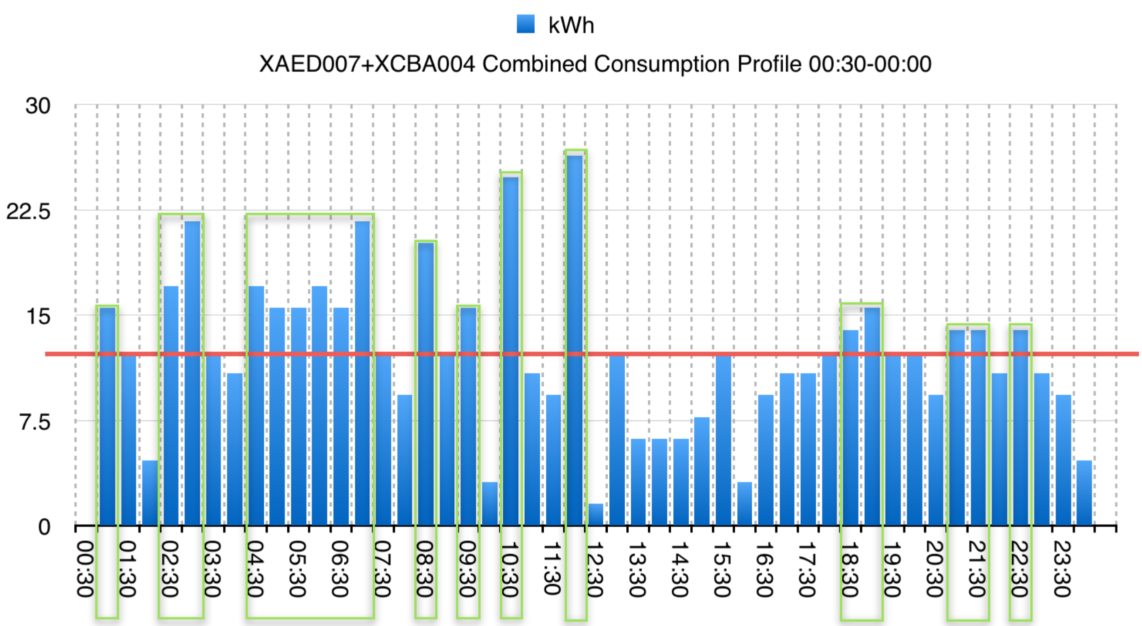
It should be noted that although the values will increase, the visual profile will remain the same.

Graph 5 shows the Demand vs Supply response profile of XAED007 & XCBA004. It is clearly visible that there is a significant over production of energy taking place. Overall, the supply remained above the demand needs. This brings into question whether the units are appropriately sized, and if there is an actual need for two assets to electrify the same designation (The Village).



Graph 5 (Demand vs Supply)

Graph 6 shows the energy which has been generated by XAZX134 (aka XAZX143). it must be noted that this data does not correlate to demand data in Graph 5. This can be attributed to offset in the sample rate and the duration of demand. The below data indicates significant energy consumption over prolonged period of time: 01:00, 02:30-03:00, 04:30-07:00, 08:30, 09:30, 10:30, 12:00, 18:30-19:00, 21:00-21:30, 22:30.



Graph 6 (Generation Profile)

Based on the collected data of assets, the following table can be created to identify peak consumption periods.

	XCKW009	XAZX134 (aka XAZX143)	XAED007+XCBA004
Peak Period	09:30-12:00	00:30	01:00
	19:30-22:00	02:30	02:30-03:00
	03:30	03:30	04:30-07:00
	07:30	05:00-05:30	08:30
		06:30	09:30
		13:00-13:30	10:30
		15:00	12:00
		16:30-17:00	18:30-19:00
		18:30	21:00-21:30
		19:30-22:00	22:30
		23:00-23:30	
Total Hours	**6**	**9**	**8.5**

Table 5 (statistic of peak periods for sampled asset)

The above data provides a clear frame-work for both sizing and control of the generation equipment, which can be used for electrification of Crew Bunkcabins, Traders and The Village at Latitude Music Festival. Based on the data outlined in Graph 1, it is of great importance to implement a generation system(s) which can rapidly respond to fluctuation in demand to produce a steady linear supply patten. While based on the data outlined in Graph 5, it is essential to size the equipment to actual demand rather than a hypothetical one. By appropriately sizing the equipment, a greater degree of control can be implemented and efficiency maximised, which in turn can minimise over production and reduce GHG emissions. Analysed data can be compared against possible hybrid system specification, in order to estimate the optimal size of battery cell storage and generation assets

6.1. Qualitative data.

Summary of Latitude trader survey 2015.

- The most appropriate time to conduct the surveys is after 10 am, as by this time the traders have made all the necessary preparations for lunch time peak. This means they have spare time to partake in survey related activities, without interruptions to their work schedule, insuring in-depth co-operation.

- Standing charge or flat power rate, is considered high by most of the surveyed traders. They come to this conclusion based on the charges from other events throughout the year. Some pay in excess of £500.

- Common consensus amongst the traders, is that the energy is overpriced when compared to similar events, which in turn raises the need for competitive pricing.

- There has been an expression of willingness by some traders to make use of communal refrigeration areas, similar to those deployed at Green Europe Capital at Bristol. It is the opinion of traders that this, can reduce the energy consumption by eliminating the need for individual refrigeration units.

- A base energy tariff is set at 2kW or 240v x 8 amp. A significant proportion of surveyed traders require much less energy, thus more flexible tariff would be welcomed.

- At first glance 5/10 (50%) surveyed are interested in a meter rather then fixed charge, however, if we discount those who don't use electricity for cooking or do not pay for electric, the breakdown will be 5/8 (62.5%). By viewing the data based on the assumption of relative need for electricity, those who don't pay or are not using electricity from the mains can be discounted, thus, percentages become more persuasive.

- The largest trader with over 47 staff responsible for catering for the crew of the event is one of the largest consumers of power, with no incentives to reduce consumption, as the energy is provided free of charge by power provider.

Summary Data of Surveyed Traders at Latitude 2015.							
	Num of staff	**Hours of operation**	**Main source of power**	**Use of energy saving tech**	**Use of energy management**	**Aware of own power requirements**	**Interest in meter**
1	50	13	Electric	N/A	N/A	No	N/A
2	47	20	Electric	No	Yes	Yes	**N/A**
3	27	18	Electric	Yes	No	Yes	**Yes**
4	25	19	Electric	N/A	N/A	N/A	N/A
5	24	16	Electric	Yes	N/A	Yes	N/A
6	20	18	Electric	No	N/A	Yes	**No**
7	15	22	Electric	N/A	N/A	N/A	N/A
8	10	13	***Wood***	Yes	N/A	Yes	**N/A**
9	10	13	Electric	Yes	N/A	Yes	**No**
10	9	19	Electric	No	No	Yes	**No**
11	8	19	Electric	No	Yes	Yes	N/A
12	7	21	Electric	Yes	N/A	Yes	N/A
13	7	24	Electric	N/A	N/A	N/A	N/A
14	7	16	Electric	No	Yes	Yes	**Yes**
15	7	21	Electric	Yes	N/A	Yes	**Yes**
16	6	20	Electric	No	Yes	Yes	**Yes**
17	5	15	Electric	No	No	Yes	**Yes**
18	5	10	Electric	N/A	N/A	No	N/A
19	5	12	Electric	N/A	N/A	Yes	N/A
20	5	14	Electric	N/A	Yes	No	N/A
21	4	18	Electric	N/A	N/A	N/A	N/A
22	2	17	Electric	N/A	N/A	No	N/A

Table 6

Key issues with the survey methodology:

- The survey form was designed for digital dissemination, however, it was printed out and delivered manually. As a result, majority of options/guidelines within the form were not visible, thus, the surveys were administered inconstantly.
- Judging by the amount of details filled into some forms and the rushed hand writing, there is a significant difference between the delivery quality of surveys, peer educator to peer educator.

Solutions to survey methodology issues:
Train a small number of peer educators (no greater than two) prior to the event, insuring that the form is disseminated as per design, i.e. digitally. Some areas of the survey form could also be considered for redesign to allow for more accurate data capture. Addressing the above outlined issues will insure that data capture is more consistent, which should provide a more accurate analysis as advised by Benz (*1998*).

Final remarks:
The survey indicates the importance of appropriately pricing energy as it has an impact on how much the user will consume. In the cases where the user pays a flat rate, there are no incentives to deploy energy saving equipment and methods, as evident in the above table. A pay as you go tariff would not only insure that energy is used efficiently, it will also provide a fair price for low power users. This in turn could encourage uptake of alternative energy methods such as gas or wood burning, as highlighted by Lefebvre (*2007*), electricity is pure form of energy and should be utilised to do work (i.e. drive an electric motor) and not be used for inefficient processes (such as heating). Finally, as some users display non or minimal knowledge of their power requirements, the event organisers may consider a compulsory PAT testing requirement of any electrical equipment that a user will utilise on site prior to arrival. PAT tester would produce a certificate of all equipment that has been tested and indicate power rating of set equipment, which can assist in appropriately sizing the generators, as the peak power requirements can be accurately estimated, insuring due diligence in forward planning. Lack of utilisation of basic energy management techniques by majority of traders is an area of concern, which can be addressed with appropriate education of the participant and backed by an incentive structure to encourage sustainable consumption.

Summary of qualitative data gathered from power providers through interviews.

During the interview process, it has become apparent that power providers and their staff recognise the importance of hybrid systems and GHG reductions. There is a significant positivity towards the technology as a whole. Power providers often deploy proprietary hybrid systems at low demand locations or where noise levels are of concern, as a means of shutting down generators for hours at a time. The performance of set systems often depends on the demand. As the demand increases, the duration of shut down decreases. It should be noted that units in question are relatively low capacity and often deploy dated technology, however, they still serve a demonstrative purpose of what could be achieved. There are after all, a difference of opinions amongst power provider's staff, in regard to technological readiness of current off the shelf hybrid systems. A great number of issues has been highlighted such as, interface, setup time and reliability. Power providers are keen to work together with hybrid manufactures, to perfect the underlining technology and make it suitable to their particular needs through custom configurations. A significant amount of R&D, as well as financial resource, is going into addressing efficiency of current generation systems and hybrid add ons.

Based on field observations, it has been noticed that at temporary events, there is no unified electrical grid. Instead, each section of an event is divided into cells. The reasoning behind this fact are as follows:

- Temporary cabling, which is installed each time at each event, meaning that complex network would be difficult to calibrate and configure within a short time period. The larger size of the event would mean that significant length of cable would have to be utilised to go from area to area, which would yield electrification economically unviable due to man hours, transport cost and capital investment into additional cabling.

- Small cells offer ease of troubleshooting and supply safety, for example, if lights go out in a single cell, it would be less time consuming to find the root cause as a single generator would power set location.

- Finally, unpredictable nature of the events means that event organisers can request traders to change locations on the day at moments notice. If a complex event wide grid was deployed, set changes would be impossible.

During the interviews with power provider's staff, it has been emphasised that power security is of strategical importance. Walk way lighting is a legal safety requirement and must be maintained without interruption, thus the lights remain on 24/7 to avoid the risk of failure in the event of rain. The main stages often deploy over sized generator unit to compensate for performers deploying their own equipment, which is not specified prior to arrival and can cause a degree of uncertainty. Furthermore, members of the media often conduct live broadcast for which power provision is critical, as often financial penalty may be imposed as part of contractual agreements for failure to provide power.

On that final note, one of the key things which has been apparent throughout, is the forward planning and reliable communication between all involved parties. Often, last minute changes to layout of traders and generation assets can cause technical issues, which require constant professional intervention.

Summary of qualitative data gathered from OffGrid energy through interviews and email correspondence.

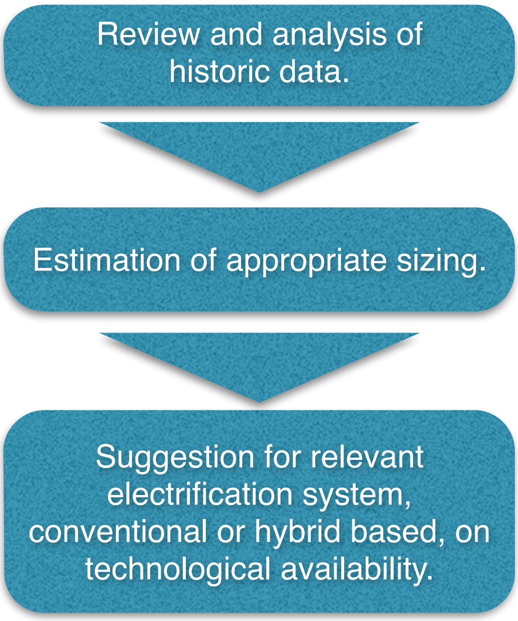
As stated previously in the methodology chapter, qualitative data was largely accumulated through unstructured interview techniques(Benz,1998), as to extract the maximum information possible without alienating the interviewee.

The key emphasis is that there is a need for cooperation between the power providers, hybrid manufactures and event organisers; in order to insure effective design, sizing and deployment of hybrid systems. Effective deployment is essential to dissemination of any novel technology or technique, as often there are those who are for and those who are against change (*ref: conversation on 13th August 2015 D.Jones from Off Grid Energy*). More often than not, the early adopters are the minority, while a significant number of key figures in the industry can be sceptical. Set scepticism can often be attributed to the lack of understanding or bad experiences with previous technology, hence, the importance for education of all parties is essential. Novel technology often has a significant number of limiting factors, which must be considered when sizing or selecting a hybrid system. Each new deployment must be treated on individual bases, meaning that a hybrid system needs to be configured for a particular application which it can be suited to.
Premature or inadequate deployment, can often lead to a false sense of ineffectiveness of a hybrid system. This can have a hindering effect on the dissemination of set technology. One must consider that hybrid technology is constantly evolving, as new battery storage and control systems are brought to market, thus it would be ill advised to dismiss the concept of hybrid systems based on past experience.

Based on the above findings all interested parties are motivated to progress the development of hybrid generation systems. There is a need to address concerns raised by all involved, in order to ensure adequate development and deployment of future solutions.

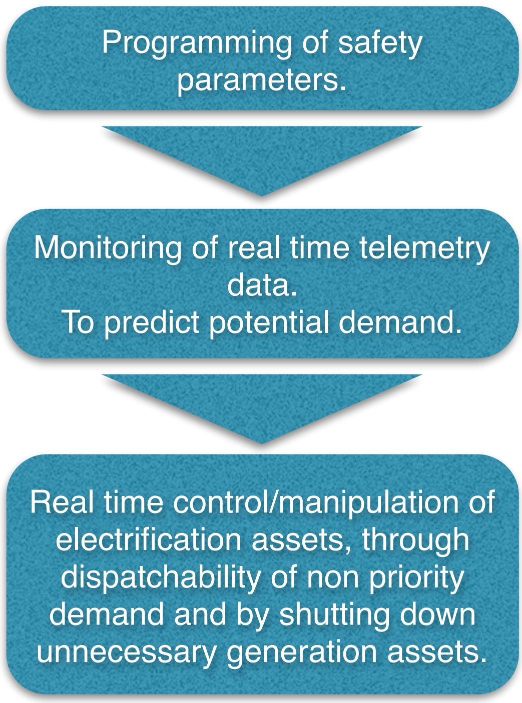
RESULTS.

Based on the above findings, the following logic can be extrapolated for development of informatics tools, designed to estimate appropriate sizing for conventional or hybrid electrification systems. In addition, set logic could be implemented in monitoring and responding to real time data, through pre-programmed control parameters.



On the left is the basic logic, that could be implemented into an informatics based solution for estimation of potential asset sizing. With an added option of suggesting whether a hybrid system would be suitable for intended deployment.
Such a tool would be aimed at event organisers and power providers, to insure a consistent process on all sides.

On the right is the basic logic, that could be implemented into an informatics based power control and management solution. That could autonomously optimise the operations of hybrid or conventional electrification systems. By analysing real time telemetry data, such tool should be able to insure that generation assets are operated at a higher load and are shut-down when demand is low enough to be met by stored capacity.



The above logic could also be utilised to estimate the potential Power Factor based on historical data. Advance knowledge of where a poor PF could be expected, can insure the cost effective deployment of PF rectification systems to affected grid.
The importance of Power Factor has been stressed throughout set thesis. As evident in the above section, PF could be as low as 0.31, which if unchecked, could eliminate efficiency savings and jeopardise supply security.

In reflection to the analysis of qualitative data, it should be noted that an effort to improve operational efficiency should be made. Such improvements could be achieved by providing a viable incentive structure for the end user to optimise the manner in which they utilise power. An over-whelming majority of users are open to the idea of being billed on pay as you use bases for their power requirements and they would welcome an introduction of power metering system. As currently, the overall consensus is that the users believe they are paying too much for power and any financial incentives could encourage a more sustainable consumption. Some of the surveyed users have suggested deployment of communal facilities, i.e. joint refrigeration systems, that could eliminate the need for traders to utilise their own equipment. A key benefit of deploying a communal refrigeration facility is that, set equipment would be more efficient,well maintained and would allow power providers to pre plan the necessary power provision for set equipment.

Based on the analysis of quantitative data, the following estimation of GHG and fuel savings could be made. From analysis of second generation asset (XAZX134) in the above section, a comparable theoretical profile has been created to demonstrate the potential benefits of deploying a hybrid system, for the same designation as the above asset. The following specifications were given to a theoretical asset:

- 30 kVA diesel generator operated at above 75% load, utilised to charge the Lithium Ion battery cells.
- 1 kVA PV array utilised to charge the Lithium Ion battery cells for up to 11 hours per day.
- 16 kVA Lithium Ion battery with 150 kWh storage provided supply on demand.

Working assumptions were that the system in question could utilise the stored energy in sync with diesel generation asset and a PV array to provide a sufficient boost in the event of a sudden demand spike. The overall system could be rated as 47 kVA, which is significantly larger than second generation asset (XAZX134). Although the hybrid could be classified as 47 kVA unit, throughout the operation cycle it would not exceed 16 kVA of the battery storage capacity. Sizing of theoretical hybrid, was produced under the assumption that the Power Factor would be 0.99 on average and thus could be regarded as perfect PF. Moreover, the theoretical asset is assumed to be fully charged to capacity, prior to a deployment, by a sustainable power source. The operational parameters do not allow the unit to be discharged below 25%. Lithium Ion storage was selected for its linear charge/discharge pattern (*Vincent, 1997*).

Table 7 presents the statistical data associated with conventional diesel generation asset.

XAZX134 (aka XAZX143) Combined profile (24 hours)
30 kVA generator

	kWh Generated	System PF		kW Demand	System kW
Maximum	5	1		12	12.12
Average	2.48	0.99		5.23	5.27
Minimum	1	0.94		3	2.7
Average kWh Consumed per 24 hours	**129.8**				

Table 7

Table 8 presents the statistical data for the theoretical hybrid unit as per the above description.

Theoretical hybrid profile (24 hours)
30 kVA Generator + 16 kVA Storage + 1 kVA PV

	kWh Generated	System PF		kW Demand	System kW
Maximum	10.95	1		12	15.95
Average	1.83	0.99		5.23	6.37
Minimum	0.45	0.94		1	1
Average kWh Consumed per 24 hours	**136**				

Table 8

Working under the assumption that a conventional diesel generator asset will be operated at an average load of 13.6% (as per Table 1) and with an estimate, by the power providers, of 1.2 kWh of power being produced per litre of diesel fuel, when generator is operated between 10%-25% load, the following calculation can be made:

$$129.8 \text{ kWh} \div 1.2 \text{ kWh} = 108 \text{ litres}$$

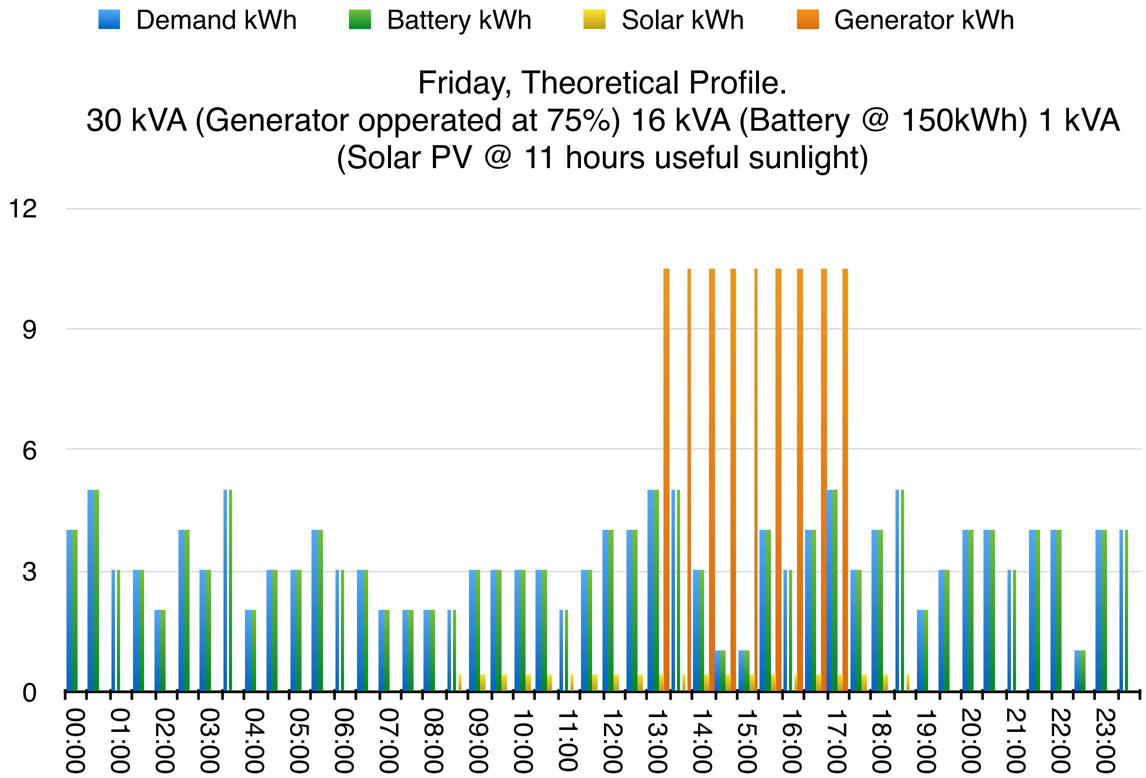
Thusly, a conventional diesel generator asset such as XAZX134, will consume approximately 108 litres of diesel fuel per 24 hours of operation.

Power providers, estimate that a diesel generation asset operated at above 75% load, would be expected to produce 3.15 kWh of power per litre of diesel fuel. Based on the operational parameter of the theoretical hybrid unit, an average of 80.5 kWh per 24 hours would be provided by a conventional diesel generator to recharge the battery storage. With that in mind, the following calculation can be made:

$$80.5 \text{ kWh} \div 3.15 \text{ kWh} = 25.5 \text{ litres}$$

Hence, a hybrid asset such as the one theorised above will consume approximately 25.5 litres of diesel fuel per 24 hours of operation.

Below is a theoretical 24 hour demand/supply profile for a hybrid system described above. Set profile highlights the 'worst case scenario' for power demand over a three day festival. The remaining two days are attached to Appendices 1.



Graph 7 (Theoretical Peak Demand/ Supply Profile of a hybrid asset)

The above theoretical profile, demonstrates that a hybrid asset can provide power from battery storage for a significant part of the 24 hour cycle and a diesel generator asset only needs to[1] be operated for a few hours per cycle.

To conclude, this thesis demonstrates the potential of a hybrid system, when considering

[1] Please note: that fuel consumption per kWh estimate is commercially sensitive data, thus the exact source is anonymised.

108 litres of fuel for conventional generation asset and 25.5 litres of fuel of a hybrid equivalent, an overall reduction of 72% in fuel consumption is feasible (please note: that this estimate is comparable to the one on page 14 of this thesis). At present time, fuel prices are significantly lower than in previous years, therefore, the author decided not to place a monetary value to this estimate, as it is outside of the scope of set thesis to dwell on commercial viability of the technology.

On a final note, to further the benefits of deploying hybrid systems, the use of biofuel for primary generation asset should be considered, as the use of bio diesel has 43% lower GHG emissions (*DEFRA,2010*) when compared to conventional diesel fuel.

DISCUSSION

8.1.Smart Grid Controls.

Throughout the course of the research, the key differentiator of the thesis has been the understanding of demand management. Although hybrid systems and battery storage have been considered by others for off grid application (*Ibrahim, 2011*), the novelty of this thesis has been to quantify, predict and manage demand on an off grid electrification system. This philosophy can be compared to Smart Grid control systems, which aim to generate, store and utilise the necessary power with minimal waste and overproduction. Quantitative data analysed in the course of this research reinforces the necessity to achieve an equilibrium between power security and appropriate sizing of generation equipment. It has been shown that without accurate estimation of the potential power requirements, the power providers will opt for security of supply by deploying large generation assets and as a result they are operated at a relatively low load. Since there is no accurate way to predict demand spikes at an off-grid music event, a requirement for an informatics/software tool is presented as the result of the conducted research. Set tool must be able to analyse historic as well as current demand and supply data, in order to better predict power demand in both real time and prior to the event. By analysing the relevant data, organisers and power providers will be able to better size the electrification equipment, which in turn could reduce the number of generation assets required, by sizing the units to run at higher load. A prioritisation can be given to different load types, meaning that certain areas such as: main stage, walk way lighting and utilities would have service priority over non essential supply. Any supply classified as non-essential, can then be a power security buffer in the event of sudden or predictable demand spikes. Set buffer could be dispatched (i.e. shut down) when required to reduce the risk of power failure. Built-in redundancy is a safety measure highlighted by Gellings (*2009*) and is crucial to any Smart Grid system. Such redundancy measures would allow for smaller sized generation assets, which can be operated at higher load.

8.2. Operational Load.

Operating generation assets at a high load, close to or above 75%, has a number of advantages. Firstly, as suggested by Lefebre (*2007*) and reinforced by various power providers, operating at higher loads increase the fuel efficiency of the generator. Basically, the kWh output per litre of fuel used is increased, which in turn would yield lower CO2 emission per kWh. Secondly, as demonstrated in the above theoretical profiling, the greater the output of a generation asset, the more power can then be diverted to be stored in the battery cells for later use.

One key draw back of operating at higher load is the risk of mechanical failure of the asset. Ibrahim (*2011*) identifies that a generation asset is nothing more than an internal combustion engine driving an alternator. Therefore, it must be treated like any other engine. A simple analogy would be running up hill at full speed for hours on end. Under these conditions even the most seasoned runner will eventually collapse from fatigue. The risk of mechanical failure goes against power provider's requirements for power security, thusly, under normal circumstances a generator will not be operated at high load, due to 24 hour operation cycle. However, the theoretical profiling demonstrates that an appropriately sized and managed hybrid unit would not require the generation asset to operate for longer than a few hours. Another possibility to consider, is to deploy a significantly sized generation asset to power a larger single grid, as oppose to clusters of smaller units. Smaller generation assets could be replaced by cluster of battery units, that would place high load on the single asset to provide rapid charging.

8.3. Power Factor.

Based on the interviews with power providers, generation assets are designed with a Power Factor of 0.8 in mind. The analysed telemetry data from generation assets, suggest that in reality Power Factor is much lower, as low as 0.3 in some instances. As suggested by the power providers, the low Power Factor could be attributed to the deployment of low power consuming devices, i.e. energy saving equipment, such as digital amplifiers and LED lighting. The importance of managing Power Factor issues have been described in the earlier chapters of this thesis, since this reduces the energy density of an asset, therefore, requiring an over sized generation asset to compensate for losses in power quality. Management of set phenomena is taken seriously by the power providers, as suggested during the course of the interviews, a significant investment has been provided into the research and development of potential solutions.

As outlined by Turchi (*2014*), solutions can range from simply adding resistance on a particular circuit, to harmonics manipulation. Analysed data, outlines the potential requirement for further study into relevant Power Factor rectification methods, that could be implemented for off-grid application in a cost effective manner. Based on the understanding gained from literature review into the subject matter, a potential solution could be the development of intelligent distribution grid. Set grid would control the direction of power flow into the equipment, which has been identified with low Power Factor potential; much like a one way valve, it would stop the interference flowing back into the main grid. Based on analysed data sets, it should be noted that, there is a potential to identify equipment which may cause power quality issues.

8.4. DC Based Systems

A fundamental flaw with performance of inverters in a hybrid generation system has been highlighted by Turchi (*2014*) and power providers. Set flaw is a limitation to the sizing of hybrid systems, as often this can be the point of failure due to demand overload. Thus, it is essential to utilise inverters of appropriate capacity, much like appropriate sizing of generator assets. Based on the literature review of hybrid generation systems, it is logical to speculate that potentially the strain on an inverter could be mitigated by utilising a DC based generation asset. Since the battery cells operate on Direct Current *(Vincent, 1997),* set generator could charge the batteries directly. Hence, mitigating losses associated with conversion from AC to DC and then back to AC. As the concept of DC power generation is by no means a novel endeavour, sufficient understanding of technological state of readiness already exists within the power generation industry (Lefebre, 2007). This could be an area of further research, which could address a lot of concerns with reliability of hybrid systems raised by power providers.

8.5.Power Density.

Previously mentioned issues of fuel efficiency, Power Factor and battery cell charging have a significant impact on power density of generation assets. When considering a conventional diesel or petrol generation asset, it's physical dimensions are governed by the sizing and fuel capacity. Often, a generator would utilise an external fuel tank to provide sufficient supply for long operational cycles. The utilisation of an additional tank reduces energy density of an asset, as often, lower fuel efficiency would result in higher fuel consumption, thus, a greater physical size is required to maintain power production. Therefore, if a higher Power Factor and fuel efficiency is maintained, a smaller sized generator without the need for additional fuel tank could be deployed, which yields higher energy density. Based on the information gathered from energy providers, an appropriately sized inverter would insure that battery cells could be charged and discharged at a suitable rate, which would allow for more compact unit to store the required power.

Image 3 (*Yates, 2015*)

8.6.Stepped Stage Generation.

Another potential solution for supply security and increased fuel efficiency is stepped generation system. Such systems have been deployed on many occasions according to power providers. The concept of stepped generation is elegantly simple. Three generators are connected in sync, i.e. small, medium and large; the small generator is the first to provide power to the grid, as the demand increases, and generators reach a preset load parameters, the next sized generator activates. Set process continues until the largest generator is activated. Once the demand subsides, the generators will deactivate in successive order. The benefits associated with such a system is the security of supply, as the generation assets are sufficiently sized to cope with all eventualities. Furthermore, due to the different sizings, the generators can be operated at high load, in order to insure greater kWh per litre of fuel ratio. It has been acknowledged by power providers in the course of interviews, that such a system has been proven to perform in real world deployment. However, it is hindered by the overall space requirements. Since the system comprises of three independent generators, a significant amount of appropriately prepared (i.e. level) area is required.

Financial viability of such system is further reduced by additional transportation costs and rental fees associated with additional generators. It has been highlighted by power providers, that such a system is not suitable to all events, due to the underlined limitations.

8.7.Logistics, Maintenance and Viability.

Finally, in the course of the research, it has become apparent that the rebound effect must be considered for any novel solution. As seen previously, the use of energy efficient equipment such as LEDs can have an adverse effect on power quality, leading to the need for additional capacity to compensate for power deficits. It has been mentioned, that power density is of great importance to an off-grid electrification, since all generation assets must be transported to site. Thus, the greater the efficiency/capacity the higher the density, hence fewer units are needed, which leads to fewer logistical miles. As highlighted by Bottrill (*2009*), the impact of transportation accounts for 1/5 of green house emissions associated with festival electrification, which is of great significance and this is often neglected. Power providers have placed an emphasis on deployment and maintenance of hybrid generation systems throughout the course of field interviews. Based on their past experiences, a significant amount of man hours can be spent on set-up and preparation of such systems.

Thus, all of these factors are capable of significantly diminishing financial viability of any novel system. The underlining issues of cost can often take precedence over environmental factors. However, throughout this thesis it has become apparent that, the event organisers are very conscious of their environmental implications and a significant number of financial resources are deployed towards trialling novel technological approaches. It should be noted, that in order to achieve tangible environmental results, the deployment of any novel technology must be preceded with appropriate education into the subject matter, to bring better understanding of opportunities and limitations. This insures that any actions or changes are planned with due diligence and relevant solutions are deployed to specific problem areas.

CONCLUSIONS.

To summaries,the theoretical demand profiling, suggests that the use of state of the art hybrid systems in combination with smart demand management, would yield significant fuel savings, that in turn would equal reductions in Green House Gas emissions. Demand management presents the novel aspect of this thesis, as there is no unified systems in place to monitor, asses or predict power demand for off-grid applications. To date, minimal research has been conducted in this specific area, which offers a significant opportunity for further research to be built up on the findings of this thesis. Set opportunity offers a significant commercial incentive, to produce a functional Smart power management and distribution system for off-grid application, as there is not only an ever increasing need for UK to curb it's GHG outputs, but also the growing renewable and domestic power storage market would benefit greatly from knowledge exchange. The thesis definitively demonstrates that the generation assets sizing can be and should be reduced significantly. It has been made clear from literature review and interviews with the power providers that in order to achieve peak efficiency, a generator must be operated at a minimum 75% load. Operating a generator of any size at a higher load would insure optimal fuel to power ratio (i.e. litres/kWh), which in turn will amount to lower GHG output per kWh of generated power. Although potentially a significant reduction in generator sizing could be achieved, it must be noted that an issue of supply security should be considered. Power Factor could be challenging to predict and even more so to economically rectify in high power application. If this is not considered appropriately when sizing a generation asset to a particular application, loss of supply would be a potential side effect. At the current technological state of readiness, the research demonstrates that hybrid deployment is not a simple off the shelf solution at present. Hybrid systems must be tailored to a specific application with consideration for technical limitations and end users understanding of set system. A significant knowledge gap has been identified in users ability to accurately size and deploy hybrid systems. Such knowledge gap must be rectified to maximise the chances of a successful deployment. Knowledge exchange is essential between manufactures, organisers and power providers to insure relevant understanding of technical capabilities and how to achieve the optimal utilisation.

On a positive note, conducted research has identified willingness by all involved parties to address the issues of Green House Gas emissions and efficient electrification. Organisers of the event have demonstrated dedication to deployment of hybrid systems, continuous monitoring and ongoing improvements to the festival's sustainability. A vital observation is that forward planing is crucial to accurately sizing generation systems and to improve operational efficiency. The human resource is an important aspect of the electrification system, insuring that maintenance and operational staff are deployed in a structured manner, with pre-planned operational tasks that can benefit the morale and reduce overall operational expenditure.

In conclusion, this thesis has presented a unique approach to the way power demand management and hybrid systems are perceived for off-grid applications. The novelty of set approach lies in the analysis of telemetry data. Historic for improved estimation for sizing of generation assets and real time, for improved power demand management. The research definitively demonstrates that by applying set approach when pre-planning an off-grid event, the upcoming power needs, can be estimated more accurately to insure that the relevant generation assets are deployed at the appropriate designations. By doing so, a reduction in GHG emissions can be achieved through reduction of the number of unnecessary generation assets and as a result, utilising the remanning ones more efficiently, by operating them at a higher load. The Smart grid element of the approach is the concept of real time data analysis, in order to govern the operation of the asset to pre-programmed parameters. Set element would insure security of supply by implementing dispatch of non-essential loads in the event of unpredicted demand spikes and reduce GHG emission by reducing the up time of generation assets, by shutting down assets when the demand can be catered for by stored power within battery cells. Set Smart control philosophy has been deployed successfully on large grid application, with significant efficiency gains according to Gellings(*2009*) and may therefore be piloted for off grid application.

As discussed throughout this thesis, Power Factor presents one of the most significant issues associated with off-grid electrification. A reduced Power Factor can significantly diminish the quality of produced power, leading to the need to oversize generation capacity to compensate for losses. The research outlined a number of techniques for Power Factor rectification, although none of the more advanced methods have been attempted on a larger scale electrification systems. There is a significant area of opportunity for further research. According to the power providers, simple resister based systems have been trialled in the past. Although they delivered some notable results, the side effects of significant heat generation and potential for surge back to the generation assets rendered this solution a high risk. Such risks are associated with applying resistance to high current loads (*Turchi, 2014*) and was one of the reasons for discontinuation of such method of PF rectification. Based on the findings of the research, it is apparent that the end user have limited understanding on the causality of low Power Factor. The power providers on the other hand understand that energy efficient equipment with low load resistance are the key contributors to set issues. Often, the deployment of such systems create a rebound effect on fuel and GHG savings, although at a glance, systems such as LED lights and digital amplifiers use less power. The resulting low PF means that more power needs to be generated to meet the demand. As the end user is often responsible for requesting the deployment of energy efficient systems, there needs to be a degree of understanding to the trade-offs associated with such systems. More often than not, such systems can cause an increase in fuel consumption and GHG emissions when there is no PF correction deployed.

The effects of Power Factor are not exclusively limited to fuel consumption and resulting GHG emissions. The current state of technological readiness, apparent in conducted research, suggests that the way power providers compensate for low PF, is by oversizing the generation assets. The oversizing of generation assets is often done to provide security of supply, which according to interviewed power providers is crucial to many applications at an off-grid event. Oversized generation systems can often mean deployment of large generation units, or greater number of smaller units; in other words the result is an increase in physical size occupied by the equipment. As a direct result of this, a significant reduction in power density is achieved. Reduced power density is produced by the physical dimension of generation asset and the amount of useful power it can produce, thus, the energy density is proportional to the Power Factor. Lower power density would mean more equipment would need to be transported and deployed on site, to provide the necessary power. This in turn would reduce economic viability of any electrification system, due to an increase in logistics, deployment and operational costs.

Power generation efficiency, is influenced by a great number of contributing factors. The most important factor of operational load has been highlighted by both Lefebre(*2007*) and power providers. It can often be challenging to quantify efficiency. For the purpose of this thesis, kWh per litre of fuel has been identified as a relevant definition. It has been identified by power providers, that a generation asset needs to be operated at above 75% load to achieve the optimal efficiency. Increased efficiency would result in lower fuel consumption and consequent GHG emissions reduction. Thus, as suggested by the data analysed during this research, appropriate sizing of generation assets based on analysis of historic data, can insure the assets are deployed in a manner that would allow them to be operated at higher loads. Then, by utilising Smart grid control philosophy and analysing real time data, hybrid unit could be managed in such away that a smaller sized generation asset could be compensated by battery storage and vice versa in the event of demand peak.

As any novel item, smart grid controlled hybrid systems have their inherited limitations, which must be appreciated and addressed prior to deploying set systems. The Achilles heel of any hybrid system is the battery cell and inverter components. As outlined by Vincent(*1997*), conventional battery cell (i.e led acid) technology has a number of limitations such as charge/discharge time/pattern and associated size constraints. According to energy providers, inverter systems which are often deployed in hybrid units, can be undersized and are prone to overloading, thus, a need for more reliable inverter systems and battery cell technology is apparent. It should be noted that the current state of technology, progresses in a rapid manner and the concerns expressed by power providers address older generations of the equipment. With the development of Lithium ion battery cells, greater power density is achieved with linear charge/discharge patterns (*Vincent,1997*). Deployment of latest state of the art technologies can mitigate a great number of limitations associated with previous hybrid systems. However, as always, commercial viability is a major limitation that cannot be addressed at this end of the industry. The commercial viability aspect limits the potential applications of hybrid systems, for example, according to power providers, the current maximum size of a hybrid system stands at 150 kVA in a single unit. This would mean that a hybrid system of such size cannot be utilised for main stage application, as the smallest unit deployed for set application is 300 kVA.

Throughout the interviews with power providers and traders, a knowledge gap has been identified. Set knowledge gap can predominantly be attributed to end users understanding of hybrid systems and electrification in general. As a result of this gap, the limitations of electrification systems are often neglected by the end users, and this may result in last minute changes which are often made to deployment of electrification equipment. In order to insure successful deployment of hybrid systems, the users need to be educated in regard to system limitations and appropriate sizing of assets, as more often than not, if technology is inappropriately or prematurely utilised, the desirable performance cannot be achieved. This can have a hindering effect towards future incorporation of such systems through lack of user confidence.

On a final note, there are a number of potential benefits for deploying hybrid generation with smart-grid controls. A significant reduction of Green house gas emissions can be achieved in-line with reduced fuel consumption. Set benefits can be obtained by accurate estimation of necessary generation assets prior to deployment and real time demand management through telemetry analysis. The knowledge obtained in the course of this thesis is transferable into comparable electrification applications. Set knowledge prepares the foundation for future research into Power Factor rectification and informatics-based demand management, to further the necessary understanding essential for successful development and deployment of hybrid systems. In retrospect, the objectives of set thesis have been met to a satisfactory degree. The overall aim of achieving reductions in fuel consumption and GHG emissions, have been theoretically demonstrated through use of hybrid generation systems, with smart grid control philosophy.

RECOMMENDATIONS

One of the underlining issues made apparent in the course of this thesis are the issues associated with power quality. Importance of the Power Factor has been clearly emphasised as essential for security of supply and power density. A low Power Factor would yield potentially undersized generation assets, which in turn can result in supply failure. In the course of the research, the issues of Power Factor rectification have been touched on briefly. However, there needs to be further exploration. The field of Power Factor rectification present a separate field of study that could be suitable to an industrial or PhD based research. A number of potential solutions could be explored in greater detail, in order to ascertain the most suitable methods for the most appropriate applications. As part of further PF research, the relations to harmonics could be considered as a potential means of addressing PF issues, as the literature review has identified a direct correlation between high harmonics and low Power Factor. One of the main drivers for addressing the Power Factor issues is the energy density. Although at first glance energy density should be attributed to the type of technology utilised for power storage/generation (*Ibrahim, 2011*), without a reliable Power Factor correction, a way of compensating for the issue is to over size the equipment. By over sizing the equipment, a secure supply can be insured through over production and over storage, as has been identified in the course of research. Direct implication of oversizing equipment due to low energy density would be an increase in physical dimensions of set equipment. As outlined previously, the issue of additional equipment transportation, would then have a rebound effect on any potential reductions in Green House Gas emissions achieved during generation of power.

The requirement for accurately accessing, monitoring and presenting power demand data is of equal importance, as Power Factor rectification. Further research into this area could be conducted from informatics perspective. A reliable algorithm, or a piece of software, needs to be developed with capability to analyse past usage/generation data, in order to predict future demand, for the purpose of power management and generation asset sizing. Such informatics tools should have the capability to graphically display live data to end user in a simplified format. Information provided could be utilised as a means of oversight to allow for operators to execute emergency controls of the equipment. Furthermore, the tools must be programable to preset parameters so that it may carry out autonomous control of power grid, considering the input from live data and pre-programmed parameters, in order to remove dispatchable loads during peak demand or shut down unnecessary generators to increase the load factor on remaining equipment.

In summary, further research effort can be directed towards Power Quality controls and Informatics based management tools, as a means of maintaing high power density and a smarter, more secure power grid. The proposed research, is capable of extending additional knowledge, into other power related fields such as, national or micro grid electrification, as well as permanent off-grid/remote electrification.

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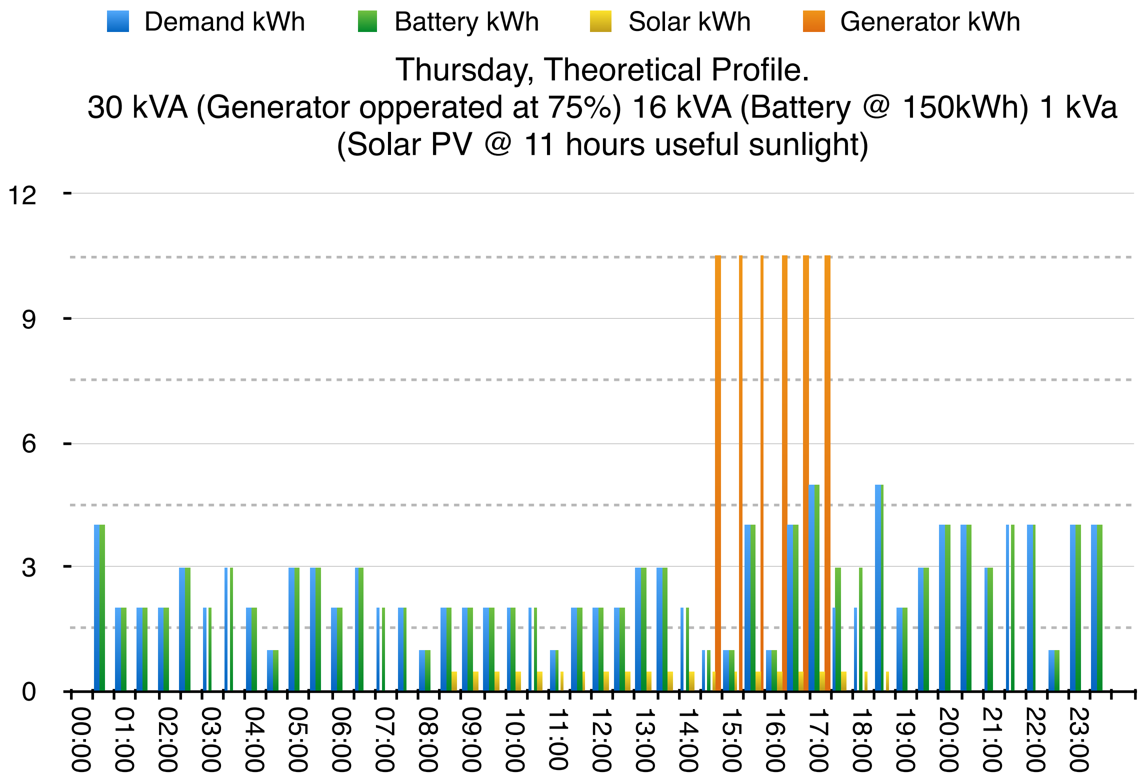
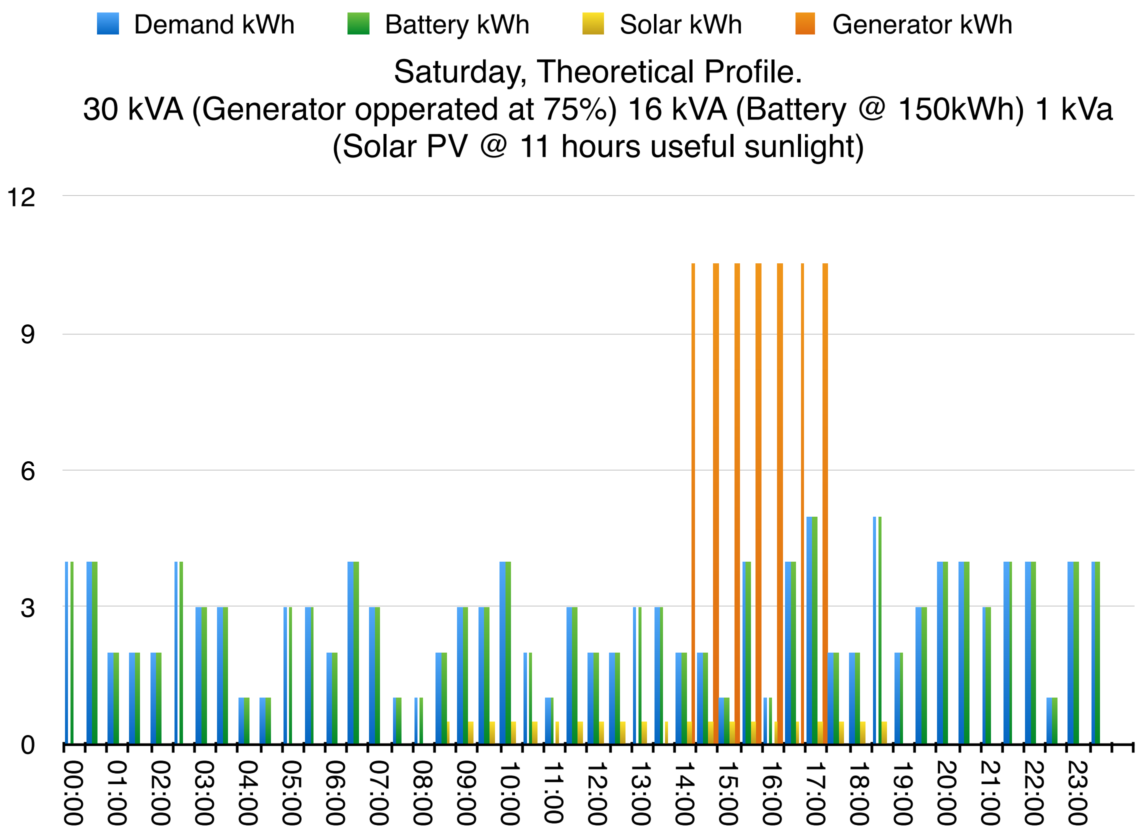
APPENDICES.

Appendices 1 (Theoretical Hybrid Demand Profile)





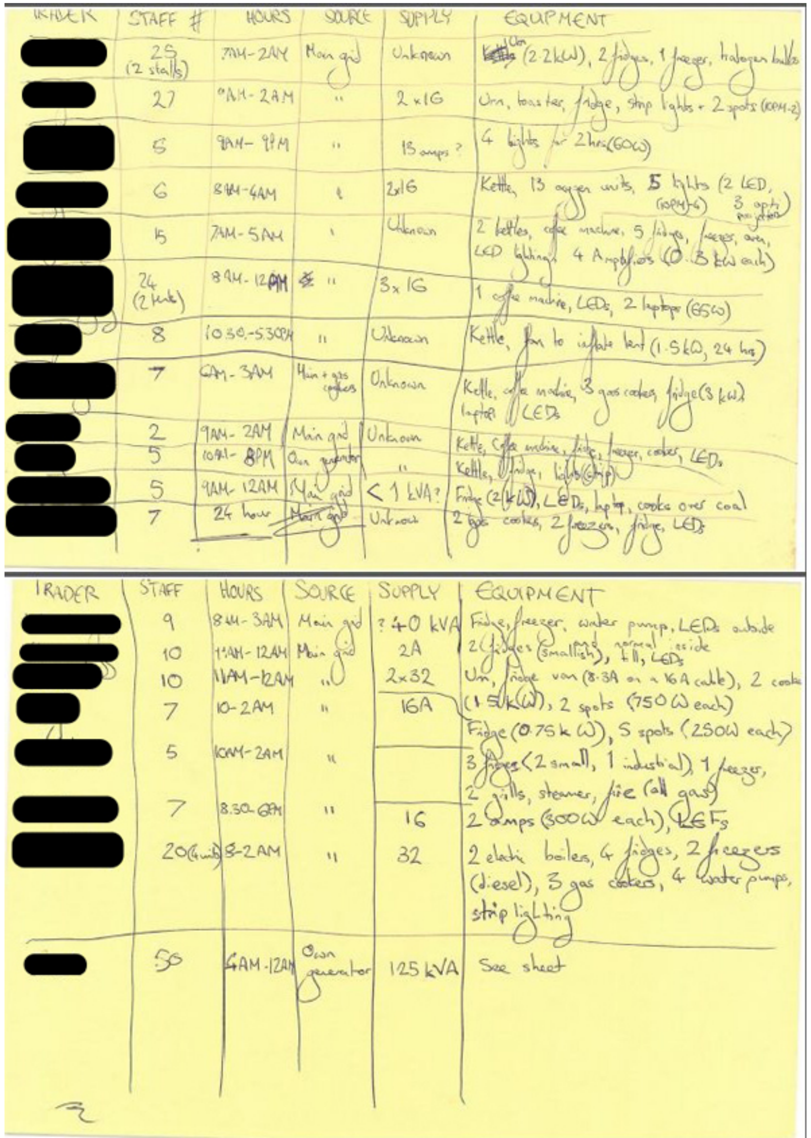
Appendices 2 (Blank Trader Survey)

Latitude 2015 Energy Survey For Traders.

1. Name of the Trader?
2. Location of the Trader?
3. Primary Function/Purpose?
4. Number of Staff?
5. Hours of Operation?
6. Power Source?
7. Power Supply Requirements?
8. Type of equipment deployed?

Electric equipment used	Type of equipment Gas or Electric	Number of Units	Power Rating (in Watts or kW)	Hours of use
Kettle(s)				
Coffee Machine(s)				
Toaster(s)				
Refrigerator(s)				
Freezer(s)				
Cooker(s)				
Water Heater(s)				
Water Pump(s)				
Climate Control(s)				
Lighting(s)				
Communication/ IT				
Other				
Comments				

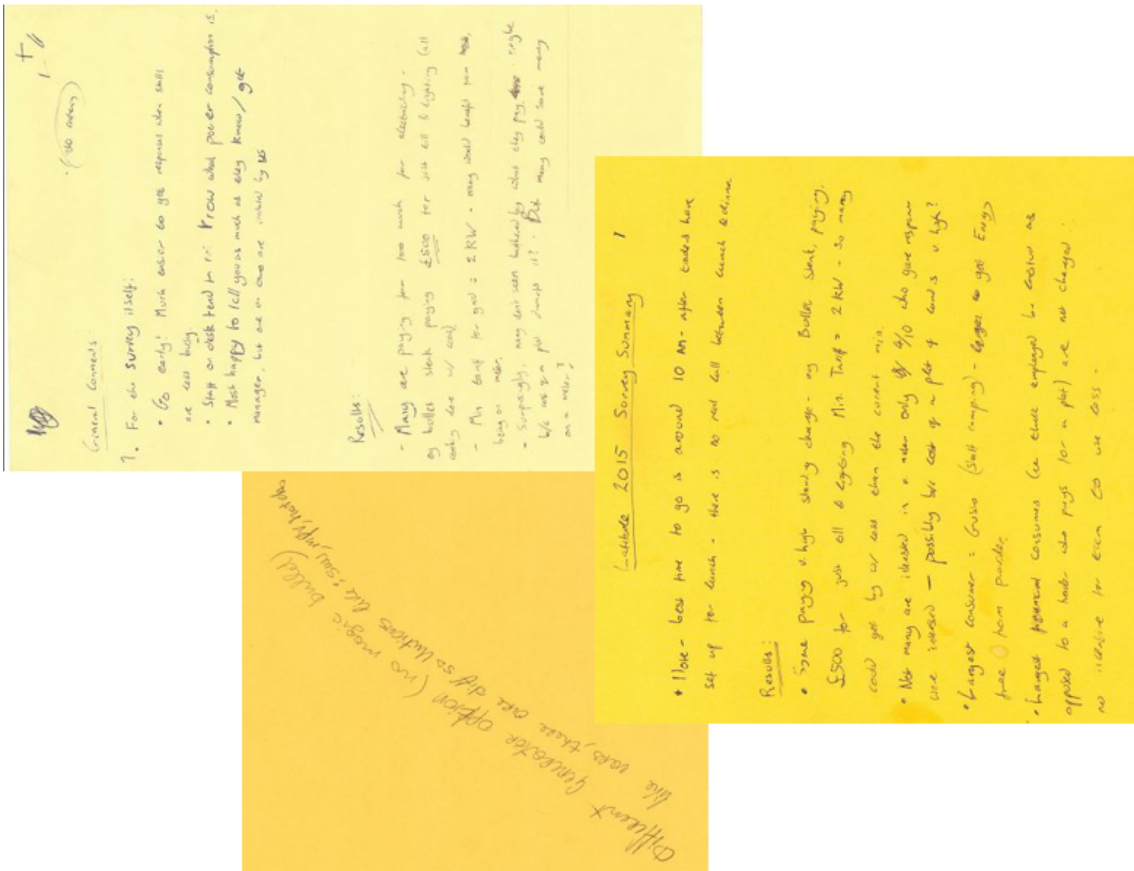
Appendices 3 (Trader Questioner Notes)



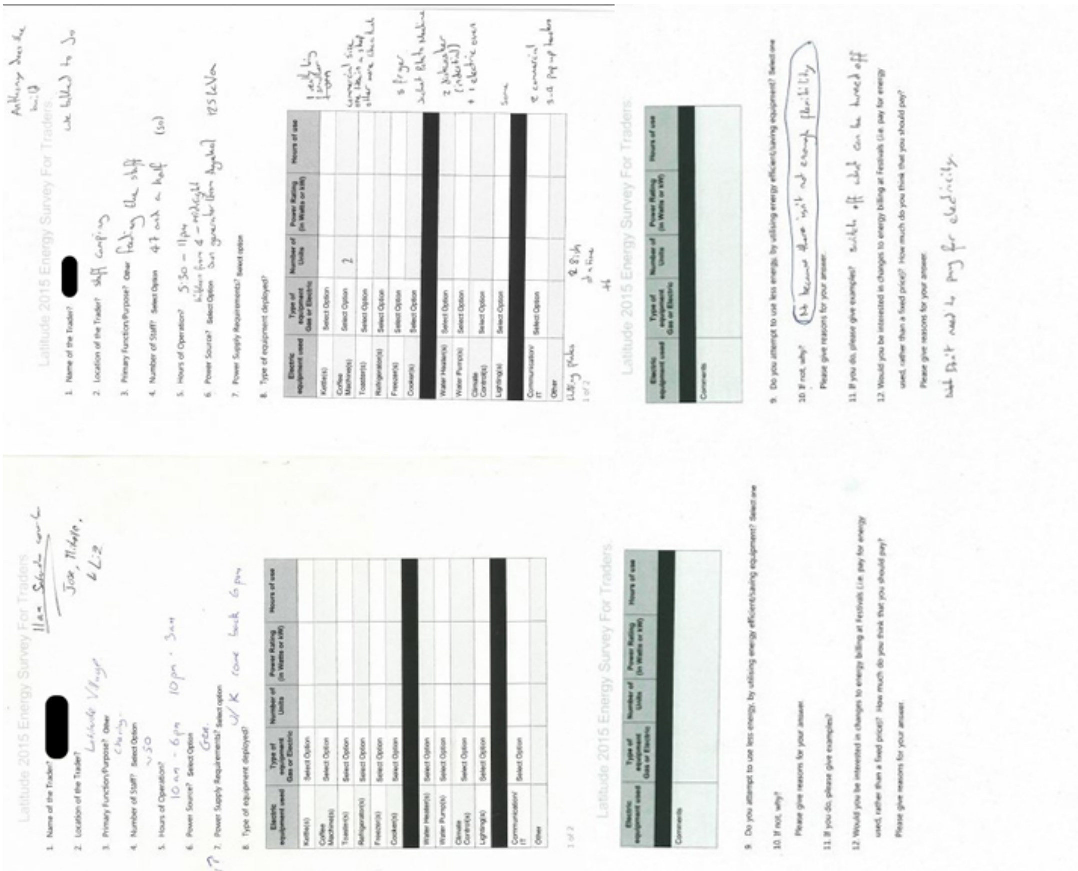
TRADER	STAFF #	HOURS	SOURCE	SUPPLY	EQUIPMENT
[redacted]	25 (2 stalls)	7AM-2AM	Main grid	Unknown	Urn (2.2kW), 2 fridges, 1 freezer, halogen bulbs
[redacted]	27	9AM-2AM	"	2 x 16	Urn, toaster, fridge, strip lights + 2 spots (10PM-2)
[redacted]	5	9AM-9PM	"	13 amps ?	4 lights for 2hrs (60W)
[redacted]	6	8AM-4AM	"	2x16	Kettle, 13 oxygen units, 5 lights (2 LED, (10PM)-6) 3 spots projectors)
[redacted]	15	7AM-5AM	"	Unknown	2 kettles, coffee machine, 5 fridges, freezer, oven, LED lighting, 4 Amplifiers (0.3 kW each)
[redacted]	24 (2 kiosks)	8AM-12AM	"	3 x 16	1 coffee machine, LEDs, 2 laptops (65W)
[redacted]	8	10.30-5.30PM	"	Unknown	Kettle, fan to inflate tent (1.5kW, 24 hrs)
[redacted]	7	6AM-3AM	Main + gas cookers	Unknown	Kettle, coffee machine, 3 gas cookers, fridge (3 kW), laptop, LEDs
[redacted]	2	9AM-2AM	Main grid	Unknown	Kettle, coffee machine, fridge, freezer, cooker, LEDs
[redacted]	5	10AM-8PM	Own generator	"	Kettle, fridge, lights (strip)
[redacted]	5	9AM-12AM	Main grid	< 1 kVA?	Fridge (2kW), LEDs, laptop, cooks over coal
[redacted]	7	24 hour	~~Main grid~~	Unknown	2 gas cookers, 2 freezers, fridge, LEDs

TRADER	STAFF	HOURS	SOURCE	SUPPLY	EQUIPMENT
[redacted]	9	8AM-3AM	Main grid	? 40 kVA	Fridge, freezer, water pump, LEDs outside
[redacted]	10	11AM-12AM	Main grid	2A	2 fridges (smallish and normal), till, LEDs inside
[redacted]	10	11AM-12AM	"	2x32	Urn, fridge van (8.3A on a 16A cable), 2 cookers (1.5kW), 2 spots (750W each)
[redacted]	7	10-2AM	"	16A	Fridge (0.75kW), 5 spots (250W each)
[redacted]	5	10AM-2AM	"		3 fridges (2 small, 1 industrial), 1 freezer, 2 grills, steamer, fire (all gas)
[redacted]	7	8.30-6PM	"	16	2 amps (300W each), LEDs
[redacted]	20 (4 units)	8-2AM	"	32	2 electric boilers, 4 fridges, 2 freezers (diesel), 3 gas cookers, 4 water pumps, strip lighting
[redacted]	50	6AM-12AM	Own generator	125 kVA	See sheet

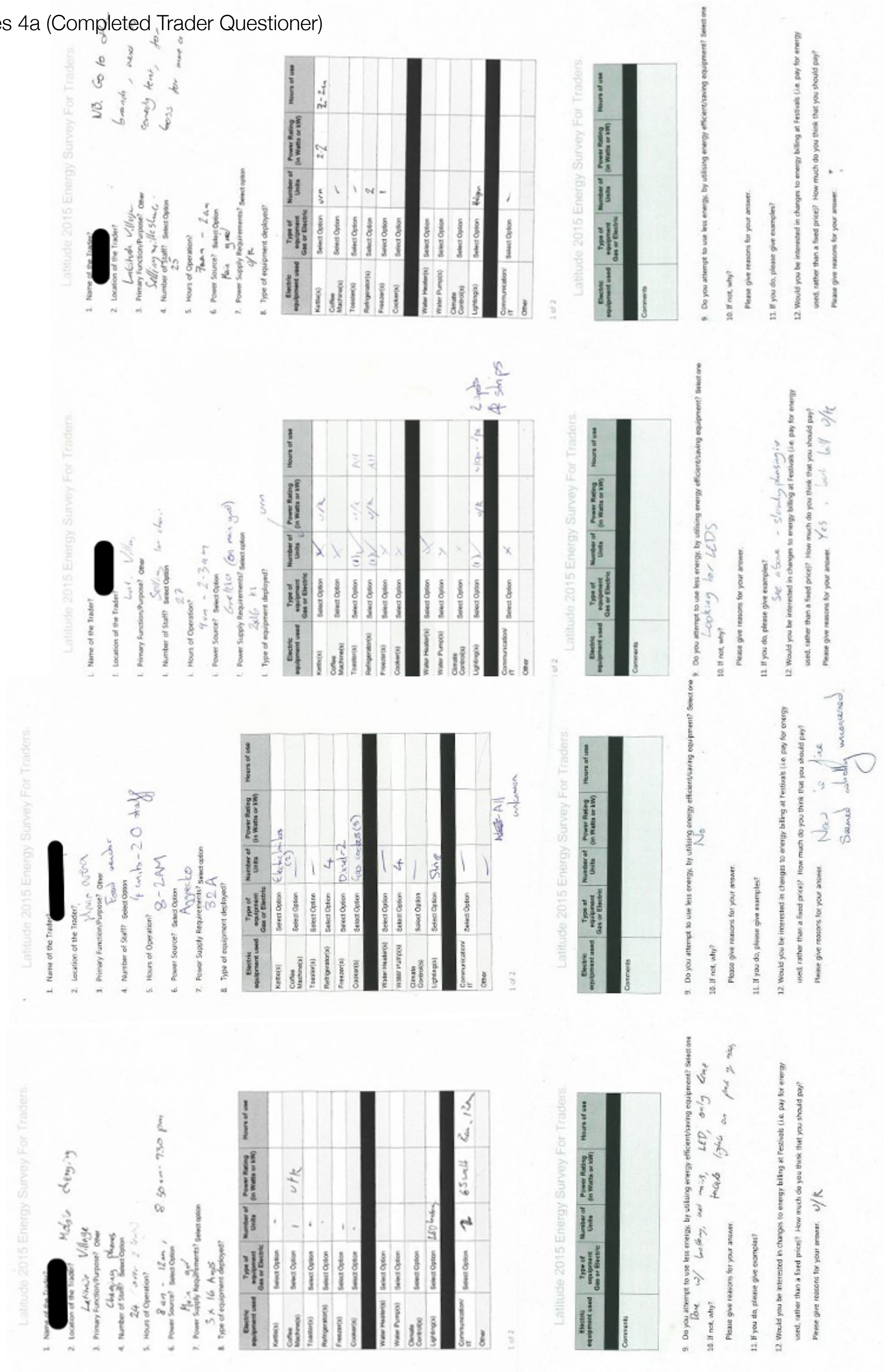
Appendices 3a (Trader Questioner Notes)



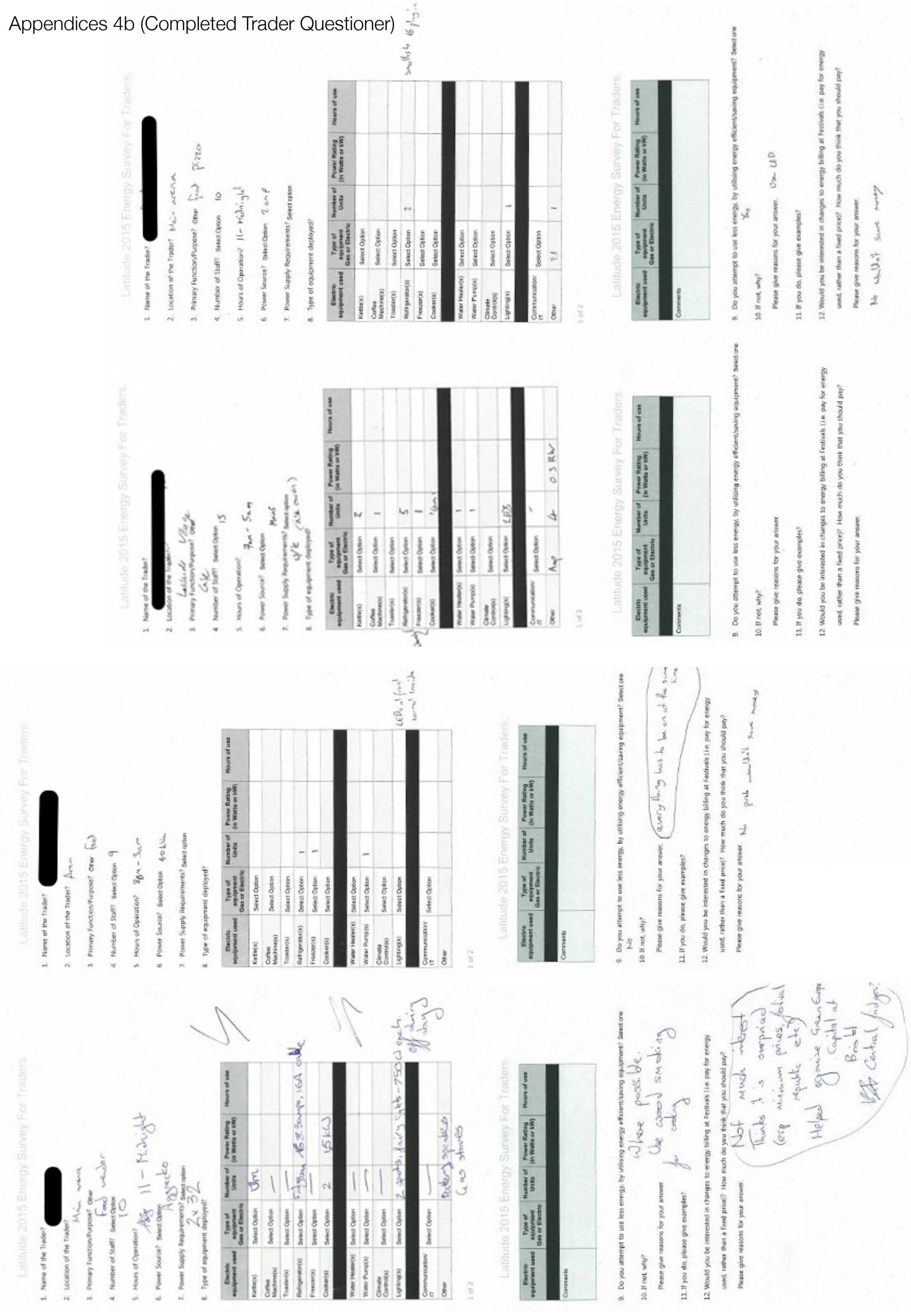
Appendices 4 (Completed Trader Questioner)



Appendices 4a (Completed Trader Questioner)



Appendices 4b (Completed Trader Questioner)



Latitude 2015 Energy Survey For Traders.

1. Name of the Trader? [redacted]
2. Location of the Trader? Main arena
3. Primary Function/Purpose? Other Food vendor
4. Number of Staff? Select Option 10
5. Hours of Operation? 11 – Midnight
6. Power Source? Select Option Aggreko
7. Power Supply Requirements? Select option 2 x 32
8. Type of equipment deployed?

Electric equipment used	Type of equipment Gas or Electric	Number of Units	Power Rating (in Watts or kW)	Hours of use
Kettle(s)	Select Option	Urn		
Coffee Machine(s)	Select Option	—		
Toaster(s)	Select Option	—		
Refrigerator(s)	Select Option	Fridge	16 3.5amps, 16A cable	
Freezer(s)	Select Option	—		
Cooker(s)	Select Option	2	15kW	
Water Heater(s)	Select Option	—		
Water Pump(s)	Select Option	—		
Climate Control(s)	Select Option	—		
Lighting(s)	Select Option	2 spots, fairy lights – 750W each, off during day		
Communication/IT	Select Option	—		
Other		Battery speakers, Gas stoves		

1 of 2

Electric equipment used	Type of equipment Gas or Electric	Number of Units	Power Rating (in Watts or kW)	Hours of use
Comments				

9. Do you attempt to use less energy, by utilising energy efficient/saving equipment? Select one Where possible.
10. If not, why? Please give reasons for your answer. Use wood smoking for cooking
11. If you do, please give examples?
12. Would you be interested in changes to energy billing at Festivals (i.e. pay for energy used, rather than a fixed price)? How much do you think that you should pay? Please give reasons for your answer. Not much interest. Thinks it is overpriced (esp minimum prices, festival republic etc). Helped organise Green Europe Capital at Bristol. Central fudge?

Latitude 2015 Energy Survey For Traders.

1. Name of the Trader? [redacted]
2. Location of the Trader? Arena
3. Primary Function/Purpose? Other Food
4. Number of Staff? Select Option 9
5. Hours of Operation? 8am – 3am
6. Power Source? Select Option 40kVA
7. Power Supply Requirements? Select option
8. Type of equipment deployed?

Electric equipment used	Type of equipment Gas or Electric	Number of Units	Power Rating (in Watts or kW)	Hours of use
Kettle(s)	Select Option			
Coffee Machine(s)	Select Option			
Toaster(s)	Select Option			
Refrigerator(s)	Select Option	1		
Freezer(s)	Select Option	1		
Cooker(s)	Select Option			
Water Heater(s)	Select Option			
Water Pump(s)	Select Option	1		
Climate Control(s)	Select Option			
Lighting(s)	Select Option			LEDs at front, normal inside
Communication/IT	Select Option			
Other				

1 of 2

Electric equipment used	Type of equipment Gas or Electric	Number of Units	Power Rating (in Watts or kW)	Hours of use
Comments				

9. Do you attempt to use less energy, by utilising energy efficient/saving equipment? Select one No
10. If not, why? Please give reasons for your answer. everything has to be on at the same time
11. If you do, please give examples?
12. Would you be interested in changes to energy billing at Festivals (i.e. pay for energy used, rather than a fixed price)? How much do you think that you should pay? Please give reasons for your answer. No prob wouldn't save money

Latitude 2015 Energy Survey For Traders.

1. Name of the Trader? [redacted]
2. Location of the Trader? Lakeside Village
3. Primary Function/Purpose? Other Cafe
4. Number of Staff? Select Option 15
5. Hours of Operation? 7am – 5am
6. Power Source? Select Option Mains
7. Power Supply Requirements? Select option 1/k (ask owner)
8. Type of equipment deployed?

Electric equipment used	Type of equipment Gas or Electric	Number of Units	Power Rating (in Watts or kW)	Hours of use
Kettle(s)	Select Option	2		
Coffee Machine(s)	Select Option	1		
Toaster(s)	Select Option			
Refrigerator(s)	Select Option	5		
Freezer(s)	Select Option	1		
Cooker(s)	Select Option	1 gas		
Water Heater(s)	Select Option	1		
Water Pump(s)	Select Option	1		
Climate Control(s)	Select Option			
Lighting(s)	Select Option	LEDs		
Communication/IT	Select Option	✓		
Other	Amp	4	0.3kW	

1 of 2

Electric equipment used	Type of equipment Gas or Electric	Number of Units	Power Rating (in Watts or kW)	Hours of use
Comments				

9. Do you attempt to use less energy, by utilising energy efficient/saving equipment? Select one
10. If not, why? Please give reasons for your answer.
11. If you do, please give examples?
12. Would you be interested in changes to energy billing at Festivals (i.e. pay for energy used, rather than a fixed price)? How much do you think that you should pay? Please give reasons for your answer.

Latitude 2015 Energy Survey For Traders.

1. Name of the Trader? [redacted]
2. Location of the Trader? Main arena
3. Primary Function/Purpose? Other Food Pizza
4. Number of Staff? Select Option 10
5. Hours of Operation? 11 – Midnight
6. Power Source? Select Option 2 amp
7. Power Supply Requirements? Select option
8. Type of equipment deployed?

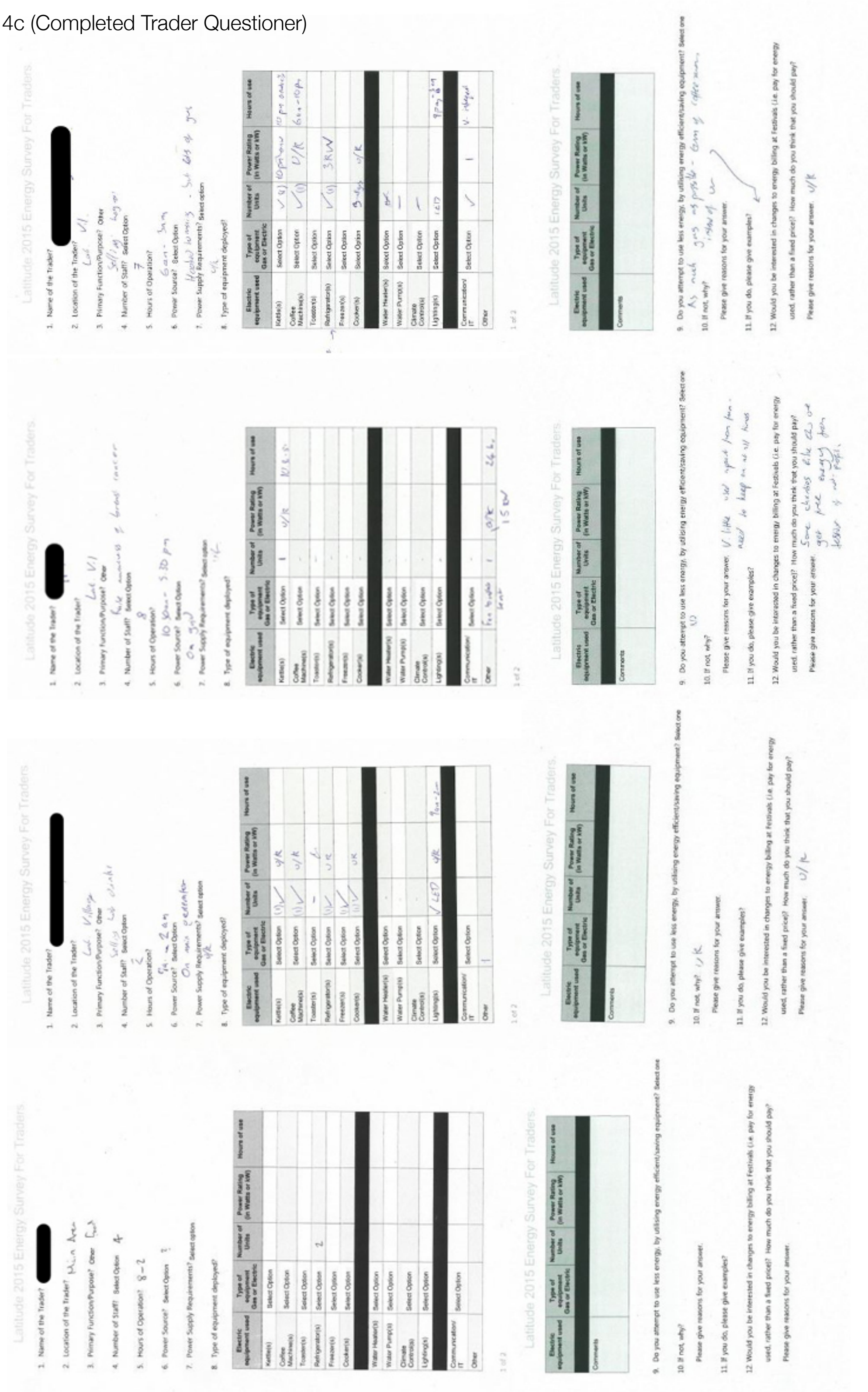
Electric equipment used	Type of equipment Gas or Electric	Number of Units	Power Rating (in Watts or kW)	Hours of use
Kettle(s)	Select Option			
Coffee Machine(s)	Select Option			
Toaster(s)	Select Option			
Refrigerator(s)	Select Option	2		small, 16 plugin
Freezer(s)	Select Option			
Cooker(s)	Select Option			
Water Heater(s)	Select Option			
Water Pump(s)	Select Option			
Climate Control(s)	Select Option			
Lighting(s)	Select Option	1		
Communication/IT	Select Option			
Other	Till	1		

1 of 2

Electric equipment used	Type of equipment Gas or Electric	Number of Units	Power Rating (in Watts or kW)	Hours of use
Comments				

9. Do you attempt to use less energy, by utilising energy efficient/saving equipment? Select one Yes
10. If not, why? Please give reasons for your answer. Use LED
11. If you do, please give examples?
12. Would you be interested in changes to energy billing at Festivals (i.e. pay for energy used, rather than a fixed price)? How much do you think that you should pay? Please give reasons for your answer. No wouldn't save money

Appendices 4c (Completed Trader Questioner)



Latitude 2015 Energy Survey For Traders

1. Name of the Trader? [redacted]
2. Location of the Trader? Main Area
3. Primary Function/Purpose? Other Food
4. Number of Staff? Select Option 4
5. Hours of Operation? 8 – 2
6. Power Source? Select Option ?
7. Power Supply Requirements? Select option
8. Type of equipment deployed?

Electric equipment used	Type of equipment Gas or Electric	Number of Units	Power Rating (in Watts or kW)	Hours of use
Kettle(s)	Select Option			
Coffee Machine(s)	Select Option			
Toaster(s)	Select Option			
Refrigerator(s)	Select Option	2		
Freezer(s)	Select Option			
Cooker(s)	Select Option			
Water Heater(s)	Select Option			
Water Pump(s)	Select Option			
Climate Control(s)	Select Option			
Lighting(s)	Select Option			
Communication/ IT	Select Option			
Other				

1 of 2

9. Do you attempt to use less energy, by utilising energy efficient/saving equipment? Select one
10. If not, why? Please give reasons for your answer.
11. If you do, please give examples?
12. Would you be interested in changes to energy billing at Festivals (i.e. pay for energy used, rather than a fixed price)? How much do you think that you should pay? Please give reasons for your answer.

Latitude 2015 Energy Survey For Traders

1. Name of the Trader? [redacted]
2. Location of the Trader? Lat. Village
3. Primary Function/Purpose? Other Selling hot drinks
4. Number of Staff? Select Option 2
5. Hours of Operation? 9am – 2am
6. Power Source? Select Option On main generator
7. Power Supply Requirements? Select option U/K
8. Type of equipment deployed?

Electric equipment used	Type of equipment Gas or Electric	Number of Units	Power Rating (in Watts or kW)	Hours of use
Kettle(s)	Select Option	(1) ✓	U/K	
Coffee Machine(s)	Select Option	(1) ✓	U/K	
Toaster(s)	Select Option	–	[illegible]	
Refrigerator(s)	Select Option	(1) ✓	UK	
Freezer(s)	Select Option	(1) ✓		
Cooker(s)	Select Option	(1) ✓	UK	
Water Heater(s)	Select Option			
Water Pump(s)	Select Option			
Climate Control(s)	Select Option			
Lighting(s)	Select Option	✓ LED	U/K	9am – 2am
Communication/ IT	Select Option			
Other	1			

1 of 2

9. Do you attempt to use less energy, by utilising energy efficient/saving equipment? Select one
10. If not, why? U/K Please give reasons for your answer.
11. If you do, please give examples?
12. Would you be interested in changes to energy billing at Festivals (i.e. pay for energy used, rather than a fixed price)? How much do you think that you should pay? Please give reasons for your answer. U/K

Latitude 2015 Energy Survey For Traders

1. Name of the Trader? [redacted]
2. Location of the Trader? Lat. V.I
3. Primary Function/Purpose? Other [illegible]
4. Number of Staff? Select Option 8
5. Hours of Operation? 10.30am – 5.30 pm
6. Power Source? Select Option On grid
7. Power Supply Requirements? Select option U/K
8. Type of equipment deployed?

Electric equipment used	Type of equipment Gas or Electric	Number of Units	Power Rating (in Watts or kW)	Hours of use
Kettle(s)	Select Option	1	U/K	[illegible]
Coffee Machine(s)	Select Option	–		
Toaster(s)	Select Option	–		
Refrigerator(s)	Select Option	–		
Freezer(s)	Select Option	–		
Cooker(s)	Select Option	–		
Water Heater(s)	Select Option	–		
Water Pump(s)	Select Option	–		
Climate Control(s)	Select Option	–		
Lighting(s)	Select Option	–		
Communication/ IT	Select Option	–		
Other	Fan to inflate tent	1	U/K 1.5 kW	24 h.

1 of 2

9. Do you attempt to use less energy, by utilising energy efficient/saving equipment? Select one U/K
10. If not, why? Please give reasons for your answer. V. little used apart from fan – need to keep on at all times
11. If you do, please give examples?
12. Would you be interested in changes to energy billing at Festivals (i.e. pay for energy used, rather than a fixed price)? How much do you think that you should pay? Please give reasons for your answer. Some charities like us get free energy from festival [illegible]

Latitude 2015 Energy Survey For Traders

1. Name of the Trader? [redacted]
2. Location of the Trader? Lat. V.I.
3. Primary Function/Purpose? Other Selling burgers
4. Number of Staff? Select Option 7
5. Hours of Operation? 6am – 3am
6. Power Source? Select Option Hooked [illegible] – but lots of gas
7. Power Supply Requirements? Select option U/K
8. Type of equipment deployed?

Electric equipment used	Type of equipment Gas or Electric	Number of Units	Power Rating (in Watts or kW)	Hours of use
Kettle(s)	Select Option	✓ (1)	[illegible]	[illegible]
Coffee Machine(s)	Select Option	✓ (1)	U/K	6am – 10pm
Toaster(s)	Select Option			
Refrigerator(s)	Select Option	✓ (1)	3KW	
Freezer(s)	Select Option			
Cooker(s)	Select Option	[illegible]	U/K	
Water Heater(s)	Select Option	[illegible]		
Water Pump(s)	Select Option	–		
Climate Control(s)	Select Option	–		
Lighting(s)	Select Option	LED		9pm – 3am
Communication/ IT	Select Option	✓	1	V. [illegible]
Other				

1 of 2

9. Do you attempt to use less energy, by utilising energy efficient/saving equipment? Select one As much gas as possible – [illegible] instead of [illegible]
10. If not, why? Please give reasons for your answer.
11. If you do, please give examples?
12. Would you be interested in changes to energy billing at Festivals (i.e. pay for energy used, rather than a fixed price)? How much do you think that you should pay? Please give reasons for your answer. U/K