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‘A framework for secure & sustainable electricity supply to economically developing regions with existing low renewables penetration; using the example of the Gaza Strip as a case study’

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Abstract

To truly achieve the global aim of carbon reductions and a sustainable energy system, the application of this effort needs to be truly global. This balance has been historically skewed, viewed both from the net causes of planetary warming originating in GHG emissions which are majority sourced from economically developed countries, and subsequently from the economic ability of economically developing countries to adapt and mitigate to these effects of climate change.

To achieve a more equal balance, the flow of climate finance and stimulation of the renewable energy industry in developing nations is required. Previous frameworks have been devised to help support this transition, yet these have both strengths and weaknesses. A main tenet of developing countries is their individuality, which a broad approach cannot account for well.

This paper aims to address issues with implementation of renewable electricity in developing countries, building upon the strengths of previous frameworks, and revising in favour of overcoming weaknesses. This includes the advocation for a country-specific approach to handle the various constraints faced, alongside a recognition of local participation in the process. In doing so, it is aimed to propose a considered approach towards addressing the application of renewable electricity in such areas where previous success has been weak, so as to ensure this is sustainable in the context of the entire power system.

To prove this, the framework was considered in light of the modelling of a real-world case study- the Gaza Strip- and in doing so the main principles were outlined and tested, whilst the integrity of the framework was assessed as a whole. Presented in this paper are various findings and recommendations of best practice associated with the integration of renewable electricity in developing nations, with proposals to overcome the various constraints commonly faced.

Copyright Declaration

This thesis is the result of the author’s original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed: **Jonathan Wrighton** Date: 22/08/19

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List of Abbreviations

EDC – Economically Developing Country

UNFCCC – United Nations Framework Convention on Climate Change

RES – Renewable energy system(s)/ sources

DEG – Distributed energy generator/generation

GCF – Green Climate Fund

RCGF- Refined Green Climate Fund

NIMBY – ‘Not in my back yard’

IPP – Independent Power Producer

PCBS- Palestinian Central Bureau of Statistics

A.D – Anaerobic Digestion

P.V – (Solar) photovoltaic

Introduction

The effort to limit anthropogenic greenhouse gas emissions (GHG’s) stemming from our historical and modern behaviour patterns, is in full swing. As a species we have realised that our previous energy systems are unsustainable in the long-term, and extinguishable planetary resources cannot be continued to be exploited without consequence. Therefore, in a rare case of international co-operation, multiple international accords have been drafted and implemented to curb global emissions across the spectrum of consumption- albeit to varying degrees of success.

Energy is the lifeblood which powers our lives and national economies, and its manifestations are well-known- from thermal power, through to the many functional uses of electricity. In an effort to decrease GHG’s, renewable energy devices which harness inextinguishable natural resources have been devised and their integration attempted into our energy distribution networks. In particular, renewable electricity is of highly significant importance, due to its mentioned high degree of functionality, and therefore, efforts to integrate this into electricity grids are pertinent.

International climate legislation, such as the UNFCCC 2015 Paris Agreement, has made a definitive leap in recent years to limit global temperature rise to within a certain limit, including that originating from the operation of the electricity sector. Such efforts include commitments for national transitions to sustainable energy, and also to enable climate finance to flow to those worst affected and least prepared to deal with this transition- typically, developing countries.

Developing countries typically share similar broad socio-economic attributes, but each country has its own specific issues. Various reasons exist for this increased difficulty to mitigate and adapt, and these cannot solely be overcome with financial measures alone. A framework must be created to focus on individual issues and maximise the success of integrating renewable electricity especially within such areas. Such a framework must be flexible enough to account for international variations and examine how each country of interest can best facilitate the global transition towards renewable electricity.

Research Aim & Objectives

This research paper will aim to formulate such a framework, in the process establishing the common constraints to integrating renewable electricity within the energy mix of economically developing countries (EDC's) and proposing possible and optimal solutions to overcome these. Energy and electricity are of as much importance to residents of these areas, as to those of developed countries, and having secure and reliable access will be crucial to future social and economic development, alongside meeting international climate change prevention targets.

The core aims of the framework therefore must be to help to address the problems of renewable electricity integration, so as to ensure as a power supply which is not only secure but also sustainable both in resource consumption, and also in long-term viability. Thus, relevant technical, social, financial, and other factors will need considered to ensure these aims are met. As mentioned, this framework should ideally be as flexible and transferrable as possible, so as to ensure it can be applied through-out the diverse needs' portfolio of the global EDC roster.

Finally, a key objective should be to ensure the most financially viable method to achieve this if found, so as to maximise the cost-effectiveness to both the country of interest and any relevant external bodies. Furthermore, where possible, social constraints should be overcome in a manner which is beneficial beyond what is required.

Research Methodology

To fulfil the aims of the research and to develop a framework, several steps need to be followed to ensure any output is as academically sound as achievable. This involves research into previous frameworks, identification of common constraints, proposals to overcome these, and then applying the framework to a real-world case study example to prove effectiveness. This would then require analysis of the overall effectiveness of the framework, and conclusions to include recommendations to be drawn for future research.

Literature Review: This stage allows for adequate analysis to be made of the energy systems in EDC’s and their common constraints, with key research areas being highlighted. This will form the backbone of the work the research proceeds on.

Development of the Framework: After analysis of the existing issues faced in developing countries, this section will expand on the literature review to identify existing frameworks and measures currently or historically used for tackling the issues previously mentioned. The various strengths of such frameworks will be identified and appraised, whilst the weaknesses also identified so as to formulate areas of inclusion in the new proposed framework.

This will also include the subsequent layout of the proposed framework, grown out of the findings of the previous existing framework analysis.

Application to a Case-Study: Within this section, the proposed framework will be developed further through application to a real-world case-study example EDC. This will be for the purpose of proving integrity, displaying how such a framework manifests itself in a physical world application, and also identifying any flaws or weaknesses inherent in its design.

This will almost certainly involve an aspect of energy modelling, due to the selection of a real-world country and thus the necessary examination of its energy systems both current and future, which the framework proposes to advance the spread of renewable electricity within.

Analysis/Discussion of the effectiveness of the Framework & Conclusions: This latter stage will therefore examine how concrete the frameworks proposals are in overcoming any identified constraints within the case-study example, and therefore how applicable it can be in the wider context of EDC’s. If any areas of further research or study are identified, these will be presented in this section.

CRITICAL LITERATURE REVIEW

Developing Countries- An Overview

Depending on the assessment criteria, there are numerous methods to classify a country/ state/nation as a developing one. By far the most prevalent method is through the lens of achieved economic development, and as an extension of this there are various tools used for justification purposes.

The World Bank analyses development progress against Gross National Income (GNI) per capita, typically stratifying countries' economies as such: low income *($995/$1035 or less, per capita*), lower-middle income *($996/$1036 - $3895/$4085 per capita*), upper-middle income *($3896/$4086 - $12,055/$12,615 per capita*), and high income *($12,056/$12,616 or more, per capita*) [World Bank, 2019 & UN.org, 2014].

It is observed that the borders of demarcation as either developed or developing can be indistinct, as United Nations World Economic Situation & Prospects data (UN WESP) also splits all the 195 countries of the world into three broad groupings: developed economies, economies in transition (EIT), and developing economies. Furthermore, the International Monetary Fund (IMF) categorises countries as either advanced, or emerging and developing economies.

It must be noted that classification as a developing nation is, albeit measurable via certain criteria, very subjective, and most international agencies/organisations solely assign this label for analysis purposes. This subjectivity is seen accordingly, as the low, and middle-income brackets suggested by the World Bank, broadly represent economically developing nations; the IMF underlines the emerging and developing economies as such too [Nielsen. L, 2011]; and EIT's can fall under more than one grouping yet are made mutually exclusive by WESP.

Although some mentioned economic factors exert influence over many other interconnected strands of a nation, other factors are of importance too in definition. For example, Owusu. M, [2001] communicates that the term 'third world' describes those countries with economies which are less industrialised, incompletely modernised and with a lower standard of living (than more developed countries).

Agricultural activities are still a mainstay of life and economic output in some developing nations, and inevitably “some least developed countries are at the very beginning of industrialisation” [Altenburg. T, 2011]. Average annual population growth rate, and other demographic aspects are all also vital indicators to account for when considering developing countries, and indicator tools such as the Human Development Index (HDI) assist with this [Wright. FD, 2016].

The afore-mentioned UN WESP report highlights the difference between fuel-exporting countries, and fuel-importing countries. The provided report definition of a fuel-exporting economy follows this stipulation for coal, oil and gas: “…the share of fuel exports in its total merchandise exports is greater than 20 per cent and the level of fuel exports is at least 20 per cent higher than that of the country’s fuel imports.” This is directly linked with the natural resources of any given country, with those blessed with an abundance of fossil fuels- and other valuable products- having an economic and developmental advantage over those where this is not the case.

Table 1 in the Appendix has been generated for the purposes of this report to display all of the nations of the world listed and classified in accordance with their assessed state of development, drawing upon different datasets and indicators provided by the UN, the World Bank and the IMF.

Common Issues facing Developing Countries

Due in part to some of the underlying foundational concerns outlined above, such as a lack of industrial development, agriculture composing a large share of economic activity, demographics, and minimal natural resources; there are a wider set of progressed issues facing developing countries.

With regard to some of the Least Developed Countries (LDC’s), (which the UN defines as constituting up to 49 nations in 2013) as a direct result of lower industrial development and a heavier reliance on agriculture, seasonal shocks to the agricultural cycle from unexpected weather patterns, especially due to climate change, can impact much heavier than in economically developed countries [Mendelsohn. R, Dinar. A, 1999].

This is especially prominent when considering that 86% of people living in poverty in developing countries practice agriculture as “their main source of livelihood”, according to the World Bank [Adenle. A.A, et al, 2012]. Prioritising “sustainable agriculture” therefore is vital to ensure poverty is dealt with, and there is sufficient food security, according to Adenle et al.

Climate change can again prove to be inhibitive on some developing nations, through the threat posed by mid-to-long-term sea-level changes. These are projected to impact a certain grouping of developing nations hardest; the Small Island Developing States (SIDS), of which there are 58 constituents [UN], leaving them vulnerable to loss of valuable land due to flooding and erosion [UNEP, 2014].

As briefly mentioned, demographic factors can play a key role in a nation’s resource consumption, and overall stability and prosperity. For example, there can be positive industrial growth symbiosis with certain demographic structures as mentioned by Haraguchi. N, et al, [2019], where the example is given of China growing its manufacturing base by utilising the large influx of young workers from rural to urban areas. However, there are also negative aspects to the demographic profiles typical of developing nations.

Birdsall. M & Griffin. C [1988], assess the apparent link between high birth rates/rapid population growth, and poverty. Although at a high level the connection between the two are assessed to be weak, there are some contributing factors for a high birth rate from more detailed analysis, namely a “low income, lack of education, and high infant mortality”. This is also true in the opposite direction, with a higher number of people per family unit/on a whole affecting financial resources and resource availability on both a local level and multiplied out across a national scale.

Having a national high population growth rate, through high birth rates and other contributing factors, can pose significant concern to a nation’s resources, and specifically its energy supply. This is true in particular with regard to emerging economies such as those found within South Asia and Latin America e.g. India & Brazil; as these have surging populations accompanied by high levels of economic growth, therefore mandating a demand for power.

Energy concerns for Developing Countries

By definition, economically developing countries have less free available capital to spend on, and lower investment in, the creation and maintenance of national infrastructure. The ability to generate and subsequently transport useful energy from a source location to that of the desired end-user, “underpins the rest of the economy” [World Economic Forum, 2012].

Energy, in useful formats such as electricity, petrochemicals/liquid fuels, or biomass, enables a society to conduct its everyday business with the rigid expectations’ modernity demands. However, often is the case that limiting factors stemming from the challenges experienced in developing regions, affects the ability either for the generation, or distribution of energy-aspects which infrastructure facilitates.

Several factors influence this- a notable one for example is in the high population growth rate often characteristic of developing countries, which can cause strain on energy resources and energy distribution systems e.g. an electrical distribution network such as a national grid. With an ever-increasing volume of end-users desiring to have their energy requirements fulfilled, providing for their needs can become a challenge for responsible national authorities, especially when connecting demand to supply through distribution networks.

Development, on a country scale, mandates progress over time again by definition, and therefore meeting demand is a major issue especially in emerging economies/growth regions. A World Economic Forum report suggests that the difference between developed (“mature market”) energy economies and fast-growing ones, is that economic growth spurs demand increases- “as more customers are connected to the grid, and per capita consumption grows” [World Economic Forum, 2016].

Electricity demand often outstrips supply, due to such rising demands and limited infrastructure capacity, and the generation capacity often cannot match this increased requirement [Naqvi. A, 2015]. As a result of this demand-supply mismatch and the constraints placed on the distribution system, power quality is often poor even for those connected, according to Naqvi.

Distribution of energy, e.g. electricity is often also hampered by the topology of a country, depending on the distribution model. When regarding a national grid model, with centralised power producing units, providing a grid connection to rural areas far away from the source can prove problematic due to the considerable distances involved and the type of adverse terrain which would need to be traversed by any prospective grid connection. Additionally, there are considerable transmission losses when transporting electricity over these large distances.

The variation on this problem can be fairly diverse depending on the specific geography of the country of interest. For example, a mountainous nation such as Nepal may struggle to establish a fresh inter-connector across substantial natural boundaries, whereas an island country such as Vanuatu could suffer from poor inter-island connection and rural isolation from any centralised power generating source.

Such distribution issues could be attributed to the lack of financial flexibility of a developing nation, depending on the level of investment in key energy infrastructure (such as rural grid connection) from the government. Therefore, this often leaves large swathes of a country without electricity access, most notably rural areas. In rural Africa, only 1 in 8 people have access to electricity, and in Ethiopia for example, only 10% of rural areas are electrified, leaving 70 million inhabitants without electricity [Barnes. D, et al, 2016].

This therefore has an adverse negative effect on the further socio-economic development of an area, and for example a specific region could become isolated in this sense from surrounding regions, advancing any existing gaps in inequality. Therefore, a government's primary energy policy concern often is to provide universal energy access across its jurisdiction. Taking the Indian example, to align the country with Sustainable Development Goals (SDG's), the national policy was to provide for total rural village electrification by 2012, and to provide a more stable supply to those already electrified [Kamalapur. G.D & Udaykumar. R.Y, 2011].

However, such targets were ambitious and were missed, instead being rescheduled forward to 2019 [Malakar. Y, 2018]. The scale of the Indian challenge was highlighted by the specific lettering of the policy and the process by which total rural electrification was to be achieved, with Malakar pointing out that "a village is considered electrified when at least 10% of its households have electricity connections, irrespective of the quality…". Additionally, there is a wealth divide underlying the quality of the connections and whether a household received supply at all, due in part to the Indian caste system and local corruption, whereby poorer households may not reap the same benefits from village connection as wealthier ones may do.

Such widespread electrification and provision of power to all, is nonetheless set against the backdrop of international cooperation on climate change action, such as the 2015 UNFCCC Paris Agreement, which mandates immediate measures to curb greenhouse gas emission levels to prevent long-term damaging global temperature rise. Whereas as stipulated in the Agreement- economically developed nations should take the lead role in total system transformation to a low-carbon future; developing nations too “should continue enhancing their mitigation efforts” alongside to achieve global reduction [UNFCCC].

Indeed, this dual approach is outlined best by Kaygusuz. K, [2012], who states that “making energy supply secure and curbing energy's contribution to climate change are often referred to as the two over-riding challenges faced by the energy sector on the road to a sustainable future”. However, as outlined above it is often the case that developing nations will favour universal energy access as top priority, rather than ensuring the majority fair share of energy contribution stems from renewable sources.

Yet, due to this often, heavy reliance on non-renewable sources to meet the demand which accompanies growing energy access requirements, Kaygusuz writes that “if governments do not implement policies” then “energy consumption will increase by 53%”, the “energy mix will remain...dominated by fossil fuels” and “CO2 emissions will increase by 55%”. This is in relation to efforts which need to be introduced in developing nations in regard to improvements in energy efficiency and demand reduction, alongside a more widespread shift to renewable energy technologies.

Such a shift is seen as crucial to aiding the attainment of the 2030 Sustainable Development Goals (SDG’s), which mandates climate action, affordable and *clean* energy for all; combining environmentally beneficial measures with socio-economic progress [Amin. A/ IRENA, 2019].

Renewable energy resources are wide and varied, with their scope including wind, solar, hydro, marine, geothermal and biomass. Location dependent, some of these resources are more available than others, yet an interesting observation can be made in the geographical distribution of developing countries around the globe (refer to *Table 1*- Appendix), as a large proportion are focused in equatorial, intra-tropical regions. Due to these tropical latitudes, it is often the case that there is an abundance of renewable resources available in the forms of solar energy and stored energy in biomass.

Despite this availability of energy resource, the penetration of renewable energy in the energy systems of developing nations is often poor, although this is not exclusive. There are a few exceptions, including e.g. the case of Brazil, which is blessed with a vast land area to grow energy crops, and varied natural resources such as a high hydro and solar potential; and Nicaragua, which has achieved a high level of penetration, yet has a low electrification rate. The reasoning for the often- low penetration rates elsewhere is largely varied, although mostly stem from political and/or social and/or economic and/or technical constraints.

One significant reason is that significant subsidies were/are still being awarded to conventional (non-renewable) energy technologies on an international scale, thereby creating a restrictive environment for non-conventional (renewable) technologies to operate [Hirschl. B, 2009]. Hirschl states that studies performed show that during the 1990's, global annual energy sector subsidies were 96% in favour of conventional energy technologies, thus leading to the strengthening dominance of fossil fuel energy systems globally during this period.

There is also an observed lack of global multilateral energy policy, unlike global climate policy developed through the likes of the UNFCCC; and this is attributed by Hirschl to the viewpoint that energy policy is demarcated under an individual country's sovereign decision-making. Alongside this, global oil price commonalities and strategies with the input of OPEC nations, has also led to waning interest in renewables in the past few decades before present, for example, when the oil price is low then interest in renewable energy typically historically falls.

Murombo. T [2016] expands on several of these economic, legal and policy-based barriers facing renewables expansion in developing countries, in contextual relation to the situation faced in South Africa. It is stated that conventional energy sources are often favoured over renewables in countries of abundant fossil fuel resources due to their subsequent low expense. This enables governments or responsible authorities to set pricing strategies for electricity with relatively low sales prices to consumers, which in turn aids in the socio-economic development of the nation as electrically connected end-users have lower living expenses.

The author indicates that this is the case in South Africa who chose to pursue such energy policies in the 1990's to encourage healing of the economic divide in existence after apartheid. The aimed transition to a low-carbon energy mix is therefore fraught with concern due to the possible ramifications it could have on socio-economic dimensions if not well controlled, a concern shared with other developing countries. The often significantly high financial cost outlays necessary to introduce and reform the electricity infrastructure is also off-putting to governments in developing countries who likely would rather focus available capital expenditure elsewhere.

Nicolli. F & Vona. F [2019] elaborate that centralised energy production and distribution is often prevalent in developing countries, with the presence of large-scale fossil fuel consuming power assets, and therefore the necessary capital needed to develop and integrate the decentralised energy generation of renewables being a cause for concern. This movement from traditional centralised to more decentralised generation, also brings the issue of energy market liberalisation into focus.

Energy liberalisation is an inherent economic market factor of renewable energy integration due to the introduction of distributed energy generators on decentralised levels, and thus the greater choice available for consumers. However, the transition from a more rigid market to a liberal one can be opposed by stakeholders in the previous system, who consequently often place political pressure against any significant change. Indeed, liberalisation can at first provide a barrier to renewables due to increased competitiveness with cheaper conventional forms of energy [Painuly. J; 2001].

Fossil fuels such as coal often also play a very significant role in the energy supply for the industrial sector, which is typically more advanced than other sectors in some developing countries. This is due to its regarded stability and security of fossil fuels as an energy resource, being freely available, often of low expense, and with the ability to cope with the capacity requirements of heavy industry. Industrial stakeholders can therefore be biased in favour of the status-quo and join other staunch supporters of a conventional energy based, centralised distribution system in applying political pressure against system reform.

The process of liberalisation and creating a market which is enthusiastic towards renewables typically requires government intervention or external/internal stimulation until such a point that renewable energy can price-match conventional energy in such places. Indeed Murombo. T outlines this issue by stating that “cost competitiveness is therefore one of the major obstacles to the transition to renewable sources of electricity”.

The primary capital costs are involved with the initial purchase and implementation of renewable electricity assets, both on individual application basis, and on a potential national infrastructure overhaul scale. However, after this initial expenditure the maintenance costs are aggregately typically on par with their predecessors, and running costs are most often inherently non-existent due to the availability of free natural resources.

Murombo writes that the necessary financial outlay for enabling further renewables penetration cannot be justified when examined against the existing legal-regulatory and economic indicators and frameworks, due to their existing and long-standing bias and partiality to the opposite degree. There would need to be reform in this area to encourage more non-conventional assets can be invested in. This reform would be primarily in the changing of regulatory measures to take account of the afore-mentioned large subsidies and other costs which are channelled into, and associated with, fossil fuels- highlighting that renewable energy does not yield such wild cost variations in comparison.

This could take place within the environment of liberalised energy markets, but with market authority oversight to ensure that fossil fuel and conventional energy generation is price-accounted for in its contribution to climate change. However, additionally there are typically weak financial institutions present in developing nations, which could present issues for handling any incentive or subsidy scheme for renewables (outside of the existing typical fossil fuel framework). Nevertheless, combined these constraints can present an uneasy investment environment for renewable energy/electricity to thrive within developing nations.

A World Bank/ EDF report [1993] highlights that caution should be exercised with regard to reform, especially when incentive-based, due to the chance of complications with complex systems and uncertainty over whether it will work in specific countries. The report stipulates that any reform should be “…tailored to specific country situations…” and advocated for “a taxonomy of country types based on either institutional framework or macroeconomic environment…”.

The general distrust of renewable energy over conventional energy is also a major social issue which often prevails in both developing and developed countries [Ghimire. L & Kim. Y; 2018]. A lack of public awareness of the potential benefits of renewable energy and belief in misinformation, accompanied by the high initial costs and probable lack of subsidy schemes are cited as the primary drivers behind this distrust and disinterest by the general public. Ghimire. L & Kim. Y write that an effective solution to this in EDC's would be to enable better knowledge dissemination and community acceptance through a local level approach.

A significant technical concern which has emerged over the past few decades as developed countries have looked to increase renewable electricity penetration levels in their energy mix, has been the integration of renewable, distributed energy generators (DEG's) into the energy system. This can become an issue with regard to the concept of grid inertia, with the introduction of certain renewable DEG's contributing to lower available inertia in this respect.

Grid inertia is a very useful and vital phenomenon of traditional large interconnected electricity systems, in which small-scale fluctuations stemming from attached generators and other faults, can be offset and smoothed by other attached generators which possess inherent mechanical inertia. For example, when tying in large turbine sets within conventional power stations to a national grid, the kinetic inertia of these spinning turbines allows for a degree of flexibility when supply/demand fluctuates, as the turbine will continue spinning and thus generating electricity.

This is due to the link between electrical and mechanical power which is typically the conventional source of electricity generation; as due to this relationship, there is the capacity to absorb changes in frequency via the kinetic energy of the rotating generator. Ulbig. A, et al, [2014] states that "rotational inertia…minimises Δ f in case of frequency deviations". Within an interconnected system, having such a setup allows for a greater response time grid-wide to react to system faults and thus increases the stability of the system by smoothing any variations.

In theory, there should be a low a Δ f as technically possible to safeguard components attached to the grid, hence modern power grids are designed to operate at 50 or 60 Hz +/- 0.5 Hz. Ulbig. A, et al posits that any larger deviations would lead to "damaging vibrations in synchronous machines, and load shedding"; all unconducive to a stable, modern power system.

To contextualise, a generating device with high mechanical inertia (such as a gas turbine), would continue to generate electricity for a period after the resource is not readily available. This is not the case with asynchronous devices with low or zero mechanical inertia, such as solar PV and inverter-connected wind turbines- as when the resource disappears, generation halts immediately or nearly immediately.

For example, on a moderately cloudy day the sun can become rapidly obscured, dropping generation output from a solar PV unit significantly. This sudden loss of generation can seriously affect grid frequency and stability if not controlled effectively. This immediacy of resource-generation reliance also however allows for immediate generation come the re-emergence of resource availability; e.g. solar PV can begin generation immediately after cloud cover passes, a quality which high inertia devices don't have, with these requiring a warm-up period before achieving full capacity. This can lead to large frequency fluctuations with *high ramp rates*.

De Marco. C, et al [2012] also highlights the common Doubly Fed Induction Generator (DFIG) wind turbine design, stating that the asynchronous nature of the design, although more efficient than synchronous at harnessing the wind; does not enable effective "coupling of rotational speed to system frequency", and thus the "inertial response…is very weak". This is true if not accounted for with power electronics, yet even this only works within a certain frequency "bandwidth" which is not in matching with that achieved by "true inertia".

It is precisely this quality which can affect grid stability, as when a high proportion of *low inertia*, renewable DEG's are connected to the grid, the risk of large-scale frequency deviations from the normal is increased. Gao and Preece [2017], also speak on this matter, referring to rate of change of frequency (ROCOF), and writing that "it is inversely proportional to the total system inertia". Therefore, with such rapid variations in generation output, and the reduced stabilisation effect of having fewer connected high inertia devices in operation, frequency could change so quickly that conventional frequency control systems would not be able to cope- potentially leading to cascading failures and ultimately blackouts.

This lack of grid inertia flexibility is a component of the reason in why most nations with transitioning energy systems have an upper saturation cap on renewables penetration in supply, albeit temporary. This is also framed alongside the more general issue of relying on inconsistent renewable resource generation and the necessary capacity upgrades to handle the influx of fresh supply (particularly pertinent in growing economies). This is therefore a major technical concern to consider with regard to the integration of renewable energy into the energy infrastructure of developing countries, due to both financial concerns of upgrading and the necessary technical complexities.

The technical solutions proposed to account for these issues are predominantly rooted in the influence energy storage can play in wide-spread renewables integration, yet also consider synthetic inertia or inertia-mimicking capabilities of renewable technologies, especially wind. Taking the latter solution first, both Ulbig. A et al, Gao & Preece, and De Marco. C et al, emphasise the potential for synthetic rotational inertia from renewable generating devices.

With asynchronous wind turbines this is achieved as mentioned above via the engineered implementation of power electronics schemes, which aim to mimic any lost or unavailable inertial effect. This is achieved, as quoted from De Marco. C et al, via "a control signal proportional to the rate of change of bus frequency… fed through the external control loop". This therefore has the responsibility for allowing extra power flow in the direction of, or from the network, aligning in response with any frequency changes, thus bypassing the indirect electro-mechanical connection.

However, as Gao & Preece indicate, should there be an increase in the number of wind turbines fitted with inertia mimicking controllers, and that if enlarging the importance of wind energy to the overall grid stability control (i.e. by increasing wind share in energy mix due to traditional reliance on grid for this purpose); then "there will be a trade-off between improvement of ROCOF and deterioration of frequency nadir". Essentially this means that if this approach were to be taken, then the system could be impacted by larger frequency deviation, yet this change would be more controllable on a time basis.

The author labels this as "counterintuitive", given the role in which synthetic inertia should have in smoothing any frequency variations. The given explanation is associated with the interplay between reliance on frequency support from turbines, and the rotational dynamics of the turbine. Should the period of frequency support be prolonged due to larger frequency deviations, then there will only be a finite length of time in which the spinning rotor can deliver extracted power from the wind, with this eventually reaching a point in which "the turbine will try to recover its rotor speed by extracting power from the system… as an additional load". It is this extra load which will result in lower frequency 'nadir', or deviation.

An additional proposal would be to combine such control systems with blade pitch angle control, enabling a higher proportion of energy extraction from the wind during the stabilisation/ synthetic inertial response. These measures are all relatively simple to implement into existing or future turbine designs, often already being sold integral to a unit; however, there are limitations imposed with regard to mechanical stresses imposed on blade pitch angle alterations, and bandwidth not replicating “true inertia”.

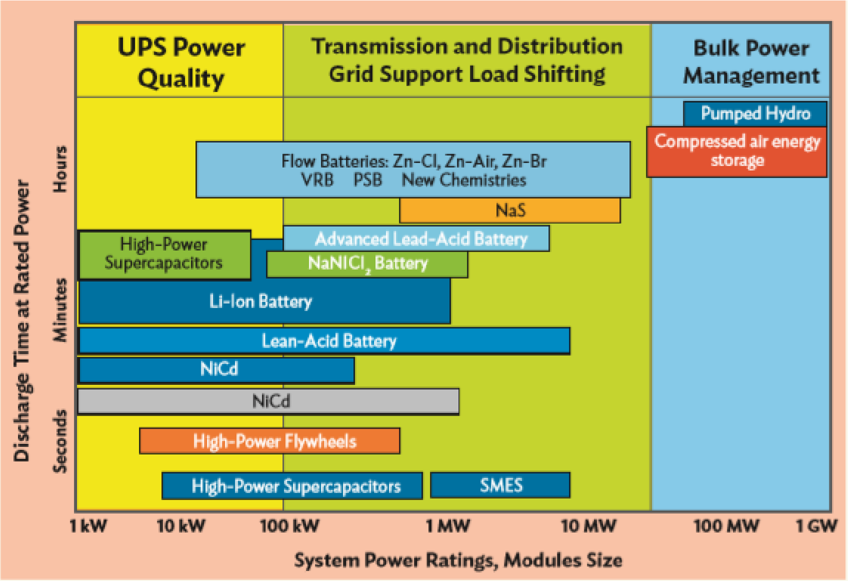
One of the most pressing issues is also that this method relies on the wind resource being available when required, which is not always the case due to the stochastic nature of most renewable energy. Therefore, even with a large proportion of DEG’s, separated in geographical diversity, then there will still not be *total* security of frequency support with this method.

More specialised energy storage systems such as grid-scale batteries and super capacitors could subsequently play an important, more application-specific role in frequency regulation. The implementation of energy storage technology has generally been spearheaded by more islanded grid networks, with these being the frontrunners primarily due to the greater sensitivity faced in these contexts to the variable output and challenges inherent to renewables integration. Therefore grid-level energy storage, with regard to wider interconnected energy networks, is a relative newcomer; yet will play a dominant role in the future of such systems, especially as costs fall [Jain. P/ Asian Development Bank (ADB), 2017].

Energy storage technology brings many benefits and is widely accepted in the energy industry to be symbiotic to the increasing prevalence of renewable energy. In an electrical context, by absorbing energy from renewable energy/electrical systems (RES) at moment of generation, storing this and then releasing the stored energy at a later time, this helps to address the success-critical issue of the stochastic nature of renewables, and the resultant inevitable demand-supply mismatch.

Indeed, the 2017 ADB report *above* highlights that the issue of energy storage was of high strategic importance to achieving the goals for Intended Nationally Determined Contributions set out in the Paris Agreement, although “the exact level of penetration of variable renewable energy which would require energy storage is grid-specific”; and the report also makes clear that “energy storage is the key enabler to a high level of renewable energy penetration”.

By integrating such storage, it is stated that the benefits awarded to frequency regulation in light of increasing renewables penetration, especially of low inertia RES, involve “frequency support, voltage support, ramping support, peak-shaving, load-shifting, transmission deferral”. There are different technology types associated with storage, with different specific specialities, and these electrical technologies approximately fit categorically into: mechanical (flywheels, pumped hydro etc.), chemical (hydrogen), electrochemical (batteries), electric field (supercapacitors), or thermal (molten salt).



NaNiCl=Sodium Nickel Chloride, NaS=Sodium Sulfide, NiCd=Nickel Cadmium, PSB=Polysulfide Bromide, SMES=superconducting magnetic energy storage, UPS=Uninterrupted Power Supply, VRB=Vanadium Redox Battery, Zn-Air=Zinc Air, ZnCl=Zinc Chloride.

Source: A. A. Akhil. 2015.

Figure 1- *Differing electrical storage technologies, compared against discharge time, power rating, and application; sourced from Jain. P/ Asian Development Bank report; 2017*

These technologies are listed against their various merits in Figure 1, and it is observable that in terms of grid manipulation and applications, firstly pumped hydro-electric schemes and compressed air energy storage (CAES) are suited for bulk power management, as these boast the largest discharge capacities and discharge times. Secondly, electrochemical batteries are best applied in practice of load shifting and peak shaving, being able to sustain this manipulation through discharge to the order of multi-minute periods or up to several hours.

To assist in very short-term power quality and frequency control functions, high powered flywheels, supercapacitors and SMES superconductors are the optimal solution. These are able to offer immediate output of stored energy within the sub-second range, a crucial ability for a grid seeking to stabilise grid frequency.

Due to the operational nature of energy storage devices, with the absorbance and release of power from/to the grid, there are attached financial aspects in terms of cost/unit electricity handled or purchased. This cost is commonly measured internationally in US$/MW, or US$/MWh but can be performed in local currency if desired. Additionally, to be considered is the concept of marginal cost of production, which determines which generating asset should be preferentially selected to meet the projected demand at a certain time reference during daily grid balancing. This is measured and decided using an indicator of fuel consumed/kWh electricity produced.

Due to this measurement, renewable plants which harness freely available natural resource such as solar PV arrays and wind farms, have zero marginal cost of production and hence are prioritised unless the grid is expected to suffer potential instability at that time. The common specific arrangement of power purchase agreement (PPA)- “take or pay”, requires the buyer of renewable electricity to pay for the energy both produced or neglected/curtailed. The latter eventuality occurs rather frequently with the logistics of supply-demand matching from renewables.

During times of low demand, the baseload conventional generators are too costly to divert from normal generation, and thus for example the electricity buyer e.g. the utility, pays for the producer of renewable energy to cut generation instead, but never receives any actual electricity supply for this cost burden. Therefore, energy storage could be viewed by the utility to have economically beneficial qualities, in such that the need for curtailment payments is reduced and any electricity produced by renewable assets can be effectively utilised, whether directly or through storage, dependant on the demand.

Storage can also be used to yield benefits in a very specific application to the grid infrastructures of developing countries. As will be discussed later on, the typical demand profile for such areas usually constitutes- during the day (e.g. 9-4.30pm)- lower industrial, and higher domestic loads, which amalgamates into a fairly low overall daily demand.

The ADB report indicates that if introducing a high level of renewable electricity into this system during this time period, maximising for example the solar resource available at midday through solar PV generation, then demand could be too low and halting PV generation is necessary. Being able to harness the difference between renewable supply and specific demand and store it for use at a later date when there is higher demand, means that the penetration of renewable electricity onto a grid can be progressed.

As stated earlier, it can often be the case that in developing countries some regions can become isolated from the main national grid, otherwise known typically as wide area synchronous grids. Rural regions are typically poorly served, or in general the quality of power delivered from said grid networks can be of a low quality. A lack of financial funds available for rural grid connection, especially given that such areas are often of low strategic priority, hampers energy access amongst inhabitants of these regions.

Additionally, as has been identified, any electrical connection to the grid can have pitfalls in terms of delivered power quality, as there needs to be *sufficient infrastructure* in place to handle the daily fluctuations in supply-demand, especially when considering renewable electricity. Although a large conventional interconnected network can more readily handle faults due to inertia and economics of scale, this same property of size and many interconnected components can more readily allow for the risk of potential faults on the network, which can cascade to other connected areas.

There have been several examples of the vulnerability of wide area synchronous grids negatively impacting connected customers, three relatively modern occasions of which will be examined here. The first concerns the 2003 North-East Blackout, which affected 55 million customers mostly in the United States and also the Canadian province of Ontario. The primary initiating event for this loss of electricity provision was attributed to ineffective control system monitoring for the shared grid, both automated and through human error. As a result, several faults which could have been avoided resulted in line overloading, and subsequent cascading failures which resulted in the entire region losing power [Pedersen. K; 2019].

The same principle of cascading power failures was observed in the European Blackout of 2006, in which according to Van der Vleuten. E & Lagendijk. V [2009], a routine line disconnection in Germany and the subsequent fallout, was the primary initiating event. There were schedule alterations to this planned disconnection, and miscommunication of such changes, which lead to numerous lines becoming overloaded after the disconnection, followed by the tripping and failure of these lines. This cascading failure spread across a large swath of continental Europe, also affecting parts of northern Africa via the Spain-Morocco interconnector.

The most recent major example occurred in June 2019, when a power outage affected several South American nations, including the majority of Argentina (Tierra del Fuego runs on a separate grid system), the entirety of Uruguay, and some areas of Paraguay. The resultant blackout affected approximately 50 million people in these countries and was attributed to the Argentine section of the power grid. Due to the relatively recent nature of the event, details are still forthcoming, but it is believed the initiator was the failure of a key interconnector to the large Yacyretá hydroelectric dam.

Unrelated to this event, Venezuela -a developing country- has also experienced electricity failures on its main area grid recently, due in part to the political situation in the nation but also due to its ageing transmission infrastructure and under-investment [Pietrosemoli. L & Rodríguez-Monroy. C; 2019]. Combined, these examples indicate that due to the interconnected nature of national electricity grids, with diverse geographical reaches and many interconnected loads and demands; the risk for cascading failure is high, despite the many advantages such systems can bring.

Thus, the concept of smaller distribution networks, including but not limited to microgrids, has emerged bringing alongside aspects of greater system resiliency. Hussein. A, et al [2019] states that “the use of microgrids for resiliency enhancement has gained popularity”. These smaller-scale networks “are capable of functioning autonomously as a small-scale electricity grid” [Hayes. B; 2017], integrating various DEG’s to sustain self-reliance in autonomous islanded mode, or in operation connected to the main national grid.

There are several variations of microgrid design: AC, DC, or hybrids of such [Patrao. I, et al; 2015]. The point of inter-connection to the main grid is termed ‘the point of common coupling’ and is essentially a component of this during connected operation and maintaining a similar voltage to the main grid distribution arm until disconnection. After this, the microgrid runs at relatively modest voltage grades supported by low voltage distributed generators, with Patrao. I et al suggesting a general range of sub-10 MW power capacity, however this is variable.

The benefits often associated with microgrids are that they allow for greater electricity access and reliance of supply, not being fully reliant on the national grid and the inherent higher risk of failure associated with these, especially if underdeveloped. Therefore, they have very specific appeal to areas/regions where electricity supply may not be afforded by an expensive connection to a wide area synchronous grid. This quality also considerably reduces transmission losses, as there isn’t the requirement for long-distance electricity transfer. Such systems allow for theoretical uninterrupted supply should the remainder of the grid network fail due to a fault and are thus self-sustaining and reliable.

Indeed, such examples are found in the likes of island electricity networks such as Qimei Island/ the Penghu chain, in the waters surrounding Taiwan, which has an isolated microgrid operating on a combination of diesel generators and solar PV plant [Hsu. C, et al; 2019]. Additionally, small-scale solar PV microgrids were studied and implemented in several populated villages in rural Malawi, utilising batteries as energy storage backup- a necessity for renewables-dominant, smaller-scale networks [Eales. A, et al; 2018 & Coley. W, et al; 2019].

Alongside microgrids, in light of the changing requirements of traditional grid networks, another evolution comes in the form of smart grids which utilise a wide array of smart system control to better manage resources. This can enable a greater uptake of renewable DEG's, with better management of the added constraints this can bring, altogether aiding to improve efficiency and reliability. This is achieved by making use of increased inter-asset communication, smart meters and controllable smart appliances, and through energy storage [Tsiatsis. V, et al; 2019 & Worighi. I, et al; 2019].

The International Energy Agency (IEA) defines smart grids as using "digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users". Another beneficial factor is present in being able "…to operate all parts of the system as efficiently as possible, minimising costs and environmental impacts while maximising system reliability, resilience and stability" [IEA, 2011].

Worighi. I, et al underlines the deficiencies of traditional grid structures to handle the influx of RES DEG's, and logically then highlights the ability of smart grids to manage operational aspects to greater avail. A key aspect of smart grid architecture is the ability for "bi-directional communication… and power exchange between suppliers and consumers". The author states that this is necessary to support the integration of RES into the energy mix, simultaneously balancing local loads and demands through communication, whilst regarding a system-wide level too.

The proposal to integrate a smaller, distributed generation network such as a microgrid, with the architecture of a smart grid, is also feasible with the aim being to combine the benefits of each to maximise the effectiveness of RES DEG integration at differing levels of scale. The applicability of microgrids in their nature of resilient, distributed generation could be best served in concordance with the inter-connected control scope of smart grid technology.

Smart meters and smart appliances are vital factors in demand side management control and are integrated under a smart grid's realm of influence. By gathering information on user consumption patterns and enabling customer-supplier communication, smart meters and appliances operating within a smart grid superstructure can play a role in demand response by analysing peak load periods and helping to load-shift to periods of lower demand [Gelazanskas. L & Gamage. K; 2014].

Operating in this fashion mandates that control over appliance usage patterns be delivered, either partially or wholly, to the electrical operating authority or more specifically, the control system underlying the smart grid. Gelazanskas. L & Gamage. K emphasis that this would aid in better demand side load control, leading to a more stable supply and lower risk of peak-demand faults, although coming at the potential expense of user comfort.

An added benefit of having "on-site generation" in terms of RES in this context of greater customer-supplier communication, is listed by the author to be greater supplier recognition of consumer self-generation and thus lower electrical bills and load burden on the wider grid. This decentralised generation reduces potential peak-time strain on generation/transmission infrastructure, yet also better allows for the sale of excess power to the supplier through interconnected smart networks during said peak periods. The different components of the connected system work in greater harmony when facilitated under a main, intelligent control system.

Various authors stipulate the benefits that smart grids can bring to the penetration of renewable electricity to a country's energy network, with one such author e.g. stating that the "Smart Grid will promote the integration of high volumes of Renewable Energy Sources (RES) into the grid, facilitating its management and coping with its unpredictable nature" [Ponce-Jara. M, et al; 2017]. However, the same author indicates that there are differing drivers between developed nations and developing ones in terms of smart grid implementation.

In developed nations such as the United States, and also most of those of the European Union, often the onus is on such places to lead the way in electricity infrastructure reform with regard to renewable energy roll-out and energy efficiency improvements, based on their high wealth and knowledge base and in line with climate change commitments. Therefore, to facilitate this it is a clear assumption to state that smart grids are viewed as being an integral part of the solution to the challenges faced to this effect.

In contrast, the author posits that developing nations often have differing priorities with regard to improvements to their electricity infrastructure and networks, a point reinforced earlier. Energy access is still a primary driver of investment concern in many such countries, alongside capacity upgrades and halting energy losses including due to power theft. The concept of smart grids had been first advocated for by “foreign energy lobbies”, primarily for economic reasons. There are significant cost burdens to be overcome however, and this is a major obstacle.

However, it is now being pushed by the governments of *some* developing nations e.g. India and Brazil, as part of future planned growth and development of their electricity sector, primarily to deal with a large influx of renewable electricity. The drive for advancement is country-specific, as each nation faces its own respective issues. The author notes that some developing countries are starting to consider smart meter integration into their energy systems, but developed nations have already planned and invested ahead on a holistic level for their implementation.

FRAMEWORK DEVELOPMENT

Existing Frameworks for RE Advancement in Developing Nations

It is true that there are technical barriers to renewables penetration in developing countries, which have grown over time sometimes hidden from view, with other energy related concerns often presenting themselves at the forefront of investment attention instead. There is nonetheless rising attention, mostly driven by international accords and pressure groups, towards the role renewable electricity can play in achieving lower emissions simultaneously with increasing development prosperity.

Achieving this goal requires an organised approach, accounting for the diverse struggles faced by EDC's. Previous attempts have been made to further quantify these struggles, to frame them within a contextual backdrop. Alongside technical constraints, these are often listed as political, social, environmental and economic in nature, and as such several proposals have been made to address these within the guise of frameworks designed to guide best practice in overcoming difficulties.

Some of these constraints are laid out and examined by El Fadel. M, et al [2013], who subsequently proposes a framework to address them. A primary constraint which encompasses all four identified barriers, is identified by the author as the lack of knowledge base in developing countries, and the subsequent inefficiencies in knowledge transfer from/between other more developed nations. They posit that amongst other factors, "…a lack of information sharing and awareness, a lack of regulatory frameworks…" (and) "…a restricted access to RE technologies…" are responsible for the poor penetration of renewables into developing countries.

The report states that there is "…a clear absence of an orderly method to access quality information". This can be traced to developed countries not making available discovered information, methods or research on RE integration and ensuring stable access to this, with the lack of information sharing leading to "…an incomplete realisation of RE penetration…in developing countries…". Another (political) side note to add here would be related to any sanctions imposed by developed nations on developing ones e.g. US-Cuba relations, which would hamper access to foreign technologies and knowledge.

What El Fadel. M, et al indicates is that in order to facilitate the phased implementation of renewables in developing countries, there needs to be good quality and sustained knowledge sharing of the potential issues which may be faced based on the practical experience of developed countries. This knowledge sharing can foster the growth of RES in EDC's, assisting in attempts to overcome the most common barriers, and creating a fertile environment for their progression to take root in.

This can be achieved on all scales including at global, regional and local levels, consisting of "…awareness raising, information sharing and exchange, capacity building efforts as well as technology transfer…" These collectively aim to achieve a fertile environment by targeting the various different areas viewed as necessary to promote growth- with the most direct action potentially being the transfer of technology.

Commonly observed with regard to existing small-scale international development energy projects, in which organisations (either private or charitable) help to introduce RES technology to a village or region (refer to previous Malawi example- page. 27); technology transfer is a crucial outcome benefit of wealth and knowledge sharing. However, either due to the often-charitable nature of such transfers, or the relatively insecure private investment environment of potentially targeted areas, it could be said that there is a relative inadequacy of such actions, reinforcing the mentioned lack of effective knowledge sharing.

Any technology transfer in this case therefore often ends up being older or low-end, delivered with conditions attached in terms of expected returns, or without any expected post-installation aftercare, i.e. a proverbial hit-and-run approach, leaving the new project owners to handle any maintenance or unexpected problems which may arise. This is also identified with regard to advisory services- another aspect of knowledge sharing- with any assisting contributions to renewables policy formation often neglecting to consider their combined effect on the comprehensive development environment of RES in the country of interest.

The author also notes that efforts in this area are usually directed towards economies in transition (EIT- refer to Appendix, *Table 1*). When applied to the wider roster of developing countries it is typically achieved in a non-effective manner, by not considering all of the other knowledge sharing components which are necessary for fruitful and long-term RE integration. Critically, a random approach to aiding renewable energy take-off in developing countries is ineffective, as it does not consider the specific individual needs of said places.

Instead it is often common to find the ad-hoc application of small-scale projects, which developed nations may consider to be beneficial, hoping to achieve a critical point of investment which flows over into widespread renewables adoption. This may deliver some local benefits, yet in terms of fostering further local or regional RES progression, such efforts by international donors or organisations often don't consider specific issues such as societal norms, local training and possibility of expansion.

This point is also emphasised in an ICEPT paper [2013], when considering the impact of renewable energy 'toolkits' in their application in developing countries. A toolkit essentially aims to parcel package all the relevant "technical, economic, social and financial dimensions" of renewable energy integration with an attempt to ease the transition and increase the available knowledge base in the area of application. Such mechanisms are advocated for by organisation such as the World Bank, IEA, UN and USAID in their expressed purpose.

Such package components include for example policy components such as tariff setting guidance, renewables targets and market access improvements. However, these toolkits can have several downfalls, namely in that they are set up in a manner which can potentially encourage "poor decision-making and analysis of information", and that they are "poor in overcoming social and cultural barriers to renewables".

It is stated that toolkits typically only address barriers at a high or theoretical perspective. By doing so they also lack the ability to address specific issues or react to specific circumstances faced in any given project and this results in a potential for such afore-mentioned poor decision making. Continued farther, the guidance offered may not be readily flexible to adapt. Additionally, the toolkits don't address some cultural-social issues well, especially in the context of a learning environment.

This is primarily attributed to the delivery of such systems, being predominantly IT based and therefore carrying a high risk of being one-sided and lacking bipartisan human interaction. This is linked with the issue of inflexibility with specific issues faced, as there is often little provision for questions to be raised to aid in both problem solving and the growth/ self-development of the end-user.

The problem is compounded by language barriers faced, as according to the report some toolkits are only released in English, although there are capabilities for Spanish and French versions; with language barriers often largely excluding local participation. Altogether it is concluded that *one-sided*, IT heavy toolkits are not wholly conducive to effective learning and skill acquisition and are not effective in overcoming some social constraints.

An insufficient knowledge base often exists in developing nations in regard to renewables integration, partly due to the underdevelopment of the industry hence pointing to the possible subsequent experience potential of its maturity. In addition, there is *likely not* to be a strong research and development environment in existence in general [UNESCO, 2010]. In order to support this maturity and development, specific focus should be applied to fostering local learning as a key tenet.

This is advocated through the framework suggested by El Fadel. M et al, who stipulates action taken on a short, medium and long-term basis. In the proposed framework, this is achieved through an increased co-operation between developing countries and knowledge/research organisations. In the short term up to 5 years from present, national resource potential studies are to be undertaken, alongside the development of an "integrated knowledge management system" to combine easy access to RE information under the one system, including at a local level.

On a longer term up to and further than 10 years from present, it is proposed by the author to further integrate efforts taken by different organisations, and to "establish a RE roadmap" to further promote cooperation between countries, bringing the right resources to those who need it to achieve long-term integration. Also proposed is the selection of "a leading entity" to help develop this framework, and to galvanise and guide efforts in international knowledge transfer to developing nations in pursuit of greater RE penetration.

This framework makes good strides to facilitating better implementation of renewables into developing countries. However, it is noted that the framework operates at a relatively high level and some observed missing details from this proposed framework include greater detail or expansion on how specific goals will be achieved to reflect a true multi-dimensional issue, including e.g. technical-specific solutions and considerations.

This multi-dimensionality of renewable energy planning is the key component of another reference framework- Multi-Criteria Decision Making (MCDM) systems, which are explained further in their role facilitating renewable energy development by Kumar. A, et al [2017]. Such systems reflect the altered nature of energy planning from "…a single objective simple system to a more complex system…", according to the author, and thus incorporating all of the afore-mentioned economic, political and technical constraints which are emblematic of renewables integration.

MCDM actually refers to a family of criteria analysis models grouped under the one titular function and derive their strength from enabling "…the decision maker to give attention to all the criteria available and make appropriate decisions as per the priority". Simply this allows all relevant criteria in decision analysis to be covered yet allows flexibility for priority to be allowed to certain areas or constraints, given any operational boundaries or overarching strategic priorities. In a renewables context this would present itself in an example such as the trade-off decision between environmental protection (e.g. wind turbine decommissioning/site restoration) and necessary financial cost outflow.

The three main model groupings are listed as "…Value measurement models, Goal, aspiration and reference level models and Outranking models", which each having their own specific advantages, disadvantages and specific areas of application. It is discovered that with the provided application of MCDM in energy systems, there is a heavier influence on specific technology applications rather than a balanced, holistic integration approach, however this advanced detail carries some applicable outcomes.

Value measurement models (VMM), are commonly used for assessment of energy technologies, e.g. listed as concerning energy storage. The Analytical hierarchic process (AHP) was considered to be the most effective of this model grouping and operates by assessing the desired outcome (such as success of a solar PV plant) against a hierarchical model, involving weighted criteria. This allows simplicity and the qualitative and quantitative analysis of criteria. The hierarchical structure allows for a greater focus on individual criteria and thus increases the adaptability of this model to suit certain situations.

Outranking models are commonly used in demand side management aspects of energy planning, especially the ELECTRE-III variant. This uses a combination of indexes which rank criteria in terms of relevance (concordance and discordance) with desired outcome. This model has been used in regional power systems planning [Abu Taha. R, & Daim. T, 2013], however is stated as being less versatile than for example the AHP method. Both methods have capability to assess different scenarios. Goal, aspiration and reference level models will not be explored here due to relatively little explanatory depth given in the context of this author's work.

Altogether the benefits of MCDM can be interpreted through their considerate stance on the multi-dimensional characteristics of renewable energy planning and the qualitative and quantitative, ordered approach taken to assessing constraints. Additionally, Kumar. A, et al points out that having different scenarios with several constraints is most likely to represent the "real-time solution" which is required in developing countries. However, a significant identified downfall lies in the subjectivity of the priority setting of constraints mentioned earlier.

By allowing decision-makers to set priorities of how important certain constraints are- although needed sometimes depending on the specific circumstance- this can open up the door to potential corruption and ethics issues, especially due to the often-higher corruption rates observed in developing countries [Owusu. E, et al; 2019]. Another aspect of MCDM which could be improved in terms of its applicability to renewables implementation, is its mentioned lack of presence at the local scale- a factor earlier identified to be of importance. If implemented, this could be beneficial due to the possibility of reverse hierarchical movement of best practice from local to wider geographical scale, and hence better knowledge transfer.

The Green Climate Fund (GCF) is a final element to be considered in terms of facilitating the double-pronged benefits developing countries can reap from reducing their climate change emissions and encouraging energy access, through the application of renewable energy technologies. In existence under the financial mechanism arm of the UNFCCC, and after being approved at the 2010 Cancun Climate Summit; the GCF framework provides "support to developing countries to limit or reduce their greenhouse gas emissions and to adapt to the effects of climate change" [Antimiani. A, et al; 2017].

It is applicable in this context due to the mechanism operating through the funnelling of financial resources from developed nations to aid existing or new "projects, programmes, policies and other activities" in developing nations in both aspects of mitigation and adaptation. This partially fulfils historical and conciliatory climate finance action obligations and attempts to influence global action against climate change through the allocation of enabling monetary resources. There is particular attention paid to the SIDS, LDC's and a majority of African States, which combined represents 50% of funding allocation, according to Antimiani. A, et al.

Crucially, the emphasis on working with local and national organisations, and the development of strength in institutional and regulatory frameworks in the country of interest, should be reinforced to be of importance to any successful intervention in developing countries. This is highlighted in an example proposed project funded under the GCF operating in Mali, West Africa to promote rural electrification through the application of solar PV microgrids [GCF Report, 2019].

In this proposed project, to meet the demands of some of the 62.5% of the Mali population who reside in rural areas, and therefore to raise the country's development prospects, a total of approximately 5 MW capacity is to be developed alongside sector strengthening. This reinforcing focuses on "putting in place an institutional framework…to strengthen its capacity" and to "positively contribute to the regulatory framework" in existence in an area of rural Mali.

The main noted weakness of the GCF as a facilitating tool, however, is that there needs to be more achieved with how to deal with individual countries' needs, especially with how to assign GCF funding resources based on these specific needs, to avoid conflict. This is borne out of the wide diversity of how to define a developing country, or one which requires financial aid to fulfil its responsibilities. The author writes that burden-sharing of climate responsibility can also sometimes be skewed, and countries can 'free-ride' on funding and/or diminished responsibility.

Therefore, to ensure equal burden-sharing and because the GCF is in part a compensatory climate finance mechanism, there should be a well-designed system to ensure that for each recipient nation, funding allocation and potential climate damage costs are considered concurrently. Other country-specific factors such as GDP and current emissions track records should be considered also, as these determine to what extent a nation has been previously willing or financially able to implement measures to reduce its GHG emissions.

For example, countries which suffer the greatest potential impact from climate change such as those with a high reliance on agriculture, should be prioritised for funding, although if such nations are also heavy polluters then funding should be more carefully considered. An additional country-specific need noted of importance and potential improvement, is the allocation subject of mitigation or adaptation measures. Again, this could be based on economic status, e.g. with those deemed more at risk receiving greater proportion of funding dedicated to mitigation measures, meanwhile EDC's with slightly greater financial flexibility could have increased adaptation measures funded.

Combined, the previous examples of the several framework type structures and organisational methods in existence are relatively concrete in their efforts to maximise the effectiveness of renewables penetration in developing countries. The identification of the need for an overseeing body/ leading entity as mentioned by El Fadel. M, et al is integral to any planned future development in this area, due to the amalgamated direction of efforts achieved through this. The studies overall concentrate efforts at both macro and micro scales of detail and overview, albeit this existing in separate frameworks.

A notable outcome is that knowledge-sharing requirements are highlighted to be of high importance. This is due to the heavy attribution which is identified and needs to be given to the future development of developing countries to be relatively self-sustaining in all aspects of their energy systems, with the progressive roll-out of renewable and sustainable energy projects at the centre of this effort.

This should be achieved as the previous frameworks indicate through the fostering of a fertile environment for RES with the application of different knowledge and equipment transfer measures, including the stimulation of institutional/regulatory sectors. Involvement should be high at the local level e.g. individual projects, villages etc. so as to maximise the alleviation of social barriers.

There is further space for improvement within the examined frameworks too, due to the several areas of identified weakness which could improve overall success if rectified and combined into a new approach. Such a refined framework has been identified as requiring a balanced oversight of constraints, with no extreme bias towards certain components- downfalls of the El Fadel. M et al and the Kumar. A et al MCDM frameworks, with the former being too high-level and lacking on technical on-the-ground detail, and the latter leaning heavily technocratic.

As afore mentioned, a local level approach should be adopted, with substantial involvement of communities and local stakeholders for the prime benefit of enhanced knowledge learning and capacity building. Additionally, within a new framework, there should be an emphasis on adaptability and recognition of individual national circumstances as key tenets, also advocated for by Thiam. D [2011]. This will help in creating an inclusive atmosphere in which developing countries can prosper according to their own specific situational needs on their path to further renewables penetration.

Physical attributes of a new Framework

Overview

The following core elements are proposed for the new framework, which will be expanded upon in the following section.

- *Step 1*: Identification of renewable energy resource potential in country of interest.
    - Availability, selection and use of resource databases.
- *Step 2*: Demand and technical analysis of renewables potential and integration (modelling).
- *Step 3*: Identification, analysis and overcoming of major overarching constraints facing roll-out at varying stages of community, town (and city) in specific country of interest:
    - Technical
    - Political
    - Regulatory
    - Socio-economic
- *Step 4*: Effectiveness/ general anticipated success of framework in country of interest.

Expanded physical attributes

Identification of renewable energy resource potential in country of interest

An initial stage in this proposed framework is the detailed scoping assessment of the renewable energy resource potential of the selected country of interest. In the context of economically developing countries there is the likelihood that such scoping studies have been previously performed, although this is not guaranteed, and neither are levels of detail on previous studies guaranteed to be at the desired level. Therefore, it is crucial that in this introductory stage of the framework seeking to analyse the most effective method to achieve better renewables penetration, that there is a solid understanding, evidence of and/or access to reliable resource potential statistics/data in the targeted area.

To maximise country specific and local involvement, this can be achieved first through the application of easily accessible preliminary resource assessment tools such as global resource atlases, situated online and produced in graphical format. The internet allows for significantly faster and smoother resource dissemination if present at this stage but is not guaranteed in every situation, therefore resource atlases should be kept and distributed in-print to ensure universal access to the data, and/or internet infrastructure development should be prioritised.

The World Bank has released easily accessible online tools for resource assessment as such in the form of the Global Solar Atlas & the Global Wind Atlas, alongside the development and support of various other country-specific resource atlases in small-scale hydro and biomass [World Bank/ESMAP reports, 2013 & 2016]. Additionally, NASA have made online access available for a global resource mapping tool, which has been utilised before for application in the literature [Ermolenko. B, et al; 2017], and IRENA have useful global resource mapping software.

These resources typically present a GIS-derived global atlas covering all of the nations of the world, often detailing intelligible colour gradients to represent resource availability and prevalence, with other indicative tools for resource assessment included too.

Preliminary resource assessment at this scale and in this format is often beneficial to both clarify future steps on the potential harnessing of renewable energy resources, and to drive interest amongst any potential investors, especially due to its ease of access. Indeed, reliable data is necessary for investment commitments and also theoretically guarantees efficient energy output. A subsequent stage after preliminary examination of the resource potential is the initiation of more detailed studies and analysis. This can be performed through a number of tested methods, and across a range of potential technologies.

Solar and wind energy are two of the most commonly harnessed resources and are respectively directly measured typically using tools such as pyrheliometers and anemometers, respectively indicating the direct beam solar irradiance (W/m^2) and wind speed (m/s). Other resources include marine, hydro, biomass and geothermal, with various energy indicators employed e.g. water head & biological % dry matter content. This aspect of data gathering is crucial at some point for any given location, however, can either be collected from pre-existing meteorological databases such as the aforementioned if available, or directly measured at the desired site.

Direct measurement is necessary either if concrete, location-specific datasets are not in existence, notably often the case in rural locations; or if the existing datasets are not detailed enough to support an investment decision on RES site application. In any case, when considering solar resource potential in the cases of direct measurement or analysis of existing datasets, then several factors are required to be examined.

Incident solar radiation on any given surface on Earth is composed of three components- direct, diffuse and reflected radiation, which cumulatively amass to the total solar flux on a given site (W/m^2). If no existing datasets are available on the solar flux at a given site, most notably with regards to direct normal irradiance (DNI/I_{DN}/direct beam), then this requires measurement using afore-mentioned specialist equipment such as pyrheliometers (which measures I_{DN}) or pyranometers (which measure either diffuse or total irradiation levels. Measurement should be conducted over a long period (in excess of 10 years) if possible, although this is not always likely with project time-constraints.

This is largely overcome however with the development of meteorological satellites in the last two decades, and the constant recording of data which these can achieve, crucially on a global scale including in rural, inaccessible regions [Journée. M, et al; 2012]. Therefore, if it is possible, then use of these datasets should be maximised, alongside any pre-existing datasets from surrounding on-ground meteorological stations, combined with the findings of the resource atlases. This is foreseen to make the design and appeal of solar power more accessible to a wider array of people with the absence of need for costly solar measurement equipment.

Once datasets have been secured over a modest amount of time for either incident solar variable, then these can be analysed to prepare the required associated solar resource data which is needed to calculate full potential. The following formulaic process for finding this associated data and the full potential is detailed as follows using a framework from the University of Minnesota [date unknown]:

Initially, the specific site location is required to be assessed in its position related to the sun, with latitude, solar declination angle, and hour angle as important variables. With the co-ordinates being known through map location, the solar declination angle (*d*- the angle between planetary equatorial plane, and the solar radiation from the centre of the sun) can be calculated using the formula: $d = 23.45 \sin [\frac{360}{365}(284 + n)]$ (n = day number of the year e.g. February 3rd = 34).

The hour angle *h* is another earth-sun angle and "expresses the time of day with respect to solar noon…at solar noon, the hour angle is zero", with this meaning that each hour of earth time is represented by 15^o of hour angle. To calculate the hour angle, solar time must be correlated to local time through the location-specific equation:

Local Solar Time (LST) = Clock. T + $\left(\frac{1}{15}\right)$ *(Long. S. Meridian – Long. site) + Eqn. T – DST*

With T = time; S. Meridian = local standard meridian; DST =daylight saving time.

The equation of time equals: $0.165\sin 2B - 0.126\cos B - 0.025\sin B$, & $B = \frac{360\,(n-81)}{364}$.

Therefore, hour angle $h = 15\,(LST - 12)^{o}$.

After this is derived, the solar incidence angle (θ), solar zenith angle (θ_H) and the azimuth value (ϕ) can be calculated at either horizontal or tilted surface orientations.

$\theta_H = \cos(l) \,.\, \cos(h) \,.\, \cos(d) + \sin(l) \,.\, \sin(d)$

$\cos\phi = \frac{1}{\cos\beta}\,(\cos(d).\ \sin(l).\ \cos(h) - \sin(d).\ \cos(l))$ & $\beta = 90 - \theta_H$

Surface tilt angle = Σ; surface azimuth angle = Ψ; $\gamma = (\phi - \Psi)$

If tilted: $\cos\theta = \cos(\beta) \,.\, \cos(\gamma) \,.\, \sin(\Sigma) + \sin(\beta) \,.\, \cos(\Sigma)$

If horizontal: $\cos\theta = \cos\theta_H$

From this, the various solar parameters can be calculated. Diffuse horizontal irradiation (Diff. H) can be calculated using the obtained I_{DN} datasets and using a dimensionless ratio given:

$I_{Diff.\,H} = C.\ I_{DN}$

Direct Solar at angle θ: $I_D = I_{DN} \cos\theta$

Direct Horizontal: $I_{DH} = I_{DN} \cos\theta_H = I_{DN} \sin\beta$

Reflected component: $I_R = \rho_g I_H (1-\cos\Sigma)/2$,

with ρ_g *= ground solar reflectance [using approximate figures from* ***Pisello. A; 2015]***

& $I_H =$ *total horizontal ground flux.*

Total instantaneous solar flux on a surface: $\boldsymbol{I = I_D + I_{Diff.\,H} + I_R}$

[Note: *Framework derived from University of Minnesota online educational resource, referenced above and in List of References*]

Concordantly, Izadyar. N, et al [2016] states that wind energy can be measured as such, using the kinetic energy equation and knowing the swept area of the turbine blades; for a single turbine:

$$P_{wind} = \tfrac{1}{2} \,.\, \rho \,.\, (swept)\ A \,.\, v^3$$

To obtain the wind speed (v), data is collected either directly from the erected anemometer mast at the site, or from wind speed/meteorological databases. Izadyar. N et al, and Ermolenko. B, et al, both recommend obtaining Weibull probability distributions for wind potentials, and the formula is as follows:

$$f(u) = \frac{K}{A} \,.\, \left(\frac{v}{A}\right)^{K-1} \,.\, e^{-\left(\frac{v}{A}\right)^{K}}$$

Where A is a scale parameter and K is a non-dimensional shape parameter (typical variation of 1-3).

Izadyar. N et al states that in order to ensure precise meteorological data, this should include "…monthly wind speed, period curves of available data, continuous wind speed with incidence above a particular wind speed, power ranges of wind speed, differences of data based on height, wind rose…". Having the most reliable data increases chances of successful energy yield.

There is a higher probability of underdeveloped wind measurement infrastructure in EDC target regions, such as dedicated long-term anemometers measuring the local wind speed over the substantial timeframe required to properly assess available wind resource (typically 3-10 + years). Due to the time constraints which are placed on many wind projects therefore it is often necessary to use extrapolation methods to assess and calculate the predicted available wind resource, and the most common method is the Measure-Correlate-Predict (MCP) methodology [Carta. J, et al; 2013].

The author here describes a 2-step process to MCP in estimating the wind resource of a specific site which has only short-term data, when there is access available to longer recorded data from nearby sites. Primarily a link is derived between the two sites, based on data series from the same time period (i.e. this will represent the short-term measurement period at the target site, and the equivalent time period from the nearby site), to assess the mathematical relationship which will be used for the second stage. Subsequently in this latter stage, "the long-term wind data series available for the reference stations are applied as input variables to the relationship established in stage 1…[to assess]…wind conditions at the target site".

The nature of forecasting or prediction is synonymous with uncertainty at whichever levels this may be present, hence uncertainty needs to be considered in this case due to the importance of prediction reliability. Carta. J et al states that to ensure uncertainty with the MCP method can be lowered, the overlapping period of both sites should be as long as possible, and the extensity of the reference site measurement records is also of high importance. Additionally, both the climate and the local terrain surrounding the measurement stations should be similar to ensure a greater certainty in predictions.

If direct or extensive measurements are necessary, they should be carried out by qualified individuals, which presents a potential problem for developing countries where the skills base in renewables engineering design and installation may be low due to lack of extensive experience. Therefore, there needs to be a process in place to account for this in order to infuse these skills into the local area, fostering a community led approach where possible. This will be reflected on later within the framework.

Biogas refers to the gaseous mixture produced upon the decomposition of organic matter under anaerobic conditions and is a valuable renewable energy resource. The biogas can be used in an electrical generation context by combustion within gas turbines to produce electricity; with fermentation typically occurring inside anaerobic digestion (A.D) tanks. With regard to developing nations in particular, with the often-large reserves of natural organic resources, and often favourable climate with warm temperatures, biogas has large potential for exploitation.

When analysing the resource potential of biogas, the following considerations are expected to take prominence. Namely, the availability of *area-specific* suitable organic matter is of importance, especially the presence of bio-wastes, such as cattle manure, or rotting food, as utilisation can help to reduce GHG’s and forms a closed loop system. Given the by-product of the A.D process can also be used as a bio-fertiliser, this aids landowners if cattle manure was previously used as an organic fertiliser instead of being diverted as an A.D feedstock.

Hamid. R & Blanchard. R [2018] appraise biogas resource feedstocks as consisting of cattle manure and/or crop residues, when considering its applicability to rural Kenya- an EDC. In truth, suitable organic matter can range from a variety of livestock manures, to food and foodstuff processing wastes (including brewery waste), crop residues, silage, organic municipal solid waste (OMSW) and human sewage flow, amongst others. The main physical parameters are carbon/nitrogen (C:N) ratios, level of volatile solids, pH and an availability of water supply [Gould. M; 2015].

Having the correct C:N ratio is essential for microorganism growth within the reactor, and the author states a ratio of 30 in favour of carbon to be the optimal ratio, whilst having too high or low levels will eventually result in reaction slowdown and cessation. A good mixture of input feedstocks is advocated for, to ensure the differing benefits each can bring are recognised. For example, fats and oils are beneficial for volatile solids formation, which in turn is good for methanogenesis, however solo reactor inoculation with fats and oils is not beneficial and requires mixing with other feedstocks to co-digest.

As anaerobic digestion and biogas production thrives in warm temperatures (approximately above 30^{o}C) and an abundance of organic feedstocks, conditions within EDC contexts can potentially be ideal, especially for reducing A.D operational energy costs. This is due to the afore-mentioned phenomenon in that most EDC's tend to be equatorial or tropical in location and, hence possessing a favourable climate negating the required artificial heat energy inputs. In addition to this, there is often increased access to organic matter such as agricultural residues and livestock manures due to the increased likelihood of proximity to the countryside and of rural living in EDC's.

Thi. N, et al [2015] report that often is the case that waste management is poor in developing countries, especially with organic wastes such as food. OMSW forms a significant fraction of the total MSW stream in EDC's and therefore, it can be proposed that to handle this, the development of A.D/composting could be a beneficial move to tackle growing waste stockpiles which contribute to GHG emissions upon uncontrolled decomposition. Sufficient water resources are also required for purposes of initiating and controlling the A.D process.

Therefore, the key factors to identify being present within EDC's for biogas resource potential include the previously mentioned physical feedstock parameters: pH, volatile solids content, C:N ratios and sufficient water supply; alongside having an abundance of organic feedstock resource in the formats outlined above. Further constraints and considerations shall be discussed later in the relevant section.

Demand and technical analysis of renewables potential and integration (modelling)

The next stage in the framework is the application of technical analysis through modelling of the demand and potential supply, to posit whether demand-supply matching is feasible through the implementation of RES to the site of interest within the EDC. This is achieved through the use of demand-supply matching software, in the context of moderately scaled electricity networks, using the gathered resource potential figures.

Software Tool Recommendations

There are various software tools available for purpose of microgrid modelling, and demand-supply matching, each with various benefits. The Homer Pro Microgrid Analysis Tool- a product of Homer Energy- is a widely recognised, industry leading tool for the optimisation of decentralised energy networks. It allows technical and economic analysis to be conducted simultaneously in the one convenient software package, allowing for sensitivity analysis of a wide range of input parameter scenarios, including analysis in regard to stand-alone systems, and also, in grid-tied modes [Deshmukh. M, Singh. A; 2019].

Merit- software available from the University of Strathclyde- is a demand-supply matching, quantitative evaluation tool for purposes of assessing the suitability of different combinations of renewable energy inputs to a building or community. This tool allows matching to be undertaken in reference to meeting demand over time with the best available capacity factor, whilst minimising energy storage requirements [ESRU summary document].

This framework advocates the use of Homer Pro software over Merit, due to its wider user base and experience, being a well-established analysis tool for the purposes desired in this project- to correctly match and design RES systems/networks to demands at largely decentralised scales. The primary purpose of modelling in this study and in the framework is to analyse the most effective approach to be taken with regard to the application of renewables at differing scales in EDC’s, in the process enabling constraints to be identified and overcome.

To enable software analysis to be performed, demand profiles are critical input material for the location of interest. Paramount to this is obtaining data regarding common loads and timing of these on a daily basis, and more broadly demand patterns on an annual basis. Such data can be obtained through either direct measurement, or through approximate prediction based on similar load profiles to the region and based on per capita energy usage at set economic brackets.

Yao. R & Steemers. K [2005] writes that a variety of physical and behavioural considerations which influence energy demand profiles within an individual property scale. The author determines that there are two primary considerations when predicting or analysing energy demand profiles: behavioural and physical determinants, i.e. those which are user-related, and those which are largely outside of user control. Behavioural determinants include occupancy patterns, energy usage attitudes, and frequency of appliance usage within a specific timeframe. Physical determinants include the technical specifications and design of building energy systems, including appliance energy ratings.

Reference can be made to local energy analysis surveys if these have been undertaken in the country of interest, which underline typical energy usage and occupancy patterns, attitudes, and also average estimates of the energy intensity of common appliances sold within such areas. If such variables are known, then according to the author, daily household *appliance* energy consumption can be found through the formula: $E_a = N \, x \, \Sigma A$, with N equalling number of household users, and A the appliance energy consumption per capita. This would be replicated for all electrical appliances within the household to obtain a total average figure.

The author also states that a combination of differing occupancy patterns and energy usage patterns should be aggregated to represent a typical load profile. Such occupancy profiles depend on the cultural context, such as having one inhabitant staying at home for most of the day, but typically consist of the following, with variation:

- Full-time employment for all inhabitants- hence non-occupancy period (9am-4/5pm).
- Part-time employment for all inhabitants- hence non-occupancy period (morning- 9am-1/2pm, or afternoon/evening- 1/2pm to 5pm or 5pm to 10pm).
- Retired/stay-at-home inhabitants- hence relative constant occupancy through a 24hr period.

Variation to this would be in terms of a combination of scenarios, with some individuals in full-time employment and some in part-time, resulting in a steadier household demand profile during the day. Also, in terms of natural variation of the populace regarding weekends, holidays and other affecting factors, this affects household energy consumption. In EDC’s, there will be variation with the specific country with regard to the extent of industrialisation (as indicated earlier some EDC’s are only at the start of this process), and thus the split of industrial/domestic loads during the day.

With higher industrial loads, these should be reflected by more notable scheduled peaks (up to 250 MW e.g.) but are more associated with towns and cities than villages. With domestic loads, load is often expected to be steady through-out the day after morning, and then peak around evening. Either way, whether through direct measurement of the end-user in the country of interest, or through prediction through average national consumption figures, usage and occupancy patterns; demand profiles need to be obtained for purposes of software analysis.

Homer Pro software allows for self-generated or auto-generated synthetic load for demand profiles, the latter of which can generate different demand profiles for residential, commercial, industrial or community scales. These can be easily adjusted and scaled for manipulation to suit individual site requirements. After this data has been integrated, modelling is performed to assess which is the optimal combination for an electrical supply to meet this demand, using a heterogenous mix of RES options and with options of storage. This allows the user to select the optimal RES design for the specific location of interest.

Identification and analysis of major overarching constraints facing roll-out at varying stages of community, town and city in specific country of interest

The next stage in the proposed framework concerns the identification of the major constraints which may restrain the advance of renewable electricity within the country of interest. These will vary according to the target location both on an international scale, and an intranational level but will typically exist in the form of technical, political, regulatory or socio-economic contexts. They will very much be informed by the previous stage, with various constraints highlighted through modelling, however generic identified constraints will be outlined here.

There is an identified need to address individual national concerns and situations- developed out of the criticism of the GCF in its flexibility and transferability- thus this mandates the identification of such constraints specific to the country of interest. On an intranational level there is a requirement for constraints analysis due to the heterogeneity of renewables application, for example at village/community, town or city integration scales.

This heterogeneity yields different population magnitudes and energy demand profiles which necessitate the analysis of constraints at these respective sub-component levels of the national scale. From a technical constraint perspective, it is necessary to take account of the projected demand on each scale, for the purposes of supply-demand matching and ensuring there is sufficient supply to meet this. There are also social and economic factors at play at different scales.

For example, from a social perspective: the potentially differing project exposure levels to inhabitants of rural or urban areas, and thus the subsequent appetite for social acceptance of renewables schemes is of importance. Wang. Z, et al [2011] & Liu. W, et al [2013] independently assess this divide in relation to China, with Liu. W, et al observing that in the *specific case study* there was an increased acceptance of renewables in rural areas. Conversely, Wang. Z, et al finds that in the case of a city such as Beijing, there is little social enthusiasm for the same. On an economic basis, there are advantages from economies of scale when applied to renewables development, especially in off-grid contexts [Boait & Gammon; 2015].

The applicability of renewables integration to any scale with the various constraints present, is identified as requiring oversight from a leading entity such as that advocated for by El Fadel. M et al. Such a body would perform the function of directing efforts to manage and overcome constraints, and also acting as a receptacle and funnel for knowledge sharing and dissemination.

The entity which displays the most promise in terms of selection, is the GCF through its ability to co-ordinate with both public and private capital and its backing by the UNFCCC. This would be manifested in a refined version, facilitating the changes recommended above to recognise country-specific needs. This refined GCF will be discussed later in the paper.

This framework proposes that all constraints and barriers applicable within a country of interest and at each scale level be examined, so that these may be identified and assessed in their role to preventing effective renewables penetration and with the aim to overcoming these. The integration scales of village/community and town-scale will be used in this framework to represent the differing sizes of potential development in a grassroots approach.

However, city-scale application will not be considered in this framework, due to time constraints. This is attributed to the sheer size of cities and the advanced amount of time integration would take to assess, their relative low frequency in relation to other sizes of settlement, and also due to the fact that it is forecast ahead of time that city-scale integration will not be an easy task. Therefore, village and town scales of application will be assessed instead, with brief implications for potential city-scale integration described later on.

Village/community scale:

Within this context, it is worth noting that most small-scale settlements such as a village are often found in rural environs, and hence face a breadth of energy issues relating to access, quality and stability reflective of this. Various authors who have examined the application of renewable electricity in various formats to village scale developments in the developing world, typically report jurisdiction household numbers within a maximum average range of approx. 30-170 households [Zahnd & Kimber, 2009; Ulsrud. C et al, 2018; Shrestha. A et al, 2019].

It is observed that in large swathes of Africa, the Middle East, and other regions with higher numbers of EDC's that the average household size is notably larger than in the likes of North America, Western Europe and other developed regions/nations [UN Population Division report, 2017]. This means that there may be a larger total community inhabitant count by number of households within villages in EDC's, compared to a similarly sized village in developed nations. According to the UN report, despite total gross energy consumption being higher for larger households over smaller ones, the total energy consumption per capita is inversely proportional to household size- hence is lower for larger households.

When considering a renewable electricity supply to a village context of this scale, within the framework it is crucial to understand approximate common demands and timing of demand so as to ensure demand-supply matching is effective. It is also wise to understand that due to the lower demand than urban areas, and the often-rural location of villages, grid connection is not always guaranteed. Sen. R & Bhattacharyya. S [2014] find that rural village energy use is significantly lower than found in an urban environment, although this is not always true.

Due to the heterogeneity of countries to which this framework can be applied to, and with the wide-ranging demand profiles which can be found within such a diverse range of locations, it is important to craft the framework to be as flexible as possible to account for this. This can be achieved by maintaining open input parameters for constraints analysis. Therefore, the following demand loads and timing are just a flexible estimation of the most common applications of load at this scale.

According to Sen. R & Bhattacharyya. S, domestic electricity use is usually applied in areas of lighting, fans (table & ceiling) and for entertainment purposes such as radio or TV access. This is replicated on a community level and often with the addition of community assets such as schools, health clinics and communal halls, which will typically have a slightly higher load demand and with the addition of heavier equipment in a medical setting. In addition to this there are any industrial loads which must be accounted for, with this typically constituting agricultural activities including but not limited to irrigation and communal water pumping, and also considering wider industry such as local processing and cold storage.

As such when considering demand timing, the highest load is expected to be during the daytime, when residents are most likely to be active and industrial activities are expecting supply to be met. An evening peak is expected for lighting, cooking related activities and entertainment, set alongside any constant demand loads which may require supply 24/7 e.g. health clinics or cold storage facilities.

When analysing the village, this framework advocates that such demand profiles should be created to detail the nature of the primary loads, their power requirement (W), how many hours per day they are expected to be used, and any seasonal variations in usage which may affect design. In doing so, this will enable effective supply-demand matching when designing any renewable electricity supply to the village.

Aspects of existing grid connection must also be considered, as a target village can fall under two categories: off-grid, with any existing supply met by diesel generators/ similar; or also grid-connected, but with unreliable quality and availability of electricity e.g. suffering long, inconvenient periods of blackout. Microgrids with RES supply inputs and storage functions have potential applications in these scenarios, as they can provide reliable, non-grid reliant power which can either provide green energy access or upgrade the quality of existing supply.

Energy storage is crucial to off-grid microgrid operation, as the grid-inertia function and general back-up supply role which the national grid often enacts in an electrical supply network, will no longer be available to be relied upon. With minimal grid inertia, the application of a heavy reliance on RES DEG’s as the supply inputs to a local electricity network, could prove a technical constraint with significant power swings and fault reactance technically possible.

Installing an energy storage capacity to the network thus seeks to reduce these constraints and assist in allowing consistent supply to meet demands during the various periods in which the RES inputs may not provide reliability under solo operation. Such example applications include when there is not enough natural resource to meet demand, either due to non-generation or due to excessive demand; and also, in a smoothing capacity to hence deal with the occasional high ramp rates of solar PV under certain cloud cover, or to cover fault reactance.

As indicated earlier, there may be several social constraints facing renewable supply integration into a village/community environment. These typically include lack of social acceptance or awareness of, distrust of reliance on, and a lack of training to maintain RES technologies. The issue is very case-study specific, for example given the previous example given by Liu. W et al, where renewable energy was generally found to be accepted amongst a Chinese rural village, but also given the prevalence of NIMBY viewpoints in relation to RES projects often found elsewhere e.g. in the UK, a developed country.

To tackle these constraints, it is proposed that local involvement be at the heart of any renewable electricity project being introduced into a village/community setting. This local involvement would include the direct training of a small number of local villagers by experienced professionals, in all aspects of the design, operation and maintenance of the RES system such as a microgrid.

This would aim to encourage a grassroots approach to all social barriers. For example, having a local section of the population being involved and responsible for the management of a RES system, this would help raise awareness and acceptance amongst other members of the local population. It would also address the quandary of local inexperience with the systems.

Training is proposed to be direct at first, with first-hand involvement from professionals either from an international organisation or from a regional or national training stakeholder organisation. The latter would be encouraged to become predominant over time as other institutional progress is made in the country of interest, e.g. in terms of improved higher education establishment training and skills acquisition. This aspect of knowledge-sharing has been identified in other previous frameworks as being crucial to achieving long-term sustainability and non-reliance on international donors.

After this period of direct training has finished, it is proposed that a knowledge-sharing link is still maintained between the village and experienced professionals, whether these professionals are in-country or outwith, internationally. This is a component of the recommendations outlined in previous frameworks (such as the ICEPT renewables ‘toolkits’) and aims to address some of the weaknesses inherent in these. A significant downfall of the toolkits was that their sole online operating nature made them one-sided and hampered efficient query-answering and skills development on the user-end.

This framework proposes that after initial RES project installation and involvement/training of locals, such a knowledge sharing link be still maintained in the form of the integrated knowledge management system advocated for earlier by El Fadel. M et al. This would constitute a multi-faceted format, with an online reference database still being maintained as a primary point of reference for questions related to the installed system, but also with other supporting components. The suggested leading entity could be responsible for this principle.

The database would be multi-lingual in nature to seek to maximise the local interaction with the project. Hence it is proposed that alongside English, Spanish and French, there are various other moderately sized language group translations common to the application areas, such as Arabic, with the potential for expansion of this. This would also maximise the flexibility and transferability of the system and of this framework’s proposals.

In addition to this, through the integrated support system there would be an option for direct communication both through the online component, and through in-situ training follow-up meetings. Through the online component this would allow for specific Q&A format sessions to be established with available professional engineers. It is also proposed that sporadic local training sessions be implemented, preferably run by any regional/national stakeholder groups if available. These would feasibly be required to be held to serve a local region, rather than each individual village scheme, and would involve representatives from each region travelling to the session for direct face-to face liaison with professionals.

Tackling regulatory constraints at this scale needs consideration of the common problem at national scales in developing countries, and the unfair advantage that fossil fuels enjoy through institutional/regulatory frameworks. Changing this at local scale is a tougher task due to the more pronounced effect a top-down transition would serve in this case, i.e. national change.

National level change could be enacted through lobbying from political pressure groups to allow equal footing for renewable energy/electricity in competition with fossil fuels, whilst the aspect of fossil fuels is brought into line with international climate change targets. Local level change could be initiated through the existence of reliable RES projects which wean communities from reliance on diesel or other carbon-intense fuels, and the subsequent example this can serve to lobbying groups. Also, over time as institutions develop, new specific codes and regulations for renewable technologies will flourish.

In addition to technical, social and regulatory constraints, financial/economic factors will also likely play a role in renewables integration on a village/community scale, integrating aspects of all the previous identified constraints. Initially however, it must be indicated that there are financial benefits to renewables integration. An RES system implemented in a village has the benefit of not relying heavily on fossil fuels and the subsequent cost required to import them to the community from suppliers. Additionally, the system is not vulnerable to pricing variations and shocks from national or global fuel-oil markets.

Despite this, financial constraints are not least attributed to the capital cost of RES network implementation and the inclusion of storage capacities. The availability of free capital which can be invested is likely not to be present in a village context and given the social barriers are likely not to be overcome until after the project is finalised, social acceptance/willingness to fund any projects will typically be low, although not always the case.

Therefore, it is proposed that external capital will likely require sourcing in order to invest in any project, which has been the case previously on most other completed significant projects in the developing world. However, a major financial constraint is the common lack of strong financial institutions in EDC's, and especially sourcing funding for renewable projects- unless the specific government in question has a set-aside monetary fund specifically for this purpose. Additionally, private capital may be hard to source due to the institutional constraints, and the possibility of corruption in EDC's serving as a deterrent.

It is proposed that international or trans-regional agencies, organisations and mechanisms (such as the GCF of the UNFCCC) support this initial capital required to develop infrastructure, whilst subsequently, nation-specific pricing models for the electricity consumers are designed and implemented. This initial funding should continue until the necessary capabilities of the host country are achieved with regard to financial institution capacity to fund projects within its own borders. There are still financial conditions to investment aid from such bodies, according to Thiam. D (above, page 37), and this could prove a potential barrier, although this is interconnected with political, regulatory and institutional change.

The GCF operates through a basis of investment with the intent to stimulate growth in the energy markets of the country of investment interest, thereby reaping the reward of initial investment in return with the social, economic and energy development of the country. This style of one-off payment is beneficial to reducing the complexities of finance arrangements which come with investment and expected return through energy pricing.

Thiam. D examines some of these various pricing models available to deploy in developing countries, to suit the specific needs and often changing environment inherent within. The author determines that investment decisions depend on “the nature of the energy tariff policy and the level of price retained”; and that the optimal method for decentralised RES system promotion is to ensure energy producers or investors a secure and lengthy income within any incentive mechanism.

This relationship includes the link between energy producer, and energy consumer. Within a village scale however, especially with regard to a microgrid solution, a common arrangement would involve the energy producers also being the energy consumers. This is at the pinnacle of decentralised energy production, as having energy producers distinct to the community is inherent of a move towards centralisation. This is aspired to and works with regard to a completely off-grid system, however eligible microgrids have the capacity to operate in grid-connected mode which brings considerations of grid-purchase agreements to energy pricing.

Within a grid-connected system, or one with grid connection capability, the role of energy producer and energy consumer varies with production capability. For example, the main grid utility will likely supply electricity to a village, meeting demand which local generation cannot supply, for the majority of the time whilst connected. In this case the utility would be the producer and the village the end-user consumer. However, there are times when the village could be producing excess power and wish to sell this back to the grid in return for a monetary purchase price; in this case the village would be the producer and the utility the consumer.

These are aspects where renewables incentives which are common in developed countries, such as the Feed-in-Tariff (FiT), could be applied in the developing country. This has the constraint of being possibly hampered by weak financial institutions available to orchestrate such schemes, as mentioned earlier. If in effect, a FiT designed for EDC’s could serve to increase the favourability and penetration of renewables over time, by offering a financial incentive.

Thiam. D recommends the renewable premium tariff (RPT) suggested by Moner-Girona. M [2009] which theoretically allows for the specific application of RES decentralised systems in EDC's. Under this scheme a premium tariff is guaranteed for an extended period of time (20 years e.g.), and can consist of an IPP scheme, or a concession scheme.

With the IPP scheme, the micro-grid connected renewable asset sells directly to the local utility under a purchase agreement and the negotiated premium tariff. The IPP covers all necessary capital costs including maintenance of the system, and the utility subsequently sells electricity at a discounted price to the end-user, to ensure affordable prices. There is an option here for international investment in IPP's. The difference in price between utility-IPP bought, and end-user sold electricity is accounted for by the utility to enable the IPP to operate in a stable investment environment. The process is overseen by the regulatory authority- either national or international overwatch agency/ the role of the leading entity.

The concession scheme differs in that it exclusively caters for stand-alone off-grid systems with no capacity for main grid-connection. The local utility handles ownership of the microgrid including the installation of bi-directional metering, selling to the end-user at discounted rates. The local energy development agency/government guarantees premium tariffs and pays for the difference in discounted price. The scope for international donor investment is achievable here to fund this difference if the government cannot afford to subsidise prices, and also for local reform to make a transparent framework.

Naturally it is observable that for this financial incentive mechanism to be included in the proposed framework, it is viable due to the multifunctional capability for handling both grid-connected and off-grid systems. The crossover point between these, with regard to microgrids operating in both islanded and grid-connected modes, requires further research but it is proposed that a combination of the two approaches could be instigated. This is especially true when considering that grid-connection does not always equal reliable power, so therefore it is necessary to consider a combined approach.

It is proposed therefore that if possible, on a village scale that the community either purchases the IPP or the local energy utility and/or acts as one and the same. This would eliminate a hierarchical step in the electricity trading ladder to the benefit of increased ownership of renewables production and increased transparency. The community would operate as producer and consumer of its own energy, with the excess being sold back to the energy utility, to other users- nearby through extension- or to the main national grid for a monetary value.

Town Scale:

Theoretically, the application of this framework with regard to a larger population magnitude demand, such as at a town scale, will have constraints not too dissimilar to application at village/community scale. However, this will be examined here, and any fresh constraints analysed with regard to the scalability of this framework.

Towns, and settlements larger than this, e.g. cities, are products of urbanisation and as such are not guaranteed, yet likely in the total global roster of developing nations. By nature, developing nations with high rural populations (e.g. Uganda) will not tend to have a high proliferation of larger-than-village urban settlements, primarily because the urbanisation rate is likely to be low or high rural populations could be attributed to other geographical factors.

However, as has been the trend in both the developed world and in EDC's with higher proportions of urban settlements, there is a broad link between economic growth, and urbanisation [Solarin. S & Shahbaz. M.; 2013]. This indicates that over time, there is a high probability that countries with historical or until-present low urbanisation rates, will see this rate increase with gradually increasing overall development and therefore causally, the prevalence of urban settlement. Therefore, this aspect of consideration within the framework is crucial both for countries like this, and also those with pre-existing high urban proliferation.

Before analysing relevant constraints to renewable electricity supply at this scale, it is first necessary to consider the population sizing limits to delimit this scale with. When analysing the electricity demand and applicability of renewables within a town in China, Ye. B, et al [2017] observed that the urban population was 20,000. Li. X, et al [2015] provides case-study analysis for another Chinese town with population of 27,000. Analysis of emerging towns in Ethiopia indicates an average population range of 30,000 to 40,000 inhabitants, yet with some outliers boasting over 150,000 people [Girma. Y, et al; 2019].

Logically, there is too much variation amongst town populations' through-out the developing world to define exact limitations, so for the purpose of this framework where flexibility is a key tenet, these figures form a simple common range of 20,000-40,000 for the reference population size of a standard town.

With regard to the technical constraints of increasing the renewables penetration of supply to a town-scale development, again it is necessary to examine the common loads which will rely on the electricity network. This is to ensure effective supply-demand matching can occur upon designing the system, with considerations of types and approximate timings of expected load.

There is an immediate noticeable difference here as opposed to village scale application, in that towns will typically already have a pre-existing grid connection for electricity supply to satisfy existing demand and help in the previous growth of the settlement. This is as opposed to villages which are more likely to have off-grid characteristics. This means that any town-scale renewables penetration will be required to integrate with grid supply, with the prospect of bi-directional flow; and the possibility of microgrid implementation still present as an option also.

The other noticeable contrast will be in the increased magnitude and variation, both in type and timing, of load demand placed upon an electricity supply to a larger urban settlement than a village. This reflects the increased likelihood of larger consumers e.g. businesses, factories, and other common built infrastructure which are common to towns, alongside a larger population. Therefore, this makes for increased complexity in preparing and analysing the demand load profiles necessary to facilitate effective supply-demand matching at this scale.

What needs examined is the degree to which the basic load profile will resemble that of the village scale profiles, and any significant deviations from this. Logically, electricity will still be required alike village-scale application, in a domestic capacity for lighting, cooling provision (fans) and infotainment services such as TV and radio. Significant variation is to be noted however in the increase in demand magnitude per household. This stems from the effect previously noted in the correlation between economic growth and urbanisation i.e. inhabitants of urban areas are likely to have access to more energy-intensive equipment, or generally more appliances; with this reinforced by studies [Elliot. R, et al; 2017].

Outside of the domestic sphere, there will likely be increased non-domestic loads such as industrial and commercial. These will typically consist alike the village application scale, of cold storage, processing and water pumping loads, but will also incorporate a wider variety of demand, and likely at a higher intensity/magnitude than at the previous scale. The nature of this will vary depending on the country of interest, e.g. a country such as Pakistan has a large cotton manufacturing industry, whilst Malawi has a large tobacco industry [UN, 2019].

The timing of demand on a daily basis will likely follow a broadly similar pattern to that of a village, with daytime and evening peaks coinciding with increased industrial/commercial (for the former) lighting, infotainment and (with lower probability) cooking electricity demands (for the latter). These will tend to be more pronounced in terms of overall magnitude, but less so on an average basis with a higher level of industrial/commercial electrical load spread out over the day, as compared to a more noticeable spike from baseline conditions within a village context.

Ye. B et al suggests that timing of demand will also likely vary on an annual basis, as well as on a daily, hour-by-hour basis, with fairly energy-intense loads such as air conditioning (a component of the cooling fan load group) experiencing increased demand in summer months, and any electrical heating loads being more prevalent in winter months. This again is location dependent, being directly linked to both the climatic characteristics of the country of interest and also the method of heating/ (cooling to a lesser degree) but is a common factor to consider in most locations.

Therefore, demand profiles are recommended to be produced and analysed for the specific town in the country of interest. This will have the effect of accounting for both the magnitude of the required demand but also its relative timing with regard to location and the effect seasonality will have on electricity demand for certain loads e.g. summer demand for air conditioning. This will mean the load profile for a very warm country such as Ghana, will appear different than that for e.g. Nepal.

Due to the predominant likelihood of existing grid connection, there exists the possibility that the quality of electricity supply received to any particular town may be poor, with frequent brownouts (voltage sags) or blackouts a potential common occurrence depending on the operational state of the national grid. This raises the possibility of microgrid implementation within the developing country, and whether this is directly translatable from village scale to a larger application such as provision for a town. This would will be assessed later through modelling.

In terms of regulatory and social constraints, these are typically similar at town scale as to at village scale applications. Regulatory constraints such as bias towards fossil fuels and weak development of the necessary regulation codes required for renewable energy to penetrate into the energy marketplace, will be most likely overcome using a top-down approach.

Social constraints, alike at village scale will typically be dominated by inexperience with electric RES, and the resulting possibility of distrust, fear or limited knowledge of/about renewables and the benefits their application can bring to the end-user. This again is a very case-specific constraint, as some settlements may be more accepting of potential integration than others, however it is forecast that acceptance will be directly tied in-part to the quality of the existing grid connection supplying any given town.

For example, if the grid connection is relatively stable, providing consistent power to the settlement, then there is a higher likelihood that broad acceptance of renewable electricity will be lower. Conversely if this connection is poor in quality and delivers frequent blackouts and load-shedding, then it is forecast that acceptance will be higher due to a greater desire to be self-sufficient in energy without reliance on an ineffective centralised supply system. Therefore, the quality of grid connection should be taken into consideration when planning for renewables integration at a decentralised town-scale (or any scale).

If social barriers exist, then it is again proposed that knowledge-sharing should form a key component of the measures to overcome these, as increasing the availability of knowledge, especially with regard to benefits of renewables, will start to tackle fear and distrust. This should incorporate direct local participation with the installation and maintenance of installations- and with the subsequent training required for this provided.

Training would be facilitated slightly differently to at village-scale, with direct on-site knowledge-transfer from experienced professionals not viable with regard to individual home solutions which would be more common-place with regard to town-scale implementation. Therefore, it is proposed that centralised training sessions be arranged, facilitated and paid for by the leading entity/ regional organisations, to directly teach both locals and with the aim of developing professionals, the necessary skills required for installation/maintenance.

The same multi-lingual knowledge database should be maintained as the village-scale application accesses, with one centralised system being more efficient than several. This should therefore incorporate all of the previous support characteristics for any questions or aid locals may require during any future installation/maintenance process.

Financial constraints again will likely play a role in restraining the penetration of renewables within a town-scale application in developing countries. This can become even more prevalent than when considered at village-scale due to the relationship of increased demand magnitude with the capital cost necessary to accommodate renewable supply measures. In theory, this capital cost outlay depends on the system configuration wishing to be pursued.

With anticipated retention of grid-connection reliance and introducing renewables at solely a domestic consumption and grid feed-in level, then this will involve a lower capital cost than if a microgrid option were to be opted for, with the subsequent necessary capital expenditure on storage and reliable supply. Therefore, again it is proposed that external capital needs sourcing from outside the town community, due to the constraints faced in terms of internal capital availability.

Furthermore, there is the common national level constraint of weak financial institutions not being capable to facilitate financial incentive schemes to encourage uptake of renewables. There is the potential for incentive schemes, or other support schemes to be slightly more feasible at town-scale due to the larger consumer base than at village scale; and hence the possibility for community-led fund-raising schemes such as those common in the UK [Walker. G; 2008].

However, it is predicted that there would be difficulty self-organising this especially in a likely non-fertile national regulatory environment and accompanied by the relevant social barriers in existence e.g. lack of knowledge. Therefore, there needs to be external influence within the auspices of the recommended international leading entity, to facilitate this capital and incentivise/organise action. International development funding mechanisms such as the GCF will also likely play a role in financing at this level alongside at village-scale.

Effectiveness and general anticipated success of framework in country of interest

This concluding section for each case study should examine all of the identified constraints unique to the targeted country/region, the proposals made to overcome them, and the general anticipated success of the framework in facilitating this. There should be consideration in a multi-dimensional manner of all of the various constraints and their inter-play with each other, especially with their contribution towards their effect on meeting the aims of the framework.

For example, the penetration potential of renewable electricity should be considered through the energy system proposed, in light of the technical and various other constraints identified. This section should be an area in which previously unsolved constraints and operation of the system should have solutions proposed if possible. However, also where honesty in meeting the goals should be important too, with potential research and further steps within each country succinctly laid out.

The framework's success within each country can be assessed through the meeting of the objectives, i.e. ensuring a secure and sustainable electricity supply, alongside considerations of achieving this through the most sensible method for financial and social considerations. In addition, cleverly designed solutions and use of best industry practice should be prioritised.

Finally, the ability to co-ordinate all of the differing constraints from all aspects of implementation, e.g. technical to the financial burden, should be assessed in the country of interest, to understand how a country-specific solution can be reached. Local participation should be exalted if present due to the previously identified benefits this can bring to success.

The purpose of this framework is to provide feasible solutions to introducing a higher share of renewable energy to the electricity supply of economically developing regions, ensuring this is reliable and proposing how to tackle any constraints faced in this implementation. In its essence, the framework is theoretical and so hence unproven as yet in its effectiveness. Hence, it is mandated that the proposals of the framework be tested methodologically through application in a real-world context, with attention paid to any potential flaws which might arise, whilst also assessing its practical benefits.

In order to undertake this, a global region/nation was selected to serve as a case-study for framework application. There were several criteria for selection, namely:

- The selected area should be classified as economically developing, with income classification as middle income or low income as suggested by the World Bank and as listed in *Table 1* (Appendix).
- The selected area should have a good representation of differing scales of demographic settlement- to quantify the village and town scales mentioned.
- The selected area should have existing low levels of renewable electricity penetration in its energy mix.
- The selected area should have existing issues with the security of its electricity supply.

Identification of the Gaza Strip as a Case-Study

One such region which meets all of the outlined criteria for case-study selection, is the Gaza Strip- the small, self-governing, coastal enclave of the Palestinian Territories (P.T) situated between the Mediterranean Sea and Israel. It is operated as a separate entity to the West Bank (which together comprise the P.T), and both are claimed as the disputed State of Palestine.

According to the afore-mentioned World Bank listings, the combined Palestinian Territories are classified as a lower-middle income geopolitical entity, indicating therefore that it has a GNI/capita rating of \$996/\$1036 - \$3895/\$4085. This rating is refined by further datasets obtainable from the U.N [UNCTAD; 2019], which state that the P.T had a nominal GNI/capita of \$3,722 in 2018, and a report which states that the Gaza Strip as a sub-entity of the P.T has a *GDP/capita* of \$425.30 [OCHAOPT; 2018].

Other economic indicators of low economic development include the high unemployment rate of 31% and the fluctuating- and as of 2012- steadily falling GDP growth rate. The demographic profile of the Gaza Strip also reveals a region-wide high population growth rate of 2.25% in 2018, with a birth rate of 31 births/1000 population, and a death rate of 3 deaths/1000 population [CIA World Factbook; 2018/2019]. Alongside this, the total fertility rate of the Strip and the P.T as a whole is estimated at amongst the highest in the world at 3.97- 4.6 children/woman [CIA World Factbook and Shaheen. L; 2013], all of these posing a strain on available resources.

Combined these common socio-economic indicators represent that the Gaza Strip, operating as a sub-entity of the Palestinian Territories, can be classified as an economically developing region. The Strip has a population of approximately 1.85-1.89 million residents, and a very high population density of 13,000 people/square mile. Of the total population, and split over five governorates, the urban population stands at approx. 76% total, and the rural population at 24% total. The population lives in a mixture of cities, towns, and villages, but due to the political situation of the Strip, some refugee camps e.g. Jabalia Camp are classified as towns.

Due to the high population density of the Gaza Strip, it is forecast and evident from demographic surveys (Palestinian Central Bureau of Statistics/PCBS) that the settlements within the Strip exceed the average sizing stipulations outlined in the framework recommendations above. This therefore indicates that a settlement which would be classified as a village in the Gaza Strip, due to the high regional population density, such a settlement would potentially be classified as a small town elsewhere in other developing countries. This presents a minor challenge to the framework in terms of adherence to the recommended nominal typical sizing limits but is intended to demonstrate the flexibility of the framework to suit different real-world operating conditions and uncertainties.

In addition to this, and one of the main drivers for the selection of the region for testing this framework, is the fulfilment of the fourth criterion, and by the way of this framework the third also, in that the Gaza Strip suffers from extremely significant power supply issues. The Strip heavily relies on imported electricity supply from neighbouring countries, primarily Israel. This poses power provision supply issues as an electricity supply- being seen as the lifeblood of any economy- is often at the mercy of the unsteady political arrangements between the two nations, with political powerplays and infighting having previously affected reliable supply.

The Strip has limited power producing capabilities of its own, as the diesel-powered Gaza Power Station is the only main energy producer within its borders; this is rated at between 60 – 140 MW capacity and operated by the Gaza Electricity Distribution Company (GEDCo). The **total electricity demand** for the Strip is estimated at between **350-500 MW**, depending on the time of year and the subsequent load profile, and the annual electricity consumption demand was approximately 1230 GWh as of 2011 [OCHAOPT; 2017 & Abu-Jasser. A; 2012]. A proportion of electricity supply is provided through the electricity lines flowing from Israel, and from Egypt to a lesser degree.

The reliance on foreign electricity imports can vary on an annual basis, depending on the operational state of the Gaza Power Station; with 17-30 MW supplied from the Egyptian feeder lines, and a typical 120 MW from the Israeli lines, according to the above authors. This results in a total foreign electricity import of 137-150 MW and combined with the maximum operational capacity of GEDCo generation, results in a **total Strip electricity supply** of between **200-290 MW**. This means supply is lower than required demand and has resulted in a chronic power shortage within the Strip of between 60-300 MW, exacerbating previous developmental issues.

This supply shortage is attributed in large to the operational state of the Gaza Power Station, which is affected by the political conflict in the region, having had its capacity reduced by both Israeli military attacks since 2006, and embargos on necessary replacement parts and critically an absence of an uninterrupted fuel supply route with affordable prices. In addition to this, the afore-mentioned political infighting is demonstrated by the Palestinian Authority's (P.A) decision to isolate the Strip through a reduced electricity quota implemented through the Israeli feeder lines as a result of differing political stances on regional governance.

This results in a combined effect of a highly unreliable electricity supply to the region. The OCHAOPT reports that due to the combination of increasing population growth, insufficient supply, and political troubles, there are resultant prolonged periods of electricity unavailability (blackouts) ranging from an average of 9-15 hours of unavailability per day as of 2019 (refer to Figure 2a). The situation has improved since 2017 and 2018, during which there was an average unavailability for over 16 hours per day (refer to Figure 2b).

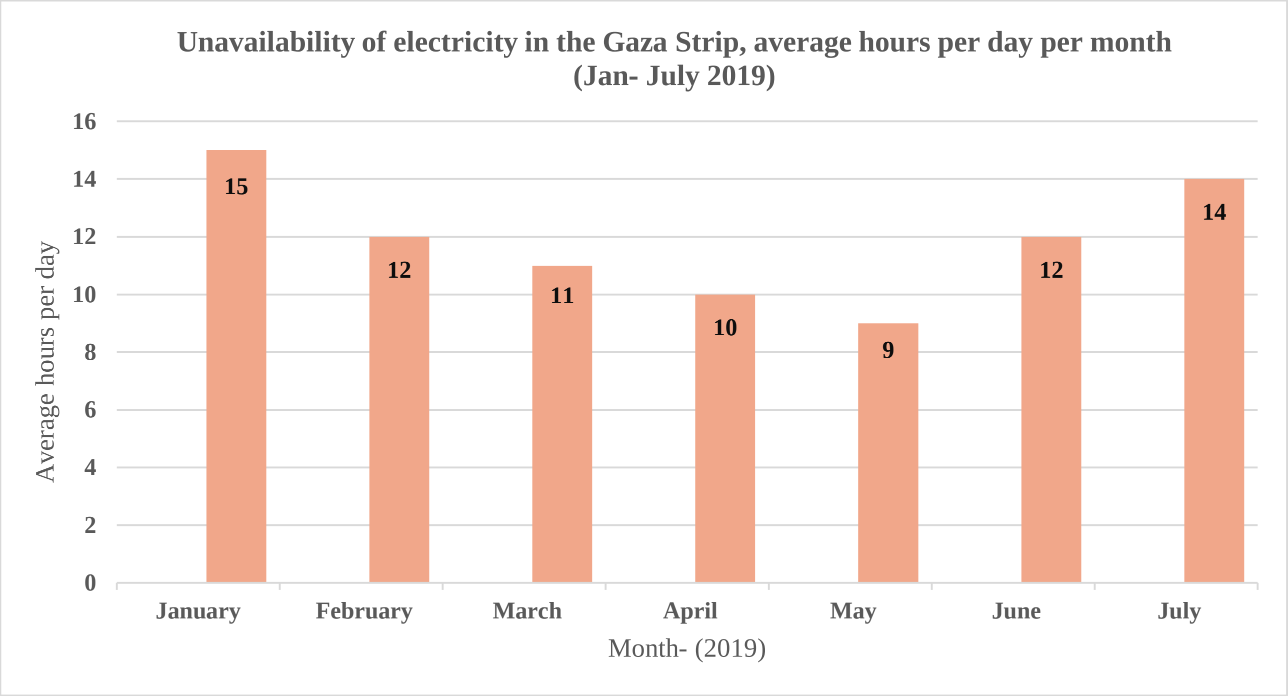


Figure 2a- *Histogram graphic displaying average hours/day of electricity unavailability within the Gaza Strip; 2019, ranked by month to date; derived from OCHAOPT data available at: https://www.ochaopt.org/page/gaza-strip-electricity-supply.*

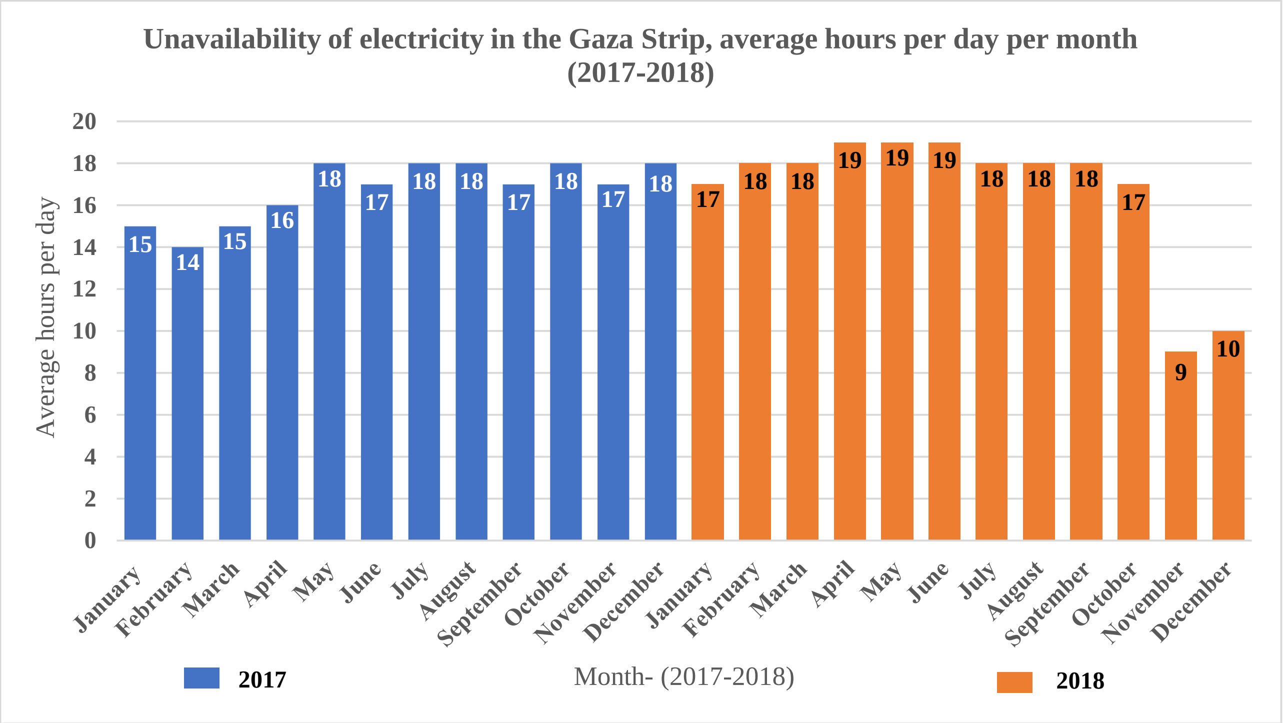


Figure 2b- *Histogram graphic displaying average hours/day of electricity unavailability within the Gaza Strip; 2017-2018, ranked by month; derived from OCHAOPT data available at: https://www.ochaopt.org/page/gaza-strip-electricity-supply.*

Daily life and business-related activities are impacted as a direct result of the blackouts, leaving hospitals to rely on fossil-fuel powered emergency generators for extended periods of time, which results in unnecessary expense on fuel, if this is available at all. In addition to this, there have been numerous deaths directly attributed to using fire-candles for lighting since 2010 [Oxfam.org article; 2019]. There is also minimal service available with regard to waste management and sanitation, including providing adequate water supply [Afifi. S et al; 2015].

Businesses cannot provide satisfactory service to customers, and due to the socio-economic effects of electricity unavailability, poverty levels rise and with this- insufficient economic access to replacement diesel generators, which are often the only common solution to the crisis. According to the OCHAOPT, these fossil fuel generators are often paid for by humanitarian aid, restricting the full impact this aid could have otherwise brought to development. Liquid fuels are often restricted with the Israeli embargo, meaning that fuels have to be brought in from Egypt although such levels are insufficient to cover demand.

Although solar *thermal* units are common on a large majority of dwelling units [Droege. P; 2018], renewable energy has only made a relatively minor foray into helping tackle the electricity crisis and wean energy reliance from fossil fuels and foreign imports. The Strip has no conventional natural resources and hence resources/ electricity provision has historically been imported from outside. A 0.5-1 MW solar PV plant opened in 2017 under EU funding [OCHAOPT article; 2017] to help power a desalination plant providing fresh water to the region, and there are small-scale efforts to bring renewable electricity to the Strip, but these are not galvanised as of yet. Hence, there is low renewable penetration in the electricity supply mix despite great potential.

It is forecast that greater penetration of renewable energy to the Gaza Strip, primarily through electricity supply, will be truly beneficial to the energy issues currently faced in the region. This is through the increased reliability of supply through the incorporation of RES technology including the potential option of energy storage, therefore reducing the reliance on ineffective and politically unstable grid connections. Furthermore, there is indirect impact on the wider society as a whole, through the socio-economic benefits secure supply can bring.

Application of the Framework to the Case-Study

- *Identification of renewable energy resource potential*

With the existing low renewables penetration in the region, there is not an over-abundance of previous studies in the potential for renewable energy resource exploitation. Of those assessments which exist, Ouda. M [2010], Nasser. Y & Alsadi. S [2019], and Alaydi. J [2013] incorporate the most data on available resources. These authors broadly conclude that the region has a good potential for solar resource exploitation given the geographical location at approximately 31°10” N latitude and 43°26” E; alongside the favourable climatic location in the Eastern Mediterranean.

For example, Nasser. Y & Alsadi. S observe that Direct Normal Irradiance is measured at 4 kWh/m^2/day in the winter, and 8 kWh/m^2/day in the summer months. Alaydi. J also writes that monthly direct solar beam averages are recorded at 7 kWh/m^2/day in the summer months and approximately 4 kWh/m^2/day in the winter months. Alaydi. J also states that average wind speed values in the region are 4.2 m/s, peaking at a mean value of 5 m/s and maximum momentary values of 24 m/s on peak occasion.

Ouda. M presents a very brief overview of the available renewable energy resource available, examining solar, wind and biogas production potential within the Strip. This author observes that average wind speeds are slightly lower than this, averaging between 2-3.8 m/s on an annual basis. Solar resource figures are given in direct horizontal irradiance, with 5.6 kWh/m^2/day available on an average annual basis. Ouda. M also analyses the potential for biogas production for heating and lighting, finding that the Strip has a modest total biogas reserve of 243.6 GWh.

To reinforce these findings, the framework advocates that further research be performed through both preliminary resource availability and subsequently detailed analysis studies. This is to ensure that concrete resource availability figures are established for system design, with cross-referencing to pre-existing recorded datasets where necessary, so as to maximise accuracy.

As recommended by the framework, preliminary resource assessment in this context can be achieved through access and analysis of renewable resource global atlases which cover the region in a relatively broad-tooth and unstratified fashion, but present reasonable assumptions which can be reinforced through further detailed analysis.

Preliminary Resource Assessment

In this case-study it is advocated for the combined selection and use of the World Bank Global Solar Atlas, Global Wind Atlas and other resources, alongside the IRENA Global Atlas for Renewable Energy for this preliminary identification stage of solar and wind resource potential in the Gaza Strip (biogas potential will be discussed later).

To achieve this, the Strip was sub-divided into the five governorates of North Gaza (Jabaliya), Gaza, Deir-al-Balah, Khan Yunis and Rafah demonstrated in Figure 3a. These were sub-divided into sub-regions to represent a more refined data-gathering approach, and consisting of coastal (A), central (B) and inland border (C) sub-regions (Figure 3b example).

A central reference data-point was then manually selected on the resource atlases in each of the governorates, and then again in each of the sub-regions of said governorate, with the solar and wind potential resource in these areas recorded. The chosen analysis variables were Direct Normal Irradiance (DNI/ I_{DN}), Diffuse Horizontal Irradiance (Diff. HI) and Global Horizontal Irradiance (GHI) for the solar resource, and wind speed in metres/second (m/s) for the wind resource. These results are presented in Table 2 below.

Figure 3a*- Map of Gaza Strip split by Governorate, and sub-region; base map derived from Global Solar Atlas [World Bank].*

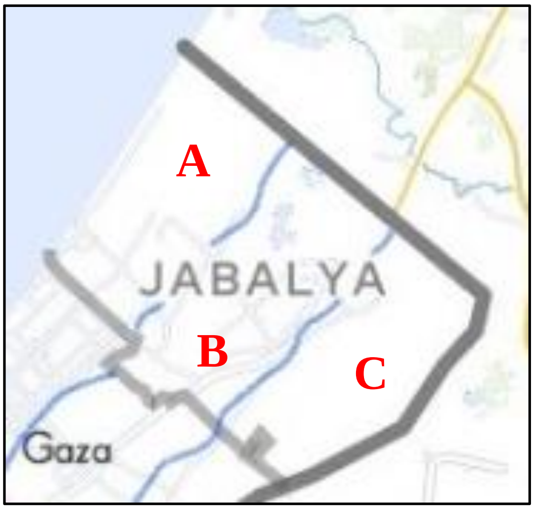
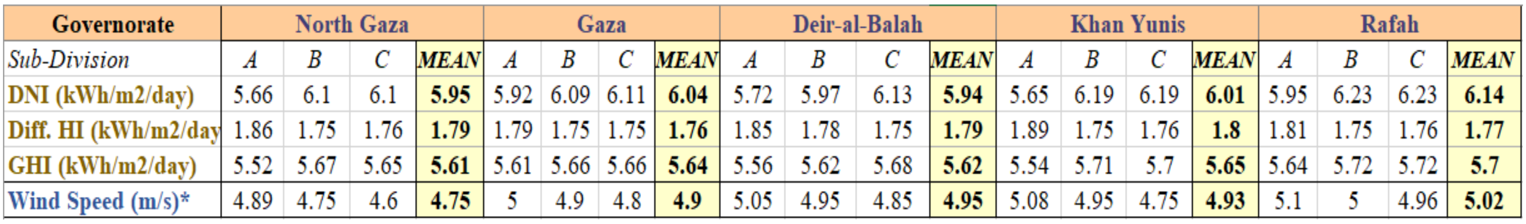


Figure 3b*- Expanded view of Figure 3a displaying North Gaza (Jabaliya) Governorate, with sub-region divisions visible.*



Governorate	North Gaza				Gaza				Deir-al-Balah				Khan Yunis				Rafah			
Sub-Division	*A*	*B*	*C*	***MEAN***	*A*	*B*	*C*	***MEAN***	*A*	*B*	*C*	***MEAN***	*A*	*B*	*C*	***MEAN***	*A*	*B*	*C*	***MEAN***
DNI (kWh/m2/day)	5.66	6.1	6.1	**5.95**	5.92	6.09	6.11	**6.04**	5.72	5.97	6.13	**5.94**	5.65	6.19	6.19	**6.01**	5.95	6.23	6.23	**6.14**
Diff. HI (kWh/m2/day	1.86	1.75	1.76	**1.79**	1.79	1.75	1.75	**1.76**	1.85	1.78	1.75	**1.79**	1.89	1.75	1.76	**1.8**	1.81	1.75	1.76	**1.77**
GHI (kWh/m2/day)	5.52	5.67	5.65	**5.61**	5.61	5.66	5.66	**5.64**	5.56	5.62	5.68	**5.62**	5.54	5.71	5.7	**5.65**	5.64	5.72	5.72	**5.7**
Wind Speed (m/s)*	4.89	4.75	4.6	**4.75**	5	4.9	4.8	**4.9**	5.05	4.95	4.85	**4.95**	5.08	4.95	4.75	**4.93**	5.1	5	4.96	**5.02**

Table 2*- Tabular results displaying obtained data for solar and wind resource in the Gaza Strip, divided by Governorate and further sub-region, with calculated mean value. Analysis is against y-axis variables of DNI, Diff. HI and GHI for solar resource, and wind speed for wind resource. Data derived from Global Solar Atlas and Global Wind Atlas, 2019. * - data for 10% windiest areas for selected map reference point.*

As can be observed from Table 2, there are some common trends with regard to solar and wind resource potential in the entirety of the Strip. Of primary interest is the gradually increasing resource potential with geographical location further south, with for example, Rafah Governorate possessing higher resource potential figures on average than the more northernly governorates. Overall averages for the Strip are as follows: DNI = 6.01 kW/m^2/day; Diff. HI = 1.782 kWh/m^2/day; and for GHI = 5.64 kWh/m^2/day.

There are increasing trends in the average DNI, and GHI with progression south, although these are not overly strong correlations. The wind speed appears to follow a similar trend, with maximum average strength in Rafah Governorate, which also records the highest overall wind speed, DNI and GHI. It can be noted that the Diff. HI is the variable with the greatest fluctuation and arguably the farthest from any meaningful geographical correlation.

In addition, the available wind resource is strongest in the coastal region of each governorate, gradually weakening with distance inland. The opposite is true for the measured DNI and GHI, with Table 2 indicating that these gradually increase with distance inland. This latter observation is confirmed in Figures 4 and 5 in the Appendix, which graphically represent the changing solar conditions across the Strip using the same software datasets, and also by Nasser. Y & Alsadi. S.

With the potential for the exploitation of biomass resources for biogas production explored briefly by Ouda. M it is necessary to undertake resource potential analysis. This is not achievable at an initial analysis scale due to the noted lack of available resource atlases for this region. Therefore, this will need examined at a detailed level using available land use patterns, and other previously outlined vital statistics for biogas analysis such as availability of sewage, and other OMSW, crop-types and livestock counts.

Detailed Resource Assessment

As the framework stipulates, after preliminary assessment of the available resources within the country of interest, with resource atlases etc., then more detailed resource analysis is then required to verify and fine-tune the business and techno-energetic cases for renewables implementation to harness these resources. This will be reflected here with regard to solar, wind and biogas analysis.

Solar

The formula proposed earlier shall be used here for resource analysis.

To predict/analyse the irradiative flux within the Gaza Strip accurately, several reference days (*n*) will be used in the formula to represent approximate summer and winter timeframes. These are proposed to include the maximum/minimum values attained by timing with the N. hemisphere summer and winter solstices (21st June & 21st December respectively), alongside on/around the spring-time vernal equinox on 21st March.

The calculation will also be made in relation to the differing spatial geography of the Strip, building on the observations from the preliminary analysis that the highest solar resource is to be found in the inland border region of each governorate. Therefore, this shall be accorded to each governorate in this sub-region as shown in Figures 6a/6b. The methodology is to use the approximate central location of the sub-region for non-bias.

However, for the sake of reducing burdensome and time-intensive calculations, the initial full working for North Gaza Governorate was calculated to identify any notable differences between the preliminary resource and the detailed analysis', and then the full set of sub-regions was adjusted using the following method.

Initially, the solar insolation variables were calculated from the North Gaza Governorate, over summer solstice, winter solstice and spring equinox timeframes, and then the annual average for each variable was calculated. The numerical difference between this average and the Strip average observed for the preliminary resource analysis was found, and then this difference was subtracted from the preliminary dataset for each Governorate over the Strip. These annually adjusted figures better represent the anticipated solar resource availability for each sub-region.

The full, detailed working for North Gaza Governorate is as follows:

North Gaza Governorate, Workings- Summer & Winter Solstice, Spring Equinox

North Gaza: Latitude (*l*) 31.5281, Longitude (Lo) 34.5360;

Reference day (*n*) at 12 noon local: Summer (172), Winter (355), Equinox (80).

Collector surface is assumed to be facing S at a tilt angle of 30^{o}; solar reflectance values estimated at an average of 0.50 (splitting the difference between rooftop 0.75 & ground 0.20).

Solar declination angle $d = 23.45\sin\left[\frac{360}{365}(284 + n)\right] =$

$23.45\sin\left[\frac{360}{365}(284 + 172, 355, 80)\right] =$ **23.45^{o} [Summer]; -23.45^{o} [Winter]; -0.40^{o} [Equinox].**

Hour angle $h = 15\,(LST - 12)^{o}$; Summer >

Local Solar Time (LST) = Clock. T $+ \left(\frac{1}{15}\right)$ *(Lat. S. Meridian – Lat. site) + Eqn. T – DST*

Eqn. T = $0.165\sin 2B - 0.126\cos B - 0.025\sin B$;($B = \frac{360\,(n-81)}{364} = \frac{360\,(172-81)}{364} = \mathbf{90}$)

Eqn. T = $0.165\sin 2\,(90) - 0.126\cos\,(90) - 0.025\sin\,(90) = \mathbf{-0.025}$

Local Solar Time (LST) = 12hr $+ \left(\frac{1}{15}\right)$ (30^{o} E – 34.5360^{o} E) + (-0.025) – 1hr = **10.67 h** (10.40am)

Hour angle h = 15 (10.67-12) = -19.95 = **-20^{o}** (summer)

Winter > B = 271; Eqn. T = 0.017; LST = 11.71h (11.40am); **h = - 4.35^{o}**

Equinox > B = -0.98; Eqn. T = -0.131; LST = 11.56h (11.33am); h = **-6.6^{o}**

Solar zenith angle $\cos\theta_H = \cos(l) \cdot \cos(h) \cdot \cos(d) + \sin(l) \cdot \sin(d) =$

Summer >

$\cos(31.5281) \cdot \cos(-20) \cdot \cos(23.45) + \sin(31.5281) \cdot \sin(23.45) = 0.943 = \mathbf{19.44^{o}}$

Azimuth: $\cos\phi = \frac{1}{\cos\beta}(\cos(d).\sin(l).\cos(h) - \sin(d).\cos(l))$ & $(\beta = 90 - \theta_H = 90 - 19.44 = \mathbf{70.56}^{o})$

$\cos\phi = \frac{1}{\cos 70.56}(\cos(23.45).\sin(31.5281).\cos(-20) - \sin(23.45) . \cos(31.5281)) = -0.336$

$\phi = \mathbf{109.63^{o}}$

Winter > $\cos\theta_H = 0.57$/ $\boldsymbol{\theta_H = 55.25^o}$; $\cos\phi = 0.995$/ $\boldsymbol{\phi = 5.72^o}$

Equinox > $\cos\theta_H = 0.84$/ $\boldsymbol{\theta_H = 32.53^o}$; $\cos\phi = 0.977$/ $\boldsymbol{\phi = 12.3^o}$

Surface tilt angle $\Sigma = 30^o$; surface azimuth angle $\Psi = 0^o$;

$\gamma = (\phi - \Psi) = 109.63 - 0 = 109.63^o$ [Summer]; 5.72^o [Winter]; 12.3^o *[Equinox]*

If tilted (30^o): $\cos\theta = \cos(\beta) \cdot \cos(\gamma) \cdot \sin(\Sigma) + \sin(\beta) \cdot \cos(\Sigma) =$

Summer > $\cos(70.56) \cdot \cos(109.63) \cdot \sin(30) + \sin(70.56) \cdot \cos(30) = 0.76 = \mathbf{40.47^o}$
If horizontal: $\theta = \theta_H = \boldsymbol{19.44^o}$

Winter > tilted $\cos\theta = 0.902 = 25.5^o$; horizontal $\theta = 55.25^o$

Equinox > tilted $\cos\theta = 0.99$/ $\theta = 6.85^o$; horizontal $\boldsymbol{\theta_H = 32.53^o}$

From this and using the average monthly I_{DN} data available from Alaydi. J, the various solar parameters can be calculated. Diffuse horizontal irradiation (Diff. H) can be calculated using the obtained I_{DN} datasets and using a dimensionless ratio given:

Summer >

$I_{Diff.\,H} = C.\, I_{DN} = 0.134 \cdot 7.845 = \mathbf{1.05\ kWh/m^2/day}$

Direct Solar at angle θ (30^o): $I_D = I_{DN}\cos\theta = 7.845 \cdot 0.76 = \mathbf{5.96\ kWh/m^2/day}$

Global/Direct Horizontal: $I_{DH} = I_{DN}\cos\theta_H = I_{DN}\sin\beta = 7.846 \cdot \sin(70.56) = \mathbf{7.40\ kWh/m^2/day}$

Reflected component: $I_R = \rho_g I_H (1-\cos\Sigma)/2 = 0.50 \cdot 7.40\,(1-\cos 30)/2 = \mathbf{0.248\ kWh/m^2/day}$

with ρ_g = *ground solar reflectance &* I_H = *total horizontal ground flux.*

Winter >

$I_{Diff.\,H} = 0.134 \times 3.56 = \mathbf{0.47\ kWh/m^2/day}$; $I_D = I_{DN}\cos\theta = \mathbf{3.21\ kWh/m^2/day}$;

$I_{DH} = \mathbf{2.03\ kWh/m^2/day}$; $I_R = \rho_g I_H (1-\cos\Sigma)/2 = \mathbf{0.068\ kWh/m^2/day}$

Equinox >

$I_{Diff.\,H} = 0.134 \times 4.323 = \mathbf{0.58\ kWh/m^2/day}$; $I_D = I_{DN}\cos\theta = \mathbf{4.29\ kWh/m^2/day}$;

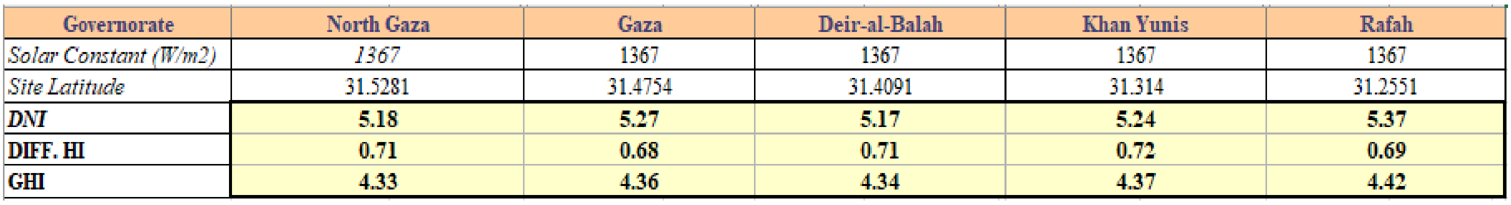
$I_{DH} = \mathbf{3.65\ kWh/m^2/day}$; $I_R = \rho_g I_H (1-\cos\Sigma)/2 = \mathbf{0.122\ kWh/m^2/day}$

This differs from that observed in the preliminary resource analysis survey, with DNI values recorded by Alaydi. J at 7.845 kWh/m^2/day, whilst Global Solar Atlas resource data in Table 2 suggests this should be at 5.96 kWh/m^2/day. During the summer solstice, the GHI is calculated at 7.40 kWh/m^2/day and the diffuse horizontal at 1.05 kWh/m^2/day, meanwhile the preliminary resource survey indicates these should be 5.61 kWh/m^2/day and 1.79 kWh/m^2/day respectively. The same difference is also observed in values for the other two reference dates.

The inconsistency between the GHI and Diff. HI at the preliminary resource and detailed analysis levels can likely be explained by the seasonality effect of e.g. the summer solstice on calculations as the detailed analysis results present a higher GHI, yet lower Diff. HI, representative of summer conditions on a clear day. In the winter, GHI is lower but so is Diff. HI, presumably because of the lack of cloud factor accounting (which makes diffuse radiation higher in winter, when weather is typically cloudier).

The dataset from the preliminary resource calculations therefore represents annual average solar factors, whereas the detailed analysis uses seasonal insolation figures, with the DNI dataset provided by Alaydi. J as geographic averages for the whole Strip. This is partially the reasoning behind the conversion to annually adjusted values for each sub-region within the Strip. This adjustment includes the original values for North Gaza to reflect the true estimation.

The calculated values that follow, reflective of all governorates, assume that there is a linear correlation between the solar variables expressed for the North Gaza Governorate, and geographic movement south. It also imposes the calculated values for the assumed highest yielding sub-region (inland border) for North Gaza, across all of the Strip using the preliminary resource assessment values. It can be observed from Table 3 that there are similar trends to that found in the preliminary analysis, in terms of increasing DNI and GHI with distance south.



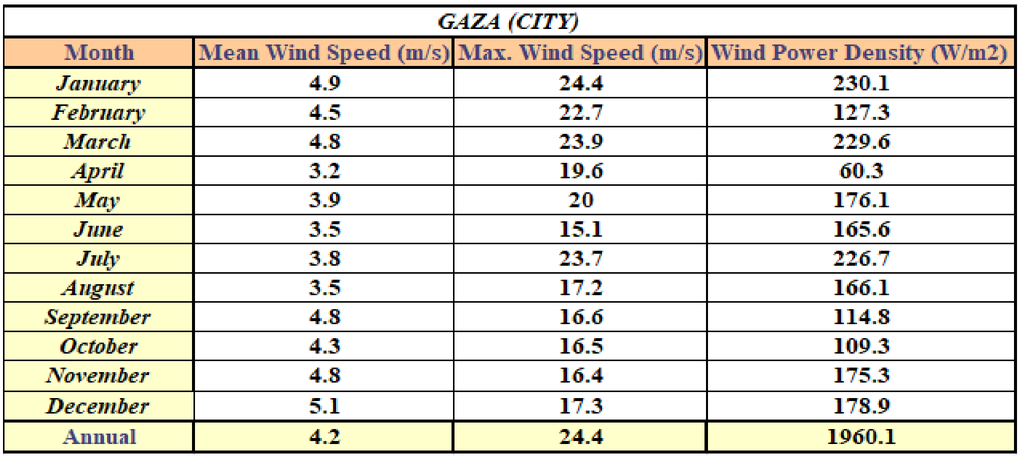
Governorate	North Gaza	Gaza	Deir-al-Balah	Khan Yunis	Rafah
Solar Constant (W/m2)	*1367*	1367	1367	1367	1367
Site Latitude	31.5281	31.4754	31.4091	31.314	31.2551
DNI	**5.18**	**5.27**	**5.17**	**5.24**	**5.37**
DIFF. HI	**0.71**	**0.68**	**0.71**	**0.72**	**0.69**
GHI	**4.33**	**4.36**	**4.34**	**4.37**	**4.42**

Table 3- *Annually adjusted solar variable values for all sub-region governorates within the Strip, adjusted using the formulaic method outlined above, based on the difference in calculated annual averages for each variable between preliminary and detailed analysis observations.*

Wind

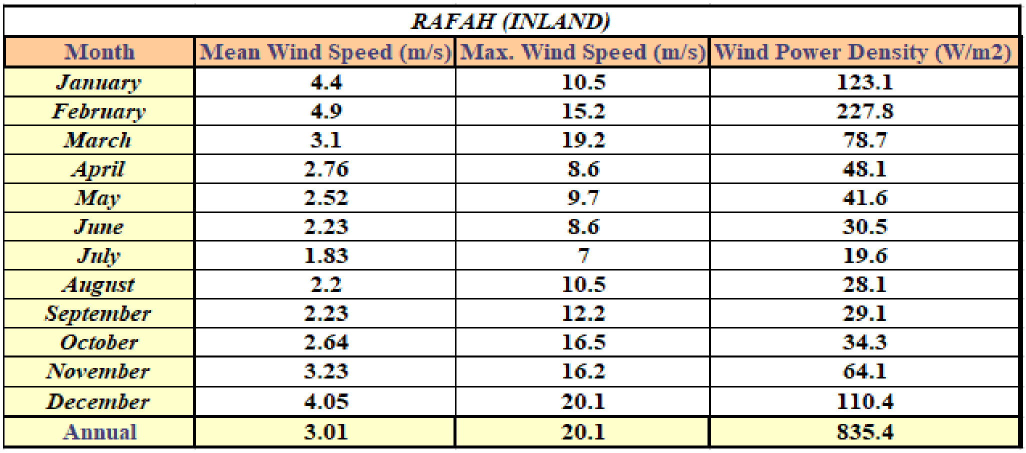
To undertake detailed analysis of the wind resource available in the Gaza Strip, accurate wind speed (*v* in m/s) measurements must be obtained for the local region, and the site if possible. These should consist of anemometer readings from meteorological stations and be obtained either directly from the site over an adequately long period of time, from datasets representing the local area or/and from the mentioned MCP method which correlates short-term site data with longer term local site data.

Meij. A, et al [2016] state that there are limited comprehensive meteorological studies on wind energy potential in the Gaza Strip, with only a few historical studies. One of these studies, again provided by Alaydi. J [2011] measures the annual wind characteristics for two measurement sites in Gaza Governorate (Gaza City) and Rafah Governorate (Gaza Intl. Airport) respectively. These correlate with Gaza Governorate sub-regions A & B (coastal/ central), and Rafah sub-region C (inland border) and cover a lengthy undefined period at 50m elevation (from 10m altitude extrapolation through the Power Law). The findings from the Alaydi. J study are presented in Tables 4a & 4b.



GAZA (CITY)			
Month	Mean Wind Speed (m/s)	Max. Wind Speed (m/s)	Wind Power Density (W/m2)
January	4.9	24.4	230.1
February	4.5	22.7	127.3
March	4.8	23.9	229.6
April	3.2	19.6	60.3
May	3.9	20	176.1
June	3.5	15.1	165.6
July	3.8	23.7	226.7
August	3.5	17.2	166.1
September	4.8	16.6	114.8
October	4.3	16.5	109.3
November	4.8	16.4	175.3
December	5.1	17.3	178.9
Annual	4.2	24.4	1960.1

Table 4a - *Mean and maximum wind speed & power density values for Gaza City, based on real monthly values. Alaydi. J [2011].*



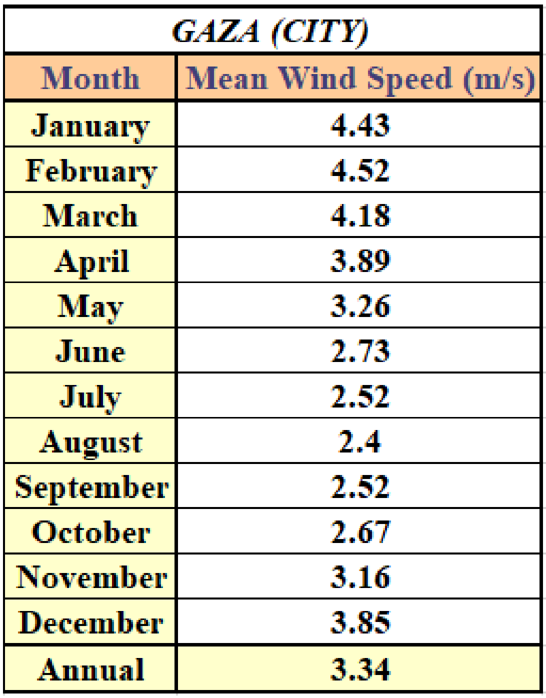
RAFAH (INLAND)			
Month	Mean Wind Speed (m/s)	Max. Wind Speed (m/s)	Wind Power Density (W/m2)
January	4.4	10.5	123.1
February	4.9	15.2	227.8
March	3.1	19.2	78.7
April	2.76	8.6	48.1
May	2.52	9.7	41.6
June	2.23	8.6	30.5
July	1.83	7	19.6
August	2.2	10.5	28.1
September	2.23	12.2	29.1
October	2.64	16.5	34.3
November	3.23	16.2	64.1
December	4.05	20.1	110.4
Annual	3.01	20.1	835.4

Table 4b - *Mean and maximum wind speed & power density values for inland Rafah, based on real monthly values. Alaydi. J [2011].*

This data in Tables 4a and 4b displays that the strongest wind resource is available in the Gaza City site over the Rafah measurement site, in terms of all wind variables. The mean annual wind speed in Gaza City is 4.2 m/s compared to the 3.01 m/s of the Rafah site, which correlates as higher peaking values and a 2.4x higher wind power density at the former. This matches up with the preliminary analysis results which revealed that coastal sites have a higher wind resource available which can likely be attributed to sea breeze and minimal surface roughness.

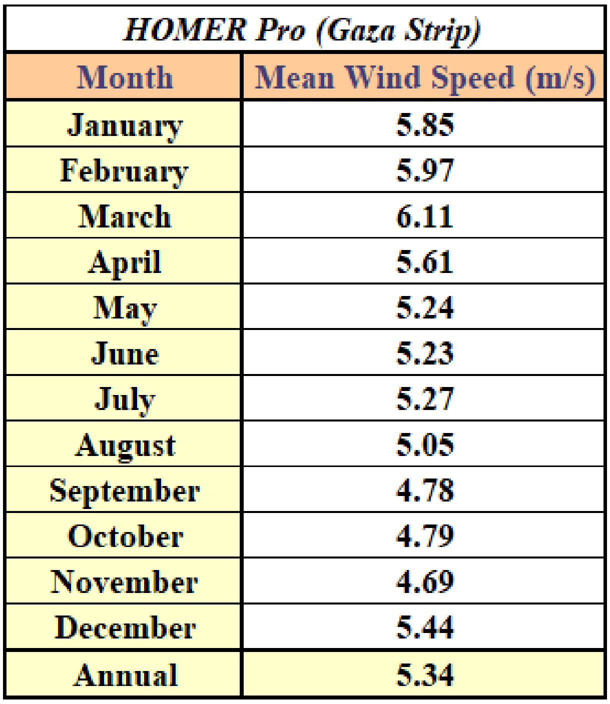
There are also seasonal variations observed with regard to wind resource potential, as during the winter months the wind profile for both sites align with higher values as opposed to during the summer months, with the annual mean wind speed value falling within this transition zone. Meij. A et al also present wind speed for Gaza City in their study, using the numerical prediction modelling tool- Advanced Research WRF- and their findings are presented in Table 5a below for a reference period of 2000 – 2011 and an annual standard deviation of 1.87 m/s.

In addition to this, the modelling software Homer Pro was consulted for purposes of obtaining the measured resource potential from the inbuilt resource databases (NASA Surface meteorology), and the results are displayed in Table 5b (it was observed through trial and error that the Homer results are homogenous for the whole Strip).



GAZA (CITY)	
Month	**Mean Wind Speed (m/s)**
January	**4.43**
February	**4.52**
March	**4.18**
April	**3.89**
May	**3.26**
June	**2.73**
July	**2.52**
August	**2.4**
September	**2.52**
October	**2.67**
November	**3.16**
December	**3.85**
Annual	**3.34**

Table 5a- *Mean wind speed values for Gaza City by month, data recorded from 2000 – 2011. Data derived from Meij. A et al; 2016*



HOMER Pro (Gaza Strip)	
Month	**Mean Wind Speed (m/s)**
January	**5.85**
February	**5.97**
March	**6.11**
April	**5.61**
May	**5.24**
June	**5.23**
July	**5.27**
August	**5.05**
September	**4.78**
October	**4.79**
November	**4.69**
December	**5.44**
Annual	**5.34**

Table 5b- *Mean wind speed values for Gaza Strip region by month, data recorded 1983-1993. Data derived from Homer Pro software weather files, NASA Surface meteorology.*

Again, it can be observed from Table 5a that there are higher recorded wind speeds during the winter months than during the summer months, yet the mean wind speed is lower than that observed from the study performed by Alaydi. J by 0.86 m/s on an annual basis. When accounting for the annual standard deviation of 1.87 m/s provided, this places the Meij. A et al dataset within the data range observed by Alaydi. J.

The Homer Pro dataset in Table 5b places average wind speeds at a higher range than any of the other datasets, with a mean annual value of 5.34 m/s. It is decided that this is due to the broad spatial measurement pattern which Homer appears to utilise, which does not account for the geographical difference inherent upon this smaller analysis scale.

Accounting should also be performed for the measured mean wind speeds for the five governorates of the Strip found from the preliminary analysis. These are as follows from Table 2: North Gaza- 4.75 m/s, Gaza- 4.9 m/s, Deir-al-Balah- 4.95 m/s, Khan Yunis- 4.93 m/s, and Rafah- 5.02 m/s.

It therefore means the mean wind speed for Gaza City can be said to vary from a minimum mean value of 2.4 m/s – 3.5 m/s, through an average value of 3.34 m/s – 5.34 m/s and a maximum mean value of 4.5 – 6.11 m/s. The combined annual mean of the three detailed datasets for Gaza City (including the regional Homer Pro data yet excluding the preliminary) results in a wind speed of 4.3 m/s (154.6/36).

The mean wind speed for Gaza in the preliminary analysis is higher than the calculated combined mean for Gaza City, but closer to the measured value obtained by both Alaydi. J and Homer Pro. Hence, when assessing a combined mean, priority bias should be given to the Alaydi. J dataset, with minimal bias given to the Meij. A et al dataset. For purposes of forecasting the potential for the entire Strip, due to the unavailability of full *representative* regional data, the coastal regions will be prioritised for wind measurement and prediction alongside the existing Gaza Strip datasets.

The framework advocates for the MCP method to be used to predict wind resource when limited/short-term data is available for a site but there is long-term data available for another site with the same characteristics in the local vicinity. In this case study context, there are multiple ‘sites’ as the estimation for each coastal sub-region in the five governorates is desired.

It is concluded that for the purposes of this study, there is too little data available to estimate wind potential across all coastal sub-regions of the Strip, and therefore an estimated prediction based on the substantial data available for the Gaza Governorate sub-region, will be made for the Strip as a whole. This will be in a similar fashion to the methodology used for the solar resource prediction and is outlined in Table 6. The automatic Homer Pro dataset was excluded from here on, due to figures falling out with the accepted range and hence skewing results.

The initial full datasets for Gaza Governorate (Gaza City) were integrated for all input authors-Alaydi. J, Meij. A, and the preliminary resource data, minus Homer Pro, to find the combined average, which was 4.15 m/s. The datapoints obtained from preliminary resource data and/or the detailed author input were then combined for each governorate and combined to find an average over these two datasets. Subsequently, the combined mean of these averages was obtained, minus the value for Gaza Governorate, and the combined value for Gaza was subtracted from the former.

This yielded the difference by which the other averages for each governorate should be altered by. Finally, this results in adjusted values for each governorate and also the combined average mean wind speed value for the Strip, which was calculated at 4.15 m/s. This result is in line with the average and lies within the average range value found by the previous authors. It is observable that there is a higher wind resource with progression South in line with the preliminary findings.

Mean Wind Speed (m/s)	N. Gaza	Gaza	Deir-al-Balah	Khan Yunis	Rafah	STRIP	
Prelim	4.75	4.9	4.95	4.93	5.02	**4.91**	
Alaydi	~	4.2	~	~	~	~	
Meij	~	3.34	~	~	~	~	
Gov. Averages	*4.75*	*4.15*	*4.95*	*4.93*	*5.02*	~	Combined Mean - Gaza
Total Averages	4.75	4.15	4.95	4.93	5.02	**4.76**	**4.913**
Adjusted (-A)	**3.99**	**4.15**	**4.19**	**4.17**	**4.26**	**4.15**	Diff w/ Gaza (A)
							0.763

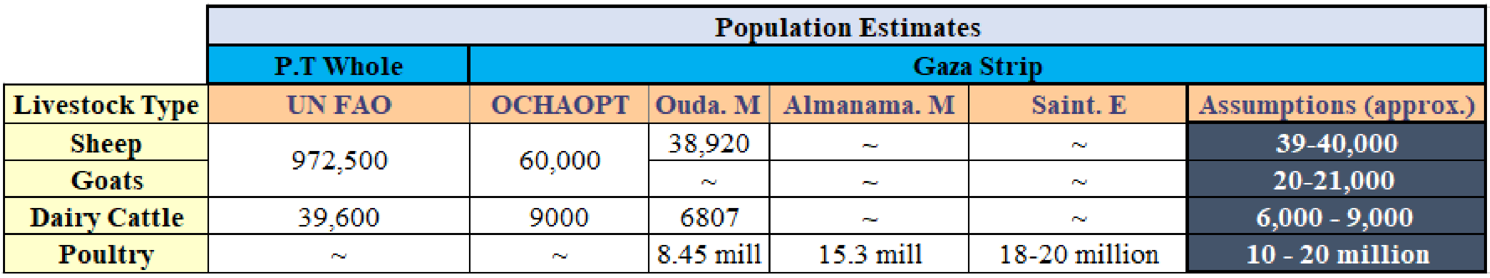
Table 6- *Wind speed results table, listed by governorate and Strip total, using methodology outlined above.*

Biogas

As mentioned earlier, biogas potential is determined by several factors within the country/area of interest, which in this case is the Gaza Strip. Availability of organic matter as a viable feedstock is a crucial factor, alongside the availability of a secure water supply, and the careful control of physical operational parameters such as temperature, pH and C:N ratios. This requires reasonably extensive surveys or estimations of the organic feedstock resource available, and in the case of the Gaza Strip several authors provide such information. From this it is possible to put together a profile on the total available feedstock in terms of livestock waste, crop wastes and OMSW.

Livestock

In a report by the UN Food & Agriculture Association [2018], the livestock profile of the Palestinian Territories as a whole consists of sheep, goats, dairy cattle and poultry (chicken). The approximate livestock population from several authors is displayed in Table 7 [UN FAO, 2018; OCHAOPT, 2017; Ouda. M, 2010; Almanama. M., 2011; Saint. E, 2013].



	Population Estimates					
	P.T Whole	Gaza Strip				
Livestock Type	**UN FAO**	**OCHAOPT**	**Ouda. M**	**Almanama. M**	**Saint. E**	**Assumptions (approx.)**
Sheep	972,500	60,000	38,920	~	~	**39-40,000**
Goats			~	~	~	**20-21,000**
Dairy Cattle	39,600	9000	6807	~	~	**6,000 - 9,000**
Poultry	~	~	8.45 mill	15.3 mill	18-20 million	**10 - 20 million**

Table 7- *Livestock Population estimates and assumed population, Gaza Strip. Data derived from authors credited above.*

As can be observed from Table 7, there is a sizeable population of various livestock within the Gaza Strip, for the relatively little agricultural land available (urban farming is predominant). Along with this data, the Palestinian Central Bureau of Statistics states that the population of **slaughtered** livestock in 2017 was approximately 7.3 million poultry birds, 37,000 cattle, 41,000 sheep and 4000 goats.

It must be noted however that the figures for cattle are high due to the large-scale annual import of cows for the Muslim holy festival of Eid-al-Adha, which go straight to slaughterhouses and hence are not viable for manure harvesting. The sheep population concurs with the Table 7 findings, alongside the lower figure for poultry. The number of goats will be lowered to 10,000 to account for the new findings.

Ouda. M presents figures for Livestock Units (LSU) on available daily biogas yield (m^3) from the various animal manures outlined, and these are as stated: 0.75 m^3/day for individual cattle, 0.075 m^3/day for individual sheep, and 0.005 m^3/day for individual poultry-birds (chicken). One LSU equals 500kg live weight of livestock, with this being equal to one cow, 8 sheep or 250 hens, and the above population figures have been adjusted to account for this.

Adeoti. O, et al [2014] details minimum livestock biogas yield values for livestock in a Nigerian study, stating 0.078 m^3/day for cattle, goat and sheep as 0.031 m^3/day, and poultry as 0.00154 m^3/day. This gives the impression that small ruminants on average produce a relatively equal amount of biogas from their manure, and so goats shall be treated as having an equal m^3/day production factor to sheep in this report.

Finally, Guo. L [2010] presents findings on animal manure production per animal, and relevant biogas yields per animal, in a Chinese study example. The author only concentrates on dairy cattle and poultry, omitting small ruminants. They find an individual cow produces around 25-30 kg fresh manure/day, yielding 0.83-1.25 m^3/animal/day, and individual poultry birds produces approximately 0.1kg manure/day, at 0.011 m^3/animal/day average biogas production.

Biogas production yields from livestock manure will be dependent on feed types, climatic conditions and other parameters, hence will be largely individual to the area of study. However, average values for biogas production from each individual livestock will be presented here as an aggregated average value of the case-study author examples, focusing on the Adeoti. O, Ouda. M and Guo. L findings. These biogas production values are as follows for the Gaza Strip:

- *Cattle*- 0.50 – 0.80 m^3biogas/animal/day.
- *Sheep*- 0.030 – 0.075 m^3biogas/animal/day.
- *Goats*- 0.030 – 0.075 m^3biogas/animal/day.
- *Poultry*- 0.0050 – 0.0100 m^3biogas/animal/day.

Using these figures, it is possible to estimate the total biogas yield from the available livestock within the Gaza Strip, both on an individual animal and then aggregate basis.

With an estimated total population of 39,000 – 40,000 sheep, with each animal producing 0.030- 0.075 m^3/day of biogas, this results in 1100 - 3000 m^3/day of available biogas resource; and 300-750 m^3/day for the 10,000 strong goat population. The following is also true for dairy cattle, at 3750 – 6000 m^3/day, and poultry at 50,000 – 200,000 m^3/day (averaged at 125,000 m^3/day).

This results in a combined, unadjusted daily livestock manure total potential of 55,000 - 135,000 m^3/day. Afazeli. H [2014] also suggests using a availability correction for manure, to account for the ease of manure collection from the total livestock populace in practice. The author used respective corrections of 50%, 13% and 99% to account for cattle, small ruminants and poultry respectively. This can only be achieved as a value for the cattle and poultry as these are the only manure volumes which can be estimated based on the Guo. L findings, however, the average biogas yield values presented are an average of different authors including the Gaza-Strip specific Ouda. M findings.

Therefore, it is decided to use an average collection factor of 85% across all livestock decided by the urban nature of the farming environment with lack of large, open fields- making it easier to collect the majority of manure. When applied to the above findings, this results in an adjusted total livestock manure-derived biogas potential of 47,000 – 100,000 m^3/day.

Crops and agricultural residues

According to the most recent PCBS reports dated 2010-2011, the Gaza Strip has a total cultivated field crop area of 24,500 dunams or just under 10 sq. Mi/2450 ha, producing 7883 metric tonnes of field crops in that survey year. In addition to this, the Strip also has 256,000 olive trees and 323,000 other horticultural trees growing over an area of 6.3 sq. Mi/1630 ha, alongside 13 sq. Mi/ 3300 ha of vegetables, producing 57,500 metric tonnes of produce.

These figures are from the year dated 2010-2011 and hence are slightly out of date, however it can be observed from past trends in the historical data that the total cultivated area for each respective crop hovers around similar figures to that stated above. Naturally however, with increasing population growth rates and the need for land, there may be slight pressure on agricultural land to be urbanised, or to increase productivity rates.

According to a report by the Applied Research Institute [2015], the main agricultural products grown and consumed within the P.T (entity, Gaza-specific unknown) are wheat, potatoes and onions, tomatoes, cucumbers, eggplants, squash, green beans, paprika, guava, grapes, dates, almonds, olives and citrus fruits. There is a surplus of agricultural product for tomato, cucumber, eggplant, green almond, grape and olive oil, thus signifying that these products are available for potential use as feedstock, although surplus food stores for times of food insecurity are also a factor of consideration. Therefore, in the context of the Gaza Strip with frequent political instability affecting food prices and supply, priority should be given to using agricultural residues/wastes for use as A.D feedstock.

There is minimal data available on agricultural wastes produced in the Gaza Strip, although secondary data [UNDP article] states that for every acre of land planted with agricultural produce (vegetables and field crops) then there is almost one tonne of agricultural waste produced, presumably on an annual crop rotation basis. An FAO report [2011] states that in developing regions there is the greatest waste of fruits, vegetables, oils and pulses, in the cultivation and harvesting stages of the lifecycle (as opposed to consumer waste), due to the harsh conditions and weather often experienced.

Using the secondary data figure provided of approximately one tonne/acre, this was quantified as 700kg/acre or 0.7 tonnes/acre/yr and transferred to the gathered figures for crop production. For the 2450 ha of field crops, this translates as 6000 acres and 4200 tonnes/yr waste (compared to the 7883 tonnes/yr harvested figure); and for the 3300 ha of vegetables, this equates to 8150 acres and 5700 tonnes/yr of waste (compared to the 57,500 tonnes/yr harvested). Combined this results in an approximate estimated annual agricultural wastes of 9900 tonnes/yr of wheat, potatoes, onions and assorted vegetables/fruit.

It is assumed that field crop waste manifests as wheat straw, and potato, onion and other vegetable/fruit waste resembles traditional mixed food waste upon utilisation as A.D. A study by Patil. V & Deshmukh. H [2015] states that several authors measure average biogas yields from vegetable waste at approximately 0.12-0.4 m^3biogas/kg input (120-400 m^3/tonne).

OMSW & Sewage

The Gaza Strip has a relatively poor waste management infrastructure [Qomboz. Y & Busch. I; date unknown, & Nassar. A; 2015], due in part to political wrangling and uncertainty, underinvestment, lack of space and high population growth. The lack of space is a pertinent issue for landfill and generic solid waste disposal, with relatively few sites currently dealing with waste disposal, after unlicensed dumping grounds were cracked down upon according to Qomboz & Busch.

In addition to this, the municipal waste stream coming from domestic, industrial and commercial operations in the Strip has a high proportion of organic waste within its composition. Qomboz & Busch state organic waste (OMSW) as composing 67% of the total waste stream, whilst Nassar. A stipulates OMSW at a range of 40-65% of total waste. Organic matter is usually food waste, either domestic-sourced or commercial/industrial derived, and upon uncontrolled decomposition contributes to GHG emissions and public health risks.

The total volume of municipal solid waste in the Gaza Strip suffers from low statistical data, however Qomboz & Busch mention a 2000 study in which waste generation is estimated as $\leq$1kg/person/day contributing to 300,000 tonnes /year. The majority of this stems from Gaza Governorate, which contains the largest population share, whilst Rafah and Northern Gaza governorates are the lowest. When combined with figures on relative organic waste composition, this yields OMSW preliminary arisings as approximately 195,000 tonnes/yr at 65% total waste stream composition. This will be treated as the lower figure for potential.

A higher potential figure is derived from the 2015 Nasser. A study, who presents total domestic waste arisings as double the original lower figure, at 600,000 tonnes/yr for the time period 2010-2015 approx., which if considering an average of 65% organic component, generates 390,000 tonnes/yr OMSW arisings. The author presents future figures for 2040 in which they estimate that the projected additional 1.5 million people will result in total waste rising to 1.3 million tonnes/yr, and 800,000 tonnes/yr of OMSW. For the year of 2020 it is presumed that the higher limit, and likely the most accurate estimation of OMSW potential is 600,000 – 800,000 tonnes/yr due to the lack of concrete figures, and hence on average 700,000 tonnes/yr of OMSW.

According to Curry. N & Pillay. P [2012], food waste (being the primary component of OMSW) can generate 367m^3biogas/dry tonne with 65% methane content (240m^3methane/tonne). Additionally, the C:N ratio of food waste was rated at 24.8 by Manonmani. P, et al [2017], with the acceptable optimum range being 16-25.

In addition to OMSW, the sewage network in the Strip is poorly maintained to necessary operational capacity for ensuring human health, with frequent pollution leakage into the Mediterranean Sea [Afifi. S, et al; above]. About 30% of the population do not even have access to sewage facilities also, posing a waste problem which could be addressed through the use of A.D to produce valuable biogas and organic fertiliser.

The author estimates that 24 million - 40 million m^3 of sewage and grey water is produced annually in the region. Estimated biogas yields from wastewater with high proportions of sewage sludge are provided by Bachmann. N [2015]. Primary/ raw sewage sludge is the most likely state for sewage to be found in upon collection for A.D and can yield *methane* at 315-400 normal m^3/tonne of organic dry matter. This assumes a methane percentage of 65%, so hence total biogas production per dry tonne will likely be 480-615 m^3/tonne.

- *Demand and technical analysis of renewables potential and integration (modelling).*

The next stage in the application of the framework to the Gaza Strip comes with the modelling of the available resource, its translation to power provision within a heterogeneous electricity network, and the identification of the best fit to meet scheduled demand. As stipulated above, Homer Pro software is the optimal software tool to use to assess these factors. The input parameters to the software require adjusting from default settings, to suit the individual geographic location of the Gaza Strip and to account for the available resource discussed above.

Homer Pro examines optimal supply-demand fit by measuring the energy contribution of aggregated RES devices connected to a load, over an adjustable timescale up to 1 year. The software input parameters include the electric load to be met, the renewable resources available to meet this load, and the renewable energy devices which harness the available resources. Allowance is made for manual manipulation of these input parameters to suit user preference; this was performed initially, to adjust to the available resources within the Strip and will be discussed in further detail momentarily.

For the purpose of this study, the modelling will examine the implementation of RES to meet the loads at village-scale applications, and town-scale settlements. Therefore, this means that individual load profiles will be applicable to each scale and will require respective modelling of attached RES supply components/devices. To represent the effect of the framework at a two-fold scale within the Strip, the village of **Al-Fukhkhari in Khan Yunis Governorate**, and the town of **Maghazi (refugee camp) in Deir-al-Balah Governorate** were selected.

It is necessary to develop load profiles for each settlement of interest, so as supply can be effectively matched to demand within Homer Pro. Each of the two settlements will have varying demand magnitudes and factors to consider when developing load profiles due to the varying sizes and nature of the load.

Al-Fukhkari (Village)

Al-Fukhkari is a medium-sized village of approximately 7,000 inhabitants in the year 2019-2020, according to data from the PCBS. It is located in Khan Yunis Governorate approximately 1.3 miles NW from the Israeli border, 3.8 miles SSE of Khan Yunis city, and 5 miles East of Rafah city; within the C- inland border region of Figures 3a & 3b. The village is located in a fairly rural area in the context of the Gaza Strip, surrounded by a significant area of fields and agricultural land. Figure 7a (Appendix) displays an aerial view of the village within its local surroundings, circled in red.

According to Figure 7b (Appendix), there are approximately 150-160 buildings located within the highlighted area- presumably 90% of these are housing units due to the rural village location. It is presumed that the electoral count includes buildings within the local zone, instead of directly within the village itself and so hence to contain the estimated reduced population of the village (i.e. according to PCBS statistics and minus outliers from the centre) of 5,000 residents, it was presumed that the majority of housing units were of the apartment style.

This falls in line with the approximately 60:40 apartment to house ratio revealed by PCBS statistics for the year 2017, and hence means that there are on average 30 people living in each housing unit/complex. With accounting for the average household size in the Strip of 6.50 +/- 2, presented by El Kishawi. R et al [2015], this would equal approximately 4-5 floors per apartment complex.

Data trends from several authors [Shammaleh. N; 2012, & Elaydi. H & Qaraa. Z; 2013] suggest that the residential sector within the Strip consumes between 60-75% of the total electricity supply requirements, with the remainder being utilised by the industrial and then commercial sectors by order of magnitude. While data on electrical demand requirements for Al-Fukhkhari village is not explicitly available, Shammaleh. N provides data on the villages of Um Al-Nasser and Al- Mussadar. A grid connection to Al-Fukhkhari is presumed in the modelling, although the validity of this assumption is unknown.

The author states that in the year 2010, the average monthly electricity consumption for Um Al-Nasser was 190 kWh/household/month, whilst Al-Mussadar was 490 kWh/household/month with household describing the subscribing payer for the connection; and with this comparing to 200 kWh/household/month in 2006 [Ouda. M] & PCBS figures for 2015 (265 kWh/household/month Strip average). The reasoning for such a high electricity consumption per household is assumed to be due to the non-payment of bills common place in the Gaza Strip, thus equalling higher levels of unrestrained usage.

Therefore, accounting for the effect of time on growing electricity demand per household and the greater bias towards a lower number from 2 of 3 authors, 250 kWh/household/month was chosen to be the average unit of measurement used to determine the load profile of Al-Fukhkhari village. This equates approximately to a daily total of 8 kWh/household/day.

Considering a resource consuming population of 5,000 people and an average of 6.5 persons/household, this equates to a total approximate number of 780 consuming/subscribing households in the village. At 99.9% electricity availability, this equals 6240 kWh/day, 187,000 kWh/month, and 2246 MWh/year for the residential sector of the village. With comparison to both reference villages, their annual consumption was rated at 1608 MWh/yr (Al-Mussadar) & 600,000 kWh/yr (Um Al-Nasser); which correlates well with the higher subscription number for Al-Fukhkhari and the resultant annual figure. It must be noted though that there is uncertainty with the Shammaleh. N figures due to the measurement being by subscription, rather than by household.

To consider the total electricity demand for the village, aerial maps were examined to discern the level of industrial and non-residential electrical activity in place. It was discovered that there is a mosque in the western end, and scattered farms through-out the core of the village (approximately two). This differs from region-wide residential/commercial/industrial electricity consumption variations (indicated above) but is suggested to be the manifestation of such at village level. The main electricity demand for the mosque was predicted to be lighting and electric heating.

Therefore, with user capacity factored in, this figure was estimated at 25% more than a typical household and predicted at 10 kWh/day. For the farm holdings, the primary electricity demand outside of household use was determined to be for irrigation purposes and small machinery- this is predicted to contribute up to 5 kWh/day atop normal household use, based on average irrigation pump/ machinery size of 1-2 kW and 1-2.5 hours usage. Therefore, a farm holding would total approximately 13 kWh/day. Combined, the total village electricity load is estimated at 6280 kWh/day, 188,500 kWh/month and 2260 MWh/yr, with a 1.59 MW average maximum daily load. The technical breakdown of load is presented in Table 8 (Appendix).

Maghazi (Refugee Camp)

Maghazi is a well-established, town-scale refugee camp of approximately 30,000 inhabitants as of the year 2019-2020, according to PCBS statistics. It is located in Deir-al-Balah Governorate in the central Gaza Strip, again approx. 1.3 miles NW from the Israeli border, 2 miles ENE of Deir-al-Balah city, and roughly the same distance due South of Nuseirat Camp; mostly located within the B- central region of Figures 3a & 3b. Maghazi is located again in a relatively rural area, for the context of the Strip, with open field space to the North-East, South-East and South, but is located adjacent to the village of Al-Mussadar and Az-Zawayda town on other cardinal fronts.

Figure 8a (Appendix) displays an aerial image of the camp, circled in red. Due to the larger population and area than at village-scale, it was decided that a different method should be adopted to assess number of buildings and hence domestic/commercial/industrial demand. The area of the camp was digitally measured within ArcMap at an initial 1.0 km$^{2/}$0.38 sq. Mi, including parks and open land; however, when adjusted to account for empty land, the figure drops to 0.77 km^{2}/ 0.30 sq. Mi.

An easily definable sub-section (e.g. a neighbourhood block) of this was separated on the map and measured at 0.03 sq. Mi. The buildings in this 0.03 sq. Mi sub-section were counted using street map perspective on ArcMap (Figure 8b), and this was found to be 175 buildings. Using this representative urban area sub-section, the total number of buildings within the camp was estimated at a lower bound of 1750. To account for variations in building density, this was expressed as 1750 +/- 150 buildings, to give a range of 1600-1900 buildings; approximately 10 times the level found within Al-Fukhkhari.

It is visible from both Figures 8a & 8b that there is a higher level of non-residential properties within Maghazi than was found previously within Al-Fukhkhari including at least one medium-sized healthcare facility. This can be reinforced by findings from UNRWA, who report that there is a health centre, five school buildings (8 schools- two are single shift, 6 are double shift), and a few governmental offices.

Digital map analysis reveals that there are also at least 5 mosques, two factories, and a few shops in an around the camp. As the healthcare facility was not included in the initial area calculation of the camp and due to the small area occupied by the factories, mosques and shops, using such data it could be assumed that there are on average 1750 housing units, 2 industrial units, and 12 commercial/other units present. To first account for the housing units, if 30,000 residents live within the camp, then this equals an average of 16-19 residents per housing unit (based on Strip average of 6.5 people/household), equating to 2 – 3 floors (approx. 3) per complex.

Therefore, with 30,000 residents, and an average of 6.5 people/household, this equates to 4600 consuming/subscribing households within the camp (due to 99.9% electricity availability within the Strip *in terms of homes connected*- [PCBS]). It was decided both for the sake of simplicity, and also with the logic that residential demand would change with magnitude but not significantly with regards to rural-urban appliance energy consumption/prevalence; to keep residential consumption the same at both scales. If village and town-scale electricity consumption per household is assumed to be constant, then the same figure of 250 kWh/household/month would be used to determine the load profile for Maghazi camp/town- this again approximating to 8 kWh/household/day.

Using this similar household consumption figure as village-scale, over 4600 households, electricity demand for the residential sector would be 36,800 kWh/day, 1104 MWh/month, and 13,250 MWh/yr or 13.25 GWh/yr. This approximately correlates with the findings of Shammaleh. N for a similarly sized town-scale settlement (Kaser Elhakem, Gaza- 1200 subscriptions) which had annual consumption of 7700 MWh/yr, approximately half of the calculated figure for Maghazi.

To consider the total electricity demand of the camp, it was necessary to calculate the approximate demand profiles for the non-residential consumer components. It was presumed that individual residential and mosque load profiles would remain the same. The average load profile for a shop would comprise lighting, cooling and general electrical load; the school would require lighting, cooling, general electric, including computers if available; the health centre would require lighting, cooling, electricity for appliances, and general electrics; and the average factory would require lighting, cooling and heavy machinery load.

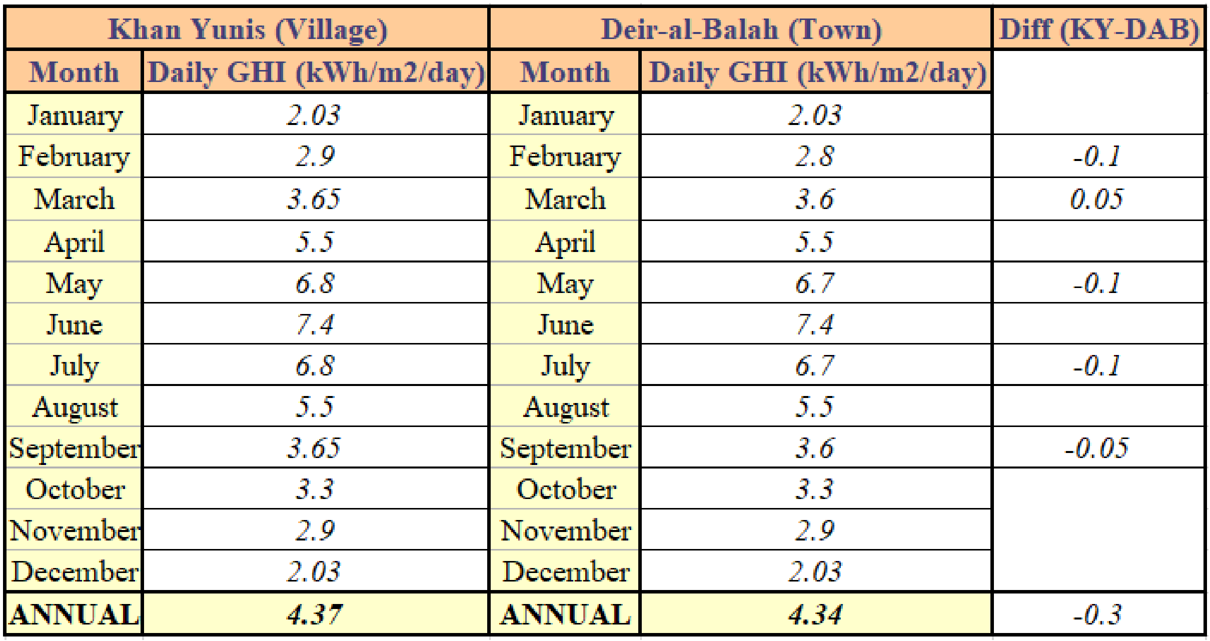
The technical breakdown of these load profiles is displayed in full in Table 9 (Appendix). It should be noted that to account for the school usage patterns (some with double shifts, some single shift), the usage/day was averaged over the five buildings at 10hrs. Therefore, the total daily consumption demand for Maghazi is calculated to be 37.3 MWh, monthly at 1119 MWh, and an annual consumption of 13.42 GWh. Average maximum load is estimated at 119.4 MW, with the largest share (61.3%) drawn by the two factories.

Homer input parameters for the available solar resource include solar GHI and DNI datasets- these can be automatically downloaded for the region, or manually inserted. For manual insertion, Homer requires monthly averages (kWh/m^2/day), which cumulatively yield an annual average. For the purposes of manual insertion, the data was adjusted around the calculated annual mean for both Khan Yunis and Deir-al-Balah governorates by anchoring the respective means around the calculated GHI for the summer & winter solstices, & equinox for North Gaza Governorate.

This assumes that there will not be a substantial difference in output from movement within the same 0.3 of a degree of latitude. Through a trial-and-error approach, the annual mean was obtained in this manner within the software. The monthly GHI input data to Homer Pro is displayed in Table 10a below. The software however does not require solar DNI values for flat-plate PV calculations, with this only being necessary for concentrating solar power (CSP) systems, which are not to be proposed within this study due to the large area required.

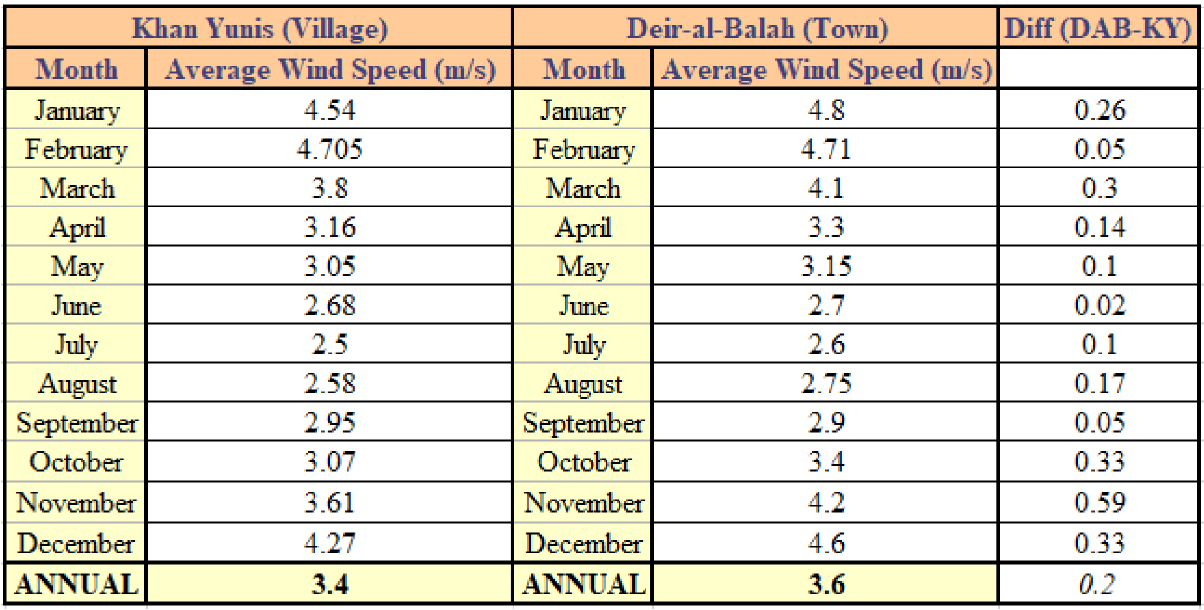
The wind resource input parameters dictate inputs of average wind-speed (m/s) on a monthly basis, providing an annual average windspeed alongside. This can be auto generated by Homer or again manually inserted. To manually input the windspeed figures on a monthly basis for both governorates of interest, a similar process was followed as to the solar resource values, with the annual mean for each governorate being generated through a trial-and-error approach and using the adjusted monthly wind speed profiles from Figures 4a – 5a.

A combined average was taken for the Alaydi datasets (Gaza & Rafah), and another for the Rafah and the Meiji Gaza dataset, before finally another average was taken of these generated averages. This generated an approximate value for the geographic location of both governorates (being relatively nearby each other), and from here each was adjusted slightly to account for higher or lower wind speeds in their respective locations (Deir-al-Balah- higher; Khan Yunis- lower) using a factor of 0.20 m/s found in the preliminary analysis. The resultant monthly windspeed data into Homer Pro is available in Table 10b below.



Khan Yunis (Village)		Deir-al-Balah (Town)		Diff (KY-DAB)
Month	**Daily GHI (kWh/m2/day)**	**Month**	**Daily GHI (kWh/m2/day)**	
January	*2.03*	January	*2.03*	
February	*2.9*	February	*2.8*	*-0.1*
March	*3.65*	March	*3.6*	*0.05*
April	*5.5*	April	*5.5*	
May	*6.8*	May	*6.7*	*-0.1*
June	*7.4*	June	*7.4*	
July	*6.8*	July	*6.7*	*-0.1*
August	*5.5*	August	*5.5*	
September	*3.65*	September	*3.6*	*-0.05*
October	*3.3*	October	*3.3*	
November	*2.9*	November	*2.9*	
December	*2.03*	December	*2.03*	
ANNUAL	***4.37***	**ANNUAL**	***4.34***	*-0.3*

Table 10a- *Daily GHI (kWh/m2/day) Homer Pro input values for Khan Yunis & Deir-al-Balah governorates, with calculated annual mean and adjusted monthly values.*



Khan Yunis (Village)		Deir-al-Balah (Town)		Diff (DAB-KY)
Month	**Average Wind Speed (m/s)**	**Month**	**Average Wind Speed (m/s)**	
January	4.54	January	4.8	0.26
February	4.705	February	4.71	0.05
March	3.8	March	4.1	0.3
April	3.16	April	3.3	0.14
May	3.05	May	3.15	0.1
June	2.68	June	2.7	0.02
July	2.5	July	2.6	0.1
August	2.58	August	2.75	0.17
September	2.95	September	2.9	0.05
October	3.07	October	3.4	0.33
November	3.61	November	4.2	0.59
December	4.27	December	4.6	0.33
ANNUAL	**3.4**	**ANNUAL**	**3.6**	*0.2*

Table 10b- *Average monthly wind speed (m/s) Homer Pro input values for Khan Yunis & Deir-al-Balah governorates, with calculated annual mean and adjusted monthly values.*

Finally, for the A.D resource input, a slightly different approach was taken. Homer Pro allows for the addition of custom generator components to the simulated electricity network, and in this case, it was necessary to calculate a preliminary electrical base output of an A.D system with attached biogas engines. This required generator sizing through the use of an A.D calculator, which converts organic feedstocks into an electrical output, so in this case the Andersons/NNFCC Anaerobic Digestion Economic Assessment Tool Version 2.2 [2010] was used for this purpose. Preliminary output can be adjusted later on to suit demand requirements.

This requires application at both levels of study, village and town-scale, both of which will yield different levels of organic feedstock. It was necessary to calculate how much of the available national potential resource could be utilised at these different scales. For Al-Fukhkhari village, there is an approximate area of 90 ha of fields to the SE and 70 ha to the NW. Presuming that energy crops are not specifically grown, due to the intense competition for land area inherent to the Gaza Strip and its contested area, field crop waste could be processed from this area.

At 0.7 tonnes/acre/yr, this would equal approximately 280 tonnes/yr of crop waste from the surrounding fields, supposing 100% collection rate and ownership rights to this area. This will be adjusted to 80% to reflect collection efficiency and village-field ownership rights. Presuming this adjusted 225 tonnes/yr is split between wheat straw and vegetable wastes in an equal collection manner, this would equal 112.5 tonnes of each.

The A.D calculator allows either manual feedstock input parameter manipulation, or auto-generated figures, and hence suggests wheat straw has a biogas yield of 292 m^3/tonne, which would generate approx. 33,000 m^3 biogas/yr. Using the previous Patil. V & Deshmukh. H figures of 120-400 m^3/tonne from vegetable wastes, this would yield (at 260m^3/tonne) 29,000 m^{3}biogas/yr. Combined, field crop waste could generate 62,000 m^{3}biogas/yr, delivered at 9 tonnes/month (18 tonnes/month combined) feedstock allocation.

According to PCBS statistics on agricultural livestock count for the individual governorates, Khan Yunis (governorate) had 4,600 cattle, 36 sheep and 105 goats slaughtered in the year 2017. Data is also given on the total number slaughtered within the Gaza Strip (19,700), which is sizeably higher by approx. 10,000 heads (45%) than that found earlier by authors. Again, it is assumed that this includes imported cattle for religious sacrifice purposes and does not represent the total annually dwelling livestock population in the Strip or governorates.

To account for this, the published cattle population for Khan Yunis was reduced by a factor of 30-45%, to attain a new population of 2530-3220 (2875 average); sheep and goats are relatively unaffected by this. Due to the unavailability of village-specific livestock statistics, a rudimentary methodology of digitally mapping the ratio difference in area between the agricultural land of Khan Yunis (approximately 30 sq./ Mi) to the agricultural area surrounding Al-Fukhkhari (approximately 1 sq. Mi) was used.

This 30:1 ratio was applied to the estimated cattle population of 2875, and the village available livestock was observed to be approx. 95 cows. The number of other livestock is negligible at this scale. Using a cattle population of 95 and biogas production as 0.50-0.80 m^3/animal/day, at 85% manure collection factor, this results in 40-65 m^3/day. Over an annual period, this would result in 14,600-24,000 m^3 of biogas produced. Using the A.D calculator, at 85% collection rate, and 27kg manure/cattle/day, this equals a total cattle population manure production of 2180 kg/day and 795,700 kg/yr. (795.7 tonnes/yr.), which yields 28,600 m^3/yr. biogas, bringing the combined production total to 90,500 m^3biogas/yr., alongside crop wastes.

To estimate the OMSW A.D feedstock potential of Al-Fukhkhari, a solid waste generation/capita figure of 0.35-1.0 kg/day was used in accordance with findings [Ramachandra. T, et al; 2018, & Singh. A; 2019]. When considering the population of the village whose waste could contribute to a potential A.D plant, waste management must be considered. So hence the village waste would be gathered as an entity of the 7000 residents, rather than the 5000 in the village proper for which the demand profile accounts for.

This results in an average total of 2450-7000 (4725 av.) kg/day collection potential, assuming an effective waste management system is in place (discussed later). Assuming an organic component composition rating of 65% of the total waste stream, this results in approx. 3070 kg/day, and 1121 tonnes/yr. of OMSW. Assuming this composes majority vegetable waste, this contributes 290,000 m^3biogas/yr. according to the A.D calculator, using the same biogas yield per tonne as for crop waste. This increases total feedstock biogas production capacity to 380,000 m^3/yr.

The final feedstock for consideration to the A.D potential is human sewage, collected from the village. Assuming that there is a sewage system in place (energy potential is a major reason for investment in upgrades if not), sewage feedstock potential can be calculated from production per capita village population. Using an approximate value of 0.04-0.09 kg dry matter/capita/day (0.065 average) [EEA; 1997 & Karagiannidis. A, et al; 2011], this yields 325-455 kg/day and

118 – 166 tonnes/yr. for the village. Assuming a dry matter percentage of sub-10% (8.5% approx.) and a biogas yield/dry tonne of 550m^3/tonne (average of previous estimates), this yields 65,000-91,000 m^3/yr. of biogas.

With the combined feedstock within the A.D process, this yields a total of 460,000 m^3/yr. of biogas. According to the A.D calculator, this could support a biogas engine with a 106-kW capacity, however this will be rounded down to 100kW for modelling purposes. The capital cost of such a sized A.D plant could be obtained from an average of several authors recommendations for capital expenditure at this electrical output.

Lukehurst. C & Bywater. A [2015] advise that there is an average expenditure/kWe of £3,300/$4000 for A.D plants sized between <100kWe – 250kWe. This range is reinforced by Andersons [2010], who states that expenditure/kWe can range between £2500- £6000, ($3000-$7000) averaging at £4000 ($4800)/kWe. Therefore, this 100kW plant would have a capital cost of approximately £330,000-£400,000 ($400,000-$485,000).

To synthesise the A.D potential for Maghazi camp, the surrounding field area was digitally mapped to present an approximate acreage which could be used for crop residues. This was calculated at 100ha to the NNE, 60ha to the East, and 130ha to the South, totalling 290ha of usable land assuming the town has access to this. At 0.7 tonnes/acre/yr, this would equal approximately 500 tonnes/yr of crop waste, again this will be adjusted to 80% of the total to represent ownership rights and collection efficiency; yielding 400 tonnes/yr.

Presuming this adjusted 400 tonnes/yr is split between wheat straw and vegetable wastes in an equal collection manner, this would equal 200 tonnes of each. The A.D calculator allows either manual feedstock input parameter manipulation, or auto-generated figures, and hence suggests wheat straw has a biogas yield of 292 m^3/tonne, which would generate approx. 58,000 m^3 biogas/yr. Using the previous Patil. V & Deshmukh. H figures of 120-400 m^3/tonne from vegetable wastes, this would yield (at 260m^3/tonne) 52,000 m^{3}biogas/yr. Combined, field crop waste could generate 110,000 m^{3}biogas/yr, delivered at 17 tonnes/month (34 tonnes/month combined) feedstock allocation.

Livestock statistics from PCBS indicate that Deir-al-Balah Governorate in which Maghazi is situated has the lowest proportion of slaughtered livestock of any governorate, with only 1324 cattle and 9 sheep being reported to have passed through a licensed slaughterhouse in 2017. However, differing from the Khan Yunis example, there does exist other detailed agricultural *production* statistics for this governorate [ARIJ, 2005], which states that there are 986 cattle, 12,700 sheep, 940 goats, and 3.1 million chickens. This cattle count actually correlates with a 30% head reduction on PCBS statistics to adjust for religious imports- which would yield approximately 900 cattle.

Again, adjusting for local specific agricultural grazing area from this wider governorate cattle population, the total agricultural land of Deir-al-Balah was estimated at between 5-10 sq. Mi (of a 22 sq. Mi total area of the governorate). This was translated to the again approximately 1 sq. Mi of mixed agricultural land surrounding Maghazi and formed a ratio of between 5:1 or 10:1. This therefore delivered an area adjusted cattle population of 100-200 cattle, 1250-2500 sheep and 90-190 goats.

[Side note: An important note must be made here about the validity of some of these relatively crude calculations, including the relationship between village-and town-scale livestock population data, with this being heavily influenced by the lack of available data. Therefore, many assumption have been made about available potential, but this only uses the available data and best-estimation calculations. The area of effective data collection is therefore a definite subject of improvement highlighted in this framework and will be covered later on.]

Using a cattle population of 150 and biogas production as 0.50-0.80 m^3/animal/day, at 85% manure collection factor, this results in 60-100 m^3/day. Over an annual period, this would result in 22,600-36,500 m^3 of biogas produced. Using the A.D calculator, at 85% collection rate, and 27kg manure/cattle/day, this equals a total cattle population manure production of 3240 kg/day and 1,182,600 kg/yr. (1182.6 tonnes/yr.), which yields 42,500 m^3/yr. biogas, bringing the combined production total to 153,000 m^{3}biogas/yr., alongside crop wastes.

To estimate the OMSW A.D feedstock potential of Maghazi, a solid waste generation/capita figure of 0.35-1.0 kg/day, for the 30,000 residents. This results in an average total of 10,500-30,000 (20,250 av.) kg/day collection potential, assuming an effective waste management system is in place. Assuming an organic component composition rating of 65% of the total waste stream, this results in approx. 13,160 kg/day, and 4800 tonnes/yr. of OMSW. Assuming this composes majority vegetable waste, this contributes 1.25 million m^{3}biogas/yr. according to the A.D calculator, using the same biogas yield per tonne as for crop waste. This increases total feedstock biogas production capacity to 1.41 million m^3/yr.

A sewage collection system is presumed to be in place, which should be the case for a larger urban settlement like Maghazi, although this is not guaranteed to be connected to every property, especially since its status as a refugee camp (although a well-established one). Due to this reason it is decided to examine at 2 different collection rates of 70% to 100% given the status as a refugee camp, and hence two different A.D potential figures will be generated.

70% collection rate: Using an approximate value of 0.04-0.09 kg dry matter/capita/day (0.065 average) this yields 840- 1890 (1365 av.) kg/day and 300-700 (500 av.) tonnes/yr. for the camp. Assuming a dry matter percentage of sub-10% (8.5% approx.) and a biogas yield/dry tonne of 550m^3/tonne (average of previous estimates), this yields 165,000-385,000 (275,000 av.) m^3/yr. of biogas.

100% collection rate: Using an approximate value of 0.04-0.09 kg dry matter/capita/day (0.065 average) this yields 1200- 2700 (1950 av.) kg/day and 440-985 (712 av.) tonnes/yr. for the camp. Assuming a dry matter percentage of sub-10% (8.5% approx.) and a biogas yield/dry tonne of 550m^3/tonne (average of previous estimates), this yields 242,000- 542,000 (392,000 av.) m^3/yr. of biogas.

With the combined feedstock for the A.D process this generates a total of 1.68 million m^3 of biogas/year at 380kW (70% collection rate), or 1.79 million m^3 of biogas/yr at 410kW (100% collection rate). For the purposes of modelling Maghazi, the lower figure was chosen as this is believed to more accurately represent the sewage collection rate found within refugee camps.

Therefore, the 380kW potential A.D electrical output from this organic feedstock will be rounded down to 370kW alike the village-scale system. With an average expenditure/kWe of £4000 ($4800)/kWe stated by Andersons [2010], this 370kW plant would therefore have a capital cost of approximately £1.48 million/$1.79 million.

Modelling Application of Homer Software: Village-scale

The above input parameters were inserted into Homer. As Homer specifically requires manual input of an hourly-timestep load (kW) for the village, this was achieved by the following method. Firstly, the ‘Community’ synthetic load profile was selected from Homer to reflect the average daily consumption patterns of a community. This was then adjusted via manual insertion of power values (kW), to approximately follow the load profile, and to achieve the calculated 6280 kWh/day village load and 1.59 MW peak average daily load, through a trial-and error process.

After this was achieved, a series of simulations were run to determine the optimal renewables combination for the village. There were several aims to determine this, requiring fine-tuning of simulations to account for each. The primary aims were to **minimise the required capital cost, to meet the demand of 2260/2290 MWh/yr., to maximise the use of renewable energy in the supply, and to minimise the reliability on the grid connection**. A secondary aim was to account for the minimisation of energy wastage by the system.

There were two main scenarios (and various sub-scenarios) tested against these aims, namely testing for off-grid potential of RES integration, and also grid-connected RES integration. The sub-scenarios involved variations on a base case. The base case for each scenario typically represents the combinations presented by Homer for the specific selected overarching architecture (e.g. having a moderate battery size). Hence, the sub-scenarios presented variations on this in the form of architecture component size variations.

To calculate the grid-connected scenarios, the total supply achievable by the grid to a connected load, was calculated from the mixture of imported and generated electricity. This assumes that there is a total of 2.8 million kWh/day imports [Nassar. Y & Alsadi. S] presumably with the import lines running at 85% capacity, and a total of 3.36 million kWh/day generated from the Gaza Power Plant assuming that it is running at its full operational capacity. This equals a combined total of 6.16 million kWh/day (6165 MWh/day) available grid supply capacity. This equals 2251 GWh/yr, and when translating that into the annual kW requirement (8760 hrs), this becomes an annual purchase capacity of 257,000 kW.

To synthesise the unreliability of the current grid, this was manually manipulated and modelled within Homer to reflect a mean outage frequency of 4,100 events/yr with a 1-hour repair time for each. This represents 4,100 hours per year (of 8,760 total hrs) and equates to a 46.8% annual grid outage rate, correspondent with the average 11-12hrs daily outage experienced across the Strip in the last few years [refer to Figures 2a & 2b].

To best fit the low wind speed range common through-out both village and town scale applications in Khan Yunis and Deir-al-Balah governorates, a Gaia Wind 11kW wind turbine with the optimum wind-speed to power output for this low range was chosen. The wind speed-power curve is as follows in Figure 9.

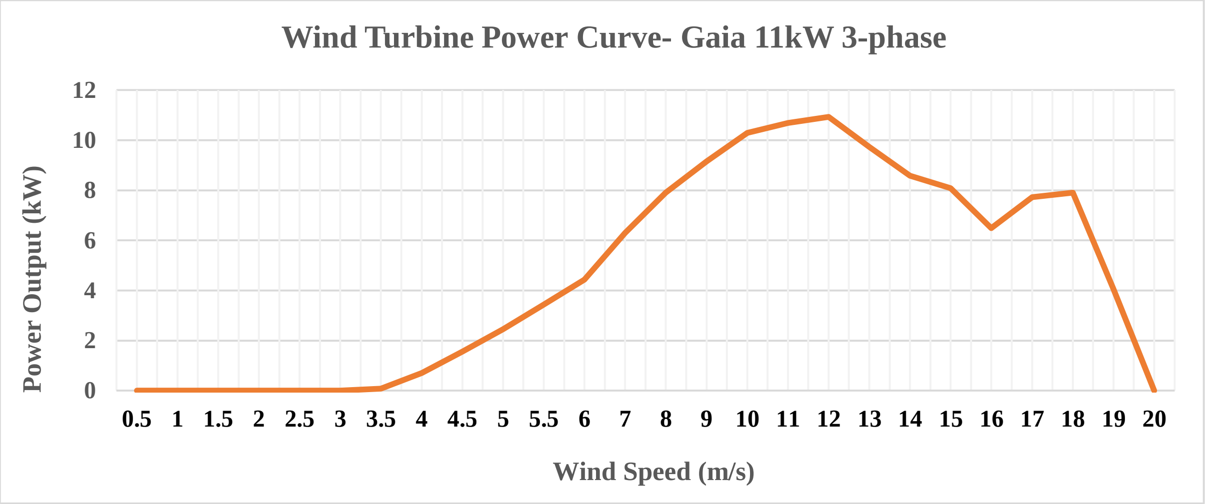


Figure 9- *Wind Turbine Power Curve for Gaia Wind 11kW 3-phase wind turbine, used in modelling within Homer Pro software; cut-in speed- 3.5m/s.*

Village Modelling: Off-Grid findings & recommendation

Please refer to Tables 11a & 11b (Appendix). It is established that off-grid storage capacity is required at approximately 6-10 MWh/yr. With increasing systems attached, this is lower and with decreasing RES this is higher. With a smaller size of A.D plant, more alternative RES is required to meet the demand but with relatively equal battery size at 1 x100 kWh; more batteries are generally required at larger battery rating sizes and also with no wind turbines.

All systems at an off-grid level are sized by Homer to meet the demand and hence the demand is met, fulfilling an aim, as observed by the production exceeding the consumption and a capacity shortfall of just 5% on average. In addition, this is achieved by renewable sources (classifying biogas as renewable) fulfilling another aim. There is however fairly excessive energy production exceeding demand, which the battery systems cannot absorb. This is calculated within Homer and is evident from the difference between the energy production and the village demand.

The highest excess energy was found when there were no wind turbines surprisingly, and these yielded greater expenses too. This is presumably due to the increased prices of more batteries in the system. However, it was also discovered that the system with the highest capital cost also had the greatest number of installed PV capacity as a result and yielded the highest excess energy. It was also generally observed through-out the rest of the scenarios that installed PV capacity had the greatest effect on capital cost and excess electricity production.

It was observed that at the smaller A.D sizing, the required increase in other installed RES (namely PV) results in a larger level of excess electricity than with the same storage configuration at the larger A.D sizing, and hence at greater capital cost and/or one or the other. Therefore, the larger A.D sizing is advocated at this level as it better reduces excess electricity wastage in off-grid contexts with the same battery architecture, and at reduced capital cost (including accounting for A.D capital).

Therefore, the optimal off-grid system advocated to serve the village load for Al-Fukhkhari consists of the following system architecture: 1 x 100kW A.D w/ biogas engine, approx. 2500 (2526) x 1kW PV panels and/or this equal power capacity, 14 x 11kW wind turbines, and an 8-string combination of 1MWh capacity battery storage. This totals $18.7 million in capital costs. All aims are met in terms of renewable supply (being grid-independent), meeting of the annual demand, minimisation of the capital cost and also of electricity wastage.

Village Modelling: Grid-Connected findings & recommendation

All calculations can be found within the datasheets of Tables 12a to 13b (Appendix), outlining the optimal selected configuration of A.D and battery sizing for grid-connected operation of Al-Fukhkhari village.

With the differing penetration levels (30-35%, 50%, 70-75% and highest possible) of renewable energy into the village grid-connected electricity network, several different factors were examined, and findings observed, with trends often specific to the different levels. At penetration levels of 30% and 50%, storage capacity in the form of batteries is required at approximately 2.2-6.0 MWh for both sizes of A.D sizing.

This is affected by the battery configuration, as the 100kWh string arrangements (1 & 2) tend to require a storage capacity bracket towards the lower end, whilst the larger 1MWh string arrangements require an average of the middle-upper bracket of capacity within this range. When considering a higher level of penetration (i.e. 50-100%), substantially more storage capacity is required to sustain this, with the smaller battery arrangements requiring a range of 4MWh to 10MWh, with the larger arrangements requiring approximately the same range, but with slightly less capacity required.

With increasing penetration levels at both A.D sizes, there is also a clear positive trend with regard to excess electricity produced, with the highest levels always being found at the highest percentage share of RES on the network, and the lowest levels naturally always observed at the lowest percentage share. With regard to each battery configuration, it was noted that the lowest excess was primarily found to be at the configurations with A.D, and the lowest PV and highest wind installed capacities, i.e. the most technically diverse portfolios. Therefore, it was also observed that the opposite was true for the least diverse configurations correlating with higher excess.

There was also an identified trend between capital cost/net present cost (NPC), and the excess electricity generated. This was often present as an inverse correlation, i.e. with the lowest excess achievable, this usually demanded a higher NPC. This was typically the case for the larger battery configurations at the 100kW A.D sizing with small variations, with these variations increasing at smaller battery sizes and also at 50kW A.D sizing with the larger battery sizes, and the inverse correlation being stronger in the lower cases.

This indicates that there is higher NPC required for lower excess at the larger battery and larger A.D sizing, whilst this isn’t strongly visible at lower battery sizes for the larger A.D or at the larger battery sizes for the smaller A.D. Therefore, to fulfil the aim of reduced electricity wastage, there should be a focus on lower battery sizes for the larger A.D configuration, and larger battery sizes with the smaller A.D configuration. NPC was also lowest at the lowest sizing battery configuration (1-string 100kWh), and highest at the largest (2-string 1MWh), increasing towards the latter. Lowest NPC was relatively equal at both A.D sizes across all battery configurations, and typically found where the RES penetration is the lowest.

The highest capacity factor for A.D was observed consistently at the lowest percentage share of RES on the network (i.e. 30% penetration level), and the inverse was true for the highest RES penetration. This generally remained equal for all battery sizing, with the exception of the 2-string 1MWh battery configurations where this was lower. There was an observed higher capacity factor at the 100kW A.D sizing compared to the 50kW one, indicating that it was working more effectively at the larger sizing.

To recommend an optimal grid-connected system at each level of RES penetration, comparison must be made between the variables across the different configurations, to identify the system which would meet all or the majority of the required aims.

At 30-35% penetration: alongside the lowest NPC being for A.D configurations, rather than no A.D, the lowest NPC was observed for Base Case 2 (2 x 100kWh config.) at the 50kW A.D sizing. The lowest excess was found to be for Base Case 3 (1 x 1MWh config.) for the 100kW A.D sizing, and the highest A.D capacity factor of all to be for Base Case 4 (2 x 100kWh config.) for the 100kW sizing.

However, the next best capacity factor was found to be the same as Base Case 3 for the 1 x 1MWh config, i.e. the same architecture as the lowest excess. This avenue was pursued, and the NPC was revealed to be $8.5 million which is higher than found at other configurations, however the double combination of lowest excess and high capacity factor for A.D proved to favour this combination for this penetration level. Therefore, at 30% (29%) penetration, the optimal combination was determined to be: 1 x 100kW A.D, 354 x 1 kW PV, 2 x 11kW wind turbines and 3 x 1MWh Li/Ion batteries, at 24.5% A.D capacity factor, excess of 161,200 kWh/yr, and at an NPC of $8.5 million.

At 50% penetration: the lowest NPC for this level of RES penetration was observed to be with the smaller 50kW A.D sizing, and at 1-string x 100kWh battery configuration ($8 million), meanwhile the most expensive system architecture was found to be for the 100kW A.D sizing and the 1-string x 1MWh configuration. It was observed that the systems with the lowest excess typically also were amongst the most expensive, with the second lowest being found to be for the highest NPC 1-string 1MWh configuration, and the least excess being for the 1 x 100kWh battery at 50kW A.D. The highest A.D capacity factor was observed to be found with the 2 x 100kWh battery configuration and 100kW A.D (Base Case 2).

The architecture which had the lowest NPC, excess and highest capacity of all of the combined configurations considered was observed to be with the higher 100kW A.D sizing and the 1-string x 100kWh battery sizing. This has an NPC of $9.45 million (which is averagely recurring through-out this A.D sizing) and an A.D capacity factor of 14.6% (second highest). The configuration found at the same A.D sizing but 2-string x 100kWh battery setting had slightly lower excess, slightly higher grid penetration and a higher capacity factor, but there was a slightly higher NPC of $9.62 million.

Therefore, these two are the recommended systems, but for the cheapest capital cost the former architecture should be pursued, and this consists of: 1 x 50kW A.D, 1047 x 1kW PV, no wind turbines, and 26 x 100kWh batteries, with an NPC of $9.45 million and A.D capacity factor of 14.6% (Base Case 1).

At 70-75% penetration: the lowest NPC for any configuration at this penetration level is observed at 100kW A.D sizing and with 2-string x 100kWh battery sizing ($11.41 million). The lowest excess of electricity was observed at the same A.D sizing but with 1-string x 100kWh battery configuration (324,300 kWh/yr). The highest A.D capacity factor (6.5%) was observed at both the 1-string and 2-string 1MWh battery configurations, for the 100kW A.D architecture.

Combining these factors to find the optimal solution for this level of RES penetration, it is observable that the architecture which brings the combined lowest NPC, lowest excess and highest A.D capacity factor all in the one configuration, is that for the 100kW A.D sizing, and 2-string x 100kWh battery sizing (Base Case 2). This has the lowest NPC for this penetration level of any configuration ($11.41 million) and consists of the following architecture: 1 x 50kW A.D, 1866 x 1kW PV, no wind turbines, 44 (22 x 2-string) 100kWh batteries, at a 6.2% capacity factor.

At the highest possible penetration: there was an approximate maximum range of 91.7% RES penetration into the system, with this decreasing with increasing battery configuration sizes (e.g. 1 x 100kWh to 2 x 1MWh), and hence the largest penetration was observed at the 1 x 100kWh battery sizing at both A.D ratings. However, both the lowest NPC and the lowest excesses were found at the 2 x 1MWh ratings. At these levels, 85.5-85.8% penetration was achievable, however one system utilised 50 kW A.D and one did not utilise A.D at all.

The 50kW A.D system ran at a very low capacity factor (2.3%) and hence this was not deemed to be satisfactory for investment in A.D, so hence the other system was chosen in this regard. The no A.D system also yielded the lowest NPC by nature, however had a slightly larger excess. Nonetheless, the optimal configuration for this penetration level (Base Case 4), based on lowest NPC and excess, was determined to have the architecture: no A.D, 3584 x 1kW PV, no wind turbines, and 4 x 2-string 1MWh batteries (NPC of $14 million).

If pursuing the highest possible penetration levels, then it would be advised to opt for the 1 x 100kWh battery sizing at the 100kW A.D rating, as this equals the lowest NPC in comparison to the 50kW system, and approximately equal excess electricity.

Modelling Application of Homer Software: Town-scale

The above input parameters were inserted into Homer. The hourly timestep synthetic load profile for Homer was simulated in the same process as performed for the village profile. This was performed so as to meet the 37.3 MWh (37,300kWh) daily profile, however the average peak daily load was modelled by Homer to be slightly higher at 155 MW. Efforts to reduce the average peak daily load to fit that calculated were successful but this resulted in the daily demand profile being lower so hence this new figure was used.

After this, simulations were again run to match the load profile to the optimal RES combination. The primary aims were again to **minimise the required capital cost, to meet the demand of 13.42 GWh/yr., to maximise the use of renewable energy in the supply, and to minimise the reliability on the grid connection**. A secondary aim was to account for the minimisation of energy wastage by the system. Again, the grid was modelled to reflect an annual outage frequency of 46.8%, with 4100hrs/yr average downtime, and with 257,000 kW annual purchase capacity, and at 2251 GWh/yr.

Town Modelling: Off-grid findings & recommendation

All calculated configurations are to be found in Tables 14a and Table 14b (Appendix) and outline the optimal selected configuration of A.D and battery sizing for off-grid operation of Maghazi camp.

It is observed that approximately 70–110 MWh of off-grid storage capacity is required to sustain energy supply to the town. Net Present Cost increases with increasing RES components attached including PV, wind turbines and batteries, and highest NPC is typically observed at configurations with no wind, and no A.D. Lowest NPC is found at configurations with the most RES diversity i.e., with all components attached (but not necessarily at the highest number attached of the total studied configurations).

Lowest excess electricity was observed generally when there were 2-strings of batteries attached (2 x 100kWh, and 2 x 1MWh) and both PV and wind attached. When A.D was attached, the excess was smaller at the smaller A.D rating, but in the situations without A.D this was at a similar level. A.D capacity factor was often observed to be highest when there was no wind capacity attached, however the opposite was true in the cases of Base Case 4 (370 kW A.D), and Base Case 2 (185 kW A.D) where the wind attached configuration was found to have the highest A.D capacity factor.

Base Case 4 (370 kW A.D) also had the highest A.D capacity factor of all those found at both rating and battery sizes and had the lowest excess for the higher A.D rating and the 3rd lowest excess overall. It was also observed to have the 2nd lowest NPC of all of the configurations. Therefore, this option was selected as the optimum configuration for off-grid operation to provide power to Maghazi and consists of the following architecture: 1 x 370 kW A.D, 23,280 x 1kW PV, 617 x 11kW wind turbines, 76 1MWh batteries (38-strings of 2), and has excess of approx. 24,400kWh/yr, A.D capacity factor of 2.61% and an NPC of $188.8 million.

Town Modelling: Grid-Connected findings & recommendation

All calculated configurations for this stage are to be found in Tables 15a – 16b (Appendix), outlining the optimal selected configuration of A.D and battery sizing for grid-connected operation of Maghazi camp.

With the differing penetration levels (30-35%, 50%, 70-75% and highest possible) of renewable energy into the grid-connected electricity network for Maghazi, several different factors were examined, and findings observed, with trends often specific to the different levels. At penetration levels of 30% and 50%, battery storage capacity is required at approximately 15-24 MWh for both sizes of A.D sizing. At 50% the storage capacity is also found to be lower than required at 30%, for both A.D sizes and all battery rating categories.

At increasing penetration levels, storage capacity is observed to steadily rise, with an average capacity bracket of 16-50 MWh, with more frequent demand for 30 MWh+ capacity. This is common at all scales, although is slightly less pronounced with the 1 & 2-string 1MWh battery configurations. Alike that which was observed at village-scale, with increasing RES penetration levels, there is a marked increase in excess electricity produced.

Lowest excess was also observed with systems which contain A.D, as opposed to those without, with this most notable at lower penetration levels- as the trend was less clear at RES penetration of 70%+. The lowest excess was also noted always with the most diverse attached RES portfolios, alike at village-scale, although this was primarily not found to be true for systems with under 35% RES penetration.

There is a correlation between NPC and increasing RES penetration and the resulting excess electricity produced. There is also an observed link between attached components e.g. batteries, solar PV panels etc, and NPC which is assumed to be natural. Again, alike village-scale it was observed that to achieve lower excess electricity production, it was necessary to have a higher NPC. However, in contrast to village-scale it was noted that this is a much weaker trend at all levels, i.e. the lowest excess often didn’t mean the highest NPC, actually this often meant the cheapest NPC (with the strongest trend found for this at the 50% penetration level).

A similar relationship between an increasing A.D capacity factor and the lowest RES percentage share (of total) was observed alike at village-scale. This was evident in most configurations with the frequent exceptions of the 70-75% penetration level and less frequently, the 50% level. Alike at village-scale, there was a noted discourse from the trend with the 1-

string 1MWh battery configuration, although this was present at the larger A.D sizing. Also, again there was observed higher A.D capacity factors at the larger 370kW sizing than at the lower, indicating a better operational state.

To recommend an optimal grid-connected system at each level of RES penetration, comparison must be made between the variables across the different configurations, to identify the system which would meet all or the majority of the required aims.

At 30-35% penetration: the lowest NPC was noted for Base Case 3 of the 185 kW A.D sizing, the lowest excess was observed for Base Case 1 (1 x 100kWh) for the 370 kW A.D sizing, and the highest A.D capacity factor was also noted for Base Case 1 for the larger A.D plant. However, the Base Case 3 (185 kW) configuration had an excess which exceeded that found at the lowest scales of the larger A.D sizing and so hence this was discounted.

The lowest excess (Base Case 1- 370 kW) was also discounted due to the lower A.D capacity factor than what was found to be averagely achievable at other configurations, and hence the next best settings were examined until the optimal excess-A.D capacity factor was achieved with Base Case 4 for the larger A.D (2 x 1MWh). This had a slightly higher NPC (by $0.3 million) than those of lower excess, although was determined to be the best fit for the capacity factor.

Therefore, Base Case 4 was chosen with the architecture composed of: 1 x 370kW A.D, 2321 x 1kW PV, no wind turbines, 18 x 1MWh batteries (9-parallel), and at an NPC of $47.9 million and A.D capacity factor of 47.5%.

At 50% penetration: the lowest NPC for this level of RES penetration was found to be jointly held by Base Cases 1 & 2 for the 370 kW A.D sizing, the lowest excess was observed again in Base Case 2, however Base Case 4 (185 kW A.D)) was slightly less. Despite this, Base Case 4 had substantially higher NPC and hence Base Case 2 was also chosen for lowest excess.

The highest A.D capacity factor was found for both Base Cases 1 & 4 (both 185 kW), at 40.2%. The next highest capacity factor was observed for Base Case 2 (370 kW), at 39.9%, and due to the lower NPC and lower excess than the other combinations including those for the highest A.D capacity factor, Base Case 2 was chosen as the optimal combination for this penetration level. The architecture consists of: 1 x 370 kW A.D, 4424 x 1kW PV, no wind turbines, 158 x 100kWh batteries (79-parallel), with an NPC of $47.5 million, and A.D capacity factor of 39.9%.

At 70-75% penetration: the lowest NPC for any configuration at this penetration level was observed for Base Case 4 (370 kW A.D), the lowest excess was observed for Base Case 2 at the same A.D rating, and the highest A.D capacity factor was found at Base Cases 1 & 3 for the 185 kW A.D. Base Case 1 had a lower NPC but slightly higher excess, however it was chosen to negate Base Case 3.

Eventually it was concluded that Base Case 4 was the optimal fit for this level of RES penetration, due to it being the joint second-best capacity factor after Base Case 3, and the best correlating lowest excess against the other 2 measured variables. The architecture is as follows: 1 x 370 kW A.D, 10,879 x 1kW PV, no wind turbines, 14 x 1MWh batteries (7-parallel), at an NPC of $57.2 million, and an A.D capacity factor of 33.7%.

At the highest possible penetration: there was an approximate maximum range of 94% to 96.7% RES penetration, with the highest percentage being attained with the smaller A.D rating when attached (generally with A.D it was higher than without), and also at smaller battery ratings (100kWh combinations). At this stage however, A.D capacity factor was considered insignificant and it was decided that there is no investment sense in building a plant to run at <0.1% capacity.

The lowest NPC and excess achieved was found for Base Case 4 with A.D both attached and detached, and subsequently as a result of the poor investment choice of minimal capacity factor A.D, the non-A.D choice was chosen. This architecture is composed of: no A.D, 37,301 x 1kW P.V, 339 x 11kW wind turbines, 32 x 1MWh batteries (16-parallel), at an NPC of $146 million, and at 94.8% RES penetration.

Layout of RES Supply Proposals

Upon the conclusion of modelling of the renewable resource integration to meet the demand of the different scales of example settlements, the different constraints can be identified, and proposals made to facilitate their overcoming. Firstly, and as an aid to better identifying constraints, there is a need to briefly outline how the layout of the systems would be presented at the different scales.

It can be seen that with the renewable supply solution developed for the village of Al-Fukhkhari, there are two aspects to examine: off-grid and grid-connected. The off-grid solution includes a mixture of a 100kW biogas engine, supplied by an A.D plant, 2500kW of solar PV (in the form of individual panels), 14 x 11kW 3-phase wind turbines, and a storage block capacity of 8-strings of 1MWh batteries. The grid-connected solution includes various combinations of the same components, but for a majority at a smaller scale due to the effect of the grid supply.

The same can be said for the off-grid solution developed for the town-scale refugee camp of Maghazi. In this case the architecture composed of a 370-kW biogas engine/A.D plant, 23,280 x 1kW PV, 617 x 11kW wind turbines, and storage capacity of 76 batteries (38 strings of 2). With differing levels of RES penetration, there were different numbers of components required to handle this but stemmed from approximately 2300 kW of PV at 30% penetration, to 10,000-37,000 kW at the higher levels.

With increasing RES penetration at grid-connected scale, to support the reduction in carbon emissions from the electricity supply to both settlements, there comes increasing numbers of renewable components required to handle this contribution. The cross-over point between number of off-grid scenario components, and grid-connected scenario components, arrives after 50% RES penetration, at approximately 70-75% and above. A brief analysis of the location allocation of these components is necessary to inform all possible constraints.

For solar PV allocation, it is proposed that there will be a mixture of domestic-located rooftop panels, and ground-based ‘solar farm’ panel clusters. From a solely technical viewpoint, in the scenarios which account for wind turbines, these need to be positioned to maximise the resource available around the settlements and cannot be located on rooftops due to the size and potential disruption. A.D plants are centralised and modularly contained so therefore a sole location is required for these, which can be located around the village although several constraints have to be considered here.

Taking the off-grid scale for Al-Fukhkhari as an example, there are 2500 individual PV panels which need located. Since the village only has a building count of approximately 150-160, the sub-division of PV will be skewed in favour of ground-based systems. The average solar PV panel is 1.65m^2 [Dower. B; 2018], and for this system it is proposed that an individual PV panel will generate 140W- therefore a 1kW (panel equivalent) system would require approx. 7 individual panels.

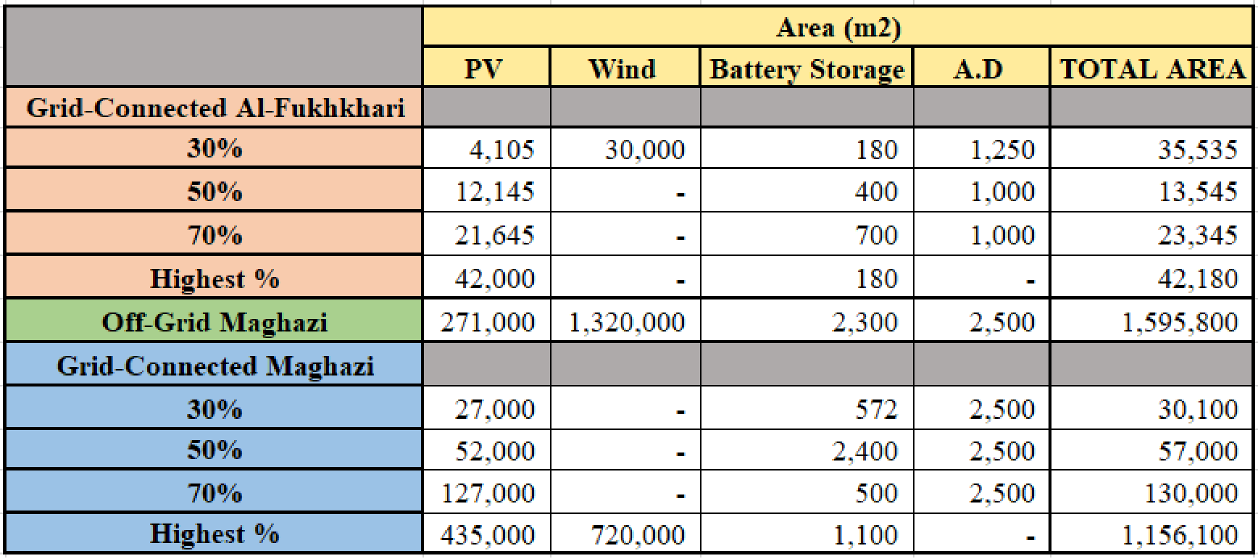
This would take up 11.6m^2 of area for every kW of solar PV required, and means that for a 2500kW off-grid system, 29,000m^2 (0.01 sq. Mi/7 acres) of land would be required. Due to the relatively small size of this, and the easier maintenance and installation of economies of scale with land area, it is proposed that all PV panels be ground based.

Wind turbines require an average spacing of 4 rotor diameters between them to ensure minimal interference effects [Kusiak. A & Song. Z; 2010]. The Gaia Wind 11kW wind turbine used in the Homer modelling has a rotor diameter of 13m [Homer], so therefore if the 14 turbines were arranged together in a semi-cluster pattern of 3-abreast parallel lines spaced 52m apart, this would have a footprint area of approximately 143m wide, by 270m long, equalling 39,000m^2.

Several online sources quote 1MWh batteries to be sold in a containerised fashion within 40ft shipping containers [Electrocell; ABB]. Considering average shipping container dimensions of 40ft x 8ft, this equals an area of 320ft^2 (30m^2). With the proposed combination of 8-strings of 1MWh batteries, it is proposed that using a stacking system of 2-high, and a spacing of 2 metres, a battery storage facility would cover 120m^2-200m^2 of area (with tie-in facilities attached). This is no larger than the footprint of a large house.

An anaerobic digestion/biogas engine system will require land area adjacent to each sub-component, and includes space for the digestor tank itself, pre-processing and loading facilities, and the engine. Considering a compact A.D capacity of 100kW, it is forecast that an average of 1000-1500m^2 of land area would be required to operate the plant. This amounts to a total land area requirement of 64,500m^2 (15.9 acres).

The data in Figure 10 displays the approximate land area required for the other scenarios.



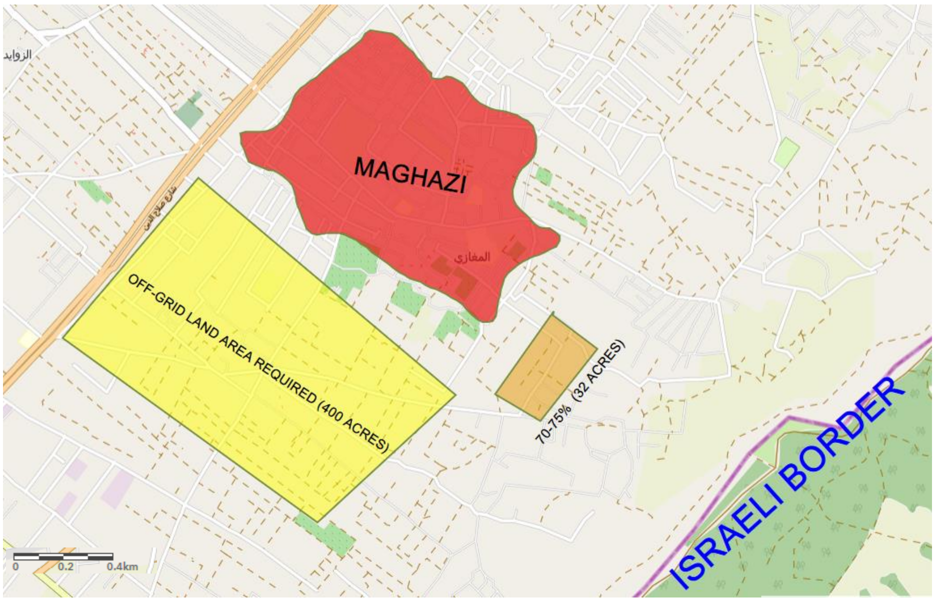
	Area (m2)				
	PV	**Wind**	**Battery Storage**	**A.D**	**TOTAL AREA**
Grid-Connected Al-Fukhkhari					
30%	4,105	30,000	180	1,250	35,535
50%	12,145	-	400	1,000	13,545
70%	21,645	-	700	1,000	23,345
Highest %	42,000	-	180	-	42,180
Off-Grid Maghazi	271,000	1,320,000	2,300	2,500	1,595,800
Grid-Connected Maghazi					
30%	27,000	-	572	2,500	30,100
50%	52,000	-	2,400	2,500	57,000
70%	127,000	-	500	2,500	130,000
Highest %	435,000	720,000	1,100	-	1,156,100

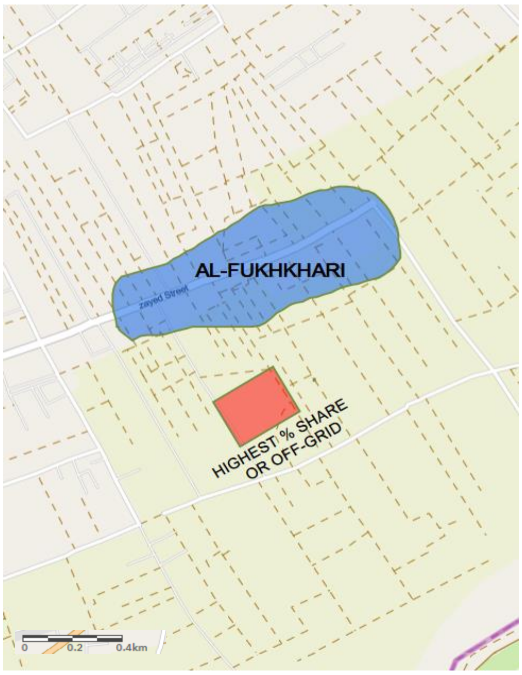
Figure 10- *Approximate land area required for optimal layout configurations with different scenarios (m^2).*

As is revealed in this data, and as expected the highest land area required of all the configurations is for the off-grid Maghazi scenario, in which 1.596 million m^2 of land (400 acres/0.6 sq. Mi) is required. The lowest land area required overall and for the village scale is for the 50% RES penetration level for Al-Fukhkhari, at 13,545m^2 (over 3 acres/0.005 sq. Mi).

The highest land area required for Al-Fukhkhari is found again for the off-grid system at 64,500m^2 (15.9 acres), which is 5-6 acres more than that found for the highest % share configuration. The lowest land area required for Maghazi was observed with the 30% RES penetration level, with 30,100m^2 (7.5 acres) required. An interesting note here is the lower overall land area required for the village-scale solution, which can be explained by the heavier reliance on battery storage (which has a higher energy density and lower ground footprint as a power source), with no land-intensive wind power contributing to this.

Considering the land area of Maghazi is approximately the same size as the land area required for the combined RES installation, a wholly ground-based solution is deemed relatively unfeasible with regards to land area (Figure 11a). Contrasting this with the off-grid solution for Al-Fukhkhari village, the 10 acres required to facilitate total off-grid operation is more readily implementable in terms of land area, outside the village (Figure 11b). It was decided to establish the feasibility of the off-grid solution developed for Maghazi if solar PV footprint was divided more evenly across both rooftops and ground-based installations.





Figures 11a & 11b- *Equivalent scale digital map extract of Maghazi (left) and Al-Fukhkhari (right), with overlays displaying land area required for differing RES supply scenarios/configurations. ArcMap software, 2019.*

Using digital mapping to yield an estimated average roof size of 100-150m^2 within Maghazi, this could accommodate 8-12 kW of PV capacity per rooftop, however this will be approximated at 8kW with consideration of space for other users of the rooftop and weight concerns. The total building count is estimated at 1600-1900 (1750 av.), however PV systems will not be feasible or desired atop very building so hence this is examined at 3 levels: implementation of 100% , 75% and 50% of total building stock.

At total 100% implementation, this would equal 14,000 panels at 14MW installed capacity, at 75% this reduces to 10.5MW, and at 50% implementation this is calculated at 7MW. Therefore, to facilitate total off-grid supply with solar PV contributions of 23.2MW, this would require ground-based installations of 9.2MW (107,000m^2) at 100%, 12.7MW (147,500m^2) at 75%, and 16.2MW (188,000m^2) at 50% rooftop implementation. This reduces the externally required total area to 1,431,800m^2/353 acres (100%), 1,472,300m^2/364 acres (75%) and 1,512,800m^2/374 acres (50%).

However, even with an unlikely 100% implementation, this still requires a lot of land area for off-grid operation. At 70-75% penetration for Maghazi, the total land area required is only 130,000m^2 (32 acres), with most of this from solar PV. However, to achieve 100% of the 10.88MW solar PV capacity required *at this penetration*, only approximately 80% of the buildings within Maghazi require rooftop PV installations and hence this is seen as a more feasible layout in terms of land area than with off-grid status.

At village-scale, with 30% RES penetration and considering a total of 8kW capacity/house and 160 houses, this could facilitate 1280 panels generating 1.28MW from rooftop capacity. With 8 panels/house this amounts to an area of 14,850m^2 (11.6m^2 x 8kW/house x 160 houses), however the total area of 4105m^2 required at this penetration level could be achieved by 2 PV panels on every house, and 393m^2 (34kW) of PV panels on the ground.

- *Identification and analysis of major overarching constraints facing roll-out at varying stages of community and town scales in specific country of interest*

In this section any identified constraints to RES implementation at the differing applications of village and town-scales will be examined in light of the findings from Al-Fukhkari and Maghazi, and to further the framework development as a whole. These will build on the general constraints observed earlier, consisting of technical, socio-economic, political and regulatory, and propose how to overcome these with regard to the respective scales.

Technical Constraints

Village/community scale- Al-Fukhkhari

Initially, it must be stated that the various proposed solutions to promote renewable electricity at village scale within the case study proved that it is possible to integrate RES at this level to provide green power without a grid connection, or also to meet the demand through varying penetration levels of RES, whilst using the grid as a backup, all for a sum not in excess of $20 million. Either combination would likely aid the residents through the reduced dependence on the unreliable grid present within the Gaza Strip, until such time as conditions change which is unforeseeable in the near future.

For the off-grid system, and with systems approaching grid-independent status (i.e. highest penetration levels) it was observed that storage capacity was a necessity, with the highest capacity of connected batteries noted at this level. This confirms predictions made earlier, and the presence of storage on the network, especially with regard to totally off-grid/microgrid configurations like that modelled, is needed to balance system shocks stemming from minimal grid inertia.

Minimal grid inertia on a microgrid such as that modelled for Al-Fukhkhari off-grid system is a significant technical constraint, due to the high proportions of connected solar-PV on the network. This minimal inertia is worsened by the low wind speeds common to both areas- in comparison to sites where wind turbines would excel- and also from the low A.D sizing capabilities of the organic feedstock from the settlement. All of these factors contribute to a high reliance on solar PV which subsequently can contribute rapid ramp-up/down rates, both with passing cloud cover, and towards nightfall.

These rapid variations in grid output and frequency of supply are therefore fairly detrimental to the stability of the inter-connected network, and this is especially prominent towards nightfall, when it is possible that variations could increase due to the failing of the light and the possibility of increasingly prominent cloud cover from the coast. From the developed demand profiles, it is prominent to see that with most communities, including Al-Fukhkhari, the highest peak demand is observed between 5pm-8pm, concurrent with evening light decay and nightfall.

Therefore, this is a period of potential significant disruption as rising demand requires matching with fluctuating solar PV. However, as indicated through modelling, the optimal solution includes the addition of energy storage, and through this addition the majority of these technical issues subside. This is due to the absorbance of excess energy during the daylight hours from wind/solar and A.D, and from the previous nights' wind-power & A.D power; which then can be used to smooth any shocks which may be experienced during daily operation.

There is an excess of production within all of the cases, with this varying from approx. 160,000 kWh/year, to 1MWh/year, above and beyond that used by the connected loads including the batteries and that sold back to the grid (with the grid-connected scenarios). With off-grid scenarios, excess was typically observed to be highest, in comparison to grid-connected, probably due to the ability of grid-connected systems to shed the excess electricity onto the grid for a cash value. This therefore allows some leeway with regards to variations in demand, and also extra battery charging- although it is proposed that the batteries charge at 95-99% each full-cycle.

Another technical constraint which must be considered is the degradation of storage and generation units over their lifetime, with this being especially pertinent for batteries in developing country contexts. Adverse weather conditions including dust and sandstorms which are common across the majority of the Middle East and Africa, can all contribute to poor working conditions for battery components.

In addition, if the housing facilities for the batteries are inadequate to protect them from weather conditions and general wear-and-tear, and maintenance is also inadequate, then the lifespan and operational efficiency of storage systems will degrade more rapidly with time. This therefore can lead to potential issues with the network, due in part to the heavy reliance on storage units at both off-grid and high RES penetration scales.

Concern is also present with generic lifespan degradation from excessive over-reliance on batteries and hence rapid cycle degradation. Wang. Y, et al [2016] writes that “frequent and deep cycles accelerate cyclic ageing and reduce the cycle life”, hence indicating that exploiting the battery for full-cycles at the expense of investing in extra generation capacity can be detrimental to the overall health of the storage system, and hence the overall system health.

It is proposed that battery degradation concerns are overcome by proper housing of any connected storage units within adequate facilities, e.g. not an ill-designed, general purpose shipping container, but ideally that which is designed by the battery manufacturer for housing. This should include proper ventilation, cooling and moisture-control systems (HVAC) to minimise all unnecessary maintenance due to poor physical conditions. Convenient yet secure access should also be made to the battery storage facility to ensure rapid response and minimising downtime should faults occur.

Wang. Y et al also proposes that to minimise the effect of frequent deep cycle charging degradation, effective control programmes should be put in place by the network controller system. These should maximise the availability of existing renewable generation via a co-ordinated programme with short-term resource forecasts e.g. to maximise the output of stochastic inputs such as wind. In the case of Al-Fukhkhari this is not as important an issue as it could be, due to the often-low proportion share of attached wind power and the high predictability of solar and A.D outputs. However, for the cases where it is attached, and as an example for other countries, this should be prioritised.

The absence of heavy loads, and a generally smooth daily demand profile found from the lower variation of village-scale, all serve well to maintain the stability of the network more so than would be expected at larger levels of variation and load. Therefore, this suits loads with constant base demand well e.g. cold storage and street lighting to a partial extent, although these loads are especially at risk during night-time hours, when solar PV output is non-existent.

Subsequently, this is a time when battery degradation in high RES systems may occur should over-reliance on storage systems be necessary to maintain the supply to base loads, and therefore it is crucial to plan well-sized alternative renewable generation and to control this well.

Town-scale- Maghazi

The majority of the identified technical constraints applicable to village-scale are theorised to also be applicable to town-scale, however the modelling results will be analysed to determine any significant variations at this larger scale and propose solutions to adapt to these.

Initially, it was noted that storage capacity is generally significantly higher at this level, again being highest at off-grid operation (70-110 MWh for off-grid), and lower at grid-connected, although still higher than required at village scale. This increase in storage capacity is mirrored by an increase in renewable generation capacity, so therefore there isn't as much a strain on battery storage to supply electricity as if this wasn't the case.

At lower levels of RES penetration, the numbers of attached components verge near to that found at village-scale with high levels of penetration, and also with regard to the lower A.D configurations found at village scale (1000-2000 kW PV). Therefore, it could be initially assumed that there is a possibility for over-working of the battery system to cope with this decreased level of renewable plant, however it is evident from modelling that optimal configurations have an increased number of batteries in comparison to village scale.

Despite this, the optimal system selected each time has among the lowest batteries of the sub-set analysed. There is an evident cost-benefit argument here which will be discussed further later on, in terms of the trade-off between optimal cost-selection and having enough diversity of battery capacity to avoid over-reliance and degradation.

Another significant technical constraint evident at this scale is the increased variability and nature of the load profile of a larger urban settlement. This is due to the higher probability of random load spikes with a higher share of attached loads on a network, including those of an inherent larger nature e.g. factories and industrial units. This was the case with the Maghazi model, which has two factories and a medium-sized healthcare centre, all which draw a substantial load: 19.2kW/80.4kWh/day (health centre), and 36.6kW/ 112.8 kWh/day (per factory).

With these large units, there can be fairly rapid ramp-up rates in terms of demand, e.g. if heavy machinery is switched on and starts drawing a load, this can have potential network stability impacts. This is especially pertinent with off-grid and high RES capacity configurations with large amounts of PV, as the impact of low grid inertia can mean for greater risk of failures from frequency fluctuations, whereby the control system would automatically enforce black-outs to protect attached loads. This is another side-note for consideration, as control systems which enable this need to be integrated with the wider redesigned RES network in the context of developing countries, where they may not already be enforced.

Therefore, storage systems are of necessity at this scale, and even more so than at smaller scales. These need to be adequately sized to instantly cope with spikes in demand, so as to smooth any deficiencies in generation and also any frequency fluctuations. However, it must also be important to not place excessive over-reliance on storage systems, because although necessary to facilitate renewables integration, frequent deep cycling can lead to lower efficiency and degradation- which ultimately leads to lower operational stability margins.

Furthermore, this necessitates reliable non-stochastic generation (i.e. other than wind and solar PV to an extent) which, if in the interests of promoting a sustainable energy supply, provides a reliable non-grid baseload. In the case of Maghazi this is provided by A.D/ biogas engines, which utilise the organic feedstocks originating from the city. However, there is another constraint here which is presented in the form of potential seasonal insufficiency in feedstock for a generator of this nature.

For example, harvesting crop residues is often a seasonal affair, potentially on a bi-annually basis, hence this feedstock would not be available consistently, unless rationed per month, as was done for modelling purposes. In this instance, heavier reliance would need to be assigned to other feedstocks, such as food-waste and sewage treatment, however the collection efficiencies of these would need to be as high as possible, and an effective collection system would need to be in place- something which may be scarce in developing countries due to lack of funds. This will need to be an issue best addressed in economic constraints analysis later.

A final A.D- related technical consideration therefore is achieving the correct balance of feedstocks in terms of physical parameters of pH and volatile solids content. This theoretically should be viable with a combination of high-moisture-content sewage sludge and slightly drier food waste OMSW, although consideration of this should be given when designing A.D systems to be reliable base load generators. Attaining a reliable water source is also a major constraint, as this is crucial for attaining the right hydro-chemical balance within the reactor, but water can be a contested resource in some developing countries.

Within the Gaza Strip for example, there is a lack of clean water supply [Aish. A; 2013]. Therefore, with the model application, there is a potential novel alternative, with the high percentage of water originating from the sewage sludge, and this could be combined with other wastewaters coming from the town, e.g. rainwater and other greywater. This could in essence develop a solution to the frequently cited wastewater issues experienced in the Gaza Strip [Afifi. S, et al], by providing a process which utilises and cleans up the sewage, whilst providing an energy supply. However, using the by-product sludge as bio-fertiliser will likely require costly clean-up processes before land application is permitted.

A significant technical concern at both scales of application is the ability of the wider electricity grid to handle the influx of renewable electricity from such projects if they were implemented on a local, or repeated scale. This stems from the afore-mentioned issue of grid inertia, and connecting stochastic devices, or those with high ramp rates and a considerable share of the electricity mix, to the grid and this thus posing the potential for reduced fault reactance and increased frequency variations.

It is assumed that the scale of this problem is directly correlated to the percentage share of renewables on the wider national grid, with the larger this prevalence being, the greater the potential for instability. A notable example of the effect a large proportion of renewable energy can have on a regional/national grid system is observed with the 2016 blackout in the state of South Australia. The loss of power was attributed to the effect which a significant grid-share contribution of wind energy had on the aftermath of the loss of transmission lines in adverse weather. Protection mechanisms within the turbines automatically shed power from windfarms to the grid, causing a cascading failure.

If a renewables saturation limit of national grids exists, it is for protection purposes due to the inadequate architecture found within ageing systems to cope with a higher degree of variability. In developing countries/regions such as the Gaza Strip, there is likely to be a sore need to upgrade electricity transmission networks to cope with the effect of a higher renewables share to the electricity mix.

It is already known that the Strip does not have sufficient generation capacity to serve the totality of its national demands, with the Gaza Power Station running at partial capacity, and imports required from Israel and Egypt. Subsequently, alongside significant upgrades to the integrity of the GEDCO-owned national transmission network, storage batteries should be added to the system to facilitate the increased penetration of renewable generation.

Alternatively, depending on the advancement of the numbers of individual settlement-scale projects/grid-connected microgrids (and therefore crucially depending on the success of pilot schemes such as the Al-Fukhkhari and Maghazi proposals), the existing battery storage schemes within such microgrids could be utilised for this same purpose by the grid. The settlement-scale storage units could absorb excess power from the grid, which includes other renewable generators such as net-energy-positive microgrids, and also deliver any excess power generation of its own back to the grid for a monetary value.

This serves a benefit to the consumer, who would receive a more reliable energy supply through a combination of a local electricity network which can operate largely independently from the grid, but also making the grid more reliable with the knock-on effects of higher RES levels. Therefore, there is an increased likelihood that power will be available to the consumer when desired, unlike the present scenario with rolling blackouts.

Political Constraints

This section will focus solely on a national level perspective, due to the absence of notable applicability at the different scales.

The Gaza Strip is a highly politicised area, with frequent and ongoing conflict with its neighbours, particularly Israel- where the majority of imported electricity supply originates. Additionally, the Strip is controlled by the group known as Hamas, which have been variously deemed as a terrorist organisation; whereas the West Bank is under the control of the P.A. The Strip is under an Israeli embargo on a large majority of consumer goods and construction materials.

Furthermore, due to the energy crisis, national energy policy is most likely to focus on providing demand satisfaction through any means possible, even though demand is not being fully met currently. Hence this means subsidies or a preference for fossil fuels could be the dominant national philosophy to meet this demand before renewable electricity is considered. These are some of the political constraints which could potentially hamper increased renewable electricity penetration efforts.

The framework builds on previous calls by other authors, by advocating for the creation or further development of an international leading entity to organise and galvanise efforts for the promotion of renewable energy development in developing areas. The requirement for this is clear- having the presence of an international organisation to direct efforts largely bypasses all accusations of bias, whether political or institutional, which may be directed at any proposals.

Additionally, the organisation would serve as a focal point for knowledge dissemination should the educational or institutional base of the target region be weak. This knowledge dissemination allows for the previous constraint of poor availability of data on renewables implementation to be corrected, alongside the availability of online knowledge databases at local participation scale. Having a country specific entity taskforce responsible for implementing energy solutions unique to that country, also helps to aid progress through a more focused approach.

Such similar organisations or entities already exist, such as the World Bank, or the UNFCCC and its financial arm: the GCF. The GCF being a fledgling entity founded in 2010 which aims to enact climate finance to developing areas of the world, utilises public finances from developed countries to then “catalyse private finance” to build upon this initial public seed capital. This is progressed through the initial development of policies and funding to developing nations, which will then hopefully allow the door to be opened for investment from private partners.

The framework proposes that should a *refined* GCF (RGCF) or another freshly developed organisation be considered as the leading entity required, this would- alike the existing GCF- continue to support the development of national and local action plans in conjunction with authorities in target areas. It would also allocate funding resources based on a more balanced and considerate approach of potential climate damage, existing infrastructure and ability to upgrade i.e. GDP/GNI. Concurrent the proposed institutional change and increased policy persuasion would need to occur, so as to advertise the benefits of renewable electricity in changing national energy policy.

The Gaza Strip faces a unique situation when it comes to the application of this framework, due to the afore-mentioned political constraints. Using the RGCF as an international medium, it is proposed that funding be provided for the integration of renewables projects proposed for the Strip, using the examples of Al-Fukhkhari and Maghazi as a template for the required urban energy solutions.

These solutions would be ideally funded through a RGCF, due to the identified ability for an entity to assess individual country needs and this being most prominent with regards to the present electricity situation with recurrent blackouts demanding energy storage and/or microgrids. The Strip has a moderate agricultural sector, with approx. 8% of the labour force employed in this [PCBS statistics; 2015], so there isn't an over-reliance on the sector which could be a potential trigger consideration for climate change adaptation funding measures. In addition, with increasing urbanisation within a small area, farmland may become scarcer.

There is however a heavy reliance on food imports, which does not emphasise food security, so therefore within a fragile political situation, this could serve as the afore-mentioned trigger consideration by the leading entity for funding allocations. The primary driver for funding is the poor availability of electricity at present, with under-developed electricity infrastructure, a heavy reliance on imported power and the frequent power outages. Since the P.T is variously classified as a lower-middle income nation, then this also mandates action in terms of GNI.

However, due to the controversial status of the Palestinian Territories, and the Israeli relationship, this may come under contention. Israel may wish to uphold its diplomatic conflict with the Strip through the economic pressures applied with its embargo, and the P.A too may not wish for increased economic vitality with regard to its previous decision to limit electricity supplies to the Strip through Israel, due to tensions between the P.A and Hamas.

This also raises the question of how to apply funding to the Strip in the midst of internal tensions within the P.T, as the Strip does not exist as a separate geopolitical entity. However, it is proposed that any case against proposals argued for by Israel or the P.T could be challenged for humanitarian reasons due to declining living conditions within the Strip due to lack of power. Furthermore, the role of the RGCF in recognising country-specific differences would need to extend to intra-country differences and act in a political neutral yet firm manner.

Political neutrality is a key tenet which needs to be developed, due to the potential for political undertones to be applied to any financial aid delivered to the Gaza Strip. This is important due to the contention which may be made by international donors, depending on the foreign policy of the donating nation, and for example would not help in bringing the United States (a frequently cited political supporter of Israel) back under the auspices of the Paris Agreement.

Therefore, it is proposed that funding decisions are only made on the basis of true need under international law and human rights charters and should remain impartial where possible. How this could be achieved however alongside the same decision initiators such as emissions track records and previous funding decisions/societal oppression by governments, is yet to be seen and likely forms a need for future work. In the same manner, safety guarantees would need to be made for RGCF workers operating in regions, in return for the benefits reaped from funding.

Overall, developing a clean and secure electricity supply within the Gaza Strip could actually be viewed to be a promotion of peace in the region. This is due to the reduced need for electricity imports to Gaza from Israel primarily, and also from the reduced stress and improved living conditions which could be found from such a supply arrangement, with this in turn contributing to increased levels of prosperity and contentedness.

Social Constraints

Village-scale: Al-Fukhkhari

This section will examine some of the social constraints which may be faced by the integration of renewable technologies into the electricity mix of the Gaza Strip, and developing countries in a wider context, beginning with application and potential issues found at community levels. As indicated earlier, generic social constraints identified from previous frameworks include a lack of social acceptance or a prevalence of general distrust amongst members of the targeted area and also a lack of skills and/or adequate training.

Since the modelling performed was technical in nature, only the application of the proposed systems in context of location can be used to determine potential constraints. Initially, the proposals are mixed with regard to the extensiveness of their use of land area around the settlements. This will no doubt generate a potential for social conflict over land-use, so therefore needs to be examined carefully and proposals made.

The largest user of land area for the village-scale would be the off-grid system, at 15.9 acres, and so therefore potential impacts at this scale will be examined. This is substantially less than that required for the configurations of the town-scale settlement, however as the land surrounding Al-Fukhkhari is predominantly farmland, and a scattering of accommodation amongst this, there could be conflict about location siting of the different components. Social considerations are often found under the umbrella of Environmental Impact Assessment (EIA) processes, common in developed nations, however in less developed regions it is unlikely that such processes will exist, or if they do then will be less effective and thorough than hoped for.

Solar PV farms do not tend to cause much environmental aggravation, whether human or ecological, due to their absence of moving parts and low profile, however they do occupy a significant land area. Wind turbines conversely can cause potential aggravation to local residents through shadow flicker and the visual disturbance of the moving blades, alongside their more significant visual profile from the landscape.

They also can cause ecological damage depending on the local species habitat, with bats and birds often facing distress from the moving blades, either physical or barotraumatic. A.D plants and batteries also have a lower profile on the human environment; however, biogas engines can generate significant noise, and therefore dictate good siting. In addition, A.D plants also can cause odour-related issues due to the nature of the organic feedstock, which in the case of the modelling, is composed of sewage, cattle manure and food waste/crop residues. This subsequently requires consideration to the local community upon siting.

Poor consideration of such variables thus forms one aspect of a lack of social acceptance, with the other aspects being distrust over the reliability of such systems and their potential benefits. This generally stems from historical norms familiar to the local community in terms of the physical manifestation of energy supply, however- are individual to each area. In the case of Al-Fukhkhari and the Gaza Strip, there is an unreliable grid supply leading to 9-15hrs daily unavailability of power (2018 averages, *Figure 2b*). As discussed earlier, this effect can often be felt most acutely in rural areas which are under-served by the wider power grid, common due to the perceived governmental lack of investment need to reach smaller communities.

Therefore, it is predicted that compared to other regions of the developing world, where a fairly reliable energy supply may be more accessible, this aspect of social acceptance may be overcome with relative ease once the benefits are made apparent. To fully overcome social distrust and non-acceptance, the secondary aspect of component siting must be considered. The largest land user footprint for the off-grid configuration- the 14 wind turbines- actually has a low per turbine-footprint, thus meaning that the land on which they could be located could still be used for other purposes with minimal impact, such as agriculture.

The positioning of the turbines should be so that they are oriented facing NW, as the wind most commonly flows from WNW to ESE. Positioning should also account for surface roughness of the wind flow path preceding the turbine, and thus this should consist of minimal urban settlement. This rules out a site South-East of Al-Fukhkhari, due to the impact the village itself would have on the airstream, and an optimal site would be to the North of the village amongst open fields. In terms of shadow flicker, there are a few houses nearby or adjacent which could be at risk, although it is determined that the effect could potentially be at a peak during mornings, due to the houses being located West of the turbines, and the sun rising due East.

Solar PV panels take up lower overall land area than wind, however they have high packing densities prohibiting siting to a few locations. Due to the low frequency of houses to solar PV panels, it was decided that all panels would be ground-based over an area of 29,000m^2, approximately the size of a medium-sized field surrounding Al-Fukhkhari. To minimise the effect on farming the surrounding land, it is proposed that this is overcome by positioning the solar PV panels either on land which is less valuable (yet not prone to flooding), or alternatively position the panels on stilts, to allow free passage and grazing of livestock beneath.

In terms of siting the A.D plant, this should be located a distance from settlement for sake of feedstock odour and engine noise, and within agricultural areas for proximity to crop residues and manure, yet close to road access to allow other feedstock shipments. The battery storage facility should be located within the village boundary itself, as there are no moving parts present or significant noise issues which could present social issues, and this eases rapid maintenance access, although the site should be secure. Figure 12 (Appendix) displays the layout of the components.

The lack of skills experience and training within the field of installation, operation and maintenance is also identified as being common to developing countries with unfamiliar RES technology. To combat this, the framework advocates that local training and involvement with the proposed network solutions be maximised to overcome this. This would be achieved through a multi-pronged approach of direct training by the RGCF, of a small group of villagers during initial RES component installation for the local site, followed by allowing access for the village to an online database for initial queries on system issues, and further access to interpersonal training.

The aim is to minimise the dependence of locals on foreign aid and develop the skills base within the area to handle any issues which may arise. Direct local involvement is seen as necessary as a catalyst for change whilst institutional change occurs at a wider scale with regard to the development of academic knowledge in the field of renewable systems integration.

Therefore, to enable this in Al Fukhkhari and elsewhere, local translations (in this case-Arabic) would need to be integrated to the database so as to aid the rate of knowledge acquisition amongst the community after a period of direct training. Having insufficient language translations for assistance with renewables projects in developing areas was a frequently cited negative, so therefore this change would increase overall success.

After this and to address further concerns over having a solely online communication and knowledge-sharing channel, the framework proposes the additional measures of live-monitored question-answer chats, and/or the ability for questions to be answered by telephone with experienced engineers from the RGCF. This would be combined with further training sessions on a periodic basis. As indicated earlier these would likely have to occur at this scale on a sub-regional basis for time and resource management purposes of multiple villages.

With the likes of Al-Fukhkhari, this is dependent on the domino effect of other villages adopting similar practices, and if so then a governorate wide training session being held in a larger settlements such as Khan Yunis or Bani Suheila. Sub-barriers within this proposal however involve the ability of the local population to have access to internet, to read and write, and also to drive or have transport connections to the governorate training sessions. It is not known how to best overcome transport and internet infrastructure/availability issues, aside from a general improvement in social mobility and infrastructure investment in the country of interest.

There is also the quandary of how to choose those of the population who will be most effective at learning the trade skills required, and gender norms in the country of interest. For example, within Khan Yunis Governorate, there are more women illiterate than men and generally fewer women in employment in the P.T as a whole [PCBS statistics; 2018], raising questions of how best to apply a framework developed from an international perspective of equality, to areas where there may be greater gender bias for certain roles.

Therefore, within the Gaza Strip consideration must be made of local norms, which is reflective of the approach which should be taken for the framework in general, whilst aiming to maximise the social benefits brought about, including a move towards gender equality if this is accepted.

Town-Scale: Maghazi

Again, many of the village-scale constraints theoretically will be applicable to town-scale settlements such as Maghazi. Notable differences at this scale however involve the higher population and urban density for renewables development within a town, presenting slightly different potential land use conflicts. Additionally, social acceptance levels of renewables may be lower due to the existence of a slightly stronger grid connection than found at rural village level.

Due to low data collection records for Maghazi, social acceptance can only be assumed, but it is presumed that due to the camp being of a higher population and hence economic output, investment decisions for grid connection firstly exist, and also are likely to be supported by slightly more capacity resilience than at village scale. This is only an assumption however, and one which must be carefully made about any case study to which the framework applies. Therefore, social acceptance may be lower due to the perceptions of a stronger grid.

However, this could be amplified through the existence of rooftop solar PV generation within a crowded and high-density urban environment. Depending on economic arrangements, rooftop solar PV could be seen as a hindrance due to space requirements- as it is clear that there “is a general lack of recreational and social space” [UNRWA]. In addition, depending on the nature of the town-scale settlement, building construction standards may be adversely inclined to rooftop solar PV mounting e.g. in refugee camps such as Maghazi, buildings have potential to be ill-built.

In addition, the higher levels of component infrastructure required to support the various configurations proposed for Maghazi could prove of increased conflict with local landowners. This is evidenced by the substantially larger 400 acres of total component footprint required for full off-grid operation of the settlement, and the much smaller, yet still significant 32 acres for 70-75% RES penetration.

Most of the surrounding land is farmland, although this peters out into housing to the North and West, leaving a 600m wide gap to the South and East on which available land space could be built on. This therefore rules out feasibly operating Maghazi on an off-grid system, although 70-75% RES penetration in grid-connected mode could be possible. Previous calculations show that integrating 8kW of PV per roof, only approx. 79-80% of the buildings within the town would need systems to supply 100% of the supply required at this scale of penetration.

However, in an effort to combat the rooftop PV/space issue, a decreased number of rooftop systems in favour of a more even split with ground-based siting, could help solve this problem. For example, if only 39-40% of buildings had rooftop systems, this would result in an approx. 5.44 MW generation (at 63,400m^2), equivalent to 50% of the total demand. This leaves an equivalent area (15.6 acres) of ground-based installations to supply the remainder of the load and helps to reduce some of the tensions of land use within the town.

The location of the ground-based installation can again either be situated on low value land, or on stilts to allow for livestock grazing beneath. The A.D plant is larger than modelled for village-scale, with this necessitating a larger engine (370 kW), and an increased level of feedstock inputs. Therefore, to accommodate this increase in noise and odour pollution, the plant should be sited at the maximum greenbelt boundary distance from the town, amongst agricultural land and on the road to allow access. The battery storage unit should also again be situated close to the town, with no significant social impact foreseen. The proposed layout is outlined in Figure 13 (Appendix).

Economic and Institutional Constraints

Village-scale: Al-Fukhkhari

The proposed technical systems for integration of RES to Al-Fukhkhari village require total lifecycle costs (NPC) varying from between \$8.5 million – \$18.7 million (NIS 30.1 million-66.2 million), depending on the desired RES penetration level and operation of the system. The greatest expense is found with the off-grid system, and the lowest expense found with the 30-35% penetration with the grid-connected systems. With consideration of this significant cash investment with regard to the community, this equates to a potential investment of \$1700-3740 per village resident (assuming 5000 residents).

This is infeasible in a developing nation, and with the case of the Gaza Strip and it listing as a lower-middle income nation, this constitutes a range of 40-95%+ of annual salary earnings- an untenable situation if the village was expected to wholly fund this. External funding is therefore required to meet these costs, and this can stem from either the national government or, more feasibly, from international development agencies/funding mechanisms such as the RGCF.

Another significant economic constraint at all levels, included with the capital outlay for Al-Fukhkhari is the lack of renewable electricity incentive mechanisms within the P.T, stemming from the previous lack of RES penetration and also a weak institutional base. Such financial incentive mechanisms which have worked in other areas around the globe include feed-in-tariffs (FiT's) and renewables tax breaks/carbon taxes on polluting technologies [Abolhosseini. S & Heshmati. A; 2014].

With FiT's, the author raises an applicable constraint to the Gaza Strip, which is especially true at village scale: guaranteed grid access is required as an essential provision of the policy, so as to allow sale of renewable electricity when available. Although only applicable to grid-connected proposals and those that qualify for FiT, with the present unstable nature of the grid in the Strip, this is a significant constraint. This will persist until sufficient infrastructure improvements and other RES generation/storage units on the wider grid come online.

The premise of FiT's also relies on the customer/individual taking individual ownership and having the initial financial flexibility to buy a system (before being paid for generation), therefore there is little scope in promoting this mechanism unless other funding or incentive mechanisms are used in conjunction. For example, if the systems were directly funded for the villagers by the RGCF, or financial incentives where provided solely for their purchase e.g. tax breaks, then this would facilitate operation of a FiT scheme. This would form either a direct or an indirect measure to rapidly grow the domestic renewables market within the country, although simultaneous investment would be required in grid upgrades to facilitate the increasing volumes of RES connecting.

However, yet another constraint raised with this proposal would be that any investment from external sources is typically expected back in external-bound returns from an operating system if private investment is involved as would be eventually true under the existing GCF. Even with the existing grid-connected tariffs, there is an issue of non-payment of electricity bills as indicated earlier by Shammaleh. N.

Therefore, if substantial cashflow returned to individual operators through a FiT scheme for individual system generation and sale to the grid, this would theoretically reduce the revenue received to investors had any of the same systems been owned through an external power supply company. However, with the RCGF it is proposed that public capital be initially invested with no expected return, so as to open up future investment opportunities for private firms with the maintenance and upgrade costs of current equipment.

Naturally, there is a difference in the direction of power sales depending on the architecture of the system involved. This depends on whether the village is grid-connected or operated as an off-grid entity. Ideally, a microgrid would operate in grid-connected mode for the duration of power availability, before automatically switching under the guidance of a control system, to grid-islanded mode when this is not the case and operating under the power of its own generating units.

With modelling, it was possible to model the off-grid scenario to reflect the grid-islanded case whereby the village could be sustained when required, and then subsequently the various RES penetrations of grid-connected mode were modelled to represent this component of microgrid switching. Therefore, to satisfy any demand for a totally reliable power supply, grid-switching capabilities would be required with investment in the off-grid system through a point of common coupling.

This infrastructure would be used during grid-connected mode to generate electricity for the grid (to cover the demand of the village in doing so) and to generate income this way. This is possible due to the relatively small footprint area occupied by the microgrid components surrounding the village. The village would be **both** the energy producer and consumer during off-grid operation, and the village would be **either** the energy producer or consumer during grid-connected operation, depending on the generation capacity to meet village demand.

Since this is a feasible option at this scale, consideration of a financial incentive mechanism should account for the shifting system architecture of grid-islanded/off-grid, and grid-connected settings. As mentioned earlier by Thiam. D, an IPP/renewable asset or concession system could be used under the Renewable Premium Tariff (RPT) variant of the FiT; with the former system typically accounting for grid-connected mode, and the latter typically solely applicable to off-grid systems.

For any such grid-switching system to work under a financial incentive mechanism, so as to promote sustainable and secure power, and in a cost-effective and consumer attractive manner, a combination of these systems would likely be necessary to enable electricity generation sales. This would involve a combination approach of the following: the renewable asset operators selling directly to the utility under the negotiated tariff, covering all financial costs of capital and maintenance, with the utility then selling the electricity to the end-user at a discounted price; **and/or also**, the local utility owing the microgrid and selling to the end-user at discounted rates.

If the village community of Al-Fukhkhari were to purchase the IPP’s, or have them granted through external funding, revenues from the utility-guaranteed premium tariff could be reaped due to the village owning the assets. This would be applicable during grid-connected mode due to the purchase agreement of the utility buying the electricity that the community generates, and then selling it back to them at a discounted price. The Gaza government or external aid fund would pay the utility to enable the discounting. If the community were to also buy the local energy utility however, this would require a significant investment and also mean that there would be no given discounting of rates to the community without external intervention.

This latter stage would increase ownership over the renewables and increase transparency. However, as Peters. J & Toman. M [2019] writes, it is difficult to enforce a financially viable off-grid network (e.g. to finance lifetime costs and maintenance) when fully community operated, i.e. no separate local energy utility, especially given no rates discounting is automatically given. This is due to the view that renewable resources are free, social complexities, partiality towards familial ties, and the need to force people to pay the full fees to allow sustained economic operation. When the local utility enforces payments, this increases revenues by bypassing this.

To operate during grid-islanded mode, the utility would be required to continue overseeing and enabling the payment of tariffs to the village-owned IPP’s, despite no power flow to the grid connector. Therefore, installing bi-directional metering is essential to monitor the flow of electricity within the system (i.e. within a closed loop) to and from the generators, loads, and battery systems. This would represent a quasi-format of the concession scheme, whereby the local utility owns the distribution network within the village, but not the generators, enabling installation of metering systems.

Revenues from the RPT would have to be gathered for the community as a whole, due to the diverse nature and large-scale of the RES components not suiting individual residents’ ownership. This should be distributed into a community fund, with a proportion dedicated to maintenance of the system and the remainder allocated to each resident, potentially as an equal deduction on their electricity usage bills.

The role of the RGCF would be to enable the capital outlay for the community to purchase the renewable assets and begin generating in conjunction with the grid and with the capacity to operate off-grid; alongside the reparation funding of the local utility to account for the discounted prices or tariff payments. However, this would need to be adjusted over time to reflect the changing economic status of the villagers as a result of revenues, with annually adjusted decreasing discount rates (alike the UK FIT's time-dependent decreasing generation tariff payments) or developing increasing tax rates on the community fund. This would enable the direct monetary role of the RGCF to be phased out over time.

A separate institutional capacity would need to therefore be transitioned in the Gaza Strip, one which is able to facilitate both current and future discounting to utilities with fresh microgrid systems. This is due to the weakness of the current institutional base, with no functioning current FiT system in place within GEDCo, with this expected to occur through a growing academic base, and increased training/opportunities as guided by RGCF.

This input would need to form a specifically relevant pricing model to the Gaza Strip, based on the proposed energy infrastructure and with sufficient flexibility to allow for the political instability inherent to this region. This pricing model would typically look like that above, where consumer financial incentives are encouraged to facilitate an increased renewable electricity share of the national electricity mix, and to cope with the immediate failures of the national grid by incorporating off-grid capabilities. This system of microgrid clusters would serve as the backbone of generation and contribute to poverty alleviation through FiT.

Town-scale: Maghazi

Financial constraints at this application scale are considerably intensified due to the higher NPC required for implementation- ranging in the modelling from \$47.5 million- \$150/190 million for Maghazi. This again is highest for off-grid proposals, and lowest for grid-connected systems with a relatively low (30-50%) RES penetration share of the supply. This again equates to \$1600-\$5000/6000 per resident to invest in the energy system, which alike the case of Al-Fukhkhari, is equally untenable and thus requires external investment in the system.

With regard to the transferability of the framework from village to town-scales, the architecture of this system may be different. This is due to the higher daily energy demand of 37.3 MWh and the ability of the surrounding land to support a fully off-grid system to cope with this demand. A smaller system would be the only feasible option to cope with social constraints, and this would therefore need to be a grid-connected system. The 70-75% penetration configuration example displayed in Figure 13 could enable a high percentage share of renewable electricity contribution, flowing to the grid, in the process covering the town demand.

When the grid is not enabled however due to a fault or insufficient national generation, a point of common coupling would still exist, and the battery storage systems would enable previously absorbed grid-power and excess RES generated electricity to flow to homes within. This essentially forms a hybrid system and is especially the case with roof-mounted solar PV as proposed where direct electricity could flow to buildings outside distribution lines.

However, this would place the batteries under significantly more strain, as there is no grid back-up, and batteries would have their reserves depleted at a faster rate. In addition, since only a certain percentage of buildings have rooftop capacity attached, this would potentially serve a disadvantage to those which do not have this. Therefore, during periods of grid unavailability, a system of demand allocation would be necessary, which is not equivalent to 100% secure supply, but is an improvement on total grid unavailability.

Rooftop systems could supply the attached buildings, with any excess flowing to the battery storage, whereas non-rooftop buildings/loads would utilise the battery storage which is charged by all connected RES and from pre-grid unavailability periods. An economic pricing model for this would therefore need to consider financial incentives alike present at village-scale, including generation payments.

If the town-scale community was granted access to the IPP’s which are proposed for this scale, then during periods of grid availability and net production capacity, these would be set up underneath a similar RPT to sell generated electricity to the grid for a revenue. The network controller would allow for electricity to flow first to the storage units until these are at full capacity, and then the remainder would be sold to the grid. This revenue could be collected and sub-divided to the community as a whole, by contributing money/kWh generation in the same manner as the village, by deducting this amount from usage-based electricity bills.

As the community owns the totality of the IPP’s, those buildings with solar PV attached could not claim extra payment for location-based generation rights, as the community as a whole owns the IPP’s. This ensures fairness as electricity bills are only collected based on individual usage rates, whilst deductions on these are made based on community-wide generation revenues to the grid through the utility.

When there is demand outstripping the supply capability of the community generators, this supply comes from the storage, however once these reserves are depleted then the grid sells to the town solely based on individual usage rates. However, consumption rates can only start being charged by the grid when generation is outstripped, therefore usage rates need to exceed this. Again, due to the community owning the IPP's, any generation of individual rooftop mounted PV needs to be grouped with the other RES components to avoid payment bias.

When operating in a mode of grid unavailability, the system does not have enough generation capacity to sustain total load due to the space constraints of the surrounding land, so therefore all supply would need to originate from the combined output of RES generation and storage capacity of the system with the highest penetration and therefore highest output (70%). This could technically sustain load for a short period of time through the contribution of storage units, and RES output.

After storage capacity is depleted however, a system of demand allocation would need to be introduced to prioritise RES supply demand fulfilment to those properties with solar PV attached, with the remaining RES supply capacity being allocated to other buildings. When RES supply outstrips demand however (due to 70-75% penetration and therefore load capacity), demand allocation would need to be prioritised to those deemed of the highest need e.g. the health centre and the domestic sector and cutting off heavy industry until sufficient supply is available again.

The priority change from disallowing rooftop mounted PV systems to uniquely utilise generation tariffs during grid-connected mode, to allowing it during off-grid mode, is necessary to allow the overcoming of a significant social constraint of rooftop space allocation and seemingly bias towards those who enjoy space and an electricity supply. This is true even though the community owns the IPP's, as the location of the rooftop-mounted systems is a resident concession and therefore ownership rights could be temporarily assigned during periods of grid unavailability for this sacrifice.

This would hopefully encourage further properties to install solar PV capacity to their roofs- and in the process boosting national renewables capacity when grid-connected in a cost-effective manner due to the lower comparative cost of PV to A.D, and also ensuring supply when not connected to those connected, and with more storage potential too. The role of the RGCF should be to help fund the community purchase of the RES assets/IPP's, to finance the tariff payments, and to help develop a stronger institutional base within the country to supersede itself. This would enable the allocation of international climate finance from the RGCF to be distributed responsibly i.e. to ensure investment is going to bring about sustained change, whilst assisting with the short-term energy issue through a clean supply.

This concluding stage will examine the effectiveness of the framework, through lessons learned with its implementation with the case study, and then recommend best practice of application at a wider international scale to satisfy its core aims. The framework set out to examine the issue of and improve existing measures to ensure and best deliver an increased share of renewable electricity to the energy mix of economically developing countries, where existing infrastructure and penetration of RES technologies is low. This is viewed as necessary to combat the problem of increasing greenhouse gas emissions within such regions, alongside the significant financial and other constraints which have previously plagued efforts to best tackle this.

Several key factors were identified in the creation of the framework to be of importance to the success of implementing such a goal in EDC's. These included but weren't limited to identifying and overcoming common and foreseen technical, social and economic constraints which could restrain progress. The process of the framework lays out how best to deliver a flexible and inclusive, yet effective package solution to improving the success of the stated aims. Through the application of the proposals to a case study example, which in this case was the Gaza Strip, broad integrity could be tested, and any areas of weakness could be highlighted, alongside suggested potential solutions to individual issues.

A main area of the energy system transition, which was identified to be of concern, is the role of the wide area synchronous grid (national-level grid) within the country of interest. This component of electricity transmission and distribution has traditionally formed the centralised backbone of a 'modern' electricity network, connecting areas to a power supply located far afield. Yet in EDC's this benefit is often only available to urban populations, leaving rural areas without any supply. Also observed with such regions is that often there can be serious supply quality issues even for those connected, with low national funds available for maintenance and general system neglect often prevalent, attributed to various socio-economic reasons.

This was notable with framework examination of the Gaza Strip case study, which has serious power supply issues through its national electricity grid, most pertinently due to insufficient generation and excessive demand from a large population. Within the Strip, electricity demand far outstrips supply, (with domestic generation being fossil-fuel dominant); with the territory heavily reliant on electricity imports from Israel and Egypt to equal the remainder. This leads to multiple hours per day with no electricity transmission through a system of rolling blackouts initiated by the government and GEDCo to cope with the high demand, resulting in a truly untenable situation, which is characteristic of some EDC's.

Due to such underdeveloped national grid infrastructures, introducing renewable energy- which by nature is often stochastic and variable- can be seen as a major obstacle to be overcome in developing a sustainable supply in EDC's. The framework identifies two main issues to be of importance here and proposes a singular solution to largely overcome both. The first incorporates physical phenomena such as low grid inertia and high ramp rates with the increasing presence of RES devices operating on a connected electricity network.

Low grid inertia is caused by the aggregated presence of devices which lack high rotational potential, with this compromising the network ability to properly react to frequency disturbances, including that generated by the high ramp rates characteristic of solar PV for example. Therefore, when increasing the percentage share of renewable electricity within a network such as a national grid, this can lead to difficulties controlling demand and supply and ultimately to potential cascading failures and network shutdown.

The second issue is connected to and more widely known than the previous - and originates in the variable nature of renewables. With a widely fluctuating resource, entirely reliant on natural forces for electricity generation, it becomes difficult to properly assign supply to demand loads, especially during times of resource unavailability. The framework therefore echoes the wider power industry in that energy storage be integrated as a crucial component of energy networks with increasing levels of RES generation.

Energy storage was observed to be absolutely critical to achieving the aim of reliable power supply within such renewables-dense networks, when supply systems were modelled with Homer Pro to meet the assigned demand of two settlements of varying sizes within the Gaza Strip. As expected, reliance on storage was found to be of highest importance when RES concentration was high, such as was the case when off-grid microgrids were modelled and the only supply input was from renewable electricity generation. This is necessary to handle the variable nature of RES through the release of absorbed excess during times of non-generation and contribute to greater system stability by using this excess to ride through and soften variations.

Battery storage was the storage system modelled in the case study, with this presenting a flexible manifestation of the requirement through its modular nature and hence potential for further capacity upgrades. Within developing countries, especially those located in arid climates such as across Africa and southern Asia, battery degradation is a problem which can potentially disrupt supply over time if storage is integrated. This is caused by adverse weather which can degrade highly sensitive components over time, therefore proper housing units for the battery are required in such places.

Another technical constraint identified by the framework for introducing battery storage in EDC's is over-reliance on it for network supply, as this can lead to further component degradation through repeated deep-cycle charging/discharging. There is also potential relevance here with easing PPA payments from the utility to generator due to marginal COP and the presence of batteries, with this however causing strain. This thus requires careful energy system planning, involving for example, reliable short-term resource forecasting, so as to maximise the diversity of operating components within the system and therefore alleviating pressure on the storage system. This issue is especially relevant with off-grid operation, due to the increased reliance on the batteries as a supply input during periods of grid unavailability.

Maximising the use of available renewable resources should be emphasised and achieved through adequate research and study of the targeted country. This should be achieved through preliminary and then advanced studies. The combined use of resource atlases (such as Global Solar/Wind Atlas) forms preliminary analysis, so as to establish feasibility before an investment decision is made. This is then followed by location-specific advanced studies, achieved both through analysis of previous resource records e.g. wind speed databases, and/or fresh study based on the collection of new data through e.g. anemometers/pyrheliometers.

It was discovered that poor existing data sets can be a major constraint to resource assessment for all technologies, although educated assumptions can be made based on existing data. The issue arose with regard to the Gaza Strip, whereby preliminary resource data represented a higher value than that observed through both previous dataset assessment and individual calculations. This was attributed to the wide search pattern/grid-cell of the Global Atlas resource, and thus data had to be adjusted to account for all input information.

Therefore, there needs to be a sustainable data collection system whereby enough reliable information is collected for the site of interest, so as to enable sound investment decisions; meanwhile this has to be considered with time-frame constraints. It is advocated that increased national datasets be collected by national or international energy agencies, such as the RGCF, so as to ease the time burden on future feasibility studies.

The framework also proposes, through case study of the Gaza Strip, to maximise the use of organic resources within EDC's for the use of A.D as an energy source. This can be tailored to the specific country, due to the wide variety of organic feedstock which reactors can typically handle to produce electricity in conjunction with biogas engines. The benefits of A.D are that it provides a relatively non-stochastic, predictable base load to microgrid systems, whilst simultaneously enabling more effective organic waste management to control local pollution and emissions.

For example, the systems proposed for the Gaza Strip make use of the specific issue of a high urban population and therefore the correlated volumes of food waste and sewage sludge, which the latter of which would otherwise pollute groundwater. This is due to the relative lack of livestock manure potential and agricultural residues, and therefore this tailored solution allows for double benefits. The case study proved that there is a direct link between the population size of urban settlements and the available organic resource in these areas. Also, it indicated that common feedstock is related to settlement size- with village scale, there is more usable rural land, yet a lower population (therefore agricultural products are key), meanwhile for town-scale settlements there is less rural land, however a greater urban OMSW resource.

Another notable highlight which the framework discovered during real-world modelling application within the Gaza Strip, was the subsequent consequence of off-grid/grid-islanded operation on land space availability. With an increasing penetration of RES components supplying a settlement in decentralised network mode, increasing land area surrounding the settlement is required for supply generation. This was identified as most prominent with town-scale settlements, due to the often-congested land surrounding them with loose urban boundaries and satellite villages thus limiting generator site allocation.

This is also most notably the case with wind power (followed by solar PV), due to the minimum spacing required between turbines for effective wake-disturbance minimisation, and the proper siting constraints whereby minimum surface roughness is necessary on the preceding land. This thus restricts siting to specific locations within that available, which can raise land use conflicts due to the dissipated nature of the wind farm (or solar) footprint.

To handle this, the framework advocates several solutions. Primarily, related to the previous advantages and downfalls of the network role of storage, due to the small footprint of batteries in comparison to the equivalent output gained from RES generation such as a wind farm; these can be utilised to sustain a settlement with a lower land use impact. However, as indicated previously, with excessive reliance and an ill-designed system ratio of low diversity of renewable generators to storage, battery systems can degrade at a faster rate than otherwise.

Therefore, the correct balance needs to be attained between ensuring sufficiency of generation output from a wide enough diversity of generators, thereby utilising the available resource and enabling a *sustainable* system in terms of supply security; and also minimising the land area footprint occupied by such generators to reduce social tensions. In addition to battery capacity considerations, locating solar PV panels on a raised base (stilts) could allow for the continued grazing of livestock beneath. Furthermore, distributing space-intensive PV systems over rooftops within the settlement served can be a good method to reduce external land use.

To facilitate the advancement of renewable electricity in the country of interest, the framework identified that a leading entity would be needed to oversee and assist efforts, proposing improvements on the existing Green Climate Fund (GCF) to undertake this task. Such improvements would enable the refined entity (RGCF) to better address the issue of country-specific issues with renewables implementation. This was tested on the Gaza Strip, where the unique political and technical issues faced here were considered alongside others.

This included facilitating renewables integration with the previously mentioned lack of space of a highly urbanised national environment, alongside the frequent unreliability of the national grid and political instability. To overcome the issue of the Strip’s specific grid supply issues, the framework proposed that microgrid-enabled settlements were created, in a move away from a centralised system towards a more decentralised one. This would see the different scales of urban loads (village and town but neglecting cities in this paper) incorporate differing levels of RES DEG’s and battery storage to enable off-grid function to varying capacities.

[Side *Note*: that if considering city demand, with analysis of the substantial increase in consumption from village-scale to town-scale, then an equivalent population increase to city level would equal an equivalent rise in demand. This could not be facilitated in an off-grid manner with space constraints, however with an increased share of grid electricity within the Strip being renewable, any grid connection to the city would benefit from this lower carbon supply.]

These would consist of either wholly off-grid systems, or hybrid systems, the latter of which would have a point of common coupling to allow for the switch between grid-connected and grid-islanded modes. With such systems it would be possible to serve the community with a power supply even when the main grid was not available, as was modelled within Homer Pro to reflect the approx. 47% annual grid outage rate found within the Strip.

At village scale it was observed to be more feasible to facilitate wholly off-grid systems, and/or hybrid systems which could satisfy the entirety of the village load. In addition, rural areas are typically more likely to not have a grid connection, so this amplifies supply benefits through weaning of emergency diesel generators, which the proposals design out of need. Conversely, with town-scale application, as mentioned earlier, the land use constraints of a fully load-satisfying system did not often allow for wholly off-grid operation.

Instead, grid-connection had to be present, yet a hybrid system could exist, whereby when grid availability was not present, the system would **initially** utilise available RES generation and battery reserves **before switching** to a process of demand allocation due to the inability of the RES components to fully meet average load.

Financing the implementation of such systems was discovered to be a herculean task if only facilitated by the residents of the settlement community and identifies/reinforces that community purchase is often not feasible in developing countries, where mean income is simply too low. Therefore, the input of external financing is needed, and this is where a main role of the RGCF enters as proposed by this framework: in the initial capital outlay for component purchase.

The RGCF was selected due to its high-standing status as the financial mechanism of the UNFCCC in its original incarnation (GCF), and the specific focus on distributing climate finance to projects within the developing world. This external funding amounts to a potential of close to or over $100 billion per year by the approaching year 2020 and has previously allowed for renewables developments to make progress in developing nations. Additionally, the public-private partnership allows for initial one-off public fund investments to be made, which then paves the way for other private investors to capitalise on the changing energy environment within the country, concurrently boosting energy-related welfare.

Therefore, initial capital funds for financing the microgrid developments proposed for fixing the Gaza Strip's electricity issues can be progressed. Subsequently, the ideal measure which was logically advocated for enabling the spread and vitality of these networks was to design effective financial incentive schemes to promote renewable penetration. The already proposed Renewable Premium Tariff (RPT) was forwarded as the optimal mechanism to guarantee secure long-term payments towards generators of renewable electricity. This was required to be designed in a new configuration suitable for hybrid grid-switching function.

In theory this permits the community to be awarded the renewable assets financed through the RGCF, thus enabling them greater ownership over their system and hence a greater sense of responsibility in their energy affairs. This also permitted revenues to be generated from the RPT, as excess electricity beyond that which storage can absorb is sold to the utility and the wider grid during times of grid-connected operation if this exists, e.g. with town-scale developments. This revenue is proposed to enter into a community fund, which can be operated by the utility if necessary, so as to avoid social bias (although this is an area of further study), and then this is allocated to each electricity consumer through reductions on their usage bills.

The utility would be the operator who would discount electricity bills, and/or distribute tariff payments, yet this is proposed to be funded by either the government, an institutional body, or the RGCF. Discount/tariff rates would be decreased over time, so as to both allow a market rush to install systems (mostly PV) *outside of that* base capacity already funded by the RGCF, and also to allow the gradual withdrawal of international aid from the area. Additionally, a separate institutional entity would need to be created/strengthened within the country, with this being concurrently developed through international knowledge transfer partnerships.

During periods of grid availability, yet low supply capabilities from local generation, electricity is purchased from the grid based on individual consumer usage rates. This only occurs as mentioned when RES generation and storage reserve is outstripped by demand, therefore if an individual consumer such as heavy industry is drawing a substantial load approaching a period of low generation/storage reserve, then it could be an option to oblige these consumers to pay a higher network connection rate to equalise this community discrepancy. However, further best pricing research needs performed to identify the best configurations to account for this.

This has implications due to the economic importance of industry to both a country, and a town for this instance, and hence a reliable supply should be prioritised. However, within microgrids which cannot fully support off-grid functionality due to space requirements, this becomes an issue with domestic loads and energy-critical loads such as healthcare being potentially prioritised over industrial load demands. A possible solution atop of the previously mentioned one, could be to integrate extra battery storage capacity to the industry in question, through which the industrial unit pays the capital for. This equally would require extra research too.

If the national grid is unavailable as is currently common in the Strip, then for wholly off-grid systems such as that feasible for village-scale, this poses no problem due to non-grid connection, additionally the impact is lessened for hybrid systems which can cope with full off-grid load again such as that proposed for the village- and also ideal for rural areas. However, as mentioned earlier, for hybrid systems with insufficient generation capacity to accommodate 100% off-grid status, demand allocation measures were proposed to handle this.

In doing so and in contrast to other scenarios where the community acts as one entity when considering renewable generation tariffs reaped, owners of rooftop mounted PV systems-which are seen as a necessary possibility for off-grid functionality/space requirements at larger scales-will receive the full tariff for their generation. This was seen as a necessity so as to handle the social constraint applicable typically to highly urban dense settlements with potential little free rooftop space, and the perceived bias towards residents who did not sacrifice this space but still enjoyed the electricity generated for their benefit.

This scenario scale was selected as it was the last resort option and least likely, therefore it would occur only as frequently as the grid was unavailable, hence decreasing over time. However, it is projected to have the socio-economic effect of encouraging an RPT incentive drive from consumers to install systems atop their own roofs, thus boosting generation capacity both within the microgrid and also on the wider network. This again would not be funded by the RGCF but by the consumer through the individual revenues reaped from the community RPT as a whole.

After considering the financial and technical constraints, further social constraints applicable to both the Gaza Strip and the wider pool of EDC's, include the prospect of a low skills base within the target area, especially if implementing projects at local level with local ownership. This becomes a significant issue when the proposals are made for local maintenance of renewable electricity systems within any microgrid, although this method of local participation maximises social benefits and overcomes many social constraints of non-acceptance.

To overcome this, a system of knowledge transfer partnerships implemented through the RGCF mechanism (and likely requiring the creation of a new department within this), will initiate direct and indirect training and support for local people involved in the local system operation. This will improve on previous models, by combining a primary improved online-based knowledge transfer system, with face-to face training both during initial project construction, and subsequently at staggered intervals after completion- on a sub-regional scale.

The benefits of this system would involve sustainably balanced resource inputs from the RGCF, through the primary resource allocation being invested in the online system for initial Q&A requests and help manuals. This would also allow for a direct online chat service and/or manned phonelines to trained engineers and system planners, who could help resolve any issues which could not be achieved through the digital automated system- an aspect which improves on previous models through increased human interaction. This would also be required in several main base languages designed to increase participation within EDC's, notably French (West Africa), Arabic, Spanish and English, alongside capacity for further language addition.

The need for face-to-face training is identified to be critical, and the framework proposal to integrate local help and training during initial design-planning and construction is ideal to maximise the impact such systems can have on locals through their specific considerations/needs, and also through training for future maintenance. The follow-up refresher training will also be necessary to keep system stability strong, with this being operated by the RGCF/other agencies initially, followed by in-country institutional bodies after this.

Within the Gaza Strip, this could be enabled per Governorate, as there is not significant distance between settlements at this scale, and satisfies the limited resource allocation for individual systems, hence serves a sub-regional scale. However, the general question of transport links for commuting representatives on a larger scale in other EDC's needs further consideration, in addition to improvements in internet and other general infrastructure e.g. sewers. Application within a case study also forced consideration of an adequate process for facilitating the local hiring process with system implementation. Within EDC's, gender norms may be biased and there may be varying levels of literacy and core skills development with different groups of a community, therefore this selection would need to take these factors into account.

Overcoming political constraints can be a major factor in sustaining the energy transition from traditional to sustainable energy sources in EDC's. With the framework-advocated presence of a leading international entity such as the RGCF, which assists in direct change through funding, this externality could be seen as an impartial intermediary in helping overcome political impasse. With the Gaza Strip example, political tensions are amongst the highest expected, although this is not wholly originating from the energy sector, yet electricity supplies are primarily imported from Israel.

To overcome political constraints *so as to apply energy solutions* in this context, it is proposed that the RGCF and framework be as politically neutral as achievable, focusing on providing funding for all areas of the world, based solely on need. Classifying this need should be based on an assessment of ability (or lack of) to pay for the upgrades required for a sustainable transition e.g. GNI and flexible national income reserves; the present impact on living standards; and the government track record on emissions and other areas. Towing the line between remaining politically neutral and assessing government track record in this regard is identified as being difficult, with the latter being necessary to avoid free riding on the funding system and to ensure real change can be sustained from all levels.

The Strip has serious energy-related living condition issues, with various impacts on health, education and the economy, and therefore this would be a key condition for funding approval so as to both ensure a sustainable *and* secure electricity supply, since this is the area of the greatest need. Despite the current government being classified variously, as having fundamentalist sympathies, there has been previous effort made to ‘green’ the Strip through solar thermal, and the odd renewable electricity project (refer Desalination Plant).

However, caution needs to be applied due to this likely existing due to external influence through EU diplomacy etc. and possibly in historical collaboration with the P.A rather than Hamas. This proves that there is tough decision-making required within the framework to weigh the human impact of electricity poverty, to funding decisions. In addition, the World Bank rates the Strip as having a lower-middle economy/ GNI. There is significant existing aid already present within the region, however, to ensure sufficient progress and safeguarding of monetary supplies, the external influence of the RGCF present in the country would be necessary for concrete progress.

Through a system of institutional change and political pressure (through policy advocation through the RGCF and demonstration of successful pilot projects), it is also proposed that the system of renewable generation tariff payments will result in a subsequent market explosion for ‘green’ electricity. This will help to equalise renewable electricity with the subsidised fossil fuel generation; although carbon taxes on fossil fuel generators are cautiously advised against.

To summarise, the framework is deemed to be of integrity in its fundamental propositions, tested through a real-world case-study example, and therefore can be advocated as a tool to help EDC's overcome the common constraints faced when following the energy transition to a greater share of renewable electricity. This has been achieved through analysis of and the proposed overcoming of social, political, technical, economic and institutional constraints which are common to such regions of economic ill-development.

In particular, the country-specific nature of the proposals, acknowledging individual needs and circumstances of specific energy systems is seen as crucial to attaining further renewable electricity integration progress. Furthermore, local participation is a great method to overcome social constraints common to this application.

Some weaknesses of the framework were identified nonetheless, which are recommended to be worked on in future research. These focused on strengthening areas of microgrid application in communities and overcoming minor social constraints such as how to optimally facilitate off-grid functionality with limited land-space for renewables, and the various socio-economic factors which stem from this (e.g. tariff payments).

More research should be performed on how to best design an international overseeing entity with its funding powers and decision-making in relation to areas of political instability. Furthermore, as a general recommendation of the framework, a widespread yet focused effort should be made to identify and reliably categorise the potential resources available in different countries so as to aid future studies intended to bring secure and sustainable electricity supplies to EDC's.

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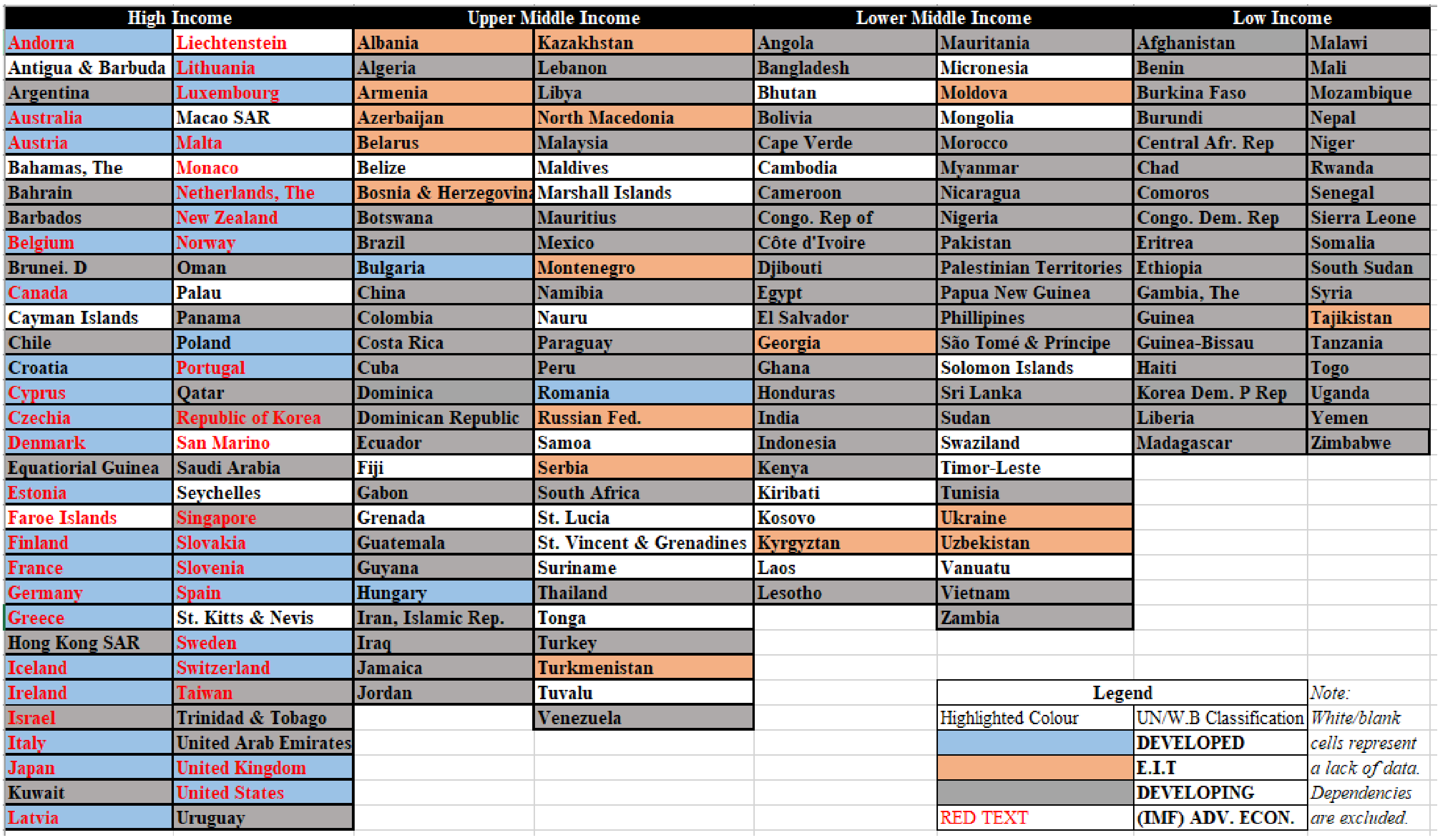
Homer Pro Microgrid Analysis Tool; Homer Energy

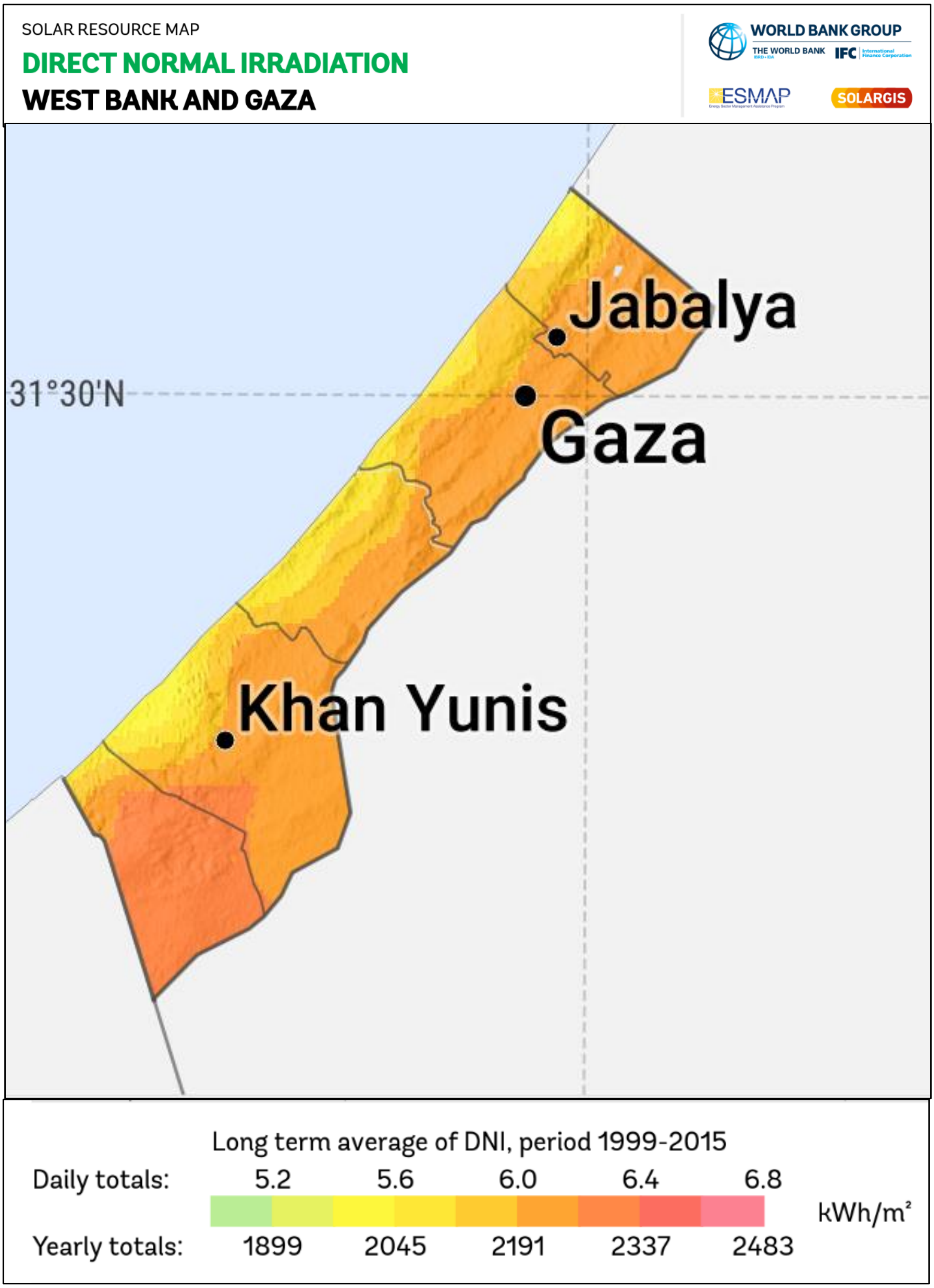
ArcMap; ArcGIS Desktop software package

LIST OF FIGURES/TABLES



High Income		Upper Middle Income		Lower Middle Income		Low Income	
Andorra	Liechtenstein	Albania	Kazakhstan	Angola	Mauritania	Afghanistan	Malawi
Antigua & Barbuda	Lithuania	Algeria	Lebanon	Bangladesh	Micronesia	Benin	Mali
Argentina	Luxembourg	Armenia	Libya	Bhutan	Moldova	Burkina Faso	Mozambique
Australia	Macao SAR	Azerbaijan	North Macedonia	Bolivia	Mongolia	Burundi	Nepal
Austria	Malta	Belarus	Malaysia	Cape Verde	Morocco	Central Afr. Rep	Niger
Bahamas, The	Monaco	Belize	Maldives	Cambodia	Myanmar	Chad	Rwanda
Bahrain	Netherlands, The	Bosnia & Herzegovina	Marshall Islands	Cameroon	Nicaragua	Comoros	Senegal
Barbados	New Zealand	Botswana	Mauritius	Congo. Rep of	Nigeria	Congo. Dem. Rep	Sierra Leone
Belgium	Norway	Brazil	Mexico	Côte d'Ivoire	Pakistan	Eritrea	Somalia
Brunei. D	Oman	Bulgaria	Montenegro	Djibouti	Palestinian Territories	Ethiopia	South Sudan
Canada	Palau	China	Namibia	Egypt	Papua New Guinea	Gambia, The	Syria
Cayman Islands	Panama	Colombia	Nauru	El Salvador	Phillipines	Guinea	Tajikistan
Chile	Poland	Costa Rica	Paraguay	Georgia	São Tomé & Príncipe	Guinea-Bissau	Tanzania
Croatia	Portugal	Cuba	Peru	Ghana	Solomon Islands	Haiti	Togo
Cyprus	Qatar	Dominica	Romania	Honduras	Sri Lanka	Korea Dem. P Rep	Uganda
Czechia	Republic of Korea	Dominican Republic	Russian Fed.	India	Sudan	Liberia	Yemen
Denmark	San Marino	Ecuador	Samoa	Indonesia	Swaziland	Madagascar	Zimbabwe
Equatorial Guinea	Saudi Arabia	Fiji	Serbia	Kenya	Timor-Leste		
Estonia	Seychelles	Gabon	South Africa	Kiribati	Tunisia		
Faroe Islands	Singapore	Grenada	St. Lucia	Kosovo	Ukraine		
Finland	Slovakia	Guatemala	St. Vincent & Grenadines	Kyrgyztan	Uzbekistan		
France	Slovenia	Guyana	Suriname	Laos	Vanuatu		
Germany	Spain	Hungary	Thailand	Lesotho	Vietnam		
Greece	St. Kitts & Nevis	Iran, Islamic Rep.	Tonga		Zambia		
Hong Kong SAR	Sweden	Iraq	Turkey				
Iceland	Switzerland	Jamaica	Turkmenistan				
Ireland	Taiwan	Jordan	Tuvalu		Legend		*Note:*
Israel	Trinidad & Tobago		Venezuela		Highlighted Colour	UN/W.B Classification	*White/blank*
Italy	United Arab Emirates				🟦	DEVELOPED	*cells represent*
Japan	United Kingdom				🟧	E.I.T	*a lack of data.*
Kuwait	United States				▨	DEVELOPING	*Dependencies*
Latvia	Uruguay				RED TEXT	(IMF) ADV. ECON.	*are excluded.*

Table 1- *Stratified income index of global nations with legend, & corresponding developmental status based on varying indicators; generated using cross-referencing of UN, IMF, and World Bank datasets (please refer to previously stated references).*



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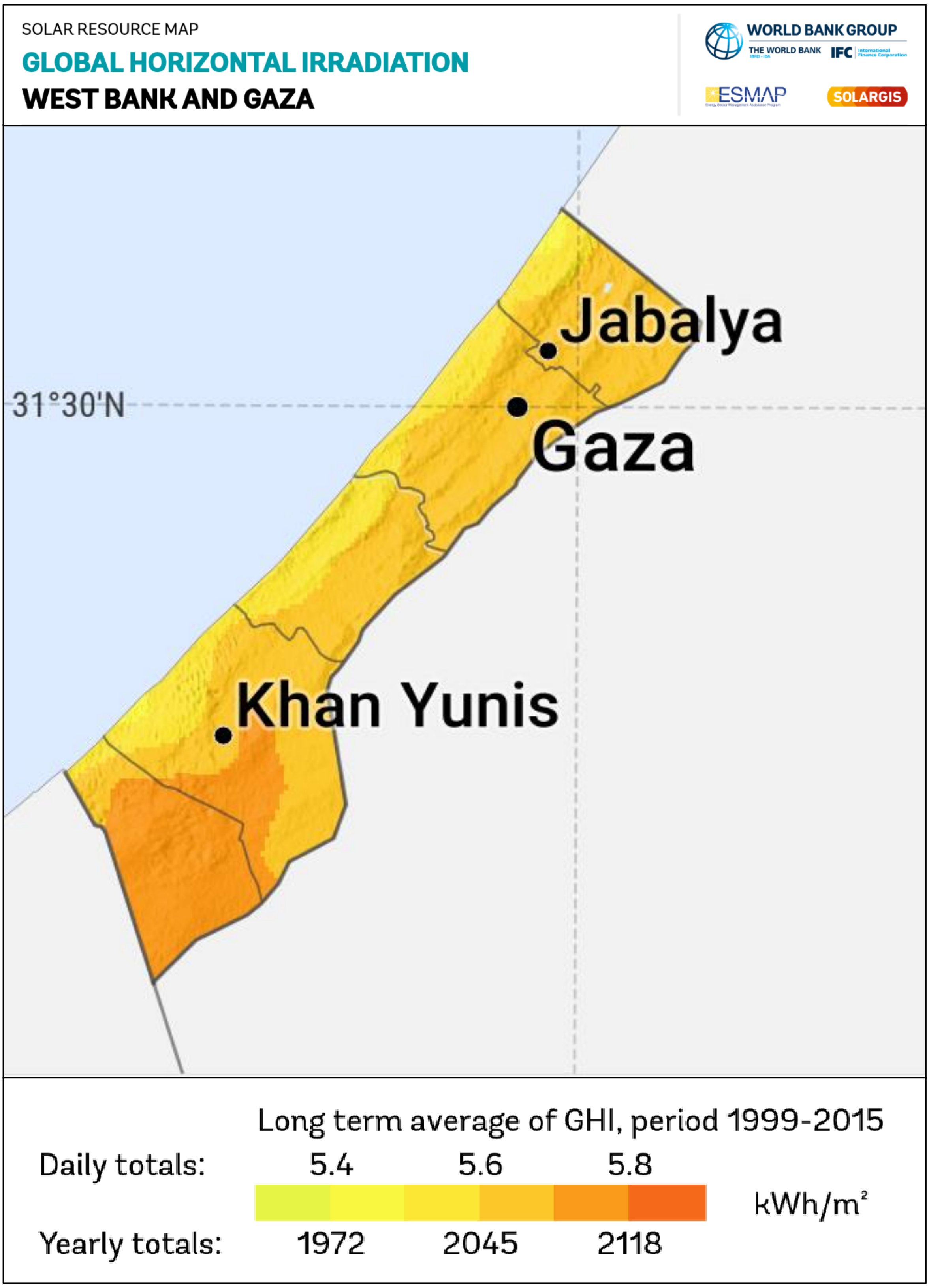

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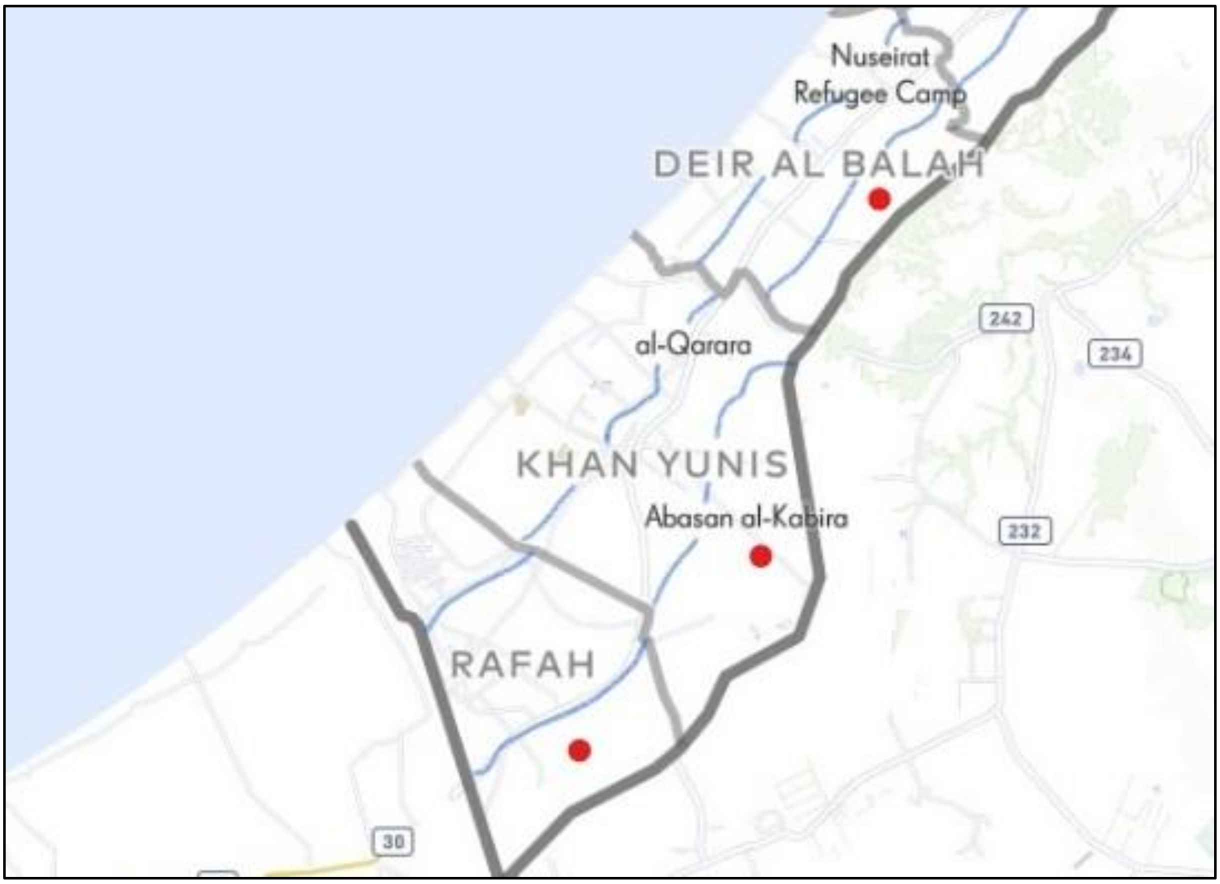
Figure 6a- *Approximate locations of solar irradiative flux calculation sites for detailed resource analysis- North Gaza/Jabaliya & Gaza Governorates.*



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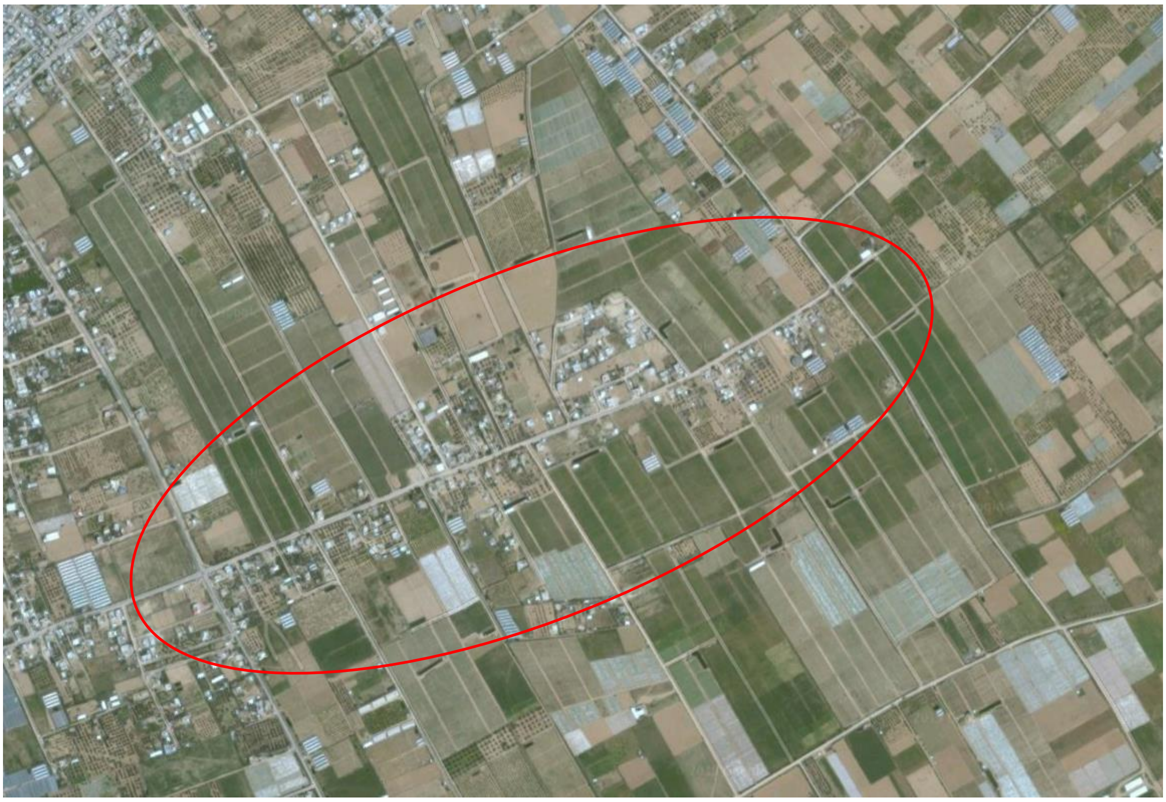

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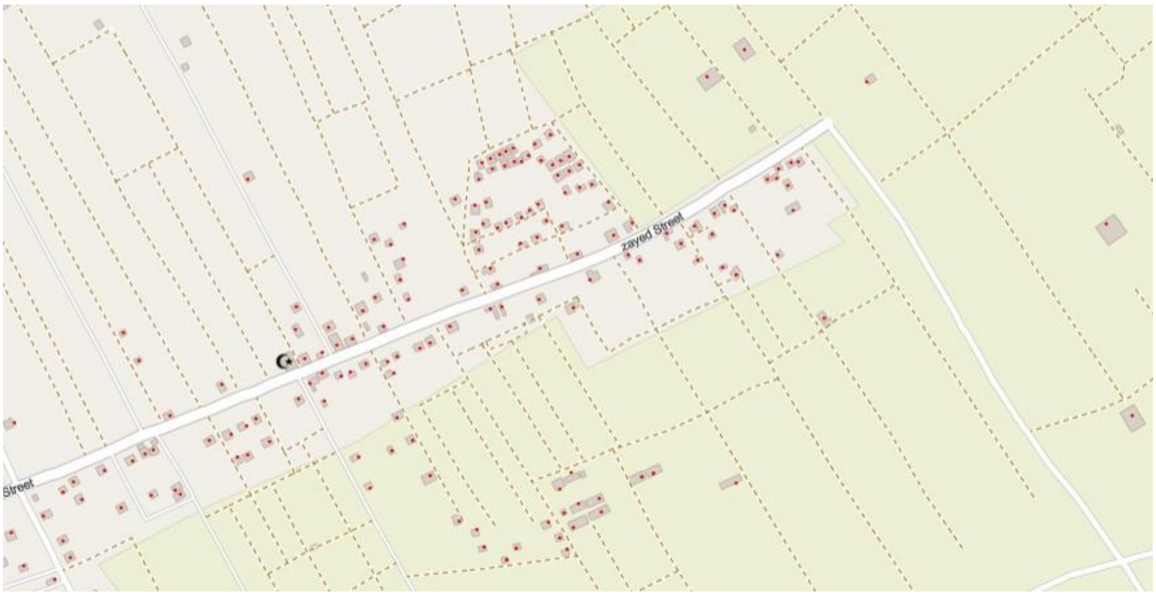


Figure 7b- *Building scale street map of Al-Fukhkhari village, red dots indicate approximate building count; sourced from ArcMap software.*

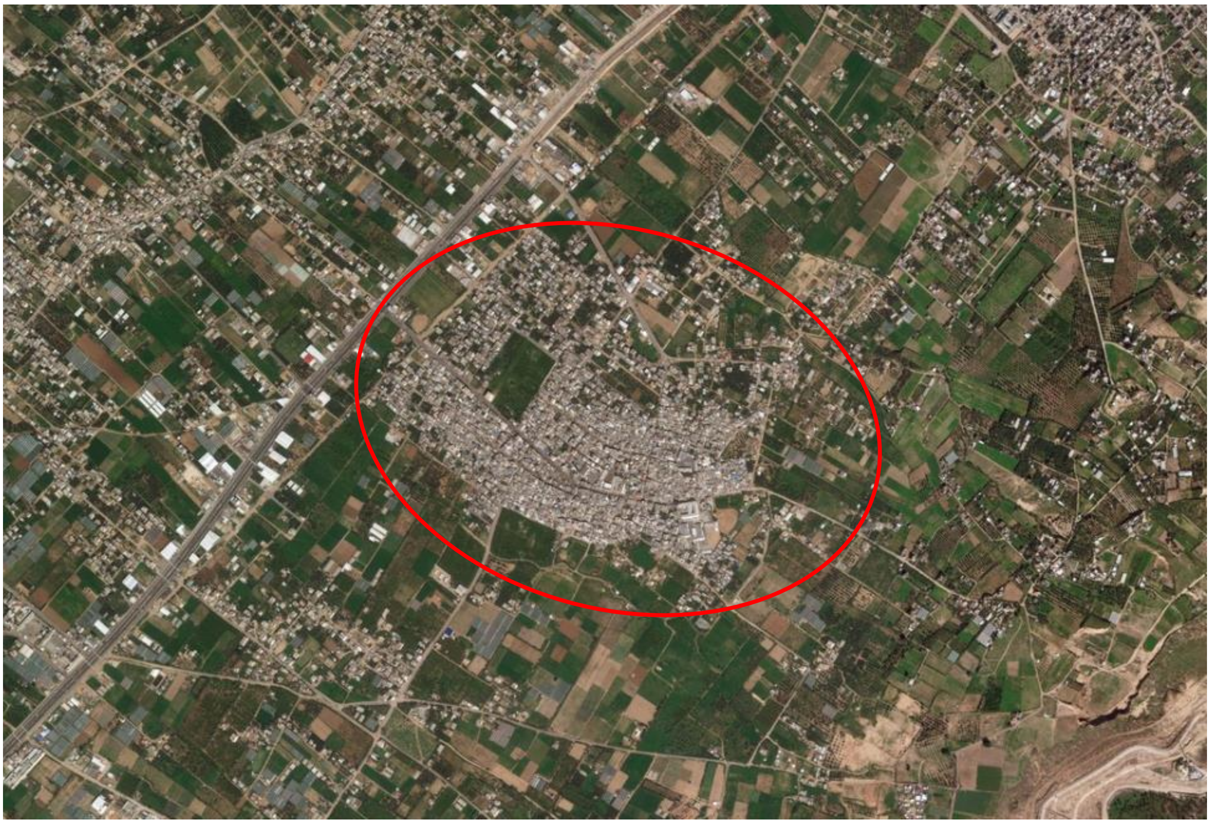
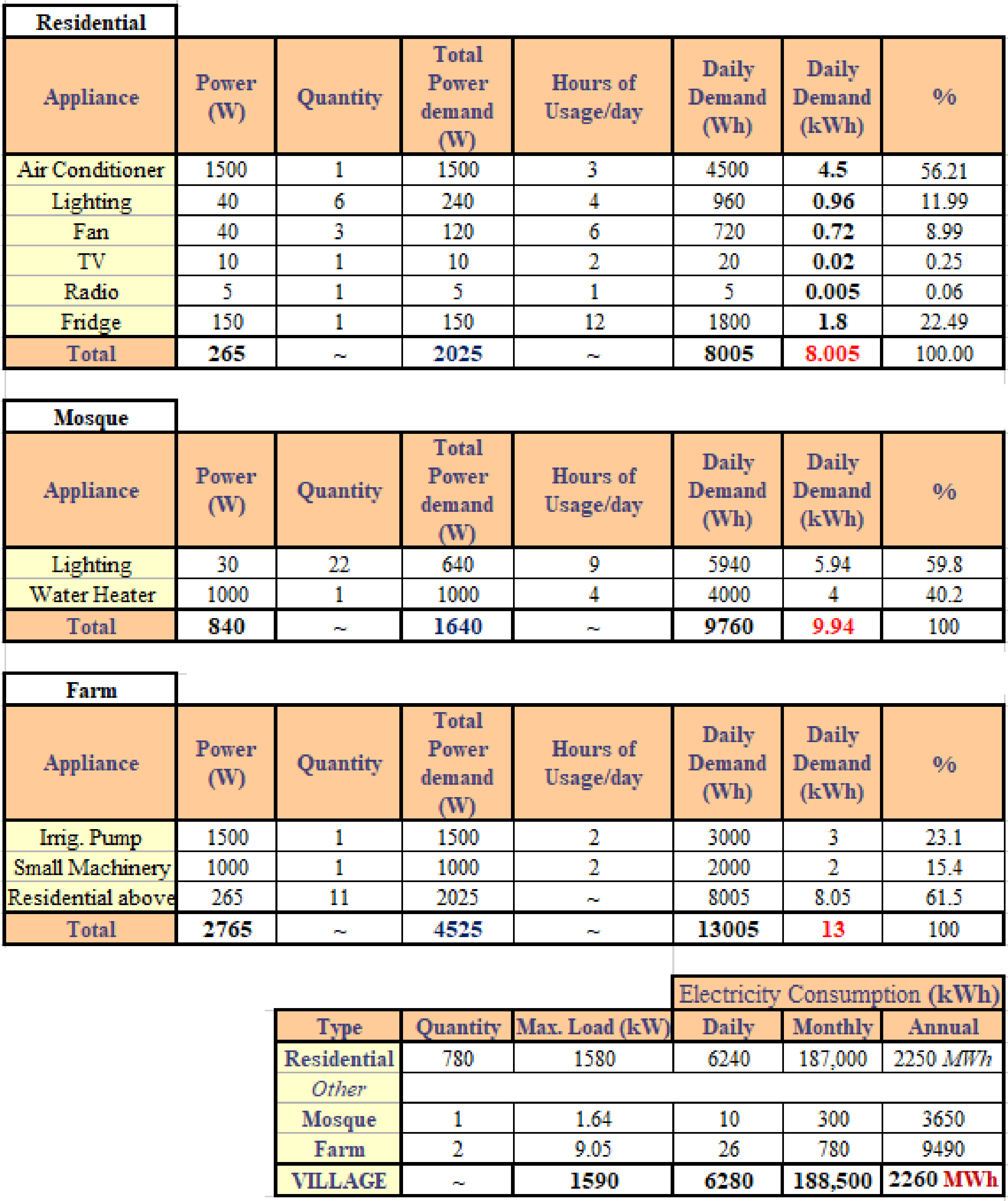


Figure 8a- *Aerial imagery of Maghazi refugee camp circled in red within its local surroundings, Deir-al-Balah Governorate; sourced from ArcMap software.*

Figure 8b- *Building scale street map of Maghazi camp; sourced from ArcMap software.*



Residential

Appliance	Power (W)	Quantity	Total Power demand (W)	Hours of Usage/day	Daily Demand (Wh)	Daily Demand (kWh)	%
Air Conditioner	1500	1	1500	3	4500	**4.5**	56.21
Lighting	40	6	240	4	960	**0.96**	11.99
Fan	40	3	120	6	720	**0.72**	8.99
TV	10	1	10	2	20	**0.02**	0.25
Radio	5	1	5	1	5	**0.005**	0.06
Fridge	150	1	150	12	1800	**1.8**	22.49
Total	**265**	~	**2025**	~	**8005**	8.005	100.00

Mosque

Appliance	Power (W)	Quantity	Total Power demand (W)	Hours of Usage/day	Daily Demand (Wh)	Daily Demand (kWh)	%
Lighting	30	22	640	9	5940	5.94	59.8
Water Heater	1000	1	1000	4	4000	4	40.2
Total	**840**	~	**1640**	~	**9760**	9.94	100

Farm

Appliance	Power (W)	Quantity	Total Power demand (W)	Hours of Usage/day	Daily Demand (Wh)	Daily Demand (kWh)	%
Irrig. Pump	1500	1	1500	2	3000	3	23.1
Small Machinery	1000	1	1000	2	2000	2	15.4
Residential above	265	11	2025	~	8005	8.05	61.5
Total	**2765**	~	**4525**	~	**13005**	13	100

			Electricity Consumption (kWh)		
Type	**Quantity**	**Max. Load (kW)**	**Daily**	**Monthly**	**Annual**
Residential	780	1580	6240	187,000	2250 *MWh*
Other					
Mosque	1	1.64	10	300	3650
Farm	2	9.05	26	780	9490
VILLAGE	~	**1590**	**6280**	**188,500**	**2260 MWh**

Table 8 - *Breakdown of Village Load/ Load Profile for Al-Fukhkhari village.*

Residential

Appliance	Power (W)	Quantity	Total Power demand (W)	Hours of Usage/day	Daily Demand (Wh)	Daily Demand (kWh)	%
Air Conditioner	1500	1	1500	3	4500	**4.5**	56.21
Lighting	40	6	240	4	960	**0.96**	11.99
Fan	40	3	120	6	720	**0.72**	8.99
TV	10	1	10	2	20	**0.02**	0.25
Radio	5	1	5	1	5	**0.005**	0.06
Fridge	150	1	150	12	1800	**1.8**	22.49
Total	**265**	~	**2025**	~	**8005**	8.005	100.00

Mosque

Appliance	Power (W)	Quantity	Total Power demand (W)	Hours of Usage/day	Daily Demand (Wh)	Daily Demand (kWh)	%
Lighting	30	22	640	9	5940	5.94	59.8
Water Heater	1000	1	1000	4	4000	4	40.2
Total	**840**	~	**1640**	~	**9760**	9.94	100

Shop

Appliance	Power (W)	Quantity	Total Power demand (W)	Hours of Usage/day	Daily Demand (Wh)	Daily Demand (kWh)	%
Lighting	30	8	240	8	1920	1.92	12.4
Fan	40	3	120	7	840	0.84	5.4
General	600	1	600	8	4800	4.8	31
Refrigeration	2000	1	2000	4	8000	8	51.6
Total	**2670**	~	**2960**	~	**15.56**	15.5	100

Table 9- *Breakdown of Town-scale Load/ Load Profile for Maghazi.*

Health Centre

Appliance	Power (W)	Quantity	Total Power demand (W)	Hours of Usage/day	Daily Demand (Wh)	Daily Demand (kWh)	%
Lighting	30	40	1200	12	14400	14.4	17.9
Air Conditioning	1500	4	6000	4	24000	24	29.9
General	2000	1	2000	6	12000	12	14.9
Appliances	10000	1	10000	3	30000	30	37.3
Total	**13530**	~	**19200**	~	**80400**	80.4	100

Factory

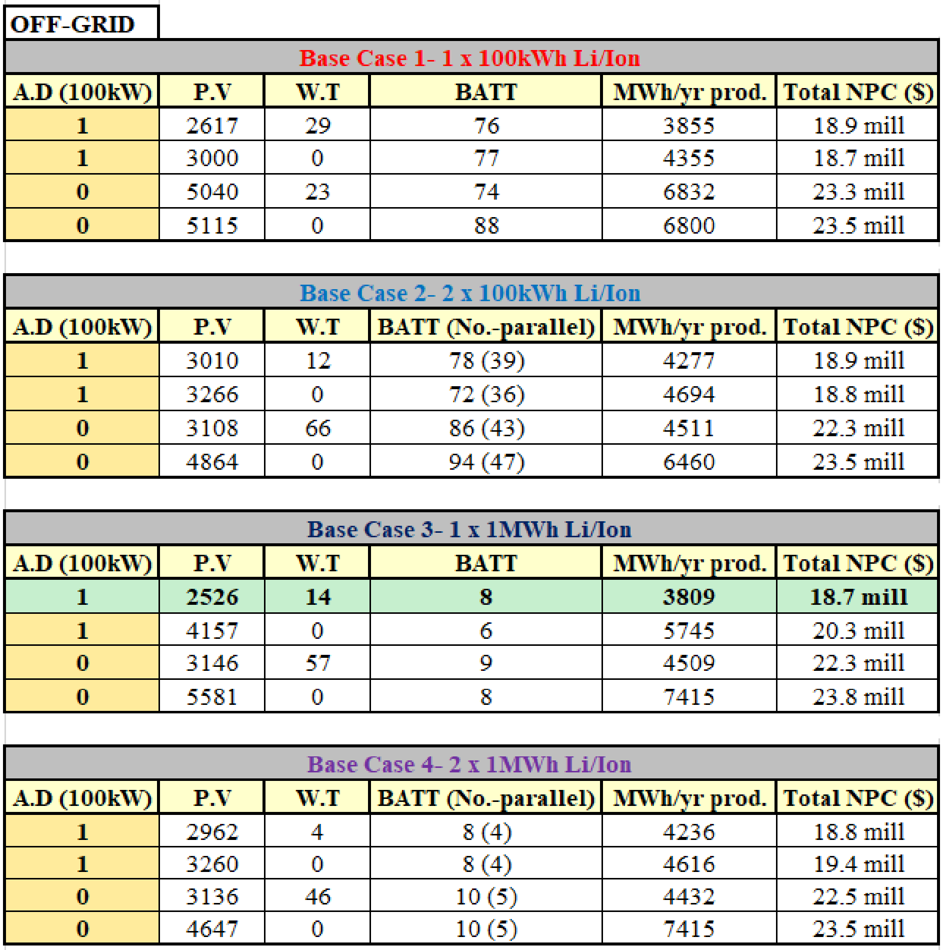
Appliance	Power (W)	Quantity	Total Power demand (W)	Hours of Usage/day	Daily Demand (Wh)	Daily Demand (kWh)	%
Lighting	60	10	600	8	4800	4.8	4.3
Air Conditioning	1500	4	6000	3	18000	18	16
Heavy Machinery	30000	1	30000	3	90000	90	79.8
Total	**31560**	~	**36600**	~	**112800**	112.8	100

School

Appliance	Power (W)	Quantity	Total Power demand (W)	Hours of Usage/day	Daily Demand (Wh)	Daily Demand (kWh)	%
Lighting	30	25	750	10	7500	7.5	39.3
Fan	40	20	800	6	4800	4.8	25.1
Computer	50	4	200	4	800	0.8	4.2
General	600	1	600	10	6000	6	31.4
Total	**720**	~	**2350**	~	**19100**	19.1	100

			Electricity Consumption (MWh)		
Type	Quantity	Max. Load (kW)	Daily	Monthly	Annual
Residential	4600	9315	36.8	1,104	13.25 *GWh*
Other					
Mosque	5	8.2	0.05	1.5	18
Shop	2	5920	0.031	0.93	11.16
Health Centre	1	19200	0.0804	2.41	28.95
Factory	2	73200	0.225	6.75	81
School	5	11750	0.0955	2.87	34.5
MAGHAZI	~	**119.4 MW**	**37.3**	**1,119**	**13.42 GWh**

Al-Fukhkhari Load Profiles: Off-Grid **(Tables 11a & 11b)**



OFF-GRID

Base Case 1- 1 x 100kWh Li/Ion

A.D (100kW)	P.V	W.T	BATT	MWh/yr prod.	Total NPC ($)
1	2617	29	76	3855	18.9 mill
1	3000	0	77	4355	18.7 mill
0	5040	23	74	6832	23.3 mill
0	5115	0	88	6800	23.5 mill

Base Case 2- 2 x 100kWh Li/Ion

A.D (100kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Total NPC ($)
1	3010	12	78 (39)	4277	18.9 mill
1	3266	0	72 (36)	4694	18.8 mill
0	3108	66	86 (43)	4511	22.3 mill
0	4864	0	94 (47)	6460	23.5 mill

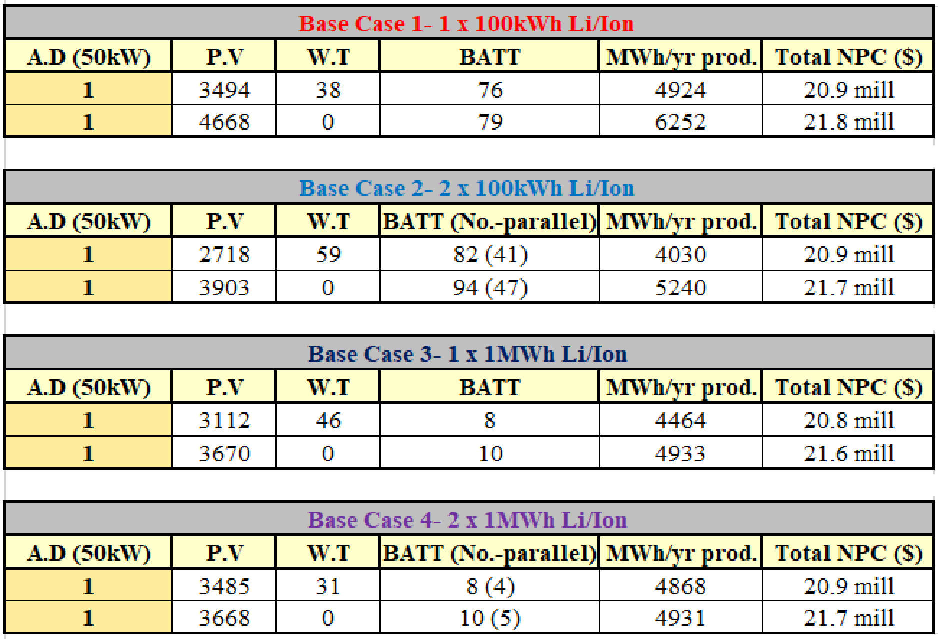
Base Case 3- 1 x 1MWh Li/Ion

A.D (100kW)	P.V	W.T	BATT	MWh/yr prod.	Total NPC ($)
1	**2526**	**14**	**8**	**3809**	**18.7 mill**
1	4157	0	6	5745	20.3 mill
0	3146	57	9	4509	22.3 mill
0	5581	0	8	7415	23.8 mill

Base Case 4- 2 x 1MWh Li/Ion

A.D (100kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Total NPC ($)
1	2962	4	8 (4)	4236	18.8 mill
1	3260	0	8 (4)	4616	19.4 mill
0	3136	46	10 (5)	4432	22.5 mill
0	4647	0	10 (5)	7415	23.5 mill

Table 11a- *Scenario configuration profile obtained from Homer Pro software, for* ***Al-Fukhkhari off-grid*** *scenario with various battery configurations, and* ***100 kW A.D plant****. W.T =wind turbine, BATT = battery configuration, NPC =net present cost. Best scenario highlighted.*



Base Case 1- 1 x 100kWh Li/Ion

A.D (50kW)	P.V	W.T	BATT	MWh/yr prod.	Total NPC ($)
1	3494	38	76	4924	20.9 mill
1	4668	0	79	6252	21.8 mill

Base Case 2- 2 x 100kWh Li/Ion

A.D (50kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Total NPC ($)
1	2718	59	82 (41)	4030	20.9 mill
1	3903	0	94 (47)	5240	21.7 mill

Base Case 3- 1 x 1MWh Li/Ion

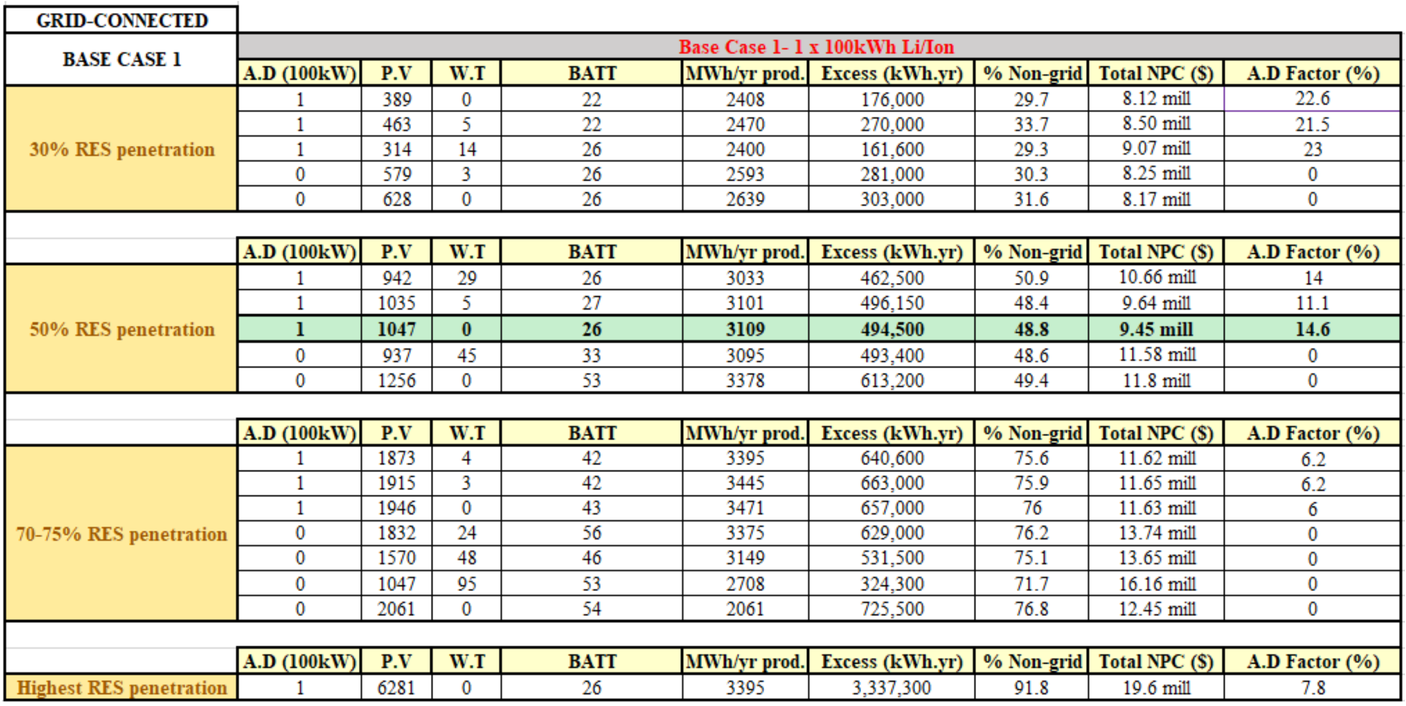
A.D (50kW)	P.V	W.T	BATT	MWh/yr prod.	Total NPC ($)
1	3112	46	8	4464	20.8 mill
1	3670	0	10	4933	21.6 mill

Base Case 4- 2 x 1MWh Li/Ion

A.D (50kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Total NPC ($)
1	3485	31	8 (4)	4868	20.9 mill
1	3668	0	10 (5)	4931	21.7 mill

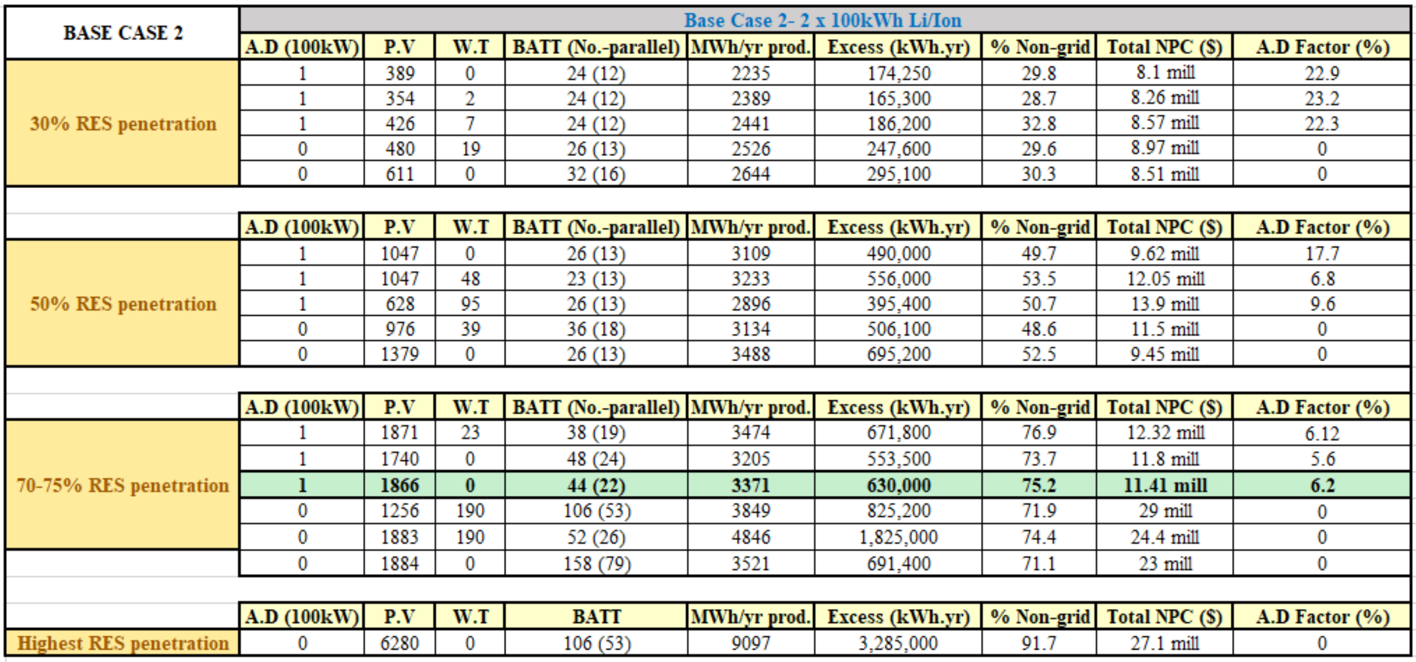
Table 11b- *Scenario configuration profile obtained from Homer Pro software, for* ***Al-Fukhkhari off-grid*** *scenario with various battery configurations, and* ***50 kW A.D plant****. W.T =wind turbine, BATT = battery configuration, NPC =net present cost.*

Al-Fukhkhari Load Profiles: Grid Connected **(Tables 12 & 13)**



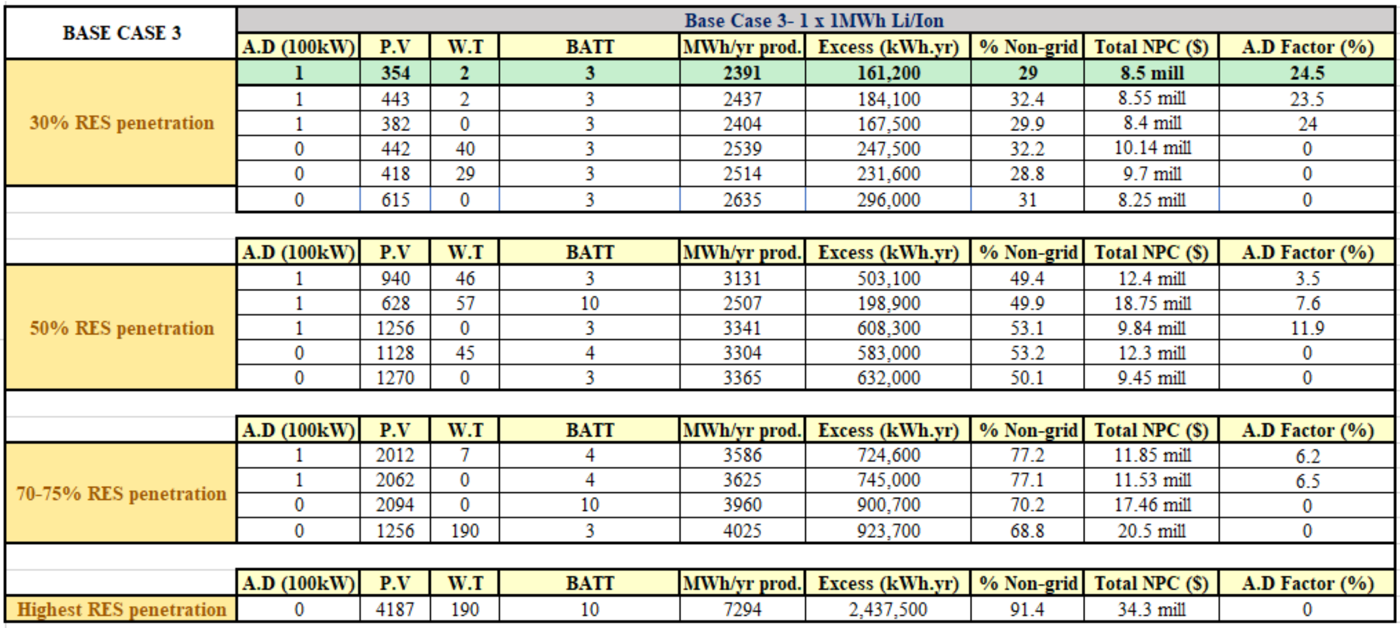
GRID-CONNECTED									
BASE CASE 1	Base Case 1- 1 x 100kWh Li/Ion								
	A.D (100kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
30% RES penetration	1	389	0	22	2408	176,000	29.7	8.12 mill	22.6
	1	463	5	22	2470	270,000	33.7	8.50 mill	21.5
	1	314	14	26	2400	161,600	29.3	9.07 mill	23
	0	579	3	26	2593	281,000	30.3	8.25 mill	0
	0	628	0	26	2639	303,000	31.6	8.17 mill	0
	A.D (100kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
50% RES penetration	1	942	29	26	3033	462,500	50.9	10.66 mill	14
	1	1035	5	27	3101	496,150	48.4	9.64 mill	11.1
	1	**1047**	**0**	**26**	**3109**	**494,500**	**48.8**	**9.45 mill**	**14.6**
	0	937	45	33	3095	493,400	48.6	11.58 mill	0
	0	1256	0	53	3378	613,200	49.4	11.8 mill	0
	A.D (100kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
70-75% RES penetration	1	1873	4	42	3395	640,600	75.6	11.62 mill	6.2
	1	1915	3	42	3445	663,000	75.9	11.65 mill	6.2
	1	1946	0	43	3471	657,000	76	11.63 mill	6
	0	1832	24	56	3375	629,000	76.2	13.74 mill	0
	0	1570	48	46	3149	531,500	75.1	13.65 mill	0
	0	1047	95	53	2708	324,300	71.7	16.16 mill	0
	0	2061	0	54	2061	725,500	76.8	12.45 mill	0
	A.D (100kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
Highest RES penetration	1	6281	0	26	3395	3,337,300	91.8	19.6 mill	7.8

Table 12a- *Scenario configuration profile obtained from Homer Pro software, for* ***Al-Fukhkhari grid-connected*** *scenario with 100 kW A.D, 1 x 100kWh Li/Ion battery configuration, and varying levels of renewables penetration (non-grid). W.T =wind turbine, BATT = battery configuration, NPC =net present cost.*



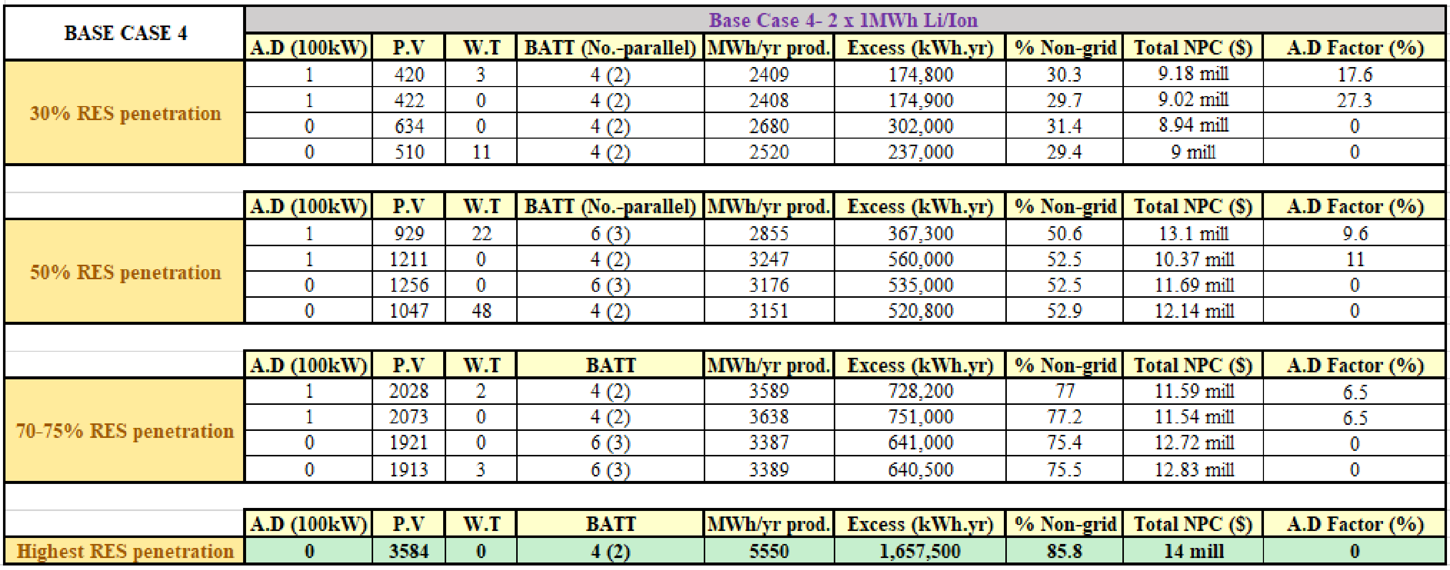
BASE CASE 2	Base Case 2- 2 x 100kWh Li/Ion								
	A.D (100kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
30% RES penetration	1	389	0	24 (12)	2235	174,250	29.8	8.1 mill	22.9
	1	354	2	24 (12)	2389	165,300	28.7	8.26 mill	23.2
	1	426	7	24 (12)	2441	186,200	32.8	8.57 mill	22.3
	0	480	19	26 (13)	2526	247,600	29.6	8.97 mill	0
	0	611	0	32 (16)	2644	295,100	30.3	8.51 mill	0
	A.D (100kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
50% RES penetration	1	1047	0	26 (13)	3109	490,000	49.7	9.62 mill	17.7
	1	1047	48	23 (13)	3233	556,000	53.5	12.05 mill	6.8
	1	628	95	26 (13)	2896	395,400	50.7	13.9 mill	9.6
	0	976	39	36 (18)	3134	506,100	48.6	11.5 mill	0
	0	1379	0	26 (13)	3488	695,200	52.5	9.45 mill	0
	A.D (100kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
70-75% RES penetration	1	1871	23	38 (19)	3474	671,800	76.9	12.32 mill	6.12
	1	1740	0	48 (24)	3205	553,500	73.7	11.8 mill	5.6
	1	**1866**	**0**	**44 (22)**	**3371**	**630,000**	**75.2**	**11.41 mill**	**6.2**
	0	1256	190	106 (53)	3849	825,200	71.9	29 mill	0
	0	1883	190	52 (26)	4846	1,825,000	74.4	24.4 mill	0
	0	1884	0	158 (79)	3521	691,400	71.1	23 mill	0
	A.D (100kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
Highest RES penetration	0	6280	0	106 (53)	9097	3,285,000	91.7	27.1 mill	0

Table 12b- *Scenario configuration profile obtained from Homer Pro software, for* ***Al-Fukhkhari grid-connected*** *scenario with 100 kW A.D, 2 x 100kWh Li/Ion battery configuration, and varying levels of renewables penetration (non-grid). W.T =wind turbine, BATT = battery configuration, NPC =net present cost.*



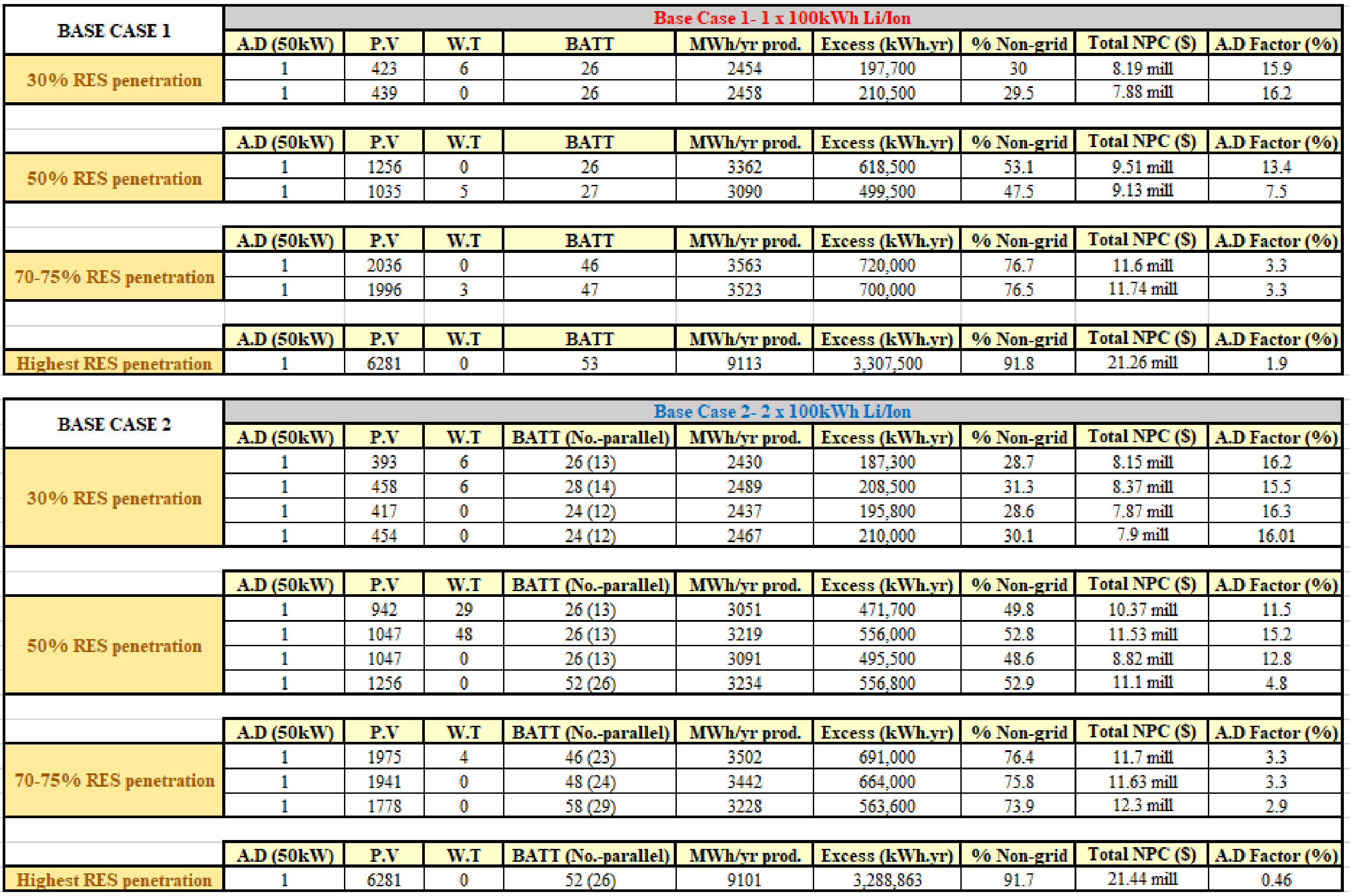
BASE CASE 3	Base Case 3- 1 x 1MWh Li/Ion								
	A.D (100kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
30% RES penetration	**1**	**354**	**2**	**3**	**2391**	**161,200**	**29**	**8.5 mill**	**24.5**
	1	443	2	3	2437	184,100	32.4	8.55 mill	23.5
	1	382	0	3	2404	167,500	29.9	8.4 mill	24
	0	442	40	3	2539	247,500	32.2	10.14 mill	0
	0	418	29	3	2514	231,600	28.8	9.7 mill	0
	0	615	0	3	2635	296,000	31	8.25 mill	0
	A.D (100kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
50% RES penetration	1	940	46	3	3131	503,100	49.4	12.4 mill	3.5
	1	628	57	10	2507	198,900	49.9	18.75 mill	7.6
	1	1256	0	3	3341	608,300	53.1	9.84 mill	11.9
	0	1128	45	4	3304	583,000	53.2	12.3 mill	0
	0	1270	0	3	3365	632,000	50.1	9.45 mill	0
	A.D (100kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
70-75% RES penetration	1	2012	7	4	3586	724,600	77.2	11.85 mill	6.2
	1	2062	0	4	3625	745,000	77.1	11.53 mill	6.5
	0	2094	0	10	3960	900,700	70.2	17.46 mill	0
	0	1256	190	3	4025	923,700	68.8	20.5 mill	0
	A.D (100kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
Highest RES penetration	0	4187	190	10	7294	2,437,500	91.4	34.3 mill	0

Table 12c- *Scenario configuration profile obtained from Homer Pro software, for* ***Al-Fukhkhari grid-connected*** *scenario with 100 kW A.D, 1 x 1MWh Li/Ion battery configuration, and varying levels of renewables penetration (non-grid). W.T =wind turbine, BATT = battery configuration, NPC =net present cost.*



BASE CASE 4	Base Case 4- 2 x 1MWh Li/Ion								
	A.D (100kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
30% RES penetration	1	420	3	4 (2)	2409	174,800	30.3	9.18 mill	17.6
	1	422	0	4 (2)	2408	174,900	29.7	9.02 mill	27.3
	0	634	0	4 (2)	2680	302,000	31.4	8.94 mill	0
	0	510	11	4 (2)	2520	237,000	29.4	9 mill	0
	A.D (100kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
50% RES penetration	1	929	22	6 (3)	2855	367,300	50.6	13.1 mill	9.6
	1	1211	0	4 (2)	3247	560,000	52.5	10.37 mill	11
	0	1256	0	6 (3)	3176	535,000	52.5	11.69 mill	0
	0	1047	48	4 (2)	3151	520,800	52.9	12.14 mill	0
	A.D (100kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
70-75% RES penetration	1	2028	2	4 (2)	3589	728,200	77	11.59 mill	6.5
	1	2073	0	4 (2)	3638	751,000	77.2	11.54 mill	6.5
	0	1921	0	6 (3)	3387	641,000	75.4	12.72 mill	0
	0	1913	3	6 (3)	3389	640,500	75.5	12.83 mill	0
	A.D (100kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
Highest RES penetration	**0**	**3584**	**0**	**4 (2)**	**5550**	**1,657,500**	**85.8**	**14 mill**	**0**

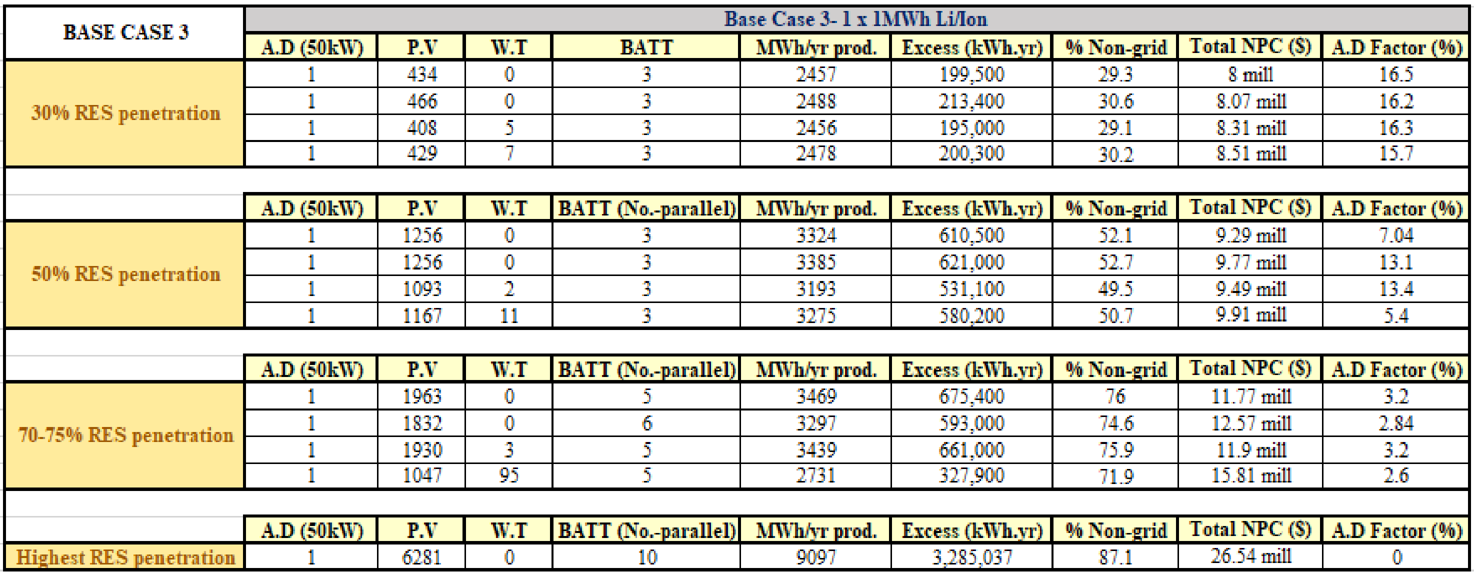
Table 12d- *Scenario configuration profile obtained from Homer Pro software, for* ***Al-Fukhkhari grid-connected*** *scenario with 100 kW A.D, 2 x 1MWh Li/Ion battery configuration, and varying levels of renewables penetration (non-grid). W.T =wind turbine, BATT = battery configuration, NPC =net present cost.*



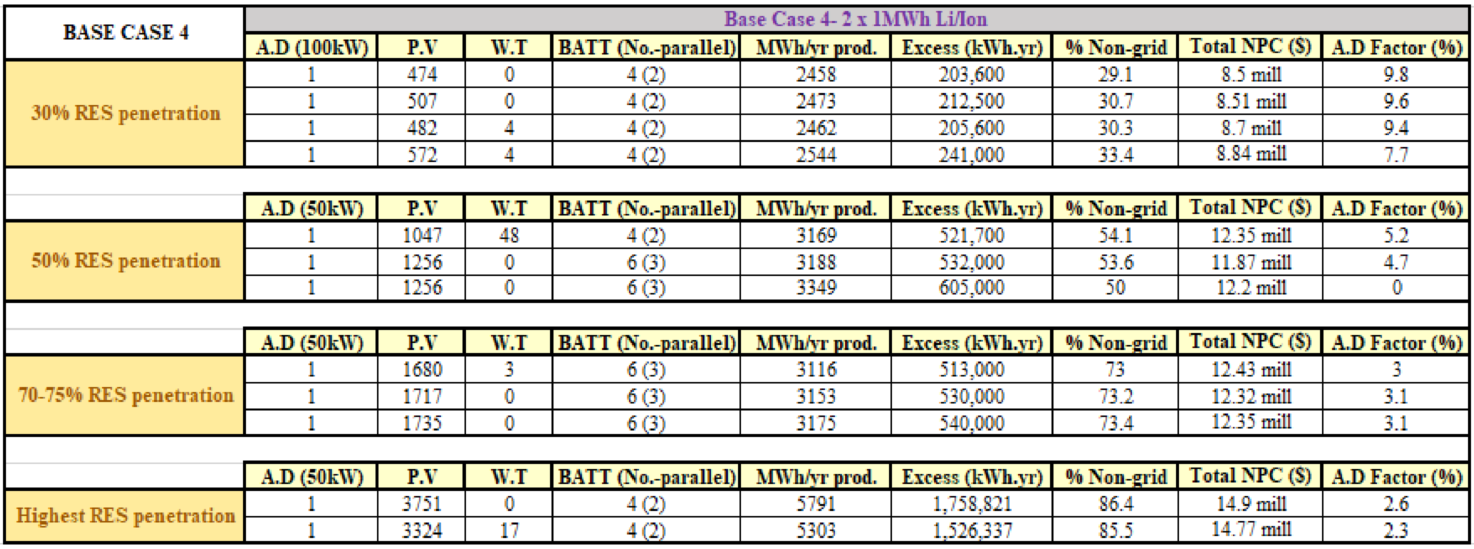
BASE CASE 1	Base Case 1- 1 x 100kWh Li/Ion								
	A.D (50kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
30% RES penetration	1	423	6	26	2454	197,700	30	8.19 mill	15.9
	1	439	0	26	2458	210,500	29.5	7.88 mill	16.2
	A.D (50kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
50% RES penetration	1	1256	0	26	3362	618,500	53.1	9.51 mill	13.4
	1	1035	5	27	3090	499,500	47.5	9.13 mill	7.5
	A.D (50kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
70-75% RES penetration	1	2036	0	46	3563	720,000	76.7	11.6 mill	3.3
	1	1996	3	47	3523	700,000	76.5	11.74 mill	3.3
	A.D (50kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
Highest RES penetration	1	6281	0	53	9113	3,307,500	91.8	21.26 mill	1.9

BASE CASE 2	Base Case 2- 2 x 100kWh Li/Ion								
	A.D (50kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
30% RES penetration	1	393	6	26 (13)	2430	187,300	28.7	8.15 mill	16.2
	1	458	6	28 (14)	2489	208,500	31.3	8.37 mill	15.5
	1	417	0	24 (12)	2437	195,800	28.6	7.87 mill	16.3
	1	454	0	24 (12)	2467	210,000	30.1	7.9 mill	16.01
	A.D (50kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
50% RES penetration	1	942	29	26 (13)	3051	471,700	49.8	10.37 mill	11.5
	1	1047	48	26 (13)	3219	556,000	52.8	11.53 mill	15.2
	1	1047	0	26 (13)	3091	495,500	48.6	8.82 mill	12.8
	1	1256	0	52 (26)	3234	556,800	52.9	11.1 mill	4.8
	A.D (50kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
70-75% RES penetration	1	1975	4	46 (23)	3502	691,000	76.4	11.7 mill	3.3
	1	1941	0	48 (24)	3442	664,000	75.8	11.63 mill	3.3
	1	1778	0	58 (29)	3228	563,600	73.9	12.3 mill	2.9
	A.D (50kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
Highest RES penetration	1	6281	0	52 (26)	9101	3,288,863	91.7	21.44 mill	0.46

Table 13a- *Scenario configuration profile obtained from Homer Pro software, for* ***Al-Fukhkhari grid-connected*** *scenario with 50 kW A.D, 1 x 1MWh Li/Ion battery configuration, and varying levels of renewables penetration (non-grid). W.T =wind turbine, BATT = battery configuration, NPC =net present cost.*



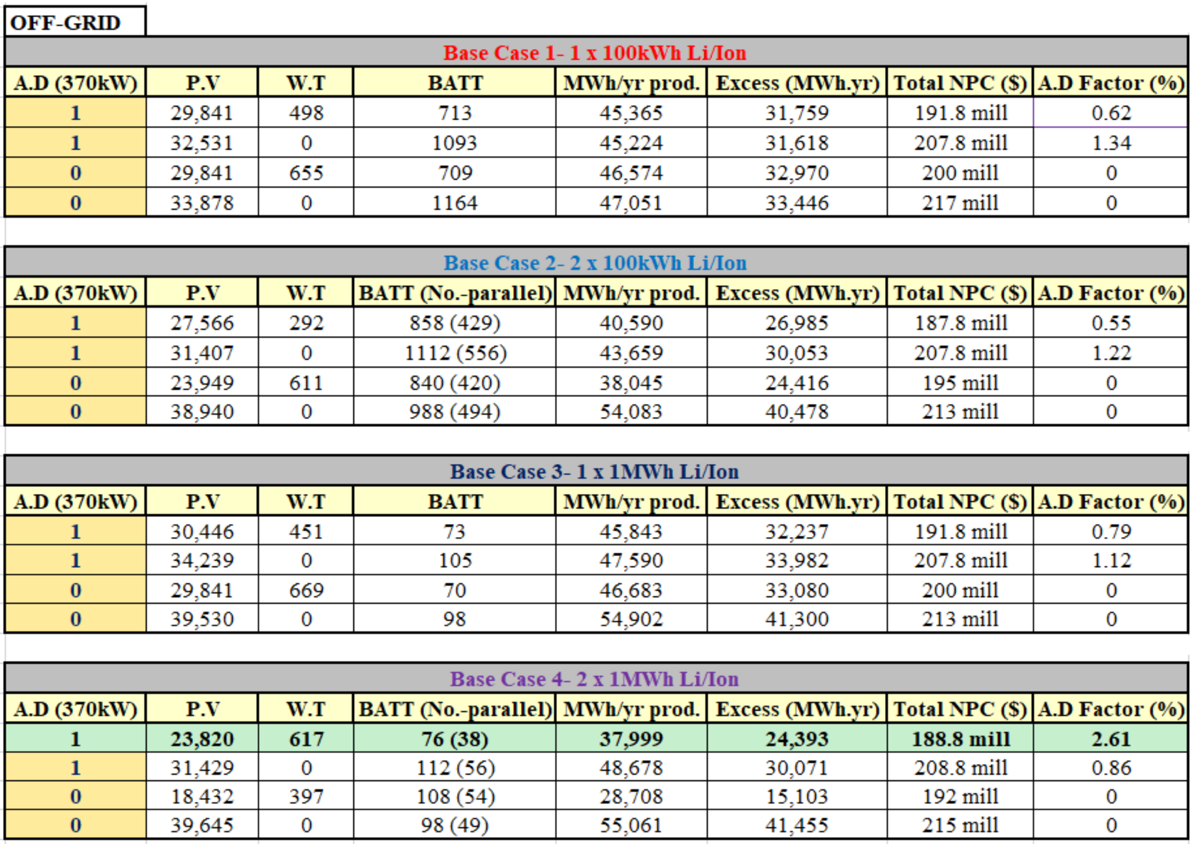
BASE CASE 3	Base Case 3- 1 x 1MWh Li/Ion								
	A.D (50kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
30% RES penetration	1	434	0	3	2457	199,500	29.3	8 mill	16.5
	1	466	0	3	2488	213,400	30.6	8.07 mill	16.2
	1	408	5	3	2456	195,000	29.1	8.31 mill	16.3
	1	429	7	3	2478	200,300	30.2	8.51 mill	15.7
	A.D (50kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
50% RES penetration	1	1256	0	3	3324	610,500	52.1	9.29 mill	7.04
	1	1256	0	3	3385	621,000	52.7	9.77 mill	13.1
	1	1093	2	3	3193	531,100	49.5	9.49 mill	13.4
	1	1167	11	3	3275	580,200	50.7	9.91 mill	5.4
	A.D (50kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
70-75% RES penetration	1	1963	0	5	3469	675,400	76	11.77 mill	3.2
	1	1832	0	6	3297	593,000	74.6	12.57 mill	2.84
	1	1930	3	5	3439	661,000	75.9	11.9 mill	3.2
	1	1047	95	5	2731	327,900	71.9	15.81 mill	2.6
	A.D (50kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
Highest RES penetration	1	6281	0	10	9097	3,285,037	87.1	26.54 mill	0



BASE CASE 4	Base Case 4- 2 x 1MWh Li/Ion								
	A.D (100kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
30% RES penetration	1	474	0	4 (2)	2458	203,600	29.1	8.5 mill	9.8
	1	507	0	4 (2)	2473	212,500	30.7	8.51 mill	9.6
	1	482	4	4 (2)	2462	205,600	30.3	8.7 mill	9.4
	1	572	4	4 (2)	2544	241,000	33.4	8.84 mill	7.7
	A.D (50kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
50% RES penetration	1	1047	48	4 (2)	3169	521,700	54.1	12.35 mill	5.2
	1	1256	0	6 (3)	3188	532,000	53.6	11.87 mill	4.7
	1	1256	0	6 (3)	3349	605,000	50	12.2 mill	0
	A.D (50kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
70-75% RES penetration	1	1680	3	6 (3)	3116	513,000	73	12.43 mill	3
	1	1717	0	6 (3)	3153	530,000	73.2	12.32 mill	3.1
	1	1735	0	6 (3)	3175	540,000	73.4	12.35 mill	3.1
	A.D (50kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (kWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
Highest RES penetration	1	3751	0	4 (2)	5791	1,758,821	86.4	14.9 mill	2.6
	1	3324	17	4 (2)	5303	1,526,337	85.5	14.77 mill	2.3

Table 13b- *Scenario configuration profile obtained from Homer Pro software, for* ***Al-Fukhkhari grid-connected*** *scenario with 50 kW A.D, 1 x 1MWh Li/Ion battery configuration, and varying levels of renewables penetration (non-grid). W.T =wind turbine, BATT = battery configuration, NPC =net present cost.*

Maghazi Load Profiles: Off-Grid **(Tables 14a & 14 b)**



OFF-GRID

Base Case 1- 1 x 100kWh Li/Ion

A.D (370kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (MWh.yr)	Total NPC ($)	A.D Factor (%)
1	29,841	498	713	45,365	31,759	191.8 mill	0.62
1	32,531	0	1093	45,224	31,618	207.8 mill	1.34
0	29,841	655	709	46,574	32,970	200 mill	0
0	33,878	0	1164	47,051	33,446	217 mill	0

Base Case 2- 2 x 100kWh Li/Ion

A.D (370kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (MWh.yr)	Total NPC ($)	A.D Factor (%)
1	27,566	292	858 (429)	40,590	26,985	187.8 mill	0.55
1	31,407	0	1112 (556)	43,659	30,053	207.8 mill	1.22
0	23,949	611	840 (420)	38,045	24,416	195 mill	0
0	38,940	0	988 (494)	54,083	40,478	213 mill	0

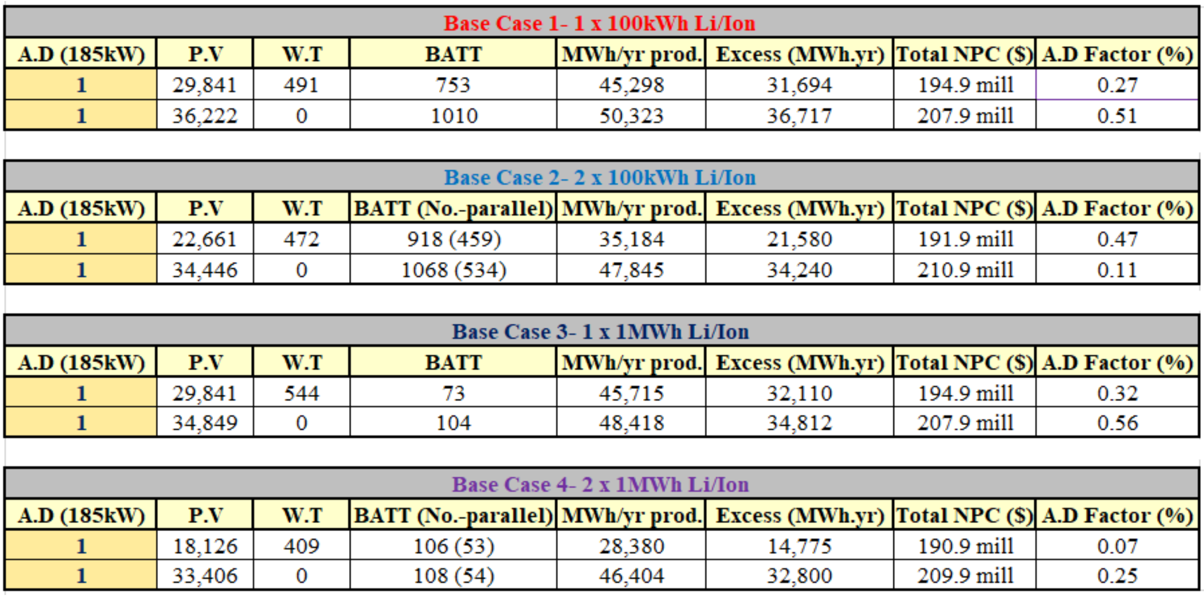
Base Case 3- 1 x 1MWh Li/Ion

A.D (370kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (MWh.yr)	Total NPC ($)	A.D Factor (%)
1	30,446	451	73	45,843	32,237	191.8 mill	0.79
1	34,239	0	105	47,590	33,982	207.8 mill	1.12
0	29,841	669	70	46,683	33,080	200 mill	0
0	39,530	0	98	54,902	41,300	213 mill	0

Base Case 4- 2 x 1MWh Li/Ion

A.D (370kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (MWh.yr)	Total NPC ($)	A.D Factor (%)
1	**23,820**	**617**	**76 (38)**	**37,999**	**24,393**	**188.8 mill**	**2.61**
1	31,429	0	112 (56)	48,678	30,071	208.8 mill	0.86
0	18,432	397	108 (54)	28,708	15,103	192 mill	0
0	39,645	0	98 (49)	55,061	41,455	215 mill	0

Table 14a- *Scenario configuration profile obtained from Homer Pro software, for* ***Maghazi off-grid*** *scenario with various battery configurations, and* ***370 kW A.D plant****. W.T =wind turbine, BATT = battery configuration, NPC =net present cost. Best scenario highlighted.*



Base Case 1- 1 x 100kWh Li/Ion

A.D (185kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (MWh.yr)	Total NPC ($)	A.D Factor (%)
1	29,841	491	753	45,298	31,694	194.9 mill	0.27
1	36,222	0	1010	50,323	36,717	207.9 mill	0.51

Base Case 2- 2 x 100kWh Li/Ion

A.D (185kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (MWh.yr)	Total NPC ($)	A.D Factor (%)
1	22,661	472	918 (459)	35,184	21,580	191.9 mill	0.47
1	34,446	0	1068 (534)	47,845	34,240	210.9 mill	0.11

Base Case 3- 1 x 1MWh Li/Ion

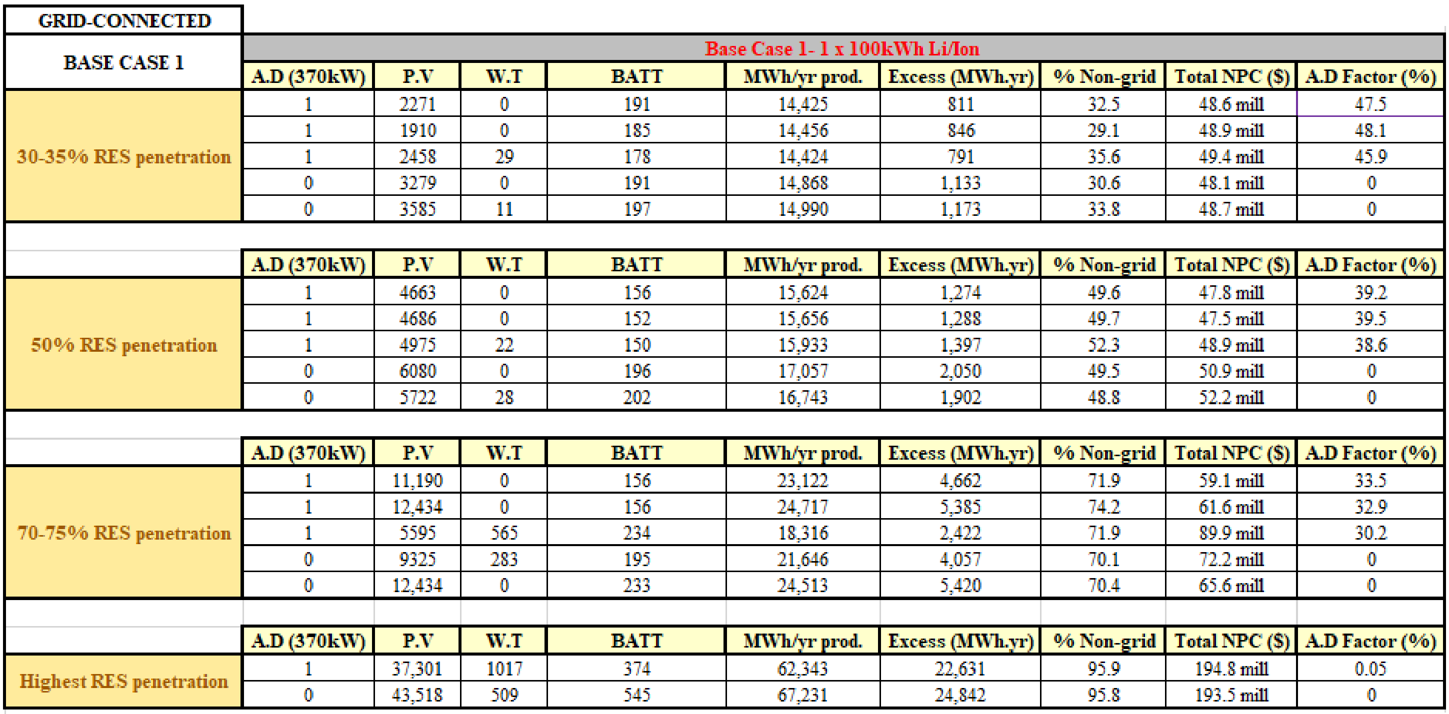
A.D (185kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (MWh.yr)	Total NPC ($)	A.D Factor (%)
1	29,841	544	73	45,715	32,110	194.9 mill	0.32
1	34,849	0	104	48,418	34,812	207.9 mill	0.56

Base Case 4- 2 x 1MWh Li/Ion

A.D (185kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (MWh.yr)	Total NPC ($)	A.D Factor (%)
1	18,126	409	106 (53)	28,380	14,775	190.9 mill	0.07
1	33,406	0	108 (54)	46,404	32,800	209.9 mill	0.25

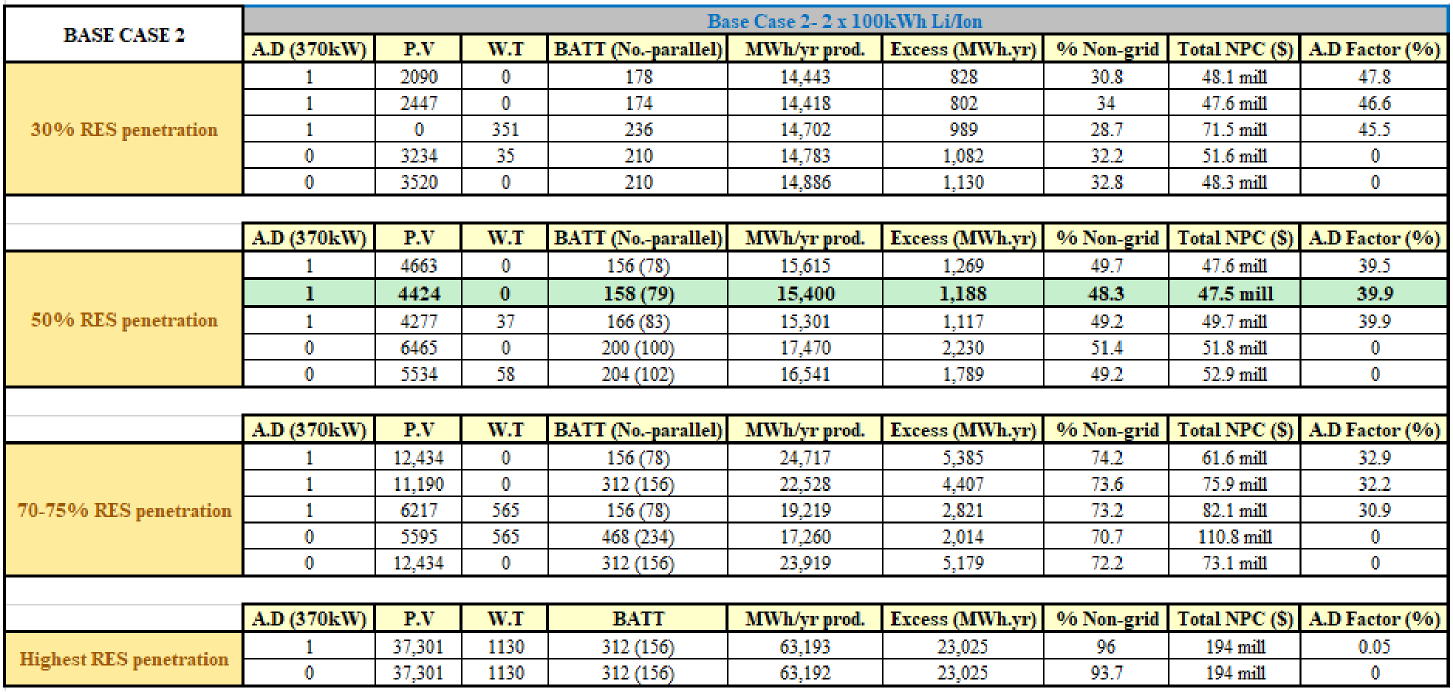
Table 14b- *Scenario configuration profile obtained from Homer Pro software, for* ***Maghazi off-grid*** *scenario with various battery configurations, and* ***185 kW A.D plant.*** *W.T =wind turbine, BATT = battery configuration, NPC =net present cost.*

Maghazi Load Profiles: Grid-Connected **(Tables 15 & 16)**



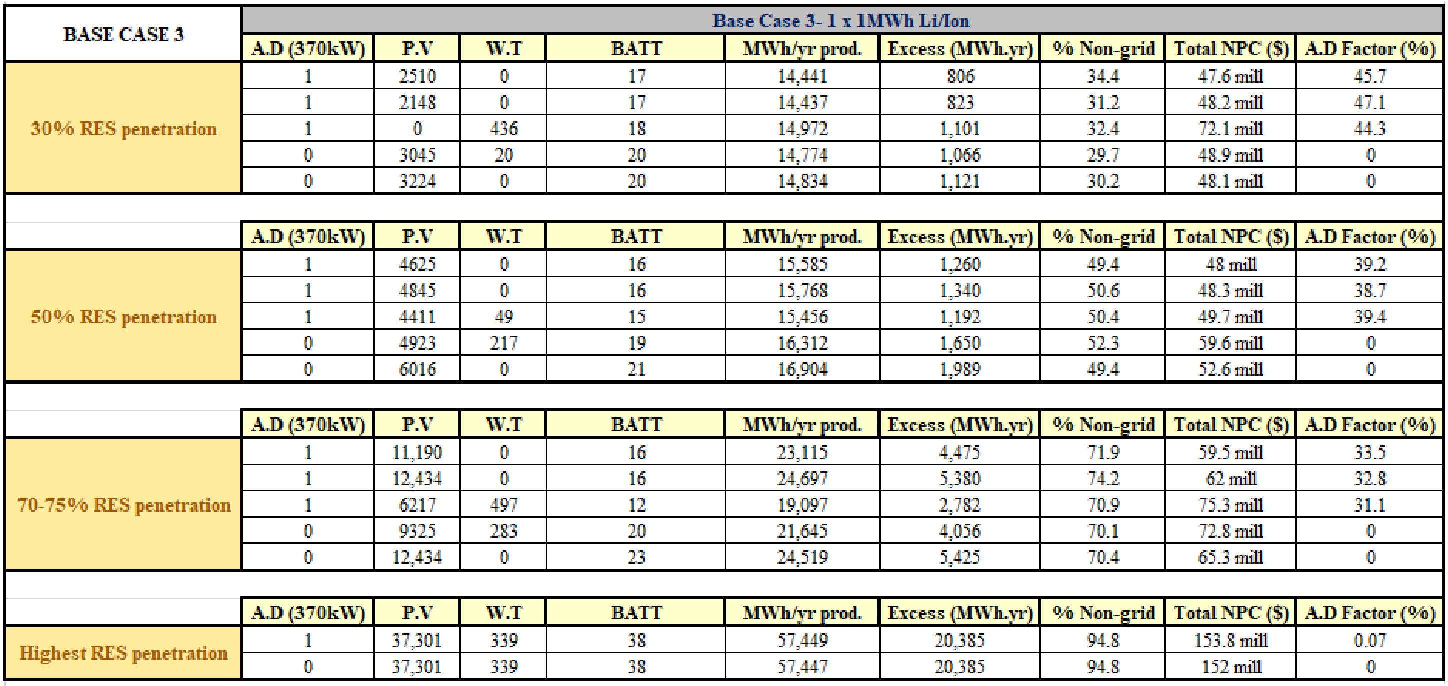
GRID-CONNECTED BASE CASE 1	Base Case 1- 1 x 100kWh Li/Ion								
	A.D (370kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
30-35% RES penetration	1	2271	0	191	14,425	811	32.5	48.6 mill	47.5
	1	1910	0	185	14,456	846	29.1	48.9 mill	48.1
	1	2458	29	178	14,424	791	35.6	49.4 mill	45.9
	0	3279	0	191	14,868	1,133	30.6	48.1 mill	0
	0	3585	11	197	14,990	1,173	33.8	48.7 mill	0
	A.D (370kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
50% RES penetration	1	4663	0	156	15,624	1,274	49.6	47.8 mill	39.2
	1	4686	0	152	15,656	1,288	49.7	47.5 mill	39.5
	1	4975	22	150	15,933	1,397	52.3	48.9 mill	38.6
	0	6080	0	196	17,057	2,050	49.5	50.9 mill	0
	0	5722	28	202	16,743	1,902	48.8	52.2 mill	0
	A.D (370kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
70-75% RES penetration	1	11,190	0	156	23,122	4,662	71.9	59.1 mill	33.5
	1	12,434	0	156	24,717	5,385	74.2	61.6 mill	32.9
	1	5595	565	234	18,316	2,422	71.9	89.9 mill	30.2
	0	9325	283	195	21,646	4,057	70.1	72.2 mill	0
	0	12,434	0	233	24,513	5,420	70.4	65.6 mill	0
	A.D (370kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
Highest RES penetration	1	37,301	1017	374	62,343	22,631	95.9	194.8 mill	0.05
	0	43,518	509	545	67,231	24,842	95.8	193.5 mill	0

Table 15a- *Scenario configuration profile obtained from Homer Pro software, for* ***Maghazi grid-connected*** *scenario with* ***370 kW A.D****, 1 x 100kWh Li/Ion battery configuration, and varying levels of renewables penetration (non-grid). W.T =wind turbine, BATT = battery configuration, NPC =net present cost.*



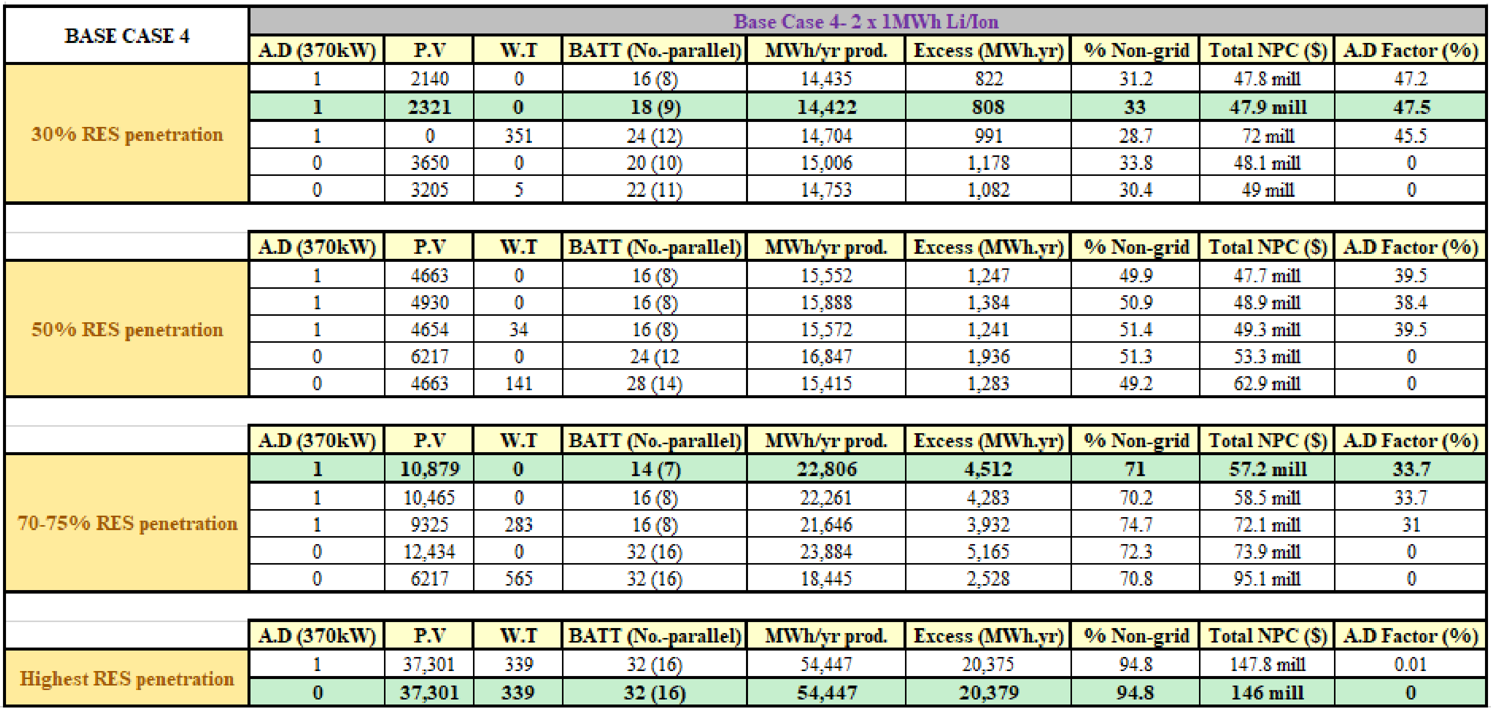
BASE CASE 2	Base Case 2- 2 x 100kWh Li/Ion								
	A.D (370kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
30% RES penetration	1	2090	0	178	14,443	828	30.8	48.1 mill	47.8
	1	2447	0	174	14,418	802	34	47.6 mill	46.6
	1	0	351	236	14,702	989	28.7	71.5 mill	45.5
	0	3234	35	210	14,783	1,082	32.2	51.6 mill	0
	0	3520	0	210	14,886	1,130	32.8	48.3 mill	0
	A.D (370kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
50% RES penetration	1	4663	0	156 (78)	15,615	1,269	49.7	47.6 mill	39.5
	1	**4424**	**0**	**158 (79)**	**15,400**	**1,188**	**48.3**	**47.5 mill**	**39.9**
	1	4277	37	166 (83)	15,301	1,117	49.2	49.7 mill	39.9
	0	6465	0	200 (100)	17,470	2,230	51.4	51.8 mill	0
	0	5534	58	204 (102)	16,541	1,789	49.2	52.9 mill	0
	A.D (370kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
70-75% RES penetration	1	12,434	0	156 (78)	24,717	5,385	74.2	61.6 mill	32.9
	1	11,190	0	312 (156)	22,528	4,407	73.6	75.9 mill	32.2
	1	6217	565	156 (78)	19,219	2,821	73.2	82.1 mill	30.9
	0	5595	565	468 (234)	17,260	2,014	70.7	110.8 mill	0
	0	12,434	0	312 (156)	23,919	5,179	72.2	73.1 mill	0
	A.D (370kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
Highest RES penetration	1	37,301	1130	312 (156)	63,193	23,025	96	194 mill	0.05
	0	37,301	1130	312 (156)	63,192	23,025	93.7	194 mill	0

Table 15b- *Scenario configuration profile obtained from Homer Pro software, for* ***Maghazi grid-connected*** *scenario with* ***370kW A.D****, 2 x 100kWh Li/Ion battery configuration, and varying levels of renewables penetration (non-grid). W.T =wind turbine, BATT = battery configuration, NPC =net present cost. Optimal architecture highlighted in green.*



BASE CASE 3	Base Case 3- 1 x 1MWh Li/Ion								
	A.D (370kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
30% RES penetration	1	2510	0	17	14,441	806	34.4	47.6 mill	45.7
	1	2148	0	17	14,437	823	31.2	48.2 mill	47.1
	1	0	436	18	14,972	1,101	32.4	72.1 mill	44.3
	0	3045	20	20	14,774	1,066	29.7	48.9 mill	0
	0	3224	0	20	14,834	1,121	30.2	48.1 mill	0
	A.D (370kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
50% RES penetration	1	4625	0	16	15,585	1,260	49.4	48 mill	39.2
	1	4845	0	16	15,768	1,340	50.6	48.3 mill	38.7
	1	4411	49	15	15,456	1,192	50.4	49.7 mill	39.4
	0	4923	217	19	16,312	1,650	52.3	59.6 mill	0
	0	6016	0	21	16,904	1,989	49.4	52.6 mill	0
	A.D (370kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
70-75% RES penetration	1	11,190	0	16	23,115	4,475	71.9	59.5 mill	33.5
	1	12,434	0	16	24,697	5,380	74.2	62 mill	32.8
	1	6217	497	12	19,097	2,782	70.9	75.3 mill	31.1
	0	9325	283	20	21,645	4,056	70.1	72.8 mill	0
	0	12,434	0	23	24,519	5,425	70.4	65.3 mill	0
	A.D (370kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
Highest RES penetration	1	37,301	339	38	57,449	20,385	94.8	153.8 mill	0.07
	0	37,301	339	38	57,447	20,385	94.8	152 mill	0

Table 15c - *Scenario configuration profile obtained from Homer Pro software, for* ***Maghazi grid-connected*** *scenario with* ***370kW A.D****, 1 x 1MWh Li/Ion battery configuration, and varying levels of renewables penetration (non-grid). W.T =wind turbine, BATT = battery configuration, NPC =net present cost.*



BASE CASE 4	Base Case 4- 2 x 1MWh Li/Ion								
	A.D (370kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
30% RES penetration	1	2140	0	16 (8)	14,435	822	31.2	47.8 mill	47.2
	1	**2321**	**0**	**18 (9)**	**14,422**	**808**	**33**	**47.9 mill**	**47.5**
	1	0	351	24 (12)	14,704	991	28.7	72 mill	45.5
	0	3650	0	20 (10)	15,006	1,178	33.8	48.1 mill	0
	0	3205	5	22 (11)	14,753	1,082	30.4	49 mill	0
	A.D (370kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
50% RES penetration	1	4663	0	16 (8)	15,552	1,247	49.9	47.7 mill	39.5
	1	4930	0	16 (8)	15,888	1,384	50.9	48.9 mill	38.4
	1	4654	34	16 (8)	15,572	1,241	51.4	49.3 mill	39.5
	0	6217	0	24 (12	16,847	1,936	51.3	53.3 mill	0
	0	4663	141	28 (14)	15,415	1,283	49.2	62.9 mill	0
	A.D (370kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
70-75% RES penetration	**1**	**10,879**	**0**	**14 (7)**	**22,806**	**4,512**	**71**	**57.2 mill**	**33.7**
	1	10,465	0	16 (8)	22,261	4,283	70.2	58.5 mill	33.7
	1	9325	283	16 (8)	21,646	3,932	74.7	72.1 mill	31
	0	12,434	0	32 (16)	23,884	5,165	72.3	73.9 mill	0
	0	6217	565	32 (16)	18,445	2,528	70.8	95.1 mill	0
	A.D (370kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
Highest RES penetration	1	37,301	339	32 (16)	54,447	20,375	94.8	147.8 mill	0.01
	0	**37,301**	**339**	**32 (16)**	**54,447**	**20,379**	**94.8**	**146 mill**	**0**

Table 15d- *Scenario configuration profile obtained from Homer Pro software, for* ***Maghazi grid-connected*** *scenario with* ***370 kW A.D****, 2 x 1MWh Li/Ion battery configuration, and varying levels of renewables penetration (non-grid). W.T =wind turbine, BATT = battery configuration, NPC =net present cost. Optimal architecture(s) highlighted in green.*

BASE CASE 1	Base Case 1- 1 x 100kWh Li/Ion								
	A.D (185kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
30% RES penetration	1	3094	0	180	14,669	964	34.2	47.5 mill	44.6
	1	0	565	233	15,459	1,388	33.3	80.8 mill	22.1
	1	1554	141	195	14,558	947	27.8	55.3 mill	25.2
	A.D (185kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
50% RES penetration	1	5440	0	175	16,378	1,674	50	48.9 mill	19.7
	1	4746	62	177	15,744	1,373	49.1	51 mill	40.2
	A.D (185kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
70-75% RES penetration	1	12,434	0	156	24,787	5,471	71.9	60.1 mill	34.1
	1	9325	283	195	21,459	3,924	73.1	73.4 mill	32.5
	A.D (185kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
Highest RES penetration	1	37,301	2261	311	71,870	27,074	96.7	265.9 mill	0.06

BASE CASE 2	Base Case 2- 2 x 100kWh Li/Ion								
	A.D (185kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
30% RES penetration	1	2960	0	216 (108)	14,579	936	33.3	49 mill	22
	1	2590	0	246 (123)	14,549	934	30	51.7 mill	23.7
	1	0	565	234 (117)	15,459	1388	33.3	80.8 mill	22.1
	A.D (185kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
50% RES penetration	1	4894	19	178 (89)	15,833	1,432	48	49.1 mill	20.1
	1	5515	0	184 (92)	16,376	1,668	50.7	49.4 mill	
	A.D (185kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
70-75% RES penetration	1	12,434	0	312 (156)	24,189	5,231	73.6	76.4 mill	32.6
	1	6217	565	156 (78)	19,399	2,967	69.9	81 mill	31.4
	A.D (185kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
Highest RES penetration	1	37,301	1130	622 (311)	63,192	23,025	96	227.9 mill	0.03

Table 16a- *Scenario configuration profile obtained from Homer Pro software, for* ***Maghazi grid-connected*** *scenario with* ***185kW A.D****, various Li/Ion battery configuration, and varying levels of renewables penetration (non-grid). W.T =wind turbine, BATT = battery configuration, NPC =net present cost.*

BASE CASE 3	Base Case 3- 1 x 1MWh Li/Ion								
	A.D (185kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
30% RES penetration	1	3108	0	18	14,674	967	34.3	47.4 mill	44.7
	1	2825	0	18	14,619	957	31.9	48 mill	45.4
	1	933	283	20	14,667	1,002	29.1	61.2 mill	46.9
	A.D (185kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
50% RES penetration	1	4663	141	16	15,863	1,405	51.8	54 mill	39.3
	1	5721	0	18	16,669	1,807	51.4	50.3 mill	38.2
	A.D (185kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
70-75% RES penetration	1	12,434	0	16	24,767	5,458	72	60.3 mill	34.1
	1	9325	283	20	21,523	3,949	72.9	74.4 mill	
	A.D (185kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
Highest RES penetration	1	57,195	0	38	82,867	32,025	95.9	174.9 mill	0.01

BASE CASE 4	Base Case 4- 2 x 1MWh Li/Ion								
	A.D (185kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
30% RES penetration	1	2951	0	22 (11)	14,560	928	33.3	49.2 mill	45.9
	1	2849	0	24 (12)	14,566	932	32.3	51.5 mill	45.8
	1	2349	70	22 (11)	14,523	906	31.5	52.7 mill	47.6
	A.D (185kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
50% RES penetration	1	4348	141	20 (10)	15,358	1,186	50.8	56.4 mill	40.2
	1	5609	0	18 (9)	16,504	1,727	51	49.3 mill	39.1
	A.D (185kW)	P.V	W.T	BATT	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
70-75% RES penetration	1	11,190	0	32 (16)	22,248	4,320	72.3	73.6 mill	33.7
	1	6217	565	16 (8)	19,379	2,960	70	81.5 mill	31.4
	A.D (185kW)	P.V	W.T	BATT (No.-parallel)	MWh/yr prod.	Excess (MWh.yr)	% Non-grid	Total NPC ($)	A.D Factor (%)
Highest RES penetration	1	37,301	339	32 (16)	57,447	20,375	94.8	145.9 mill	0.01

Table 16b- *Scenario configuration profile obtained from Homer Pro software, for* ***Maghazi grid-connected*** *scenario with* ***185kW A.D****, various Li/Ion battery configuration, and varying levels of renewables penetration (non-grid). W.T =wind turbine, BATT = battery configuration, NPC =net present cost.*

Figure 12- *Potential layout of RES off-grid microgrid components in relation to Al-Fukhkhari (circled in white). ArcMap software.*

Figure 13- *Potential layout of RES components for 70-75% RES penetration, in relation to Maghazi. ArcMap software.*