Developing Clean Energy in Nigeria:

Data-Centric Solutions for a Solar-Hybrid Company

by

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Aspire POWER SOLUTIONS

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Executive Summary

Nigerians have long suffered from high electricity prices and an unreliable grid with limited generation and transmission capacity. As a result, many residential customers and businesses have turned to generating their own power with diesel generators. While this alternative provides them with reliable power and freedom from the grid, these generators are expensive and highly polluting. Health and environmental concerns require reductions in emissions, which can be achieved through the use of renewable energy. Because Nigerians are spending so much money on expensive diesel, there is a nascent market for more affordable renewable technologies.

Aspire Power Solutions (APS) is a start-up company that addresses the reliability problems of the grid and the health problems of diesel generators by providing citizens with a cleaner, cheaper alternative: solar-hybrid systems. APS has begun selling these systems to commercial and residential customers in urban areas, with hopes of expanding into rural and off-grid regions in the future. As the company continues to grow, APS wants to leverage data in their business strategy to offer the best solutions and experience for their customers.

This Master's Project presents an analysis of data-based strategies APS can employ to

1. optimize their solar-hybrid system design,
2. determine which customers are the most creditworthy, and
3. access crowdfunding sources to finance their clean energy projects.

The paper develops recommendations for each of these three focus areas and the resources and capabilities needed to successfully implement these changes. When designing their solar-hybrid systems, APS should leverage hourly solar generation data and customer load profiles to optimize the size of the PV panels and battery for each system. To estimate a customer's ability to make payments, APS should consider their current expenses on diesel fuel and incorporate this constraint into their system design. This would help APS reach customers who may not be able to pay for a system that would reduce their diesel use to zero percent, but could afford a smaller system that would still give them significant emissions reductions and fuel savings. With respect to crowdfunding, various existing platforms are discussed along with the advantages of partnering with companies like The Sun Exchange to crowdfund projects.

This 2018 student paper was prepared in partial completion of the graduation requirements for the Master in Environmental Management at the Nicholas School of the Environment at Duke University. The research, analysis, and recommendations contained in this paper are the work of the student who authored the document, and do not represent the official or unofficial views of the Nicholas School of the Environment or of Duke University. The author may have relied in many instances on data provided by different unpublished sources and cannot guarantee its accuracy.

1 Introduction

This Master's Project proposes data-driven solutions to improve the core operations of Aspire Power Solutions (APS), a start-up company with the mission of bringing renewable energy to Nigerian households and increasing access to reliable electricity.

Nigeria is Africa's largest economy, with its GDP of $404.7 billion in 2016 easily surpassing South Africa's $295.5 billion (World Bank, 2017). However, Nigeria is also a populous country, making its GDP per capita (adjusted for purchasing power) on par with countries like Nicaragua and Vietnam (World Bank, 2018). The West African nation is also a member of OPEC and has the most oil production on the continent, with a maximum capacity of 2.5 million barrels per day (NNPC, 2016).

Nigeria's petroleum industry accounts for around 15% of the country's GDP and 70% of government revenue (Santander, 2017). However, this energy-rich country has been unable to satisfactorily supply its own citizens with energy; in fact, the development of the industrial sector has been limited due to power shortages (Santander, 2017). According to the World Bank, only 55% of Nigerians have access to electricity (World Bank, 2015). Though this is a better electrification rate than the rest of Sub-Saharan Africa (see Figure 1), it still leaves roughly 95 million Nigerians without access to power (Advisory Power Team, 2015).

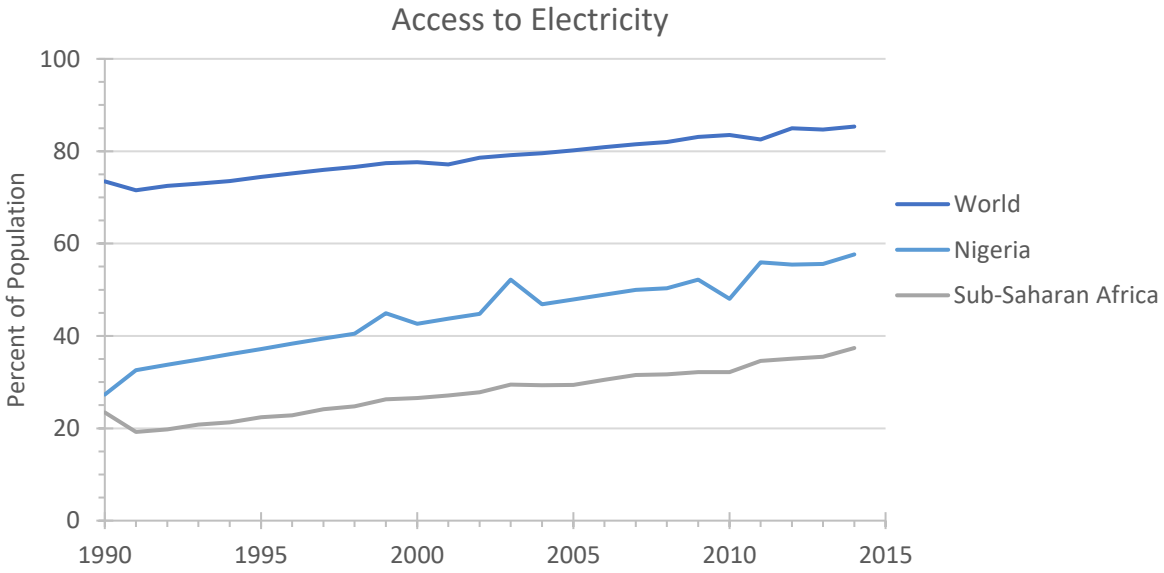

Figure 1: Percent electrification by region. Source: (World Bank, 2015).

With over 180 million people, Nigeria is currently the seventh most populous country in the world, but it is projected to grow to replace the U.S. as the third most populous by 2050 (Adegoke, 2017). The world population is expected to reach 9.8 billion by 2050, with half of that growth likely coming from Africa (Adegoke, 2017). Nigeria has four of the world's fastest-growing

cities, and “has been described as an economic powerhouse” (Adegoke, 2017). Nevertheless, this population growth threatens to decimate Nigeria’s infrastructure—especially its electricity grid.

As shown in Figure 1 above, the country’s electricity system can’t even meet current demand, and population growth will only exacerbate this problem. However, there are companies taking notice of the market opportunities in Nigeria and establishing themselves as alternatives to the traditional power system. One such company is Aspire Power Solutions (APS), a Nigerian start-up looking to bring renewable energy to customers and increase reliable electricity access.

APS sees an opportunity to improve its business strategy with the data it collects (and could collect), but the company needed some recommendations for which data streams to prioritize and incorporate early on as they continue to grow. This project was conceptualized through conversations with APS to determine what their main needs were as a company and delve into how data could be leveraged to help fulfill each of those needs. The result is a list of suggestions which APS could choose to implement in their own operations in order to strengthen their business model and continue to grow and service customers throughout Nigeria.

The rest of this paper is organized as follows: Section 2 explains the state of electricity in Nigeria, including existing power generation structures and reliability concerns, and introduces the client for the project. Section 3 presents the central question and focus areas that guided this analysis, while Section 4 describes the methods and types of sources used. Section 5 details the main recommendations for Aspire Power Solutions, along with what resources and capabilities they would need to develop to implement these changes. Finally, Section 6 concludes the paper and suggests future areas of study.

2 Background

2.1 Electricity in Nigeria

2.1.1 History and Current Status

Nigeria’s power generation dates back to 1896, when two gen-sets (portable generators that can independently produce electricity) began supplying the then Colony of Lagos (NERC, n.d.). In 1951 the Electricity Corporation of Nigeria (ECN) was established, followed by the Niger Dams Authority (NDA) in 1962 (NERC, n.d.). These two organizations merged in 1972 to form the National Electric Power Authority (NEPA), a state-owned entity that was responsible for the generation, transmission, and distribution of electricity for the whole country (NERC, n.d.).

Nigeria’s power sector was reformed in 2005 through the Electric Power Sector Reform (EPSR) Act, opening up the electricity market to private companies and transforming NEPA into the Power Holding Company of Nigeria (PHCN) (NERC, n.d.). This act hoped to address NEPA’s inability to meet the ever-increasing consumer demand, high cost of maintenance, and accumulation of debts, among other concerns (Oserogho & Associates, 2014). On top of encouraging private company participation, the PHCN was split into eleven distribution

companies, six generating companies, and one transmission company (the Transmission Company of Nigeria, or TCN) (NERC, n.d.). The 2005 EPSR Act also established the Nigerian Electricity Regulatory Commission to be the independent regulator for the power sector (NERC, n.d.).

Unbundling the PHCN was criticized by some who said "old wine has been poured in new bottles," indicating that the EPSR Act would do little to address the problems plaguing the electric grid (Oserogho & Associates, 2014). Indeed, by 2013 the power sector experienced yet another change as fifteen of the state-owned electric companies were handed over to private owners by President Goodluck Jonathan, who hoped this would further encourage investment (Soleye, 2014). A 2015 report commissioned by the federal government of Nigeria in conjunction with Power Africa details how "the Nigerian government has undertaken long-term structural reforms (which started in 2005 but gained momentum in 2010) focused on privatizing legacy power assets and instituting regulatory reform" (Advisory Power Team, 2015). However, the report also admits that "these reforms have proved insufficient and more must be done to address the challenges in the sector" (Advisory Power Team, 2015).

Nigeria's power sector currently has around 12.5GW of installed capacity, with 85% of this fueled by natural gas (Advisory Power Team, 2015). Though the country set a target to increase generation capacity to 40GW by 2020, this goal has since been reduced to 20GW (Muoh, 2016). Considering the investments that would be necessary to make this happen, it doesn't seem that this target will be met. This is a major concern for citizens, given that just keeping up with the annual population growth would require a yearly expansion of 11GW (Muoh, 2016).

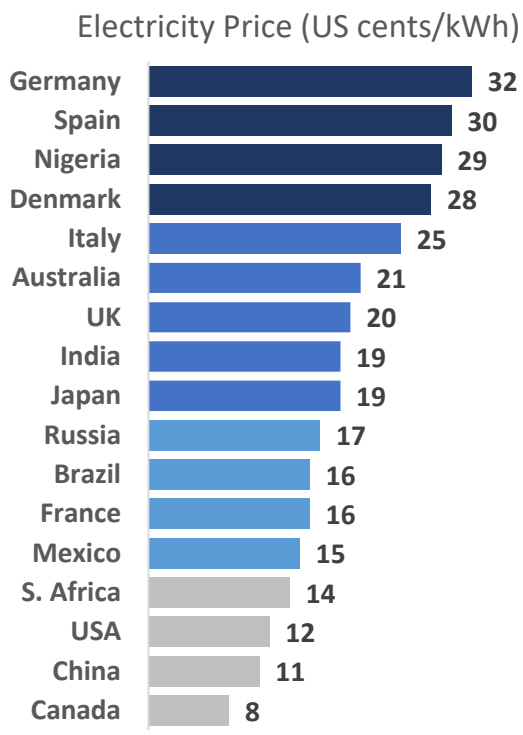

Figure 2: Average electricity prices relative to purchasing power (US cents/kWh). Adapted from (OVO Energy, 2011).

In 2015, the transmission system could distribute around 5.3GW, but this capacity is disrupted by system collapse and forced outages (Advisory Power Team, 2015). To confront this, the TCN recently launched a 20-year Transmission Master Plan that aims to increase capacity to 10GW of electricity by 2020 and 28GW by 2035 (Sunday, 2018). As of 2017 the system's capacity has improved, reaching 7.1GW in December (Sunday, 2018). With respect to distribution, Nigeria's companies continue to suffer "significant losses, with ~46% of energy lost due to technical, commercial and collection issues" (Advisory Power Team, 2015).

Taking all of these issues into account, Nigeria's electric power consumption averages just 144kWh/capita, a number dwarfed by the Sub-

Saharan average of 480kWh/capita and even further by the world average of 3,125kWh/capita (World Bank, 2014).

While considering the makeup of the power sector is important, it is also necessary to understand the price of electricity in Nigeria. Figure 2 depicts average electricity prices from 2011 adjusted to U.S. dollars using purchasing power parity. This graph shows how Nigeria compares to other countries, with electricity rates that are significantly higher than those in the U.S. and even rivals countries known for their expensive electricity, such as Germany, Spain, and Denmark (OVO Energy, 2011). On top of this, Nigeria's electricity tariff has only continued to increase since 2011.

The tariff (or bill) charged to consumers is meant to ensure cost recovery while improving performance standards for the Nigerian Electricity Supply Industry (NERC, n.d.). The Multi-Year Tarff Order (MYTO) was established in 2007 as a 15-year tariff path for the electric industry, with the ultimate objective of providing the industry with "a stable and cost reflective pricing structure that provides a modest return on investments to efficient industry players" (NERC, 2008). The 2016 tariff hike was a 45% increase, resulting in large public outcry from consumers (Muoh, 2016). While many Nigerians demanded that this decision be overturned (see Figure 3) these appeals were unsuccessful, and experts predict that the tariff will continue to rise in the coming years (NAIJ, 2017).

Figure 3: Members of the Nigeria Labour Congress and Trade Union Congress of Nigeria protest the increase in electricity tariff. Source: (Channels Television, 2016).

Besides issues with pricing, Nigerians continue to grapple with an unreliable grid and generation problems that have led the country to be called "one of the world's darkest nations" (2016).

2.1.2 Reliability Concerns

Nigeria's grid reliability is something its citizens have had to endure for a long time. People widely referred to NEPA as *Never Expect Power Always*, highlighting the issue of electricity access and supply; and after the establishment of the PHCN, the electric company was known as *Problem Has Changed Name* (Maja-Pearce, 2014).

These names are understandable, given that only a quarter of the potential energy available reaches consumers due to structural inefficiencies in both generation and transmission (Advisory Power Team, 2015). Nigeria has 25 power plants with 12.5GW of installed capacity, but due to maintenance and repair issues only 21 plants are available, with 7.1GW of capacity (Advisory Power Team, 2015). On top of this, power generation is constrained due to gas availability, water availability, and transmission constraints, among others (Advisory Power Team, 2015). This results in only 3.8GW of capacity being operational at any given time, or 31% of the installed capacity (Advisory Power Team, 2015). The Nigeria Power Baseline Report shows that all plants are running sub-optimally, with seven operating at less than 10% of their installed capacity (Advisory Power Team, 2015).

Around 2GW of this under-utilization is due to natural gas constraints, including insufficient gas-processing and pipeline infrastructure and poor economics for gas investment (Advisory Power Team, 2015). Though Nigeria has one of the world's largest natural gas reserves (see Figure 4), its low domestic prices have led producers to simply flare it off during oil extraction rather than bothering to capture it (2016). Overall, less than 10% of the natural gas Nigeria produces goes towards its power sector, compared to 41% going to exports (Advisory Power Team, 2015).

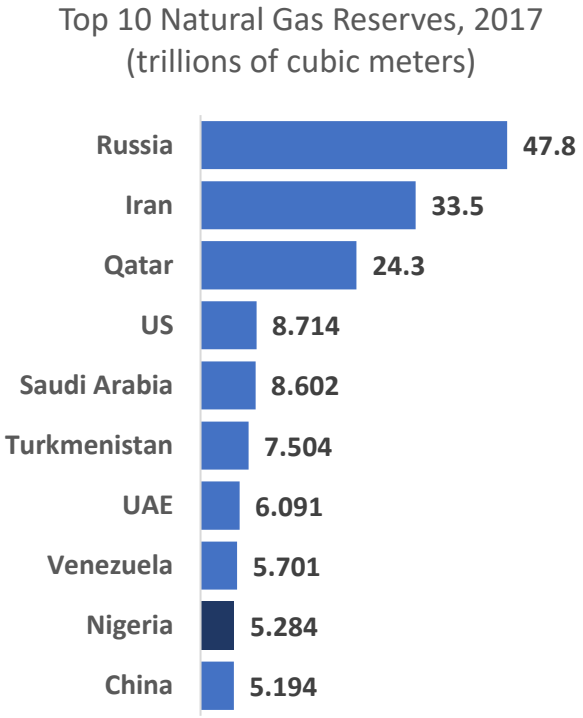

Figure 4: Natural gas proven reserves by country. Source: (CIA, 2017)

On top of this, "long-term under-investment and delays in the delivery of planned gas infrastructure have resulted in a shortage of gas-processing and pipeline infrastructure," requiring major upgrades and investment to meet even current available generation capacity (Advisory Power Team, 2015). Pipelines are also regularly vandalized. A clear example of the system's gas constraints happened this New Years, when a fire incident in a pipeline system shutdown six power plants and led to a collapse of the Nigerian grid and widespread blackout (Nnodim, 2018).

However, system collapses aren't just due to natural gas supply issues; the TCN states that "the prevailing situation in Nigeria is characterized by overloaded lines and transformers, poor quality of supply and insufficient reliability of supply—all aspects contributing to frequent outages" (Fichtner, 2018). Figure 5 shows the number of partial and total collapses the TCN has experienced in recent years.

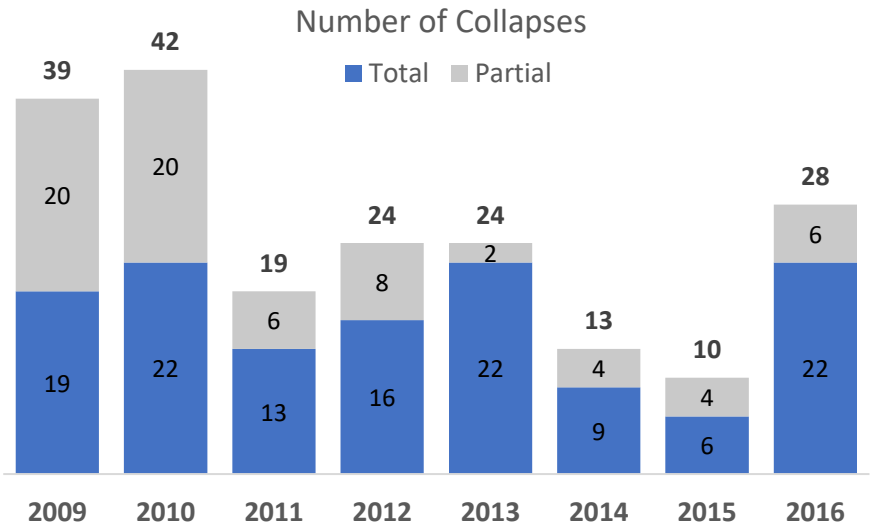

Figure 5: System collapses of the Nigerian electric power grid. Source: (NESISTATS, 2017).

These collapses are a result of a lack of investment, from both the TCN and the private distribution companies managing the grid (Soleye, 2014). And while the transmission capacity is currently higher than the average operational generation capacity, it will certainly need to increase if the TCN hopes to handle the full installed generation capacity, much less new generation growth (Advisory Power Team, 2015). These outages and supply issues led the Spectator Index to name Nigeria the country with the second worst electricity supply for 2017 (Bungane, 2018).

In response to these chronic reliability concerns, Nigerians have turned to alternate sources to supply their power, from simple candles to fuels like diesel and petroleum (Muoh, 2016). For those who can afford it, expensive diesel generators are a popular solution, with Nigerians spending over twice as much on self-generation than on grid-based power (Advisory Power Team, 2015). In 2009, an estimated 60 million Nigerians owned their own electricity-producing gen-sets (Nwachukwu, 2010). By 2016, this number rose to 100 million, per the Manufacturers Association of Nigeria (MAN) (Odutola, 2017).

Over 50 million homes spent a minimum of N30,000 a month ($83/month) on fuel for their generators, and even the offices of the President and Vice President spent N32.9 million ($91,400) to run their generators in 2016 (Odutola, 2017). However, though government ministries spent an approximate N55.4 billion ($154 million) on fuel, the majority of the N5.5 trillion ($15.2 billion) spent last year came from the residential and private sectors (Odutola, 2017).

According to the MAN President, Dr. Frank Jacobs, the “electricity crisis is the most important infrastructure bottleneck in Nigeria and all types of firms experience power outages and 85% of them own two or more generators as alternative source of power generation” (Odutola, 2017). On average, these diesel generators meet 70% of business power needs (BPS, 2017). These standby generators are referred to as captive generation capacity, which is estimated to be as high as 14 to 20GW (RECP, 2017).

With this captive generation capacity now exceeding the power sector's installed capacity, it is clear that Nigeria's electricity sector is in crisis. Citizens turn to diesel to meet needs, but this comes at a price of constant exposure to toxic fumes and noise pollution (on top of the already-expensive price tag of the generators and fuel) (Solynta, 2018). Plus, diesel engines are a source of greenhouse gas (GHG) emissions, and hence the widespread use of this fuel is a concern not only for Nigerians but communities outside of Nigeria as well (Jakhrani, et al., 2012).

On top of GHG emissions in the form of carbon dioxide (CO_2), diesel combustion is also associated with carbon monoxide (CO), nitrous oxides (NOx), sulfur dioxide (SO_2), and particulate matter emissions, including black carbon (World Bank, 2014). In Lagos, a study showed that the CO emissions from diesel generators were around 143mg/m^3, over 14 times the EU air quality standard of 10mg/m^3 (Babayemi, et al., 2017). In 2014, a report by the World Bank estimated the emissions of CO_2, SO_2, NOx, and black carbon from diesel generators in various sectors (World Bank, 2014). The analysis indicated that the diesel use in the residential sector emitted 160,000 tons of CO_2, 154 tons of SO_2, 4,069 tons of NOx, and 114 tons of black carbon (World Bank, 2014). These concentrations are concerning for both human and environmental health, and lowering these emissions requires reducing the use of diesel generators (Babayemi, et al., 2017).

2.1.3 Electrification and Potential for Renewables

In 2016 the government of Nigeria set a goal for 2GW of generation to come from renewables like biomass, small hydro, wind, and solar by 2020 (IEA, 2017). This is meant to tap into Nigeria's large renewable energy potential, increasing electricity generation in a sustainable way. With this new regulation, distribution companies will be required to source at least half of their procurement from renewables (IEA, 2017). Earlier in 2011, the Renewable Energy Master Plan (REMP) was unveiled by the Federal Ministry of Environment, including installed capacity targets for specific renewable energies (IEA, 2013). Table 1 details the capacity targets for 2025 from the REMP (IEA, 2013). The REMP also aims to improve electrification, with a goal to increase to 75% access to electricity by 2025 (IEA, 2013).

Table 1: REMP 2025 Capacity Targets. Source: (IEA, 2013).

Technology	Installed Capacity
Small Hydro	2,000 MW
Solar PV	500 MW
Biomass	400 MW
Wind	40 MW

Back in 2005 the EPSR Act established the Rural Electrification Agency (REA) as the entity responsible for the implementing the government's aggressive rural electrification goals (REA, 2017). Some of these goals are outlined in the 2016 Rural Electrification Strategy and Implementation Plan (RESIP), such as achieving 90% access to electricity by 2030 and having renewable energy as 10% of the energy mix by 2025 (FMP, 2016). To achieve this, the rural electrification strategy promotes on and off-grid solutions (e.g. grid extensions, mini-grids) and tries to couple electrification expansion with economic development objectives (FMP, 2016). The plan also encourages financial contributions towards rural electrification from state and local communities while facilitating market entry for new

participants and ventures related to power supply in rural areas (FMP, 2016). Through the RESIP, a Rural Electrification Fund was established to be managed by REA (FMP, 2016).

A recent analysis by REA, the World Bank, and RMI found that developing off-grid alternatives creates a N3.2 trillion/year ($9.2 billion/year) market opportunity for mini-grids and solar home systems that can save Nigerian homes and businesses N1.5 billion ($4.4 million) annually (RMI, 2017). REA plans to quickly develop 10,000 mini-grids to support underserved communities, hoping to show other nations in sub-Saharan Africa that mini-grids are commercially viable (RMI, 2017). To do this, REA will put $100 million of a recent $350 million loan from the World Bank towards mini-grid development, with aims to achieve 3GW of mini-grid capacity (Okafor, 2017).

While the government is working to increase electrification and renewable generation, there are also opportunities for renewable energy at the individual level. Since so many Nigerians are spending a lot of money to fuel their expensive diesel generators, renewables can offer a cheaper alternative that will still provide them with the electricity reliability and freedom they desire. A report produced by the Nigerian Economic Summit Group and Heinrich Böll Stiftung Nigeria studied the cost of electricity generation from various sources, both on and off-grid. Figure 6 shows the results from this analysis, calculating the levelized cost of electricity (LCOE) for various off-grid generation types. LCOE is a $/kWh value that incorporates both the fixed and the variable costs of building and operating an electricity-generating plant or technology. This measure allows for different technologies to be compared on the same basis, though it does not consider issues such as dispatchability or variability of resources. Figure 6 shows the LCOE for off-grid technologies calculated using various data sources and parameters (indicated by different-colored bars) (Yetano Roche, et al., 2017).

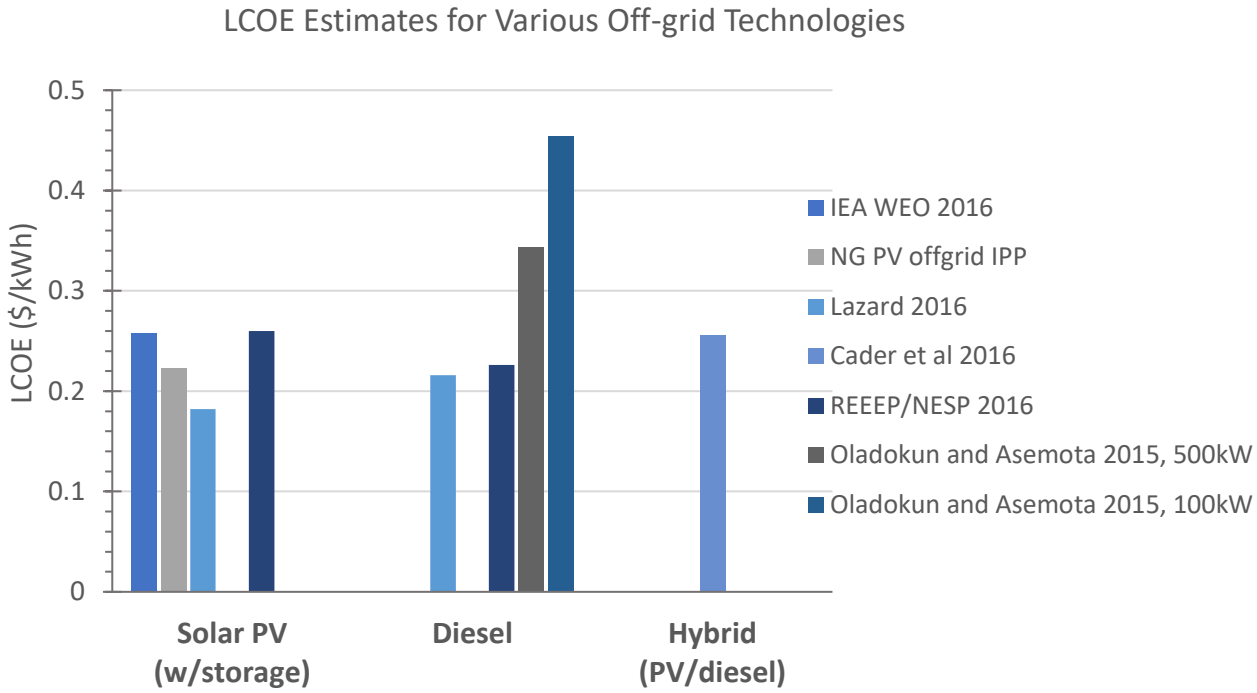

Figure 6: LCOE for select off-grid technologies. Adapted from (Yetano Roche, et al., 2017).

While the LCOE for most on-grid technologies are between $0.05 to $0.10/kWh (not shown on graph), this does not consider the reliability issues that Nigerians face when purchasing on-grid power (Yetano Roche, et al., 2017). Note also that the LCOE of grid electricity is not the price that Nigerians would pay for power, since this is known to be closer to $0.30/kWh (as shown in Figure 2). The costs of the diesel generators many Nigerians are running in their homes and businesses are better represented by the off-grid diesel category shown in Figure 6, which is between $0.20 to $0.45/kWh. When this is compared to renewable options, such as solar PV with storage, diesel can't compete. Solar-hybrid systems using PV and diesel are also a promising alternative to pure diesel generators.

These cost comparisons illustrate an opportunity for renewable companies to enter the Nigerian market, as their products could easily compete with what citizens are spending on expensive diesel. Aspire Power Solutions aims to tap into this market for renewables in order to deliver clean and affordable energy to its customers.

2.2 Aspire Power Solutions

2.2.1 Company History

Aspire Power Solutions (APS) was founded about a year ago with the mission of "eliminating the barriers that limit the adoption of renewable energy on the African continent—doing so in the smartest and most efficient way—ensuring everyone enjoys clean, reliable and affordable access to energy" (Thomas, 2017). Mustapha Abokede (CEO), Rotimi Thomas, and Tomiwa Igun came together after realizing that the weak, inefficient, and non-existent grids in sub-Saharan Africa will require Africans to continue to be productive consumers (prosumers) of energy (APS, 2017).

While a "prosumer" in western countries generally has a reliable grid connection and chooses to adopt technologies like solar PV to reduce their utility bill, this isn't the case for an African prosumer. For the African prosumer, the lack of reliable access to electricity necessitates that they produce their own energy—not as a way of reducing their bills, but as a way of compensating for their country's inability to deliver power to all of their citizens. As was shown for Nigeria, even countries that have developed grids to an extent are still having reliability and inefficiency problems that are preventing them from adequately meeting the needs of their people.

With electricity prices being so high and customers turning to their own self-generation schemes, this market also presents a unique opportunity for renewable technologies: given the cost of diesel generators and their safety and health concerns, why not switch to cleaner energies that will be cheaper and safer? While renewable technologies may find it hard to compete in other markets, the exorbitant price of both electricity and diesel in Nigeria make clean energy a more easily affordable option.

2.2.2 Current and Future Business

APS began its work in Nigeria due to its market opportunities along with the motivation of being the home country of the company's founders. The company aims to start in Nigeria, perfect their business model and strategies, and then continue to grow throughout the African continent.

The current product APS offers is a solar-hybrid system made up of a solar PV array, a battery, an inverter, and a diesel generator for backup power. APS has already installed systems that serve 50 to 100 customers in urban areas. This is the first market segment the company wishes to capture: commercial and residential customers who already have their own diesel generators for backup power and who would be willing to switch to a renewable system that would save them money. This market should be slightly easier than the off-grid space simply because the value proposition is more straightforward; customers are familiar with electricity and their needs and can agree to switch to a cheaper option.

Once APS has established itself in urban areas, they will look to expand to the off-grid market as well as other countries in the region. It may take some time to determine what price the off-grid customers are willing to pay for these systems and get access to electricity, but once this is done then APS should be able to continue growing in both the on and off-grid sectors.

2.2.3 Competitors

Of course, APS is not the only company that has taken note of the energy issues in Nigeria and considered it an opportunity to develop solutions that will help people all over Africa. Figure 7 show the main companies working to address the problem of diesel generators and grid reliability in Nigeria: Rensource, Solynta Energy, StarSight, Arnergy, and Beacon Power Services.

Figure 7: APS main competitors.

Beacon Power Services' business model targets businesses with diesel generators and provides a variety of monitoring and management solutions to optimize energy use and reduce diesel dependence (BPS, 2017). Their main offering is a software platform that allows businesses to monitor their energy use, along with enabling facilities management (BPS, 2017). The company also assists with generator resizing, peak shaving, automated controls, and energy efficiency measures—all meant to help their clients take more control over their energy needs (BPS, 2017). Finally, there's supposed to be a generation branch of the company that can help customers incorporate sustainable power options into their businesses, but this seems to be a less-developed area for the company (given the lack of information on their website) (BPS, 2017). If this arm of the company isn't fully fleshed out yet, it could be an opportunity for APS to partner with them and provide their generation design expertise in exchange for the data capabilities that Beacon has developed.

“Powering Nigeria with the sun” is Solynta Energy’s slogan, and they aim to do this by replacing generators with Solar Home Systems, with a goal of servicing 20 million Nigerian households and businesses by 2030 (Solynta, 2018). Their systems are similar to the ones APS is offering, with six options for household customers and individually-tailored systems to meet business needs (Solynta, 2018). Solynta then offers “affordable and easy payment plans” along with maintenance servicing and long-term customer care (Solynta, 2018). StarSight is a similar company, deploying solar-diesel-battery systems to commercial, multi-site clients (Helios, 2018). Their main focus is in energy efficiency and cooling, nonetheless they offer solar-hybrid systems that could compete with APS’s offering (StarSight, 2018).

Rensource offers a subscription-based energy service for its customers, with four options to choose from based on their expected energy use (Rensource, 2018). Their Solar Home Energy Systems combine a hybrid inverter, charge controller, and scalable battery capacity that can be charged from solar panels or PHCN, with options for prioritizing which appliances receive power first (Rensource, 2018). The system fits within a small box that can be wall or floor mounted, and contains DC outlets to power DC appliances (Rensource, 2018). Their two-year subscription service has a monthly fixed price, with a “Power Promise” for how much the system will deliver based on the customer’s subscription level (Rensource, 2018).

A similar subscription service company is Arnergy, who aims to “deploy affordable, reliable distributed solar energy solutions to rural and urban consumers and SMEs across Nigeria on a monthly subscription model” (Arnergy, 2018). With four packages for urban customers, three Solar Home System options for rural customers, and minigrid power solutions for off-grid customers, Arnergy seems to be doing a little bit of everything (Arnergy, 2018). Like Rensource, Arnergy provides a monthly subscription which customers must pay to receive the energy their systems are generating (Arnergy, 2018).

With so many other companies in this space it is important to understand what sets APS apart in its product and services. APS’s main competitors all offer solar-hybrid solutions for homes and businesses in Nigeria, but they generally have a few plans or system types to choose from and determine which system would be best based off of their customer’s needs. However, APS tailors its product for each customer, and optimizes the design of these systems to meet each customer’s unique energy demand and desires. While this requires APS to spend more time establishing a relationship with its customers, it also makes it more likely that the user will be happy with the system performance and design.

One final consideration is that in the long term (and under an ideal scenario for Nigerians) the most powerful competitor in urban areas would be the main grid, offering affordable, clean, and reliable electricity to its customers.

3 Central Question

As APS looks to separate itself from the competition to find and keep new customers, the company reached out for support in doing this. Through phone and email correspondence, they explained what aspects of their company they were hoping to improve, all related to the use of data as part of their business strategy. The research and analysis performed to address their questions has culminated in this master's project, with APS serving as the client for which the investigation was undertaken. The answers and recommendations given take into account their current capabilities as a company, along with what they could accomplish in the future and what resources they would need in order to be able to implement these strategies.

The central question APS posed was "How can APS use the data it collects on potential and existing customers to deploy and manage optimized clean tech solutions faster than any other competitor in the space?" This included three main areas of focus:

1. Translating data into optimized system design,
2. Using multiple data streams to identify credit-worthy customers, and
3. Leveraging data to enable crowd funding for clean tech projects.

These three questions guided the research and led to a variety of recommendations for how APS can use data in its business model.

4 Materials and Methods

The process for this project can best be broken up into three parts: collecting information on data use and best practices in the industry, analyzing APS's current data capabilities, and assessing strategies to use data to determine which ones would be best for APS.

While looking for information on what others in the field were doing, a variety of sources were consulted. This included reading recent news articles about how data was being used by different energy companies, as well as news about the current state of the Nigerian electric grid. Government and institutional websites were also checked for information on electrification and the energy profile and costs in Nigeria. Company websites were visited to take note of what competitors were doing in this space that APS could try to emulate or do even better. Keyword searches in journals were also conducted, to find any previous studies that had looked at similar questions or related topics in the past. Various webinars and conferences were attended related to crowdfunding, financing of projects, and the future of data in the energy space. TedTalks and podcasts by some industry leaders were also used to gain more background knowledge for certain topics and to delve deeper into other concepts. Finally, discussions with Duke professors gave guidance throughout the process.

Personal communication with APS was crucial to understanding the company's needs and direction, as well as their current use of data. The APS team sent over various company files to explain their business model and some samples of documents that they give their customers. On

top of this, APS shared their current system design tool, which was especially critical to understanding how they could improve their methods.

5 Results and Discussion

5.1 The System

The first aspect of APS's business that can be tackled with data is their system design; that is, how to optimize the sizing of the solar panel, battery, diesel generator, and inverter that make up the APS product. Each customer APS services has unique characteristics and energy use that must be accounted for when designing their systems. APS has already recognized that collecting customer data is critical for the efficient, cost-effective design of these systems, and they have developed a linear programming model which calculates the optimal system design. This section describes their current model and inputs, suggests improvements to their methodology and use of data, and outlines the metering and sensor capabilities that APS would need to develop in order to make these changes.

5.1.1 Existing Optimization Program

To design their current systems, APS employs a linear program using the *Solver* tool in Excel that take various inputs from their customers and calculates the optimal sizing of the system. One of the main inputs for this program is information on the appliances a customer uses, including how many appliances the household or business has and how many hours a day they want to use those appliances. For example, a company may need to power fifteen lightbulbs for six hours a day, a laptop for three hours, and two fans for ten hours a day. Based off of the electricity requirements for each of those appliances, APS can calculate the customer's energy demand for a day as well as what their maximum, or peak, power demand will be. Their system can then be designed to meet this peak demand and also deliver enough energy throughout the day for the customer's needs.

The current APS model also asks the customer for how much storage capacity they would like to have (e.g. 4 hours of storage). Taking the daily energy demand for a customer, they calculate average hourly energy use and use this to see how much energy the customer needs to store daily. Given this value and the depth of discharge for lead or lithium ion batteries, APS can calculate what size the batteries would have to be to meet the customer's specifications.

Optimization generally implies that there are constraints for a given problem, and APS also takes these into account. The main constraint for system design is the roof space available for the solar panels and system to go on. Based on the available area, APS estimates the maximum size of the solar panels they can give the customer and designs the system accordingly. For example, if a customer only has room for four panels and each one is around 250W, the maximum size for the solar part of the system would be 1kW. The optimization then takes this into account to make sure this constraint is met—while the customer could get more energy with a larger system, it

simply isn't feasible for their roof to hold a larger system, which is why this constrains the available solutions.

When sizing the final system, APS makes sure that the total energy needs of the customer (including the daily use plus the storage requirements) are met by calculating how much energy the solar panels can produce throughout the year. To do this they use an estimate for how many kWh can be produced during a year for a kW of installed capacity, derived from solar irradiance data such as the map shown in Figure 8 (note the yearly totals at the bottom of the image). The inverter is sized to meet the peak power load, and the backup generators are sized based off of how much energy can't be supplied by the solar panels.

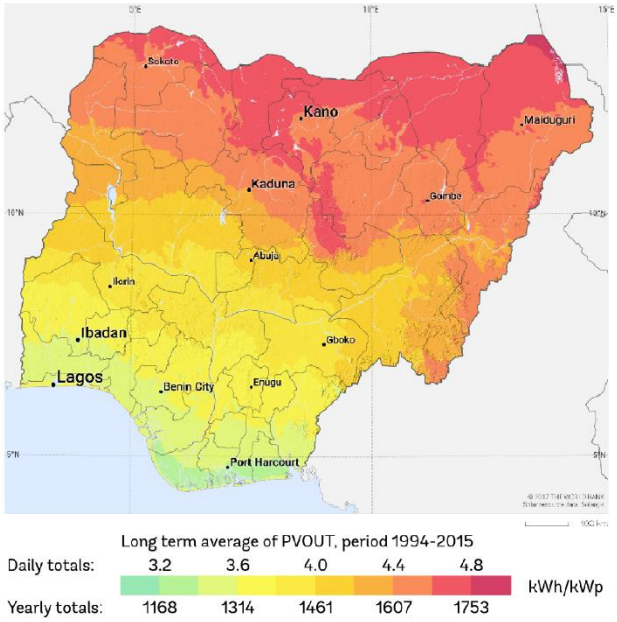

Figure 8: Map of Nigeria's solar PV power potential. Source: (The World Bank, 2017).

The costs for the system are then determined and financing options are presented for the customers. The fuel savings of switching from a diesel generator to the solar hybrid system are also calculated and reported to show customers what they save by making the change.

5.1.2 Recommendations

While APS is already on the right track to optimizing their product design, there are ways in which increasing their use of data could improve their methods. The low-hanging fruit here that could make a big impact is the use of solar generation modelling as well as collecting customer load data prior to designing the systems.

As explained earlier, APS currently uses an average value for yearly solar generation in order to determine how much energy their systems will produce and ensure that they meet the customer's demand. However, using more granular data for solar production would allow APS to compare the available energy for different hours to the customer's consumption, which could also inform modeling for the charging and discharging of the battery. By looking at the actual patterns in the generation of solar energy throughout the year APS could focus on meeting daily energy needs and hourly demand rather than the yearly amount. This solar data could potentially allow APS to reduce their system size, or show that their systems needs to be larger than expected based off of when the solar energy would be available for use.

Figure 9 shows an example for what this solar data would look like, taken from the U.S. National Renewable Energy Laboratory's (NREL) PVWatts® Calculator. This tool was developed to help estimate the solar production for a given system based on its location and technical aspects.

PVWatts works by taking solar resource data for a selected location and modeling how a PV system with a certain size and characteristics would behave in those conditions. The graph in Figure 9 was developed with data from Ghana, by designing a 23kW system. The hourly data for the estimated production was then downloaded from the website, and the average generation for different hours and months was plotted.

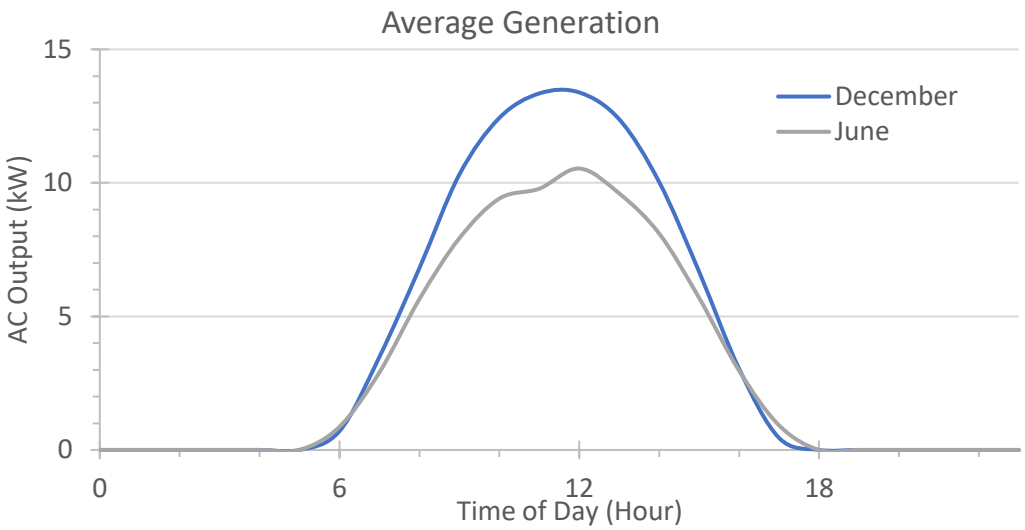

Figure 9: Average hourly solar generation for a 23kW system in different months. Source: (NREL, 2018).

This graph shows the variation in solar production for different hours of the day, as well as the seasonal variations (note that in June overall production is expected to be lower than in December). By comparing this to the customer's expected energy demands, APS can better estimate the proper sizing for their systems while accounting for these variations in generation.

The accuracy of these solar estimates depends greatly on the solar data that NREL has access to. Figure 9 was made using data from nearby Ghana, because no data for Nigeria is currently available to model systems in the country. However, a recent notice on the PVWatts website states that they will be changing the default weather data selection to be the NREL National Solar Radiation Database (NREL, 2018). According to NREL, "this change will also add many countries currently without data in PVWatts" (NREL, 2018). APS should keep an eye out for these updates so that they can begin incorporating this data into their system design. If data from Nigeria does not become available, then the company should determine whether it would be best to use data from a similar country/area or try to develop their own tools to estimate Nigerian solar production.

One of the main advantages to having hourly solar generation data is being able to compare that to the customer's hourly demand. In order to do this, APS would need to collect more detailed load data from its customers. While a survey of different appliances and the use of these is a good way to get a sense for a household or business' energy use, actually measuring their hourly energy use would yield more sophisticated results. For example, Figure 10 shows how the solar generation and energy demand would overlap, with the black region being energy the customer would consume directly from their solar panels. The gray area shows the solar energy that would

not be used (if the system had no storage capacity), and the red regions show the hours for which the customer would have to get electricity from the local grid (or most likely their diesel generators, in the case of Nigeria).

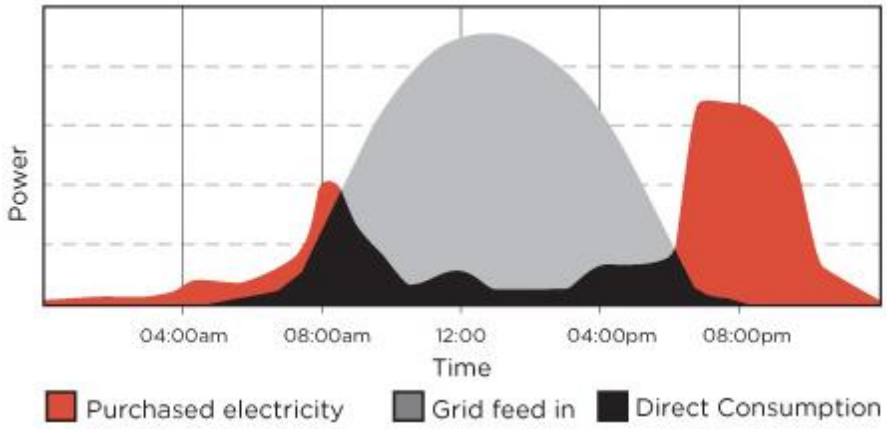

Figure 10: Conceptual graph showing solar generation and customer load throughout the day. Source: (neeoQube, 2014).

This graph also helps reiterate the importance of hourly solar data: while APS is considering yearly production and comparing that to their customer's yearly energy needs, it's clear that production and demand may not always coincide. Not using hourly data could lead to under-sizing of solar equipment or battery capabilities, as well as unhappy customers who can't meet the demand they were told their systems would handle.

Furthermore, once the hourly generation and load data can be combined, it become a lot easier to visualize the use of a batter and play out scenarios for the battery charge/discharge hours. Though customers currently ask for a certain number of hours for backup, knowing how much they can charge and discharge during different times of the day would be a better way to calculate their battery needs. Figure 11 illustrates how a system could operate by adding storage.

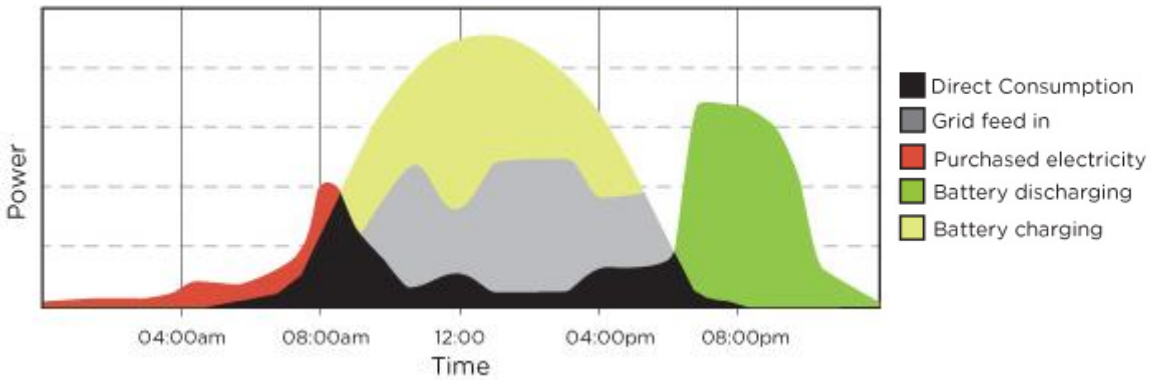

Figure 11: Conceptual graph showing hourly solar generation and consumption, as well as battery charging and discharging. Source: (neeoQube, 2014).

In this case, the gray region of lost solar generation is reduced by introducing a battery that can charge during the hours of excess production (yellow). The red area, where electricity would have

had to come from the grid or a diesel generator, is also reduced by discharging the battery during the later hours of demand (green). By changing the size of their PV system or the corresponding battery, APS would be able to increase/decrease these regions until the optimal solution for the customer could be found.

For example, perhaps the customer shown in Figure 11 could have a smaller PV array installed which would reduce the size of the peak but still allow the battery to charge as it is now (effectively reducing the gray area in the graph). Or, the customer might prefer to increase their battery capacity to charge more during those peak hours and then discharge for longer periods of time (effectively reducing the red region in the graph). With more specific solar and customer load data, APS could offer their customers more optimized solutions, with different cost ranges and capabilities. On top of this, APS could aim to design systems that would meet certain cost constraints, making them even more appealing for customers.

Finally, combining the customer load data with the survey data APS already collects would further strengthen the company's capabilities. If APS continues to offer free energy audits, including a week or so of load data collection, they could start to develop customer profiles. Essentially, by having data on the appliances a household has and by being able to compare that to their electricity use, APS would then be able to predict the demand curve for future customers based solely on the appliances they have or would like to have.

Perhaps the best application for this data would come when the company expands to off-grid markets, where load data will not be readily available. By collecting this customer data now, APS would be able to amass thousands of load profiles for customers with varying appliance use, economic status, family/company size, etc. Even if some of the people audited for a system opt out of buying one, APS would be able to use their data in the future to estimate what an off-grid family's needs may be. In the long run, this data would not only help APS in developing the systems for the urban customers they currently service, but also inform the design of solar-hybrid systems for rural and off-grid customers who may not have as much experience with electricity use.

5.1.3 Metering and Sensors

In order to collect this customer data, using sensors must become an important part of the APS business model. While installing so many sensors may sound like an expensive option at first, it would actually be feasible for APS to purchase just a few sensors that could be used for multiple customers. Essentially, APS could place sensors in a home or business only for the week of data collection and then remove them and take them to the next location being audited. With this model, APS could invest much less capital and simply buy enough sensors to service the weekly demand they expect to have for customers. Alternatively, APS could keep the sensors in a customer home for longer (e.g. a month), but this would require them to have more sensors on hand to be able to swap out customers effectively.

APS currently installs the Smappee sensor with its solar-hybrid systems, providing customers with appliance-level data for their energy use. One option they could explore is to use these sensors

before the installation in order to capture the customer's load profile. Then, if someone chooses not to purchase an APS system, the company would simply take the sensor back and use it for data collection with a new customer. If the customer buys an APS system, the same Smappee sensor that was used to collect the original data could be left with them as part of the new system.

Another option would be to continue installing Smappee sensors for data collection post-system installation, but use a different sensor for the initial characterization of the customer's load profile. Some metering options APS can explore for residential customers include the Neurio home electricity monitor, the Sense home energy monitor, and the CURB home energy monitoring system. For commercial customers, APS could use sensors like the TED electricity monitor system or PowerWise energy monitoring.

APS is already considering partnerships with other energy monitoring companies, such as AIO systems and Solstice energy solutions (Thomas, 2018). Another potential partner would be Beacon Power Services, introduced earlier as one of the competitors in this space. One of the key questions APS must answer is whether it wants to own the data it collects from customers or whether purchasing access to the data from another company would be more cost-effective.

5.2 The Customers

Once the solar-hybrid systems have been properly designed, APS must ensure that the customers they are servicing will be able to make their payments on time. Determining credit worthiness can be a difficult endeavor in African countries, where few people have any type of credit history or experience with loans and banking. However, it is possible for APS to leverage data about their customers to identify how likely they are to make consistent payments so that the company can recover its costs and continue expanding operations. This section explores a few options APS has for determining their customers' credit worthiness.

5.2.1 Customer Diesel Expenses

The simplest way to estimate the payments a customer would be able to make towards the APS solar-hybrid system is to consider how much they are current spending to fuel their diesel generator. The customer's fuel savings could reasonably go towards payments until the system is paid off.

This value should also be communicated to customers to show how many years it will take for the system to "pay for itself." For example, if a customer is spending N1,000 a day on diesel to run their generator and a N1 million system could reduce this fuel expense to zero then the customer payback would be around 3 years. Of course, this doesn't take into account the cost of financing the project, but it could help the customer visualize the initial expense in terms of how much money they will save in the future. Back to the example, assume the financing results in a total cost of N2 million over the three years. N2 million would be closer to six years of the fuel spending for the customer, but with a 20-year system life the customer would end up saving N5.3

million on fuel compared to keeping their diesel generator. Table 2 below further explains this sample calculation, along with the percent savings averaged over the life of the project.

Table 2: Example of Customer Expense and Savings, 100% Fuel Replacement

Characteristic	Value	Unit
Fuel Cost, monthly before system	30.4	Thousand N
System Cost, no financing	1	Million N
System Cost, 3-year financing	2	Million N
System Cost, fuel equivalent	5.5	Years
System Cost, monthly payment	46.8	Thousand N
System Life	20	Years
Fuel Cost, 20 years without system	7.3	Million N
Fuel Cost, 20 years with system	0	Million N
Overall Savings, 20 years with system	5.3	Million N
Savings, 20-year average	73	% of fuel cost

Note that the monthly payment for this system would be N46,800, which is higher than what the customer currently spends on fuel. This leads to some uncertainty for the customer's ability to pay for the system, so APS would have to consider other options for this customer (ways to lower their monthly payment), or choose to not install the system.

Given a customer's current fuel expense, APS could optimize a system that maximizes overall savings within the customer's budget. For example, perhaps 80% of the fuel expenses could be saved with a system that costs half as much (this could be achieved with changes to the system design, such as reducing the size of a battery that isn't used much), which may be easier for the customer to pay off. Table 3 below shows how this could change a customer's ability to make the payments for the system. Significant changes from Table 2 are shown with bolded values.

Table 3: Example of Customer Expense and Savings, 80% Fuel Replacement

Characteristic	Value	Unit
Fuel Cost, monthly before system	30.4	Thousand N
System Cost, no financing	0.5	Million N
System Cost, 3-year financing	**1**	Million N
System Cost, fuel equivalent	2.7	Years
System Cost, monthly payment	**23.5**	Thousand N
System Life	20	Years
Fuel Cost, 20 years without system	7.3	Million N
Fuel Cost, 20 years with system	**1.5**	Million N
Overall Savings, 20 years with system	**4.8**	Million N
Savings, 20-year average	**66**	% of fuel cost

In this scenario, the customer would have a lower monthly payment (N23,500 vs. N46,800) but would still incur fuel costs due to a smaller system design. However, spending 20% of their usual expense on fuel amounts to N6,100, so the total monthly cost would be N29,600. Note that this is still less than the N30,400 the customer was paying before, which means the customer would be able to easily pay for this system. Though this wouldn't reduce their use of diesel to zero, it would still allow them to get much of their energy from renewable sources instead and offer APS more certainty that the customer would be make their payments.

Note that this is only a theoretical change to the system that would allow 80% fuel reduction for half the cost, but this analysis could easily be done by APS by adding these cost considerations into the model when determining the system size. This could also allow the customer to have a few options for the system size and cost to choose from, giving customers the freedom to consider reducing other expenses to afford the 100%-fuel reduction system or decide to go with a system that has a payment they can easily meet given their current fuel expense.

If the system payments are less than the customer's fuel expenses, it would become easier for APS to securitize these cash flows to help finance future projects. And even if these payments aren't securitized, APS would more easily gain access to capital by showing that their system is guaranteed to be paid off by their customers. This is why ensuring the reliability of customer payments is so important, and why having proof of the customer's ability to pay is necessary.

5.2.2 Willingness-to-Pay Models

Another method to estimate the payments a customer can make is to use academic willing-to-pay (WTP) or ability-to-pay (ATP) models. WTP studies develop a scenario in which participants are asked to state or consider how much they would be willing to pay for a certain good or service not available on the market. These types of studies can provide a good basis for customer demand in market research as well as helping governments or companies understand the value people place in these products. In the energy access space, a decent amount of studies have been conducted regarding people's willingness to pay for solar home systems or improved cook stoves in developing countries, especially in rural and poor communities.

For example, Grimm et al. studied the WTP for three off-grid solar devices in Rwanda, showing that households are willing to dedicate a large fraction of their expenses to electricity (though this WTP was not enough to cover the system prices) (Grimm, et al., 2018). This study even considered different pay schemes for the systems, but ultimately determined government subsidies would be required to lower the cost (Grimm, et al., 2018). A similar study in Pakistan looked at the WTP for solar home systems, analyzing what level of subsidy or cost reduction would make people interested in paying for these systems (Abdullah, et al., 2017). Interestingly, less than a third of respondents stated they'd be interested in solar if it cost as much as fossil fuel generation, but when the possibility of a 50% subsidy was introduced, over three-fourths expressed interest (Abdullah, et al., 2017).

While assessing what customers are willing to pay for a good or service is critical to understanding the market, knowing what factors affect a person's WTP can also yield important insights. In the case of APS, being able to point to a few indicators and estimate what a customer would be willing to pay for a solar-hybrid system can help establish what payment plan would work for them. Similar to considering diesel expenses, WTP could serve as a cap for the monthly payments. A model for measuring WTP could take into account the diesel expenses on top of other factors that could affect how much a customer is willing to pay.

Though having this model would give APS a lot of insight into their customer's ability to pay, this specific type of study (eliciting WTP responses from a large sample and also modeling indicators for differences in WTP) hasn't been conducted for solar-hybrid systems in Nigeria. As mentioned earlier, studies looking at the WTP for different renewable technologies have been done, but these haven't assessed indicators or developed a predictive model. However, a few examples can be found in other areas, such as identifying household characteristics affecting WTP for improved cook stoves in India (Jeuland, et al., 2015).

If these indicators overlap across sectors, factors such as education level, household income, and awareness of health issues could be considered in APS's model for WTP (Jeuland, et al., 2015). However, developing a WTP study and analyzing the indicators associated with WTP would require time and expertise. To do this, APS should partner with an academic institution that could perform this analysis for them. This would ideally result in a rough "equation" that APS could use, plugging in customer characteristics to calculate their estimated WTP. Though this could give APS

a better understanding of their customers and how to structure their payment plans, this analysis would likely take anywhere from months to up to a couple of years to conduct. Due to this timeline, it would be wiser for APS to base customer systems and financing off of fuel spending rather than trying to identify the exact WTP for their customers. While an academic WTP model could offer more information than fuel spending, it would simply take too long to develop and implement, which would cost APS money and customers in the meantime.

5.2.3 Aggregate Data for Future Use

One final consideration regarding credit-worthy customers is the importance of tracking customer payments. Though this won't necessarily help APS identify which customers are credit-worthy from the beginning, this payment record would become a type of credit history that itself has value. Various companies in the energy access sector are developing their own credit data which can later be sold to other companies looking to enter the market and know more about a customer's credit history. In other words, the monthly payments customers make to APS could later be considered a form of tracking credit by showing how often payments are made on time.

Even if this "credit" history isn't given to other companies, it could still become an important source of data for APS. If a customer wants to upgrade their system, APS can consult its records to determine how reliable the payments from that customer have been. On top of this, if APS expands its product offering (e.g. to include some appliance options) they would again be able to consider customer payment records when deciding which customers will be eligible for financing in the future.

5.3 The Financing

While identifying creditworthy customers is critical for the proper deployment of APS systems, financing for both the company and their projects could also be obtained through crowdfunding. Here we consider what types of crowdfunding programs exist (particularly for energy access ventures) and how data could give APS and advantage when pursuing crowdfunding. This section describes traditional crowdfunding platforms and explains how emerging blockchain technology could change the crowdfunding space.

5.3.1 Crowdfunding Platforms

Crowdfunding for energy access projects has been growing quickly in recent years, with $8.7 million raised in 2016 compared to $3.4 million in 2015 (Cogan, et al., 2017). While it is still only a small component of the overall fundraising of off-grid energy companies, crowdfunding seems to be playing an increasing role for businesses looking to close the financing gap (Cogan, et al., 2017). Crowdfunding can take on many forms, from the donation or rewards-based campaigns that people are generally familiar with (such as GoFundMe, Indiegogo, Kickstarter) to more traditional financing types providing debt and equity. Figure 12 shows the breakdown for the funds raised in 2016, with debt and equity funding clearly accounting for the majority of energy access project funding (Cogan, et al., 2017).

Four of the top ten countries for energy access crowdfunding in 2016 (by amount raised) are in Africa: #1 Kenya, #2 Ghana, #3 Mali, and #5 Zambia (Cogan, et al., 2017). APS considers crowdfunding as a way to tap into more capital—especially from the Nigerian diaspora, currently estimated to be between five and fifteen million strong (NGEX, 2018). When starting a crowdfunding campaign, one of the most important things for a company is to find the right platform that will suit their needs. Here the top three energy access platforms for 2016 are discussed.

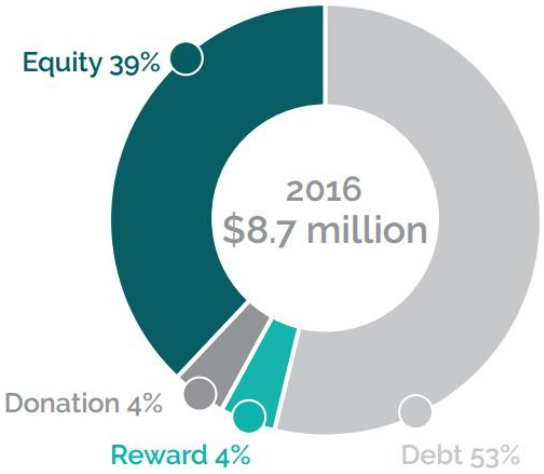

Figure 12: Crowdfunding for energy access by type. Source: (Cogan, et al., 2017).

Kiva

U.S.-based Kiva raised over $2.5 million in loans for off-grid energy products in 2016, making it the dominant platform for energy access crowdfunding (Cogan, et al., 2017). In 2016 alone Kiva launched over 4,000 campaigns, with the majority of these based in Kenya (Cogan, et al., 2017). Kiva began in 2005 as a debt-based lending platform with the mission of alleviating poverty (Kiva, 2018). By mid-2017 the company had raised over $1 billion in loans (Cogan, et al., 2017). Through Kiva, 65,000 borrowers have gotten access to clean energy (Kiva, 2018).

Bettervest

Bettervest raised the second-highest amount of money for energy access projects in 2016, despite having much fewer projects than Kiva (Cogan, et al., 2017). This platform funded five campaigns totaling $1.1 million in debt funding (Cogan, et al., 2017). Bettervest is the first crowdfunding platform to focus exclusively on energy and energy efficiency projects, through an idea conceived in 2006 and executed in 2012 (bettervest, 2017). Though the company is based in Germany, funding energy development in Africa has been very popular on the platform—recent funded projects include solar home systems in Nigeria and Uganda, solar for water desalination in Kenya, and solar for rural electrification in Namibia (bettervest, 2017).

Lendahand

In 2016, Lendahand, based in the Netherlands, raised $650,000 in debt financing for its sixteen energy access campaigns (Cogan, et al., 2017). Lendahand's mission is to create new jobs in emerging countries and improve access to basic needs (Lendahand, 2018). Lendahand sets itself apart from other funding platforms by operating as an investment firm—only offering quality opportunities for investors, conducting due diligence on all of its borrowers, and taking the charge with marketing the projects to investors (Grinwis, 2018). So far, the impact investing platform has funded the installation for over 12,500 solar home systems (Lendahand, 2018).

5.3.2 Blockchain for Crowdfunding

While there are merits to traditional crowdfunding platforms, new companies are establishing innovative ways to raise funds by leveraging blockchain technology. One example of this is the South African company, The Sun Exchange (TSE).

TSE funds solar projects by breaking them down into single solar cells that investors worldwide buy and then rent to the customers who will benefit from the energy (Parker, 2017). These projects are located in emerging markets that are "solar-rich but power-poor," allowing investors to have the biggest impact for their dollar (Aitken, 2017). TSE employs blockchain technology in two ways: 1) tracking energy and earnings and 2) transferring the earnings internationally with low fees (Parker, 2017).

Generally, if you invest in a project but don't live in the country where it will be located, transferring money across borders is expensive and time-consuming (Aitken, 2017). To help make investing easier by reducing transaction costs, TSE accepts Bitcoin as a method of payment. This allows payments to be sent swiftly, securely, and at a low cost (Aitken, 2017). Investors without Bitcoin can still put money towards a TSE project, but they will miss out on some of the advantages of the cryptocurrency's blockchain platform. However, using Bitcoin doesn't necessarily make TSE unique—their tracking process is what sets them apart.

One major risk investors face is the uncertainty of how their money is being used (i.e. trusting the organization they've given money to). When funding a project you also want to ensure that there's a system in place to track the returns on your investment. TSE designed a blockchain-enabled system that does just this: tracking the ownership of each solar cell along with the energy and earnings they produce (Parker, 2017). Figure 13 gives an example for what the tracking system would show to an investor or renter, though they would also see the earnings in real time. These exchanges are tracked through TSE's blockchain, giving investors more certainty and confidence in the projects they invest in.

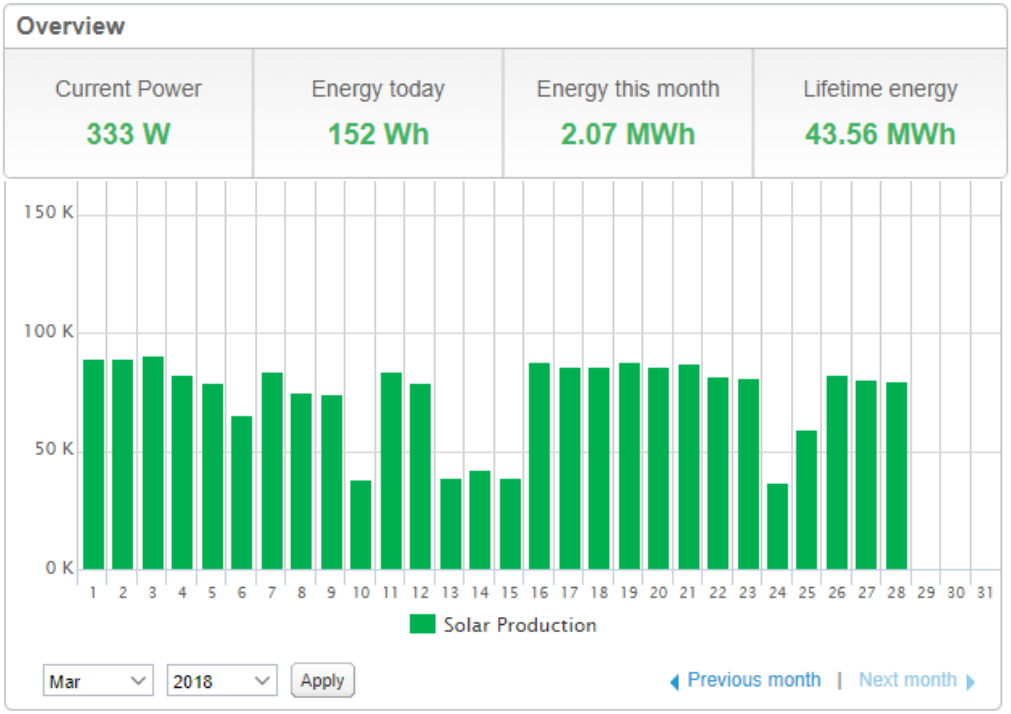

Figure 13: The Sun Echange SolarEdge dashboard, example from Waldorf School. Source: (The Sun Exchange, 2018).

TSE uses blockchain to eliminate some of the risks for investors looking to fund projects in developing countries, leveraging crowdfunding to raise the money necessary for solar projects to be financed. Since 2015, their business model has successfully funded five solar projects for South African businesses, ranging from 15kW to 60kW in size (The Sun Exchange, 2018).

Though TSE shows some of the ways blockchain can be used to assist crowdfunding, this would not be an easy thing for APS to replicate. APS would need to hire a blockchain expert to develop the technology, and the average income for a blockchain developer in 2017 was $150-200k (Petrashchuk, 2018). While this investment could increase APS's crowdfunding base it would also compete with the investment APS could put into other recommendations described here, such as obtaining the sensors that would allow for customer load monitoring for better system design. On top of this, APS would likely look to crowdfunding for commercial systems rather than residential ones due to the larger capital requirement for the commercial systems. This means that not all of APS's business endeavors would benefit from the crowdfunding capability, making the development of a blockchain platform to enable this even more unnecessary.

Rather than creating their own blockchain system, APS should consider partnering with more established companies like TSE for the crowdfunding of select projects. For larger commercial customers APS could contact TSE to make the projects more affordable, perhaps with a 50-50 ownership split between the APS customer and the TSE funders. This would allow TSE to continue expanding its operations throughout Africa with APS performing the due diligence for the projects. And, APS could make more of their projects bankable by having access to TSE's crowdfunding. Therefore, this could be a fruitful partnership for both companies.

6 Conclusion

Embracing the use of data can strengthen Aspire Power Solution's business operations by helping them optimize their system design, identify creditworthy customers, and obtain crowdfunding. In designing their solar-hybrid systems, APS can leverage hourly solar generation data and customer load profiles to optimize the size of the panels and battery for each system. To estimate a customer's ability to make payments, APS should consider their current expenses on diesel fuel or potentially partner with academic institutions to produce willingness-to-pay models. Finally, APS can partner with companies like The Sun Exchange to crowdfund projects.

While this analysis considered these main focus areas, there are other aspects of APS's business strategy that could be improved with more research. A few areas were identified with respect to the payment options for customers and how APS could make it easier for customers to meet their payments. One option to look into would be buying customer's existing diesel generators to resell or use them in future systems, with this capital potentially going towards the customer's down-payment for their system. This could make it easier for customers to make the initial investment in the solar-hybrid system by recognizing the money they had already spent to buy the original diesel generator(s) they had.

Another way to help finance the systems could come from selling the carbon credits the systems produce to corporate buyers or other entities. With the solar-hybrid systems replacing diesel generators and saving tons of CO_2 emissions annually, one can argue that these reductions could be partially funded through the sale of these carbon credits. Furthermore, APS could turn to the utility and see if they'd be interested in funding projects to meet customer demand. Since the expansion of the grid and the necessary increases in generation to meet existing and expected demand would be very expensive, the utility could see investment in or a partnership with APS as a cheaper way to meet customer's electricity needs. There could also be opportunities for the utility to pay for a larger system size that would allow energy to go to the grid rather than staying with the customer (essentially leasing the "excess" rooftop from the owner). This could again be cheaper than building new centralized generation plants.

Overall, this paper provides an overview of different ways in which APS can incorporate data as they grow to be a successful company that delivers cost-effective solutions to their customers. The three areas studied should be investigated even further, as each merits a specialized focus. Future papers can build off of this project to deliver specific strategies and guides for the implementation of data-based processes in APS's model. With this, APS can leverage data to provide the best customer experience and specialization that will outperform their competition. Given the large market need in Nigeria for reliable electricity, APS should be able to continue growing their operations and gaining experience that will prepare them to take on the off-grid market as well as expanding into other countries.

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