PAPER 16

Distributed Clean Energy: Advocating for Micro-grids as a Solution for South African Municipalities

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ABSTRACT

Reliable, clean energy is critical for sustainability today and sustainability into the future. While various leaders across the world grapple to meet greenhouse gas emission targets as well as 'keep the lights on, private industry is moving full steam ahead to find solutions to what is deemed an energy crisis for some countries such as South Africa. Steady, reliable, and cost-effective electricity production and supply is the backbone of any first-world country. It is hard to imagine how society would function without electricity, yet in this day there still exist communities located on the periphery of cities as well as remote areas with no connection to the transmission grid. In addition, the Eskom grid is under strain due to high demand and aging infrastructure and 'blackouts' have become a common daily occurrence. Considering the current constraints to generate reliable energy at a national level, it makes sense for municipalities to have the autonomy at a local level to explore and implement clean energy technologies as an affordable, reliable option to serving communities and businesses in their jurisdiction.

The reality is that there is an urgent drive across the globe to cleaner, more sustainable ways of generating electricity for various applications and renewable energy is now more prominent and prevalent in many countries. In addition, it has been seen globally that the traditional grid is ailing under increased demand from growing population and industry. There is a shift towards a decentralized way of generating and distributing electricity.

Micro-grids underpinned by advanced storage systems have been used extensively for various applications including serving large industries as well remote and rural communities. In addition, they act as a buffer for the municipality against loading shedding of the national grid, therefore, doing away with rolling blackouts in those areas. South Africa's energy crises together with the current recession create a perfect storm and exploring alternative ways of generating electricity from clean natural sources may be the immediate solution.

The global community including South Africa has acknowledged that greenhouse gas emissions are a contributor to the rapid changes to the natural environment as seen in the unusual occurrence of flooding in some parts of the world, drought in other parts.

The South African government recognizes the challenges faced by the existing national grid as well the commitment to Sustainable Development Goals and has updated the Integrated Resource Plan (IRP) to reflect the same. The latest update to the IRP (2019) sees a greater integration of renewable energy generation as well as an inclusion for energy storage technologies. In addition, the IRP (2019) gives Municipalities permission to consider alternative ways to generate electricity through the decentralized approach.

The shift to decentralized energy globally will increase significantly and with micro-grids underpinned by energy storage playing a very important role in this regard. This paper affirms that municipalities can depend on microgrids as a solution supply clean steady electricity to for key infrastructure such as water treatment and distribution thus building energy resilience.

1 INTRODUCTION

The existence of modern-day society highly depends on energy for electricity, heating, transportation, etc. Research shows that areas that have no electricity, lose out on better sanitation, health care, and education[1]. In South Africa, there are 2.2 million households still with no access to electricity[2]. And of these, 95% are classified in the low-income group, therefore not being able to afford the cost associated with connecting to the grid[3]. The South African government, through its Integrated Resource Plan (IRP, 2019) acknowledges that there are parts of the country that just don't have electricity and that a connection to the national grid would be costly, thus provision has been made for accelerated advancement of micro-grid deployment by municipalities.

It is proven that a reliable source of energy is essential for long-term population sustainability and economic advancement.

Climate Change has been the biggest contributor to extreme weather patterns thus negatively impacting the environment for humans and living organisms to thrive. The burning of fossil fuels for power generation has been identified as not sustainable and an emitter of carbon emissions.

Renewable energy has proven to be a strong alternative to fossil fuel energy. IRENA (International Renewable Energy Agency) highlights that Africa is 'endowed with substantial renewable energy resources, and is in a position to adopt innovative, sustainable technologies and play a leading role in global action to shape a sustainable energy future'[4].

South Africa is one of the 77 countries that has signed up to the Paris Agreement with an undertaking to significantly reduce carbon emissions by 2030. At a micro-level, municipalities have been given that mandate to explore and implement ways to improve energy resilience through clean energy technologies thus reducing reliance on fossil fuels for energy supply.

Microgrids powered by renewable energy technologies underpinned by battery storage has gained popularity as a proven implementable solution to providing clean energy to power various applications including residential areas. This paper seeks to demonstrate how micro-grids can assist municipalities to achieve energy security through self-generation and distribution and ultimately to support long-term development goals with a focus on optimizing battery storage.

2 THE MICROGRID

The function of the conventional national electrical grid is to transmit electricity using a network to meet end-user demands. The microgrid is also known as mini-grids operate similarly, although on a smaller scale. They are standalone isolated grids that can be connected to the national grid. Micro-grids are a collection of electricity generators, energy storage, consumption points connected to operate as a small grid as shown in Figure 1 and have proven to be reliable with transmitting low to medium voltage electricity generated by renewable energy sources such as solar PV, wind, etc.[5].

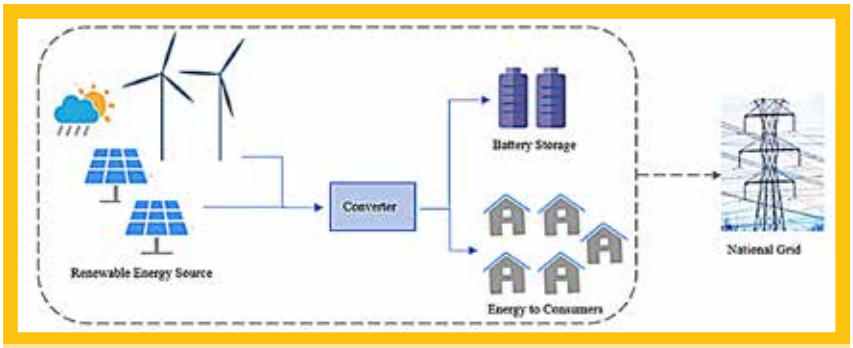

FIGURE 1: Typical Micro-grid from Renewable Energy Sources

According to ESMAP, there are '47 million people connected to 19,000 mini-grids, mostly hydro and diesel-powered, at an investment cost of $28 billion. Plus: 7,500 mini-grids planned, mostly in Africa, mostly solar-hybrid, connecting more than 27 million people[6]. Clean energy-powered microgrids can have proven to have a generation capacity from 10 kilowatts (kW) to over 100 megawatts (MW)[7].

Some examples of successful large-scale applications of the microgrid include the New York Affordable Housing Microgrid project, the powering the large commuter rail system of New Jersey as well as for strategic reasons, the powering the domestic military base for the United States of America[8].

Microgrids can act in alleviating strain on the national grid and compensate where there is a fault in the national grid which may result in a blackout or load shedding. The microgrid can be disconnected to continue operating without being affected by the fault on the national grid. Modern microgrids have unique characteristics in that they rely on clean energy generation sources and storage systems. They reduce energy consumption because of the level of controls afforded to a smaller network, as well as provide system security and flexibility[9].

3 A CASE FOR MICROGRIDS

South Africa which relies heavily on coal for energy generation, is currently faced with an energy crisis and rising cost of electricity, as the grid is under huge strain due to aging infrastructure, periodic breakdowns, lack of maintenance, and increased demand from a growing population. This has resulted in regular, rolling power blackouts (power outages), leaving parts of the country and municipalities in darkness regularly.

The energy crises have had a huge impact on the economy and have reduced the GDP growth by roughly 0.30% contributing to the further contraction of a struggling economy[10]. In addition, Municipalities have been crippled by the lack of energy supply to an area. This lack of stable electricity has had an impact on water purification and waste-water management.

Microgrids have achieved the fastest gains worldwide with deployment and have recently seen a rapid rise in popularity, by using 19 000 microgrids to provide electricity to 47 million people[11]. They are diverse in nature and size and can utilize fixed or variable speed wind turbines, solar panels, microturbines, various types of fuel cells, small hydro, and storage depending upon the load, location, and resources[12]. Microgrids have been in use in rural and remote areas for the past 20 years[13].

A microgrid very simply uses renewable energy sources for energy generation that can either be obtained via solar photovoltaic systems, wind turbines, hydropower, or biomass, or some hybrid of these which incorporates diesel. The choice of components of a microgrid (Figure 2) 'will depend on specific conditions related to location, energy source availability, density, and distribution of the houses to be served and electricity supply management[14]. The micro-grid is connected to the low to medium voltage distribution network allowing for the supply of reliable, quality electricity.

Microgrids make use of storage systems such as batteries to overcome variability and meet the demand for energy which occurs at clearly defined peaks to meet the electricity needs of the end consumer.

4 BATTERY STORAGE SYSTEMS

Energy storage which includes battery storage plays a critical function in a renewable energy microgrid in terms of making energy supply predictable and readily available on demand. Also, energy storage enhances the microgrid as well as providing a solution for operational issues such as power quality, dynamic stability, reliability, and controllability caused by renewable energy generators[15]. Further, it improves microgrid stability by acting as a buffer against renewable intermittency and mitigates load uncertainties. Therefore, for optimal performance of the overall microgrid, the most suitable battery storage system selected must be 'based on economical, technical, and environmental considerations[16].

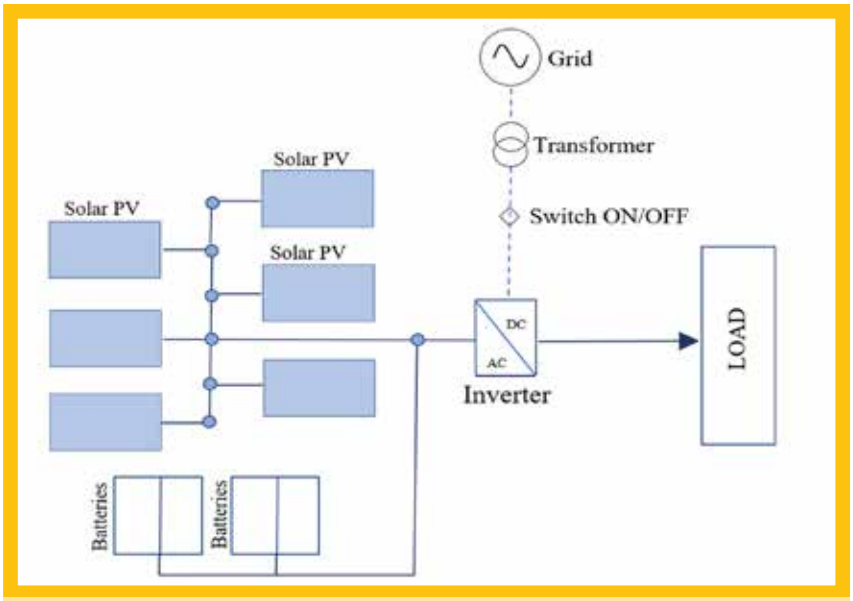

FIGURE 2: Typical Microgrid Components

Energy storage has gained vast attention especially with the increased deployment of renewable energy generation and is recognized as an essential component in clean energy supply and meeting carbon emission reduction targets. Also, energy storage has improved energy access and security, provide backup storage for peak times in the national grid thereby bringing stability to the grid.

Battery storage in microgrids currently exists in various systems and degrees of complexity depending on the microgrid application. These battery storage systems include Redox Flow batteries, Lead-acid, Li-ion, Nickel-Cadmium batteries, and Nickel Metal Hydride

batteries, with the Li-ion and Lead-acid battery having preference in the rural microgrid market. Research on energy demand at a household level has shown that energy consumption varies per user and as well as per household and that this variability introduces its challenges to understanding the dynamics of energy demand[17]. Therefore, the energy generated must be temporarily stored to cater to the variability of demand.

For the past two recent decades, battery storage has continued to grow taking strength from a growing wind and solar energy market. Storage has the potential to e deployment of renewable energy generation and is thus considered a key technology and key driver.

4.1 Battery Storage Systems in Micro-grids

Battery storage plays a significant role in micro-grid applications as well as off-grid application. The rise in demand for battery storage globally is due to the increase in deployment of distributed power. This is being driven by the reduction of overdependence on national power grids and another key driver is the implementation structural reform by governments such as the European Union, the United States of America and Japan issuing "relevant policies and support plans to promote the development of Microgrid projects" and also, China's Thirteenth Five Year Plan for Electricity Development incorporating Microgrids[18].

FIGURE 3: 10 MW Battery Installation, Texas US[19]

Battery storage systems is one of the most expensive items in the microgrid. And where financial resources are limited, cost plays a crucial role in deciding on the extent and scale of the microgrid installation. Therefore, to justify the investment and to obtain a return on the investment, it is essential to achieve optimum performance of the Battery Storage System (BSS) and indeed the microgrid, by minimizing any losses. Optimization requires an understanding of the behaviour of batteries under various operating conditions and exposure to variable temperatures as well as charging-discharging etc.[20], as these inform battery performance.

Typically, a microgrid comprises several battery storage units with each unit having a varying degree of output capacity depending on factors such as initial State of Charge (SOC), efficiency, aging (i.e., number of cycles), and temperature conditions [16]. Ideally, the BSS should function as a well-synchronized system. To be able to manage any differences between the various batteries, and to ensure stability, a Battery Management System (BMS) is necessary. Battery Management Systems can be basic whereby they are applied in simple microgrids or smarter BMS can be applied to large complex microgrids as they operate in real-time and control vital functions of the BSS[21]. The BMS provides information on the 'monitoring of temperatures, voltages, and currents, maintenance scheduling, battery performance optimization, failure prediction and/or prevention as well as battery data collection/ analysis'[21].

The function of battery optimisation must be considered as part of the overall microgrid design right from the onset to achieve maximum results from the storage system as well as from the overall ability of the microgrid to respond adequately to the energy demand.

For microgrid applications, there are some quick wins in terms of achieving optimisation of the battery. These include:

- on the ground optimizing incorporating the correct positioning of batteries, adequate ventilation, or insulation of the battery storage facility,
- fully trained resources to carry out repairs and maintenance,
- The quality and technology of the energy storage systems must be carefully selected and designed.

Studies shows battery storage worldwide growing from 2 gigawatts (GW) in 2017 to around 175 GW in 2030 and that costs will continue to fall as technology improves to provide longer lifetimes, increased numbers of cycles, and improved overall storage performance[22].

5 MICRO-GRID IN MUNICIPAL APPLICATIONS

Micro-grids offer autonomy from the main transmission grid. Because the Municipality will be involved in the design of the electrical infrastructure from the location and size of the micro-grid grid to the provision of the connection to the end-user. Also, any additional power that is not used can be pushed into the transmission grid and offset as savings to the municipality.

Some Municipalities bulk buy electricity from Eskom but are faced with revenue collection backlog leading to major financial losses for the Municipality. By adding a prepaid system at the consumer point, the Municipality obtains ownership of the electrical infrastructure and thus more control on how electricity is generated, distributed, and consumed.

With the prevalence of load shedding in South Africa, micro-grids, provide resilience against power outages or threats of destruction.

Micro-grids have proven to provide reliable and secure electricity to both rural and urban communities. And examples can be seen through applications in countries such as Indonesia, China, United States and in Africa.

FIGURE 4: St. Cloud Wastewater Treatment Facility, Minnesota, USA[23]

Municipalities can deploy micro-grids to the following applications.

TABLE 1: Micro-grid Applications	
Municipal Infrastructure	A grid-connected micro-grid network that provides power to municipal buildings that are nearby.
Urban Electrification	Micro-grids with battery storage give municipalities greater control on energy usage and thus cost savings.
Rural Electrification	As seen in rural parts of India, off-grid micro-grids have been successfully deployed. These micro-grids are managed by the locals who trade electricity.
Waste-Water Treatment Plants and Water Purification and Reticulation	These are severely impacted by load-shedding. A micro-grid is a cleaner and cheaper solution for generating energy for use only at the waste-water treatment plant. See Figure 2.
Back-Up Power to City or Town	Large-scale batteries are used worldwide to provide backup power to towns and parts of a city's operations.
Electric Bus Fleet	There is a shift worldwide for cities switching to electric buses as they are cleaner and cheaper to run. These buses can be charged by micro-grids.

6 CASE STUDIES

6.1 Electricity for African Communities: Tanzania

According to various literature, just under 40% of the population of Tanzania had access to electricity in 2017. Meaning that most of the population lived in underdeveloped areas requiring access to consistent, reliable electricity.

As a result, microgrids have become a key technology for deployment, and Tanzania is recognized as a regional leader in micro-grid deployment with over 100 micro-grid systems serving businesses and local communities[24]. Further[24], the adoption of micro-grid policy and framework in 2008 lead to the doubling of the number of micro-grids being deployed.

Micro-grids are either government-owned or owned by private developers selling electricity back into the national grid through power purchase agreements or sold directly to end consumers. Whilst Tanzania has been successful in the deployment of micro-grids, there have been challenges, one of which has been funding.

6.2 Power for Residents: Netherlands[25]

The first micro-grid installation in the Netherlands was at a holiday park in Bronsbergen, approximately 100 km west of Amsterdam. A micro-grid was built to provide 208 homes with solar-generated power of 315 kW. Micro-grid has 700 kWh energy storage to increase power quality and stability[26]. The micro-grid is connected to the national grid via a 10 kV line.

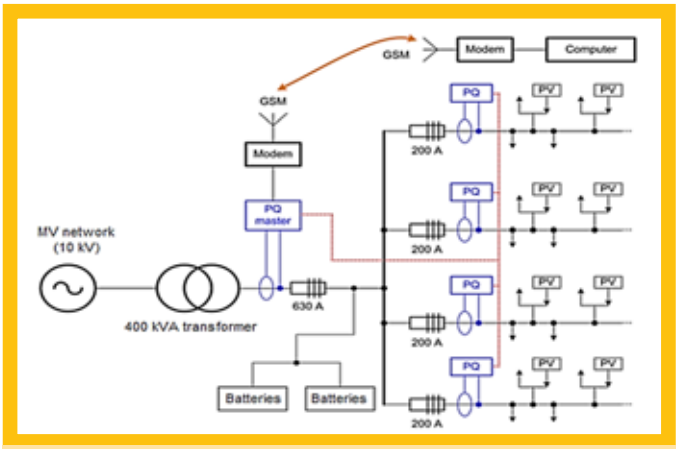

FIGURE 5: Residential Microgrid in Bronsbergen, Nederlands[25]

FIGURE 6: Residential Microgrid in Bronsbergen, Nederlands[25]

This pilot project highlighted the technical challenges of connecting to the national grid.

6.3 Clean Energy for Wastewater Treatment: California[27]

A proposed micro-grid project is underway for the wastewater facilities in McKinleyville Community Services District in California incorporating the existing diesel generators with solar PV and battery storage. The McKinleyville Community Services District (MCSD) serves 16 900 residents and provides key services such as providing clean water reticulation, wastewater processing, maintenance of parks, etc. The outcome of the project is a wastewater treatment facility that has a target of net-zero emissions. In addition, the micro-grid will provide the facility with energy resilience.

FIGURE 7: Hiller Park Wastewater Treatment Plant[27]

7 CONCLUSIONS

Ensuring a continuous reliable source of electricity is critical for the overall functioning and growth of a Municipality. Power supply has a direct impact on service delivery. And the lack of power for water reticulation or wastewater treatment can have catastrophic implications for a Municipality.

Microgrids are an attractive option for Municipalities for the many reasons listed in this document. In addition, they give municipalities greater control to improve energy efficiencies as well as options on how to deal with revenue collection due to their modularity and scalability.

The evaluation of microgrids does involve a significant degree of uncertainty and complexity which relates to two factors i.e. the design of the microgrid which considers, the scale of the energy source, the storage system, and the installation and maintenance of the system,

as well as including the long-term operation of the microgrid which involves the dispatch algorithms for storage and generation which are all interdependent[28]. Battery Storage is an essential part of the overall micro-grid system. The battery contributes to 20-30% of the overall capital cost over the lifespan of the microgrid, and therefore, understanding how the battery operates and optimizing its output and lifespan makes for a sustainable business case for investment in the microgrid.

There are many examples of successful deployment of micro-grids including opportunities for the lesson learned from which Municipalities can draw information and design a system that is fit for purpose. Funding mechanisms are available to support the deployment of micro-grids in Africa, However, the financial modelling must make a sound business case for lenders and investors.

The IRP 2019 identifies distributed generation and a key mechanism for bringing electricity to those areas that don't have electricity and it goes on to make provision for Municipalities in South Africa to investigate the deployment of micro-grid technology to bring electricity to the areas in which serve. New legislation in South Africa has now been published which allows for the generation of energy of up to 100 MW without license requirements provides an ideal opportunity for Municipalities to investigate developing micro-grids in their respective regions.

Ultimately in municipal deployment, the main aim is to produce clean electricity at the lowest cost through optimization.

8 RECOMMENDATIONS

There are many case studies worldwide of the successful deployment of micro-grids to meet municipal needs. They can assist municipalities to become energy generators for their consumption thus giving greater control.

Micro-grids could be the catalyst that can lead to the economic recovery and growth of a municipality. And therefore, should be considered in any strategic development plans for a municipality.

REFERENCES

[1] Y. Law, "www.scidev.net," Scidev, 31 January 2015. [Online]. Available: https://www.scidev.net/asia-pacific/energy/news/off-grid-power-systems-urged-for-rural-villages.html. [Accessed 25 February 2020].

[2] US Aid, "US Aid from the American People, South Africa Power Africa Fact Sheet," US Aid , 21 October 2019. [Online]. Available: https://www.usaid.gov/powerafrica/south-africa. [Accessed 04 February 2020].

[3] N. Jamal, "Options for the supply of electricity to rural homes in South Africa," *Journal of Energy in Southern Africa*, vol. 26, no. 3, 2015.

[4] International Renewable Energy Agency, "Scaling up Renewable Energy Deployment in Africa," IRENA, 2019.

[5] Asea Brown Boveri Ltd, "Introduction to Microgrids," ABB, 2020. [Online]. Available: https://new.abb.com/distributed-energy-microgrids/introduction-to-microgrids. [Accessed 23 February 2020].

[6] T. E. S. M. A. P. (ESMAP), "Mini Grids for Half a Billion People," The International Bank for Reconstruction and Development / THE WORLD BANK GROUP, Washington, 2019.

[7] IRENA, "Innovation Landscape Brief: Renewable Mini-grids," International Renewable Energy Agency, Abu Dhabi, 2019.

[8] E. J. Donahue, Microgrids: Applications, Solutions, Case Studies and Demonstrations, Intechopen, 2019.

[9] M. Liu et al., "Research on Unintentional Off Grid Characteristics of Microgrid," in 2nd IEEE Conference on Energy Internet and Energy System Integration, Beijing, 2018.

[10] Staff, "Business Tech," 12 December 2019. [Online]. Available: https://businesstech.co.za/news/energy/361772/how-much-money-eskom-load-shedding-has-wiped-off-the-economy/. [Accessed 11 March 2020].

[11] Energy Sector Management Assistance Program (ESMAP) *Technical Report 014/19*, "Mini Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers. Executive Summary," World Bank , Washington, 2019 .

[12] R. Ahshana et al., "Microgrid Reliability Evaluation Considering the Intermittency Effect of Renewable Energy Sources," *International Journal of Smart Grid and Clean Energy*, pp. 252-268, 2017.

[13] L. Brown, "Mini-grids: An Alternative to SHSS in South Africa," Sense and Sustainability, 19 September 2019. [Online]. Available: https://www.senseandsustainability.net/2019/09/19/mini-grids-an-alternative-to-shss-in-south-africa/. [Accessed 24 February 2020].

[14] Practical Action, "Micro-grids," *Appropriate Technology*, vol. 41, no. 4.

[15] Y. C. a. A. A. H. Nazaripouya, "Energy Storage in Microgrids: Challenges, Applications and Research Need," *International Journal of Energy and Smart Grid*, vol. 3, no. 2, 2018.

[16] D. Semënov et al., "A battery storage control scheme for AC microgrids," in 20th International Conference on Electrical Machines and Systems, Sydney, 2017.

[17] J. M. a. M. Hazas, "The significance of difference: Understanding variation in household energy consumption," *Energy Efficiency First: The Foundation of a low-Carbon Society*, pp. 2037-2046, 2011.

[18] Market Reports World, "Microgrid Market – 2019 Industry Trends, Size, Growth Insight, Share, Emerging Technologies, Share, Competitive, Regional, And Global Industry Forecast to 2024," Market Reports World, 6 June 2019. [Online]. Available: https://www.marketwatch.com/press-release/microgrid-market-2019-industry-trends-size-growth-insight-share-emerging-technologies-share-competitive-regional-and-global-industry-forecast-to-2024-2019-06-06. [Accessed 15 April 2020].

[19] r.-n. biz, "re-news biz," 10 April 2019. [Online]. Available: https://renews.biz/52602/powin-supplies-10mw-battery-in-texas/. [Accessed 19 August 2021].

[20] T. Blank et al., "Deep discharge behavior of lead-acid batteries and modeling of stationary battery energy storage systems," in Intelec, Scottsdale, 2012.

[21] A. Vezzini, "Lithium-Ion Battery Management," in Lithium-Ion Batteries: Advances and Applications., Elsevier, 2014, pp. 346-359.

[22] International Renewable Energy Agency, "Electricity storage and renewables: Costs and markets to 2030," IRENA, Abu Dhabi, 2017.

[23] C. Energy, n.d. [Online]. Available: https://www.clarke-energy.com/2017/st-cloud-duel-fuel-engine/. [Accessed 20 July 2021].

[24] W. R. Institute, "Accelerating Mini-Grid Deployment in Sub-Saharan Africa: Lessons from Tanzania," World Resources Institute, n.d.

[25] K.U. Leuven and T Loix, "altenergymag," 1 April 2009. [Online]. Available: https://www.altenergymag.com/article/2009/04/distributed-generationmicro-grids/565/. [Accessed 25 February 2020 2020].

[26] e-balance, "e-balance," [Online]. Available: http://ebalance-project.eu/project/demosites-overview/. [Accessed 19 August 2021].

[27] E. HOLBROOK, "Enviornment and Energy Leader," 11 March 2020. [Online]. Available: https://www.environmentalleader.com/2020/03/california-community-to-build-microgrid-at-its-wastewater-treatment-plant/. [Accessed 16 August 2021].

[28] E. Hittinger et al., "Evaluating the value of batteries in microgrid electricity systems using an improved Energy Systems Model," *Energy Conversion and Management*, vol. 89, pp. 458-472, 24 October 2015.