Optimization of Hybrid Renewable Energy Microgrid System with Considerations for Battery and Ammonia Energy Storage Systems

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Abstract
Due to the need for rural electrification, recent studies on the optimization of HRES has been conducted extensively to improve the planning process before microgrid implementation. Improvement in recent literature and practice have enabled new systems of storage to store energies as chemicals that would not be affected by the self-discharge rate, among others, of battery energy systems, albeit having its own disadvantages. Hence, this paper seeks to determine the applicability of an HRES system to consider these two types of storages and how a choice between the two can be made. With this goal, a mixed-integer linear programming model was formulated that aims to minimize the economic costs of an HRES microgrid implementation of a SPV/WTG/diesel system with battery and ammonia storage systems. The model would identify the number of each component to be installed as well as their sizes for SPV and WTG, being area and height, respectively. Since ammonia is a chemical that can be sold as fertilizer or fuel to bolster the economic viability of the system, the amount of energy needed to produce this chemical and to be sold was also determined. Moreover, the distribution of electricity from each source towards the demand loads would be determined to yield insights on the amount and proportion of energies generated, stored, and used throughout the planning horizon. Through this model, this paper has successfully formulated a model that provides decision support on several possible configurations of HRES microgrids to aid in its future developments.

Keywords
Microgrid, Hybrid Renewable Energy System (HRES), Solar Photovoltaic System (SPV), Wind Turbine Generator (WTG), Battery Energy Storage System (BESS)

1. Introduction

1.1. Rural Electrification
It is universally agreed that energy is essential towards the survival of society. Energy not only provides the means for production and transportation necessary to maintain living conditions, but it also enables the community to develop such that the technological benefits of modern medicine and societal improvement in household tasks and water quality can be enjoyed (Jiménez et al. 2017). However, due to energy production facilities being centralized, communities that are situated to be very far from these areas would incur large amounts of transmission costs due to the need for power line construction. Hence, access to sufficient energy to support daily activities and community improvement becomes a challenge for remote areas. Fortunately, technologies have been developed to circumvent the need for the energy supply of these places to be solely reliant on these centralized facilities. This type of system is known as a microgrid, which produces and supplies energy that is necessary for a smaller region. With this development, there have been several variations in the implementation of these systems. The energy production could

be from renewables such as solar, wind, hydro, or geothermal or from non-renewables such as coal, gas, or oil with the former often being the preferred energy production type. With this, there have likewise been innovations with the types of storage systems that these microgrids can employ in an effort to make these systems more viable.

1.2 Hybrid Renewable Energy Microgrid System

In recent years, providing sufficient electrical energy sources for remote areas continues to be a struggle for several countries seeking to develop rural communities due to the expensive costs of carrying energy through transmission lines despite technological breakthroughs on efficiencies of these related systems (REN21 2021). While the most recognized attitudes towards these systems recommend prioritizing renewable energies, with current technologies, microgrid systems powered solely by renewable sources are not possible in most areas, citing most evidently the inability of these systems to supply a consistent energy source. Hence, hybrid renewable energy systems (HRES) that utilize two or more renewable energy sources have been developed to alleviate the varying nature of energy production.

1.3 Problem Development

With the rise of HRES implementations, the implications of not having enough or having excess energy production facilities of each type can significantly affect the economic viability and community development of the affected area (Dawoud et al. 2018; Lian et al. 2019; Siddaiah & Saini 2016). Furthermore, the scheduling of which renewable energy source to use for production that would meet the load demands of the community would further the complexity of the decision-making methodologies (Lian et al. 2019; Mohammed et al. 2014). In addition to these complications, excess energies that are produced for the given day can be stored for use in future periods, which is another level of decision that the power distribution management should resolve (Dawoud et al. 2018). With these concerns, quantitative methods have been introduced to aid the difficulties of managing this system of interrelated parts. One of these techniques include linear/nonlinear programming that aims to determine the optimal configuration that would yield the best performance given a particular objective.

While much research has been done on the optimization of HRES as noted by the literature studies of Lian et al. (2019) and Mohammed et al. (2014), these papers also note that the objectives of most studies in the field are based on the economic benefits or costs of HRES implementation, which is also the primary objective of this paper. Storage systems have also been considered in this system as conventional battery systems can perform better or worse depending on the charge/discharge activities of a particular battery, which comprises the battery energy storage systems (BESS) (Chouhan et al. 2016; Dawoud et al. 2018). To aid limitations of conventional battery systems, technologies and studies have developed power-to-x methodologies such as renewable energy sources to ammonia as a storage medium that could be used as both fuel and as fertilizer (Palys et al. 2019).

1.4 Objective

Hence, the system shall determine the number of each type of renewable source to be selected while also identifying the amount to be stored and/or distributed to the communities with ammonia generation. The solution would likely change in that there would now be multiple ways the energy production would be smoothed, such that the overall storage capacity within the energy system can be reduced while also adding an alternative way to convert the given energy into another useful item in the form of fertilizers or fuel. With this said, the better solution outcome will be beneficial as microgrid system technologies are to be adopted by larger communities.

2. Literature Review

As the areas where these systems can be applied increase and the complexity of these systems increase to meet the increasing scale of service, there have been developments on the control of these systems. Some of these include the control of energy flow from the grid to corresponding loads through a central controller that directs the energy in a predetermined way with the possible inclusion of a monitoring software such as supervisory control and data acquisition (SCADA) (Olatomiwa et al. 2016). For standalone systems, energy management could be based on linear programming approaches where Matlab-Simulink algorithms were developed to determine the basis of when a battery should charge or discharge as well as when the fuel cell should supply energy to charge the battery depending on the state-of-charge of the battery in an attempt to optimize battery efficiency (Dursun & Kilic 2012). The research introduced an energy source that is independent from geographical locations or meteorological conditions in the form of a proton exchange membrane fuel cell (PEMFC) that acts as a backup energy source. Moreover, since it was shown for these lead-acid batteries to operate best at around 50 to 80% capacity, the study tested three strategies to determine when the batteries should charge or discharge to maintain this ideal level range and found that all three are shown to improve efficiency. Hence, the study contributes to allow an empirical energy management structure to improve battery efficiency. However, other considerations, most notably, economic costs, do not appear within their optimized strategy, and considerations for the sizing of power generation components were also absent.

Intelligent designs such as the fuzzy logic differential evolution algorithm was incorporated into a multi-objective programming problem that aims to minimize cost, unmet demand, and pollutant emissions while incorporating HRES with technical constraints on the optimal tilt angle and tower heights of wind turbines (Abedi et al. 2012). Aside from its multi-objective novel design, the study furthered the developments of holistic considerations in HRES design with predetermined optimal parameters of respective system components, but the parameters surrounding every additional system component to be installed was independent of the current desired number determined.

Vaccari et al. (2019) studies that apply linear programming approaches to grid-connected systems to generate an operation technique over a planning horizon to meet all load requirements to achieve minimum costs. The model was formulated with high accuracy of real technical processes that are occurring within the several types of energy sources such as solar energy, wind turbine, and biomass along with backup units for its system. As such, the formulation can be flexible to allow adjustable loads, batteries, and generators to be considered in its design. However, as costs are the only metric, the study may become more of an interest only by management that has little concern for other factors such as emissions and efficiency.

A novel algorithm using evolutionary approach was constructed to determine the operation management procedures of the micro-grid system as well as optimal battery sizing with consideration for the power capacity of the generators, energy capacity of the batteries, the charge and discharge efficiencies of the batteries, and the degree of satisfied load demand (Bahmani-Firouzi & Azizipanah-Abarghooee 2014). The objective of the paper was to minimize costs of a system that includes the above constraints, and through a comparison with other methodologies, it was observed that the novel method determined is superior against benchmark functions. Furthermore, their method appears to simultaneously lower costs by start-up and shut-down frequencies as well as charging and discharging frequencies of the batteries, which would increase the lifespan of these items. Similar to the previous study, the objective of this algorithm remains to be the economic considerations of implementing the system, which may not encompass considerations of other dimensions.

Zhang et al. (2021) developed a multi-criteria decision system that evaluates and selects the best RES mix for a microgrid. This method first identifies a set of renewable energy mix alternatives, so that the corresponding performance values that indicate the extent of each benefit or objective can be evaluated. To determine a common basis for comparison, the weights would be transformed so that net superiority values of each alternative can be determined. Using these metrics, the best among the different options can then be determined. Instead of the traditional linear or nonlinear programming approaches, this study determines its potential solution space and methodically selects the next best candidate RES mix for evaluation of its performance metrics. As such, this study provides an interesting perspective on how the selection of sources can be conducted, but its nature similar to an iterative branch-and-bound procedure hinders its widespread application due to the complexities that come with following all the necessary steps for every alternative that is being considered.

As it can be observed, there are a plethora of ways to determine optimal configuration of establishing microgrids as well as the optimal assignment of energy from the energy source to the energy storage before finally reaching the households. In addition, different elements in the system have been considered through various literature including the use of different energy production and storage types, the inclusion of different metrics of performance or parameters, and the consideration for various objectives and its subcomponents. Hence, this paper seeks to broaden that perspective through its endeavors in this paper.

3. Methods

This paper constructed a linear programming model that simulates the implementation of HRES in a given community, pursuing the main objective of minimizing economic costs. The energy production facilities considered solar photovoltaic systems (SPVs), wind turbine generation (WTG), and diesel engine generation, with the first two being renewable energies. Moreover, the storage systems to be considered are the battery energy storage and the ammonia storage systems. To determine the validity of the model, parameters were hypothetically assigned for simulated results to be retrieved. The model itself was coded through the General Algebraic Modeling Software (GAMS) with the results ran using the NEOS server. With this model, this paper seeks to draw insights that would be beneficial for microgrid implementation.

4. Model Formulation

4.1 Model Nomenclature

This section determines the set of symbols or phrases that would form the basis of the model.

Table 1. Indices

Indices		
i	Types of energy production	[1, I]
j(i), k(i)	Production locations for type i	[1, J]
r	Types of storage systems	[1, R]
s(r)	Storage sites available	[1, S]
d	Households to be serviced	[1, D]
t	Time periods	[1, T]

Table 2. Scalars

Scalars	
I	*Total Number of Energy Production Types*
J	*Total Number of Locations Available for Each Production Type*
R	*Total Number of Storage Types*
S	*Total Number of Storage Locations for Each Storage Type*
D	*Total Number of Demand Points*
T	*Total Number of Time Periods*
M	*Very Large Number*

Table 3. Binary Decision Variables

Binary Decision Variables	
$ProdSite_{ij}$	1 if production type i was set up at location j 0, otherwise
$StorSite_{rs}$	1 if storage type r was set up for storage site s 0, otherwise
$Spec_{ij}$	Alias for 1 if production type i was set up at location j 0, otherwise

Table 4. Nonnegative Decision Variables

Nonnegative Decision Variables	
P_{ijt}	*kW of power that can be produced for type i at location j during time t*
$SPVAreaUsed_j$	*SPV area built at location j*
$WTGHeight_j$	*Height of windmill at location j*
$FuelUsed_{jt}$	*Fuel used at location j at time t*
$AmmoniaSold_t$	*Ammonia sold at time t*
$EneGen_{ijrst}$	*kWh of energy produced for type i at location j for storage type r for device s at time t*
$StoToDem_{sdt}$	*Energy from storage device s to household d at time t*

Table 5. Parameters

Parameters	
$CProd_{ij}$	Cost per establishment of production type i at location j
$CStor_{rs}$	Cost per establishment of storage type r device s
$CSPVArea_j$	Cost per area in m^2 for SPV
$CWTGHeight_j$	Cost per m height for WTG
$CFuel_t$	Cost per liter of fuel used for diesel generation
$PAmmonia$	Profit per kg of ammonia sold
$EnviPenalty$	Environmental penalty per liter of fuel
σ	Self-discharge rate of batteries
μ_{inv}	Inverter efficiency
μ_{bat}	Battery efficiency
$AmmoniaEff$	Ammonia conversion efficiency
DOD	Battery depth of discharge
$DemEne_{dt}$	kWh of energy needed for each household d at time t
$StorMax_{rs}$	Storage upper limit of energy for storage type r of device s
$StorMin_{rs}$	Storage lower limit of energy for storage type r of device s
Ib_{jt}	Normal radiation
Rsh_{jt}	Parallel resistance availability
Id_{jt}	Diffuse solar irradiation
Rd_{jt}	Tilt diffuse
Rr_{jt}	Tilt factors
$SPVAreaAvail_j$	Available area for location for SPV at each location j
$HAvail_i$	Total operation hours available for production type i
$vref_k$	km/hr of windspeed at reference height
h_k	meters of height used for the reference speed
α	power-law exponent
$WTGA$	power Characteristic
$WTGB$	power Characteristic
$WTGC$	WTG power Characteristic
V_{in}	Cut-out wind speed
V_r	Rated wind speed
$LinV_j$	Linearization coefficient for wind speed
$LinCV_{jt}$	Linearization constant for wind speed
$LinP_j$	Linearization coefficient for power
$LinCP_{jt}$	Linearization constant for power
Pr_{jt}	Rated power of windmill for location j during time t
$DieselA$	Liter per hour fuel consumption
$DieselB$	Liters per kWh relating fuel and power
$AmmoniaDem_t$	Demand for ammonia at time t
$HUsed$	Hours used for diesel generation

Table 6. Objective Functions and Performance Metrics

Objective Functions	
$EconObj$	Economic Objective
$EnviPerf$	Environmental Performance Metric
$SocialPerf$	Social/Development Performance Metric

Table 7. Objective Functions and Performance Metrics

System Variables	
$SetupCost$	Total costs in establishment of energy production facilities and storage devices
$FuelCost$	Total costs of fuel used to power diesel generator
$AmmoniaProfit$	Profit from selling ammonia
$Stor_{rst}$	kWh energy stored in storage type r for device s at time t
It_{jt}	Irradiation at location j during time t
v_{jt}	Windspeed of location j during time t

4.2. Objective

The main objective of this model would be to minimize the economic objective, which is simply the sum of the setup cost and the fuel cost deducted by the profit to be earned from the ammonia as shown in equation 1. Equation 2 shows the components of the setup costs which includes the summation of the production site selections, the storage site selections, the area used for SPV construction, and the heights of the WTG construction. For fuel costs, this is simply computed by the amount of fuel used and the cost of using such fuel as shown in equation 3. Lastly, for the profit on ammonia, it is simply the product of the profit per ammonia to be sold and the amount of ammonia sold.

$$EconObj = SetupCost + FuelCost - AmmoniaProfit \quad (1)$$

$$SetupCost = \sum_{i=1}^{I}\sum_{j=1}^{J}\left(CProd_{ij} * ProdSite_{ij}\right) + \sum_{s=1}^{S}(CStor_s * StorSite_s)$$
$$+ \sum_{j=1}^{J}\left(CSPVArea_j * SPVAreaUsed_j\right) + \sum_{j=1}^{J}\left(CWTGHeight_j * WTGHeight_j\right) \quad (2)$$

$$FuelCost = \sum_{j=1}^{J}\sum_{t=1}^{T}(CFuel_t * FuelUsed_{jt}) \quad (3)$$

$$AmmoniaProfit = \sum_{t=1}^{T}(PAmmonia * AmmoniaSold_t) \quad (4)$$

4.3 Performance Metrics

As mentioned, the objectives that were considered in past literature have given much emphasis on the economic implications of implementing microgrid systems. Hence, this study aims to include analyses that consider the environmental and social objectives of such an implementation, which can be observed in equations 5 and 6, respectively. For the environmental objective, it is the environmental penalty multiplied to the amount of fuel used while for the social objective, it is the summation of power that could be generated by the system. Rather than setting these as objectives in a goal programming approach, these shall be considered as performance metrics, which can be analyzed simultaneously with the existing economic objective to observe their relationships amongst each other.

$$EnviPerf = \sum_{j=1}^{J}\sum_{t=1}^{T}(EnviPenalty * FuelUsed) \quad (5)$$

$$SocialPerf = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{t=1}^{T}(Power_{ijt}) \quad (6)$$

4.4 Constraints

4.4.1. General Energy Storage Systems

To start with the constraints, the general energy storage systems are as follows with equations 7 and 9 describing the initialized and the subsequent states of battery energy systems while equations 8 and 10 would be those of the ammonia storage systems. Equation 7 initializes the amount of energy required for initialization of each storage. Equation 8 ensures that ammonia can be produced and sold during the initialization time period. Equation 9 ensures that a self-discharge ratio of batteries in addition to the previous state of charge and subtracted by the amount of output during the time period would be equivalent. Finally, equation 10 shows that the amount of storage for the subsequent periods should be equal to the previous period added by what is generated and subtracted by what is sold. From this, the difference between the battery energy system and the ammonia storage system is that the battery energy system incurs a self-discharge ratio in addition to the different approach towards battery and inverter efficiencies.

$$\sum_{i=1}^{I}\sum_{j=1}^{J} EneGen_{ij,(r=1),st} * \mu_{bat} = Stor_{(r=1),st} \quad \forall r,s,t : t = 1 \quad (7)$$
$$\sum_{i=1}^{I}\sum_{j=1}^{J} EneGen_{ij,(r=2),st} * AmmoniaEff - AmmoniaSold_t = Stor_{(r=2),st} \quad (8)$$
$$Stor_{(r=1),st} = Stor_{(r=1),s(t-1)} * (1-\sigma) + \left(\sum_{i=1}^{I}\sum_{j=1}^{J} EneGen_{ij,(r=1),st} - \sum_{d=1}^{D}\frac{StorToDem_{(r=1),sdt}}{\mu_{inv}}\right) * \mu_{bat} \; \forall s,t : t > 1 \quad (9)$$
$$Stor_{(r=2),st} = Stor_{(r=2),s\,(t-1)} + \sum_{i=1}^{I}\sum_{j=1}^{J} EneGen_{ij,(r=2),st} * AmmoniaEff - \sum_{d=1}^{D} StorToDem_{(r=2),sdt} - AmmoniaSold_t \; \forall s,t : t > 1 \quad (10)$$

Battery Energy Storage Systems
In addition to the initialization and subsequent constraints involved in both storage systems, the following shows the storage constraints specific to battery storages. Equation 11 requires the storage to be within the maximum limit. Equation 12 ensures that the minimum limit is defined by the amount of depth of discharge. Equation 13 ensures that storage would be used only if the given storage site is established. Equation 14 ensures that the amount of energy delivered to each household cannot exceed the given storage amount.

$$Stor_{(r=1),st} \leq StorMax_{(r=1),s} \quad \forall s,t \quad (11)$$
$$StorMin_{(r=1),s} = (1-DOD) * StorMax_{(r=1),s} \quad \forall s,t \quad (12)$$
$$Stor_{(r=1),st} \geq StorMin_{(r=1),s} * StorSite_{(r=1),s} \quad \forall s,t \quad (13)$$
$$\sum_{d=1}^{D} StorToDem_{rsdt} \leq Stor_{rst} \quad \forall r,s,t \quad (14)$$

Establishing Site Constraints
Since the model also considers the establishment of energy production and storage facilities as its setup costs, equations 15 and 16 show that respectively.

$$\sum_{r=1}^{R}\sum_{s=1}^{S}\sum_{t=1}^{T} EneGen_{ijrst} \leq M * ProdSite_{ij} \quad \forall i,j \quad (15)$$
$$\sum_{t=1}^{T} Stor_{rst} \leq M * StorSite_s \quad \forall r,s \quad (16)$$

Site Limit Constraints
Equations 17 and 18 limits the number of production sites and storage sites available for establishment, respectively.

$$\sum_{j=1}^{J>ProdLim_i} ProdSite_{ij} = 0 \quad \forall i \quad (17)$$
$$\sum_{s=1}^{S>StorLim_r} StorSite_{rs} = 0 \quad \forall r \quad (18)$$

Demand Requirements
The demand would have to be satisfied through the various energy delivered from the storages to each household as shown by equation 19. Equation 20 simply limits the amount of ammonia that is in demand by the community. It should be noted that while the energy can be stored in the traditional battery or the ammonia storage, only the traditional battery can satisfy the needs of the demand locations.

$$\sum_{s=1}^{S} StorToDem_{(r=1),sdt} \geq DemEne_{dt} \quad \forall d,t \quad (19)$$
$$AmmoniaSold_t \leq AmmoniaDemand_t \quad \forall t \quad (20)$$

General Power Constraints
The following shows the constraints needed for power considerations. For equation 21, this simply enables the left hand side to be limited by the right hand side, so that the left hand side would become the binary variable to be used for the equation and inequality manipulations in the succeeding sections that mainly concerns power generation. Equation 22 allows power to be generated and distributed only when a given site is established. Equation 23 only allows the maximum energy that can be generated to be limited by the product of the amount of power and the number of hours of operation of the given renewable energy source.

$$Spec_{ij} \leq ProdSite_{ij} \qquad \forall i,j \qquad (21)$$
$$\sum_{t=1}^{T} P_{ijt} \leq M * Spec_{ij} \qquad \forall i,j \qquad (22)$$
$$\sum_{r=1}^{R} \sum_{s=1}^{S} EneGen_{ijrst} \leq P_{ijt} * HAvail_i \qquad \forall i,j,t\ : i \neq diesel \quad (23)$$

SPV Constraints

The following constraints concerns the power and energy related to the SPV device. For equation 24, this simply determines the amount of irradiance for the given period at a particular site. The power should then be limited by this irradiance and the area used for SPV production at the given site in equation 25. Equation 26 was used to limit the area to be used for SPV production to be limited by the area available at the site and to be only available when a production site is established.

$$It_{jt} = Ib_{jt} * Rsh_{jt} + Id_{jt} * Rd_{jt} + \left(Ib_{jt} + Id_{jt}\right) * Rr_{jt} \qquad \forall j,t \qquad (24)$$
$$P_{(i=SPV),jt} \leq It_{jt} * SPVAreaUsed_j \qquad \forall j,t \qquad (25)$$
$$SPVAreaUsed_j \leq SPVAreaAvail_j * Spec_{(i=SPV),j} \qquad \forall j \qquad (26)$$

WTG Constraints

The following are the constraints that concerns the WTG generation. Equation 27 shows the windspeed computation given the reference heights and the reference windspeeds at each location. However, since this is nonlinear, equation 28 linearizes this equation to avoid nonlinearity.

$$v_{jt} = vref_{kt} \left(\frac{h_{jt}}{h_{kt}}\right)^{\alpha} \qquad (27)$$
$$v_{jt} = LinV_j * h_{jt} + LinCV_{jt} \qquad \forall j,t \quad (28)$$

The following shows the power generated by the WTG at different windspeeds. When the actual windspeed falls below the cut-in windspeed, the power that can be generated falls to zero as shown by equation 29. Equation 30 shows that when the actual windspeed is between the cut-in and the rated windspeeds, the power generated can be described by the quadratic equation in equation 30. When the actual windspeed exceeds the rated windspeed, however, the power that could be generated should only be equal to the rated power of the device as shown in equation 31. It can be observed that these three equations are built with conditional statements, which can be converted into constraints that can be solved by the linear programming model by equations 32 and 33. It should further be noted that equation 30 is nonlinear, which is solved by the linearization method employed by equation 32.

When $v_j \leq V_{in}$,

$$P_{WTG} = 0 \qquad (29)$$

When $v_j > V_{in}\ and\ v_j \leq V_r$,

$$P_{WTG} = WTGA + WTGB + WTGC * v^2 \qquad (30)$$

When $v_j > V_r$,

$$P_{WTG} = \text{Pr} \qquad (31)$$
$$P_{(i=WTG),jt} \leq LinP_j * v_{jt} + LinCP_{jt} \qquad \forall j,t \qquad (32)$$
$$P_{(i=WTG),jt} \leq Pr_{jt} * Spec_{(i=WTG),j} \qquad \forall j,t \qquad (33)$$

Diesel Generator Constraints

Lastly, the following constraints show the diesel generation constraints with equation 34 determining the amount of fuel used per power available and equation 35 determining the energy generated to be limited by the product of the power and the number of hours used.

$$FuelUsed_{jt} \geq DieselA + DieselB * Power_{(i=Diesel),jt} - M * (1 - Spec_{(i=Diesel),jt}) \qquad \forall j,t \qquad (34)$$
$$\sum_{r=1}^{R} \sum_{s=1}^{S} EneGen_{(i=diesel),jrst} \leq P_{(i=diesel),jt} * HUsed \qquad \forall j,t \qquad (35)$$

5. Results and Discussion

5.1 Numerical Results

Using the hypothetical data, the following are the decisions on the establishment of the energy production facilities and the storage devices. It can be observed that only one of the SPV locations were chosen for production and only two for WTG locations. None of the diesel generation locations have been selected, which may imply that the system generally favors renewable energy sources for energy production. For electrical battery systems, all three battery systems were selected, which allows the storage of energies from one period to the next. For the ammonia storage systems, it appears that there is no need for the inclusion of ammonia storages for the next periods as ammonia is always satisfied and sold during the given period.

Table 8. Decisions on Establishment of Production Facilities and Storage Devices

Location\Type	SPV	WTG	Diesel	Battery	Ammonia
1	Not Built	Not Built	Not Equipped	Built	Not Built
2	Built - 2 m^2	Built - 64 m	Not Equipped	Built	Not Built
3	Not Built	Built - 35.096 m	Not Equipped	Built	Not Built
4	Not Available	Not Available	Not Equipped	Not Available	Not Built
5	Not Available	Not Available	Not Equipped	Not Available	Not Available

5.2 Graphical Results

Since the specifications and establishment of the different facilities have been determined, the model further determined the total amount of energy to be produced by each energy generation facility to meet the demands of the system. Using their energy generation information, the following distribution has been determined. It appears that the solar power generation requires the most amount of energy at 38% while the two other wind turbine generation systems were equally at second place with 31% each.

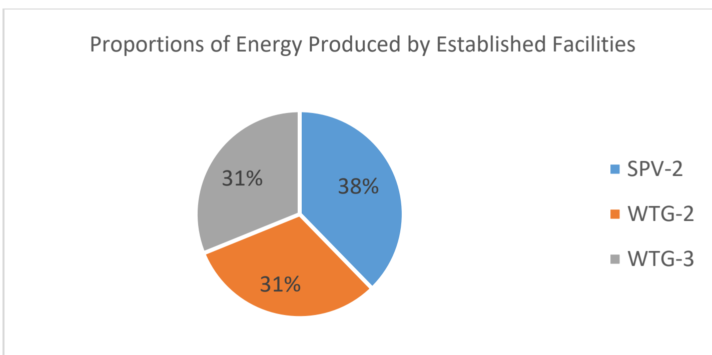

Figure 1. Total Energies Produced by Each Energy Source

Further investigation of the energies produced through time reveals that this total amount varies, with the proportion of energies produced by each selected facilities fluctuating throughout the time period and not necessarily reflecting the total amount of energy demanded.

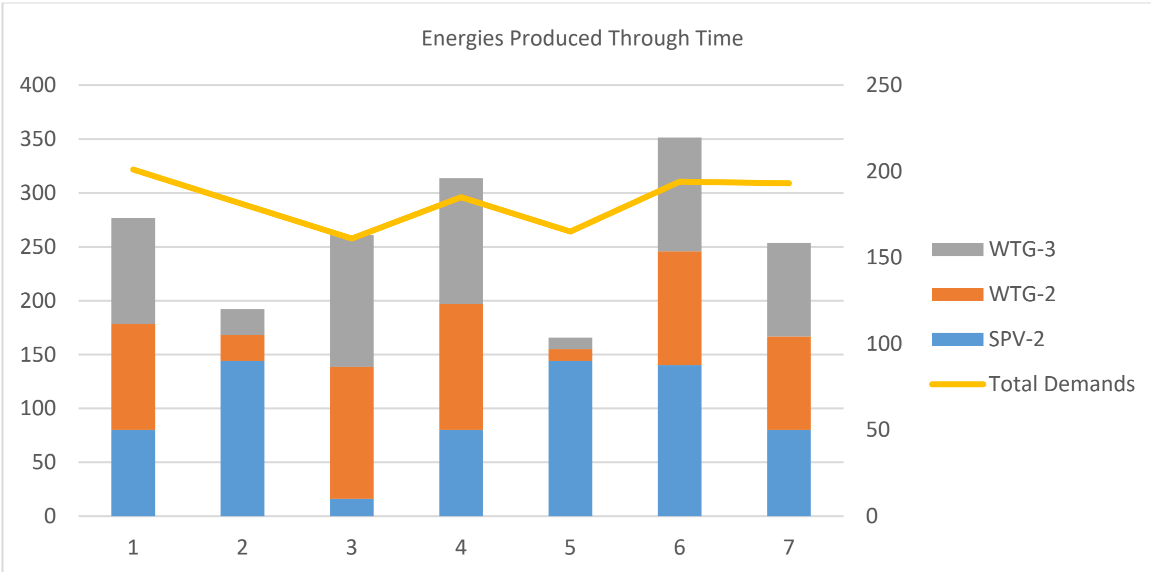

Figure 2. Energies Produced Through Time in Relation to Total Demands For Each Time Period

Further investigation by adjusting the total amount of energies that can be produced to reflect the percentages of each energy source as contribution to the total amount of energies at each time period. It can be observed that the proportions of the energies vary largely through the time periods, which means that the proportion of energies that were generated is not intuitive for microgrid planner.

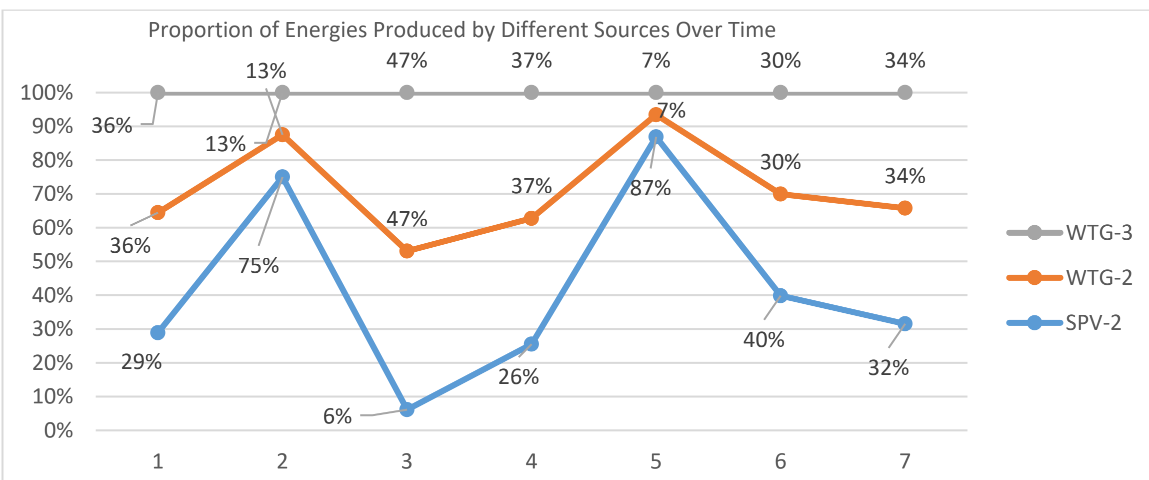

Figure 3. Proportion of Energies Produced Through Time

After consideration of the proportion of energies produced by each source, the energies of each would be delivered and stored to one of the three batteries, which are shown below. It can be observed that most of the energies produced were stored and directed to battery 1. However, this may only be the model prioritizing the storage of energies on the first battery item that can be used rather than the fact that it has special qualities. Hence, the model could be further enhanced in future iterations to include factors that may influence the use of batteries.

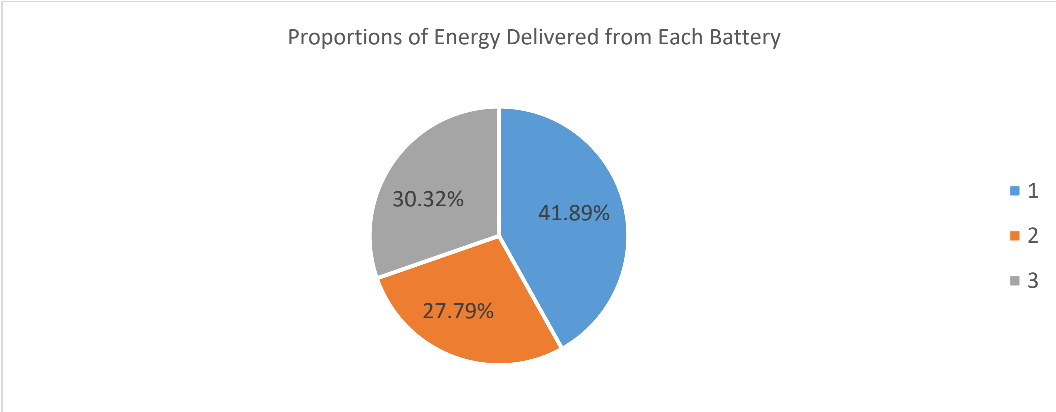

Figure 4. Percent Contribution of Energies Delivered from Each Battery

From these proportions, it can be determined that the following shows how the energies of each battery were distributed to each demand point. Likewise, future improvements on analysis could be conducted based on certain qualities of demand points and deliveries such as having delivery charges costing differently for each demand point being considered.

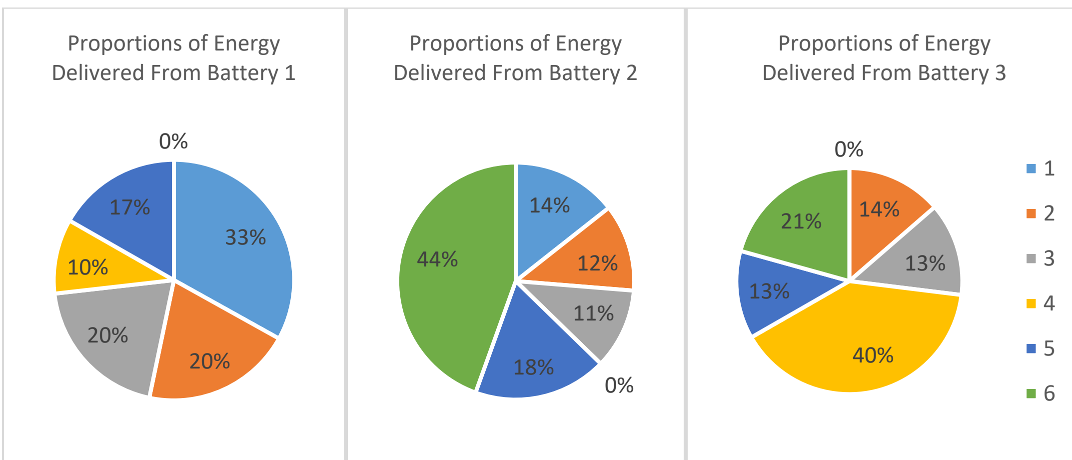

Figure 5. Energies Delivered from Each Battery for Different Demand Points

6. Conclusion

Ultimately, through this endeavor, the study is believed to have successfully formulated and analyzed a hybrid renewable microgrid system using linear programming. It can be observed that the results are not intuitive for the microgrid planner, and quantitative methods like the one used in this paper can ease the problem of production and distribution of energies from the source to storage devices up until their respective demand points. Furthermore, by having considered newer technologies such as the ammonia storage system in its design, this paper has provided room for ideas on future microgrid implementation.

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