Design of a Peer to Business Energy Trading System

Technical Report

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The gap is the ability to use potential excess solar PV energy production and avoid wasted energy produced during daylight hours from residential users to offset peak demand of industrial users to stabilize cost in overall electrical energy costs over time.

Win-Win Analysis: Lower all regulatory restrictions for residential solar PV systems collectively to trade with an industrial user, favorably renewable energy solar market on peer-to-peer energy trading, and continual use of passive renewable energy from residential users to eliminate unutilized wasted solar energy.
Context Analysis

The Commonwealth of Virginia residential and commercial electrical energy prices have been historically rising at a rate of 2.4% and 1.4% respectively since 1990. Residential prices have risen from $0.0725 in 1990 to $0.12 in 2015, while solar energy prices went from $0.13 in 2009 to $0.613 in 2015 [1]. The cost of solar PV panels has steadily declined over the past few decades, with prices dropping by 60% just between 2008 and 2014 [4], and projections for solar PV generation prices to fall below $1 per watt by 2020 [5]. According the Department of Energy’s Solar Energy Technologies Program, with potential breakthroughs in solar technology, the cost of solar energy is projected to reduce and level off at $.06 per kWh through 2030 [5].

Electrical energy demand presents a serious challenge for Commonwealth of Virginia and the nation, but renewable solar PV system energy prices dropped from since the late 1970s from $76.00 per Watt to less than $0.613 cents per Watt in 2015. With the inclusion of federal, state, and local tax incentives across the US, cheap renewable solar energy is an affordable option for residential single-family homeowners to stabilize monthly increase in their utility energy bills each month [2]. The increase in monthly utility energy bills varies, in some cases, depending on the time of year, seasonal weather changes, energy appliance loads, and daily energy consumption loads. What appears consistent with examining historical residential data is energy consumption typically follows a pattern of use from a gradual rise in energy consumption in the early morning hours, plateaus between 9am to 3pm, and rise again from 4pm to 10pm in the evenings taking on a normal business day pattern or otherwise a “bathtub” pattern of energy use. Depending on geographical location and available solar radiation, solar PV system generate renewable solar energy during the early morning hours, midday hours with peak intakes, and steadily declines in the late afternoon hours where the traditional electrical grid has peak customer demand. Once renewable solar energy generation reaches the maximum capacity during midday hours and cannot be stored any longer in the battery storage, the remaining solar energy is wasted into the ground. The phenomenon known as the “duck curve” in which, over-generating renewable solar energy is gone to waste due to the storage limitations during the daylight hours when solar radiation is the most abundant and the “ramp” when peak demand is at its highest point from the grid. Figure 1 describes this overgeneration risk over time from 2012 to 2020 resulting in potential opportunities needed to store this renewable energy when it is
required the most during peak demand in the late evening hours between 3pm and 9pm [4]. Although the larger issue with overgeneration risk from Figure 1 from the steep increase in customer peak demand may require better battery storage technology level off energy surge during evening hours, renewable solar energy produced beyond battery capacity during peak daylight hours could serve as a viable option to meet a potential industrial user with consistent daily energy demand.

![Duck Curve](image.png)

*Figure 1 Duck Curve - Overgeneration Risk*

Therefore, one solution is to utilize the excess energy to offset industrial peak demands based on historical data from George Mason University. The development of a system to bridge the gap between overgeneration and the high-energy consumption of an industrial user provides an opportunity to utilize a source of energy when it is needed during peak demand hours. **Figure 2** represents the renewable solar energy produced by residential users going to waste as result of overgeneration (marked by yellow shade); which, may offset the peak demand of industrial users with the use of the P2B energy trading system.
Seasonal shifts in residential demand coupled with inconsistent reliability within an aging electrical infrastructure with advanced in solar PV systems lower the barriers of upfront costs appears to shifted residential users towards consideration of P2B energy trading as an option to lower the monthly energy bill changes and improve reliability with the greater energy independence with the installation of a microgrid system [5]. A microgrid is “a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode.” [9]. Microgrids, depending on the type, generally have five functions: Energy Management, Protection and Control, Resiliency, Ancillary Services, and Data Management and listed in Figure 3 [9]. The project will focus primarily in the energy management function with the model replicate PV load forecast for residential and industrial users. Our research in analyzing the behavior of the model should provide a prediction solar generation and use of any potential excess solar production.
Figure 3 Microgrid Functions

Introduction

The Commonwealth of Virginia residential and commercial electrical energy prices have been historically rising at a rate of 2.4% and 1.4% respectively since 1990. Virginia also consumes 60% more than it generates in electricity power—meaning it 60% dependent on regional states across

Figure 4 VA total energy supply
an aging electric network infrastructure to meet consumer demand. The graph on the left is Virginia Electrical Supply from 1990 to 2015. [2] In figure 2, the top blue line represents the total electrical supply annually and the red line is net electrical supply. The gap between is the difference in what VA generates and what it imports in electrical supply from the regional states. The trends are expected to continue the same upward trend potential causing further seasonal shifts. The graph on the right represents the three user groups in cents per kWh: residential (blue), commercial (orange) and industrial users (gray) since 1990. Residential prices have gone from $.725 cents in 1990 to $.12 cents in 2015. The center graphs are solar energy prices from 2009 to 2015 costs as they have dropped from $.13 to $.06. So, electric energy demand present serious challenges for state and the nation and cheap solar energy may be a potential option to stabilize seasonal shifts. [2]

One of the biggest challenges is with the aging traditional energy transmission and distribution network with thousands of independent network operators providing decentralized power to retailers and end users to maintain the peak demand of the enterprise. According to the American Society of Civil Engineers (ASCE) 2017 Infrastructure Report Card, “Energy infrastructure is undergoing increased investment to ensure long-term capacity and sustainability; in 2015, 40% of additional power generation came from natural gas and renewable systems. Without greater attention to aging equipment, capacity bottlenecks, and increased demand, as well as increasing storm and climate impacts, Americans will likely experience longer and more frequent power interruptions.” [3] The electric infrastructure grid is subject to an “aging and complex patchwork system” of transmission and distribution grids, distribution lines and substations operated or owned by investor or public utility companies or independent power producers. [3] Due to the
age and condition of the US electrical infrastructure, it’s more vulnerable to disruptions from severe weather events, cyber-attacks, or vandalism. In 2015, the US reported 3,571 total power outages averaging a duration of 49 minutes. [3] The United States experiences more blackouts each year than other developed countries where the electrical grid loses power 285 percent more frequently than in 1984 resulting in tens of billions of dollars in losses on American businesses each year. [4] The International Energy Agency (IEA) states that the electrical grid infrastructure requires up to $2.1 trillion of new investment by 2035. [4] According to the International Business Times, “the power grid, which could be considered the largest machine on earth was built after World War II from designs dating back to Thomas Edison, using technology that primarily dates to the ‘60s and ‘70s. Its 7,00 power plants are connected by power lines that combined total more than 5 million miles, all managed by 3,300 utilities serving 150 million customers.” [4]. The first recommendation from the ACSE Infrastructure Report Card is to adopt federal policy that includes alternative energy sources such as renewables and distribution generation [i.e. microgrids], to meet current and future consumption demands. [3]

Power systems around the world have been shifting from being less centralized as a resource and integrated as distributed energy resources (DER) providing new options for consuming electricity as a distribution system. [5] DERs include “demand response, generation, energy storage, and energy control devices, if they are located and function at the distribution level.”[5] Some examples of DERs are air conditioners, electric vehicles, thermal storage capacity, photovoltaics panels or electric batteries.[5] A study by MIT titled, “Utility of the Future,” examines the future of electricity services based on a confluence of factors: growing presence of renewable resources, increased integration of DERs in the electrical grid infrastructure, the rapid proliferation of information, communications technologies (ICTs) with their connection to DERs. The intent is to point out the overlap and differences between the two and how the fit along the scale of more distributed versus more centralized resources. [5]

In 2014, new renewable solar energy capacity made up almost 29 percent were distributed encompassing up to 8 percent of the US generating capacity additions. A year later, new solar energy additions increased to 41 percent encompassing 11 percent of all US generating capacity additions. [5]
Thermal energy storage, lithium-ion batteries and various other energy resources like flow batteries are competitive as well. 

Heating, ventilation, and air-conditioning (HVAC) systems, water heaters, and batteries account for 80 percent of demand resources in addition to providing reserves for regional energy transmission providers like PJM in the eastern US. Essentially, three converging drivers are pushing the rate of deployment of distributed and renewable resources: (1) technological innovation, (2) policies related to the distributed and renewables sector, and (3) consumer choice and preference. We will address each one and its relevance to the project. The cost of solar PV and wind has steadily declined over the past several decades—60 percent and 40 percent respectively between 2008 and 2014 alone. Projections are on track for solar PV to fall below $1 per watt by 2020 and a 24 to 30 percent reduction in wind during the same period. According the Department of Energy Solar Energy Technologies Program, the cost of solar energy, in the figure below, is projected in wholesale parity with other parts of the world is expected to also reduce and level off at $.06 per kWh through 2030. 

According to a report on the US Recovery Act, Promoting Clean, Renewable Energy: Investments in Wind and Solar, what whole parity means is “homeowners (who pay an average retail cost of about 10 cents/kWh for electricity from the grid) and utility companies (which have average wholesale power costs closer to 5 cents/kWh) can use solar power without paying a premium over fossil-based electricity.”

Electric vehicle batteries and stationary energy storage stretching into the gigawatt scale markets have also fell 14 percent in costs between 2007 and 2014. Some of the polices instruments used to drive down renewable costs is that 51 percent of all energy-specific federal subsidies with wind and solar collectively totaling 64 percent of all federal electricity production subsidies. The last driver, consumer choice and preference can express their values through their consumption and provision of electrical energy services such as lowering costs or reducing the environmental impact, etc. Choice also translates to what resources consumers and which electrical services they select further causing implication on the future of electrical delivery systems.

Background

The power grid and electrical network infrastructure has basically remained unchanged since the 1880s with power distribution essentially serviced in one direction from the power plants to the
end users. In the 2017 ASCE Infrastructure Report Card, “Most electric transmission and
distribution lines were constructed in the 1950s and 1960s with a 50-year life expectancy, and
the more than 640,000 miles of high-voltage transmission lines in the lower 48 states’ power
grids are at full capacity. Energy infrastructure is undergoing increased investment to ensure
long-term capacity and sustainability; in 2015, 40% of additional power generation came from
natural gas and renewable systems.” [3] The electric transmission grids: Eastern Interconnection,
Western Connection, Western Connection, and Texas Interconnection are operating at full
capacity. [3]

Dominion Virginia Power is the primary energy provider in Fairfax County. Their parent
company, Dominion Power has a portfolio of 25,700 megawatts of electric generation, 15,000
miles of natural gas transmission with 1 trillion cubic feet of capacity and 6,600 miles of
electrical transmission and distribution lines. [8] Dominion has 16,200 employees, has 12 million
people and businesses serviced by the company, and more than 6 million utility and retail energy
accounts. [8] In 2016, Dominion invested $979 million in solar energy ($2.6 billion since 2013)
in the development and construction of small and large-scale array facilities and has 56 power
facilities fueled by renewables. [8] To gain a thorough understanding of the complexity of
electrical power generation and consumption in the Commonwealth of Virginia, we must have a
clear view of the entire enterprise from federal, regional, and state levels.
Figure 6: VA Energy Generation

The historical energy generation from 1990 to 2015, has seen an increased (in mega Watt/hour or MWh) of over 20,000 MWh over electrical power. The transportation, commercial and residential end users consume more energy than industrial users. Industrial users’ rates between 2006 and 2007 were the least expensive ranked 7th and 9th amongst rates in North Carolina, Alabama, Mississippi, Georgia, Louisiana, Kentucky, South Carolina, and Florida over that period. [17] Virginia fell to 11th in 2008 and 29th in 2009 sliding the industrial user rates above the national average during the period. [15] According to a 2011 Investor Owned Electric Utility Regulation in Virginia report, the increase in rates were “the result of the 2007 reregulation [Electric Re-regulation Legislation of 2007] statutes that allow and encourage excess earnings for Virginia’s investor electric utilities.” [17] From Dominion Power perspective, the legislation “would provide rate stability for consumers while allowing the company to earn sufficient return to borrow money to build additional generating capacity to meet growing demand.” [18] Essentially, the law did not leave in-place the rate base/rate of return regime over the past several decades and deregulated the electric cooperatives providing they did not increase or decrease the rates for distributed service more than 5 percent in any three-year period. [18] The Virginia SCC cannot allow “peer’ energy companies a return on equity below a “floor.” The floor rate of return is an average of the two majority companies after deducting the two companies with the highest
returns and the two with the lowest with a 300-basis point cap above average. [18] The 2011 report seems to allude to the rationale for a lower industrial rate is to incentivize businesses into the Virginia. [18] In February 2015, Governor McAuliffe signed a bill that freezes electric rates from five years until 2020. According to Senator Wagner, the sponsor of the bill, the intent was to “…keep Virginia’s electric rates the lowest in the mid-Atlantic and among the cheapest in the nation, it will protect thousands of jobs and will provide certainty as businesses plan to locate, grow and expand in the commonwealth.” [19]

Cheap Solar

The appeal of solar photovoltaic (PV) systems has been on a steady increase over the past several decades. The growth of installed solar power has seen its rate double every two years over the last 25 years [10]. The motivation of many residential users install solar PV systems is to reduce energy costs and gain greater energy independence from utility providers [11].

Despite the appeal of cheap renewable solar energy, solar panels do not generate energy over a 24 hour period. The challenge of renewable solar energy are constraints of generation during daylight hours when typical household demand is at its lowest. Renewable solar energy production generated during daylight hours when residential energy demand is at their lowest and industrial demand at their highest thus resulting in excess wasted renewable solar energy. By using a peer-to-business (P2B) network, residential solar generators could sell excess energy to either other residential users or nearby industrial users that exhibit high demand during peak demand daylight hours.

The analysis demonstrates the feasibility of renewable solar energy with an industrial user using historical energy consumption data and solar energy generation with the development of a probabilistic Monte Carlo simulation model. The model predicts, given the geographical location, the number of homes in residential subdivision that can generate enough solar energy to meet its own consumption and to an adjacent industrial user. The problem and need of the system for the primary customer to include the physical and functional characteristics of the system, the analysis of the system, and evaluation of the system is to determine feasibility of residential renewable energy trading by capitalizing on wasted solar that would otherwise be absorbed into
the Earth beyond battery storage capacity during the daytime hours when production is at its highest level.

![Solar's Price Plunge](https://obamawhitehouse.archives.gov/recovery/innovations/clean-renewable-energy)

*Figure 7 Solar Price Plunge*

The graph in Figure 7, Solar’s Price Plunge\(^1\), represents the lowering trend in solar power from 2009 over the next 20 years. Installed capacity in the U.S. grew 50 percent in 2016 to more than 41 gigawatts. The graph notes the cost per watt in 2009 at $350 per MW or .35 cent per kWh and a trend to below $50 per MW or .05 per kWh in 2024 thus on track to become cheaper than coal. That has resulted in lower upfront costs for solar PV systems. Despite the lowering cost and wider availability of solar, energy storage is the greater challenge. Those limitations on the battery storage and distribution technology presents an opportunity for utilizing wasted solar energy generated during daytime hours that would otherwise go into the ground which is represented in the graph in the lower right portion of the slide depicting solar energy being generating over and beyond what can be stored and goes unused.

**Rising Energy Demand**

The rising energy demand could result in higher costs during peak demand with lower capacity and greater dependency on regional providers. The graphs on the right are GMU Engineering Building Power Profile in a 24-hour period. The bottom is a bar graph of the energy usage and

\(^1\) [https://obamawhitehouse.archives.gov/recovery/innovations/clean-renewable-energy](https://obamawhitehouse.archives.gov/recovery/innovations/clean-renewable-energy).
top one is percentage use on the x-axis and kWh on the vertical axis. What you should notice is that at 100% of the time load on the top right graph, GMU Engineering consumes 250 kWh at a minimum every hour over a 24-hour period. We found this energy signature consistent for over 8600 lines of historical data in a 12-month period.

![GMU Engineering Load Duration Diagram](image1)

*Figure 8 GMU Engineering Load Duration Diagram*

![GMU Engineering Daily Yearly Load/Demand Profile of an Energy System/Utility](image2)

*Figure 9 GMU Engineering Daily & Yearly Load/Demand Profile*

Unutilized residential renewable solar energy could lower the energy demand from utility providers, lower costs for industrial users, and serve as a revenue stream for residents.
Our confluence interaction diagram, depicted in Figure 10, demonstrates the environmental factors discussed in our context analysis contributing the need of the MEX system. Cheap Solar, Rising Energy Costs, Rising Energy Demand and the constraints of regulators (which will be discussed in our stakeholder’s analysis) has brought us to the intersection to capitalize on wasted solar energy that would otherwise go into the ground.

**Energy Enterprise**

Dominion Power, Appalachian Power, Delmarva Power, and Allegheny Power own, maintain, and provide transmission and distribution facilities within the Commonwealth of Virginia [10]. The Virginia State Corporation Commission (SCC) must certify and approve of all new proposed electric transmission lines. The Federal Energy Regulatory Commission (FERC) regulates all transmission lines. Most transmission lines are underground with the Virginia General Assembly approving of up to 20 percent of worst performing neighborhood lines placed underground to
cooperatives is to mitigate any electrical outages, monitor federal and state policy issues, and assist in the restoration of service. Figure 2 is a picture of the electrical service territories over the entire state along with the color depiction of the electric cooperatives. The figure also lists the 16 municipal utilities, part of the Municipal Electric Power Association (MEPEV) who also has a similar role as the cooperatives in that they monitor electric policy matters on behalf of its members. The remaining portion of the enterprise is the state’s renewable resources and its portfolio’s standards with the integration of conventional power generation. Figure 11 is a snapshot of Virginia’s consumption estimates for 2015 by all sources.

Virginia’s list of renewable resources includes biomass, waste-to-energy, and landfill gas wind (offshore and on-shore), hydroelectric (not pumped storage), low temperature geothermal, and solar. Renewable electricity from the state is primary from solar photovoltaic and small wind systems with a small number of homes from the electrical grid with reliance on battery
storage. In most cases, many renewable energy users are connected to the grid as an add measure of security in the event of power loss. There are many independent renewable generation projects using contracts that sell their power to the wholesale market. Hydroelectric power is also an energy option in the state with 24 conventional hydropower facilities providing a combined 439 megawatts and two pumped storage facilities totaling 3659 megawatts of power. As for March 2014, solar photovoltaic systems constitute under 12 megawatts of power in Virginia. Virginia’s total energy consumption per capita is 30 cited by the US Energy Information Administration as of August 2017. The demography population for energy is 8.4 million or 2.6% share of the US; gross domestic product is $494.3 billion or 12th of the US. As for electricity, residential users pay 11.91 cents/kWh (13.22 cents US Average), Commercial users pay 7.87 cents/kWh (10.99 cents/kWh is US Average), and Industrial users pay 6.65 cents/kWh (7.22 cents US Average) (As of June 2017). Virginia’s total net utility electricity generation is 8,773 thousand MWh or 2.5% share of the US with renewables making up 5.6% of the total. Natural gas produces the largest share of Virginia’s electricity generation. Coal-fired power plants supplied most until 2009 when coal fell below nuclear power in the state. Electricity consumption is greater

**Virginia Energy Consumption Estimates, 2015**

![Figure 12: VA Energy Consumption Estimates](image-url)
than electricity generation in Virginia with the state getting additional power from the grid (i.e. PJM). [11]

**Dominion Power Forecast New Energy Demands**

Northern Virginia has the largest collection of data center in the US and up to 70 percent of the world’s Internet traffic is routed through Loudoun County. [12] Dominion Power uses historical trend data with interconnect data from the current and long term to forecast growth in its service territory. [9] Dominion Virginia Power is forecasting 20,000+ MWh of data center electrical demand through 2032. [9] Dominion Virginia Power also makes a load adjustment, practiced also by PJM, the regional transmission provider, with respect to solar PV facilities connected to the distribution grid or DERs mentioned earlier in this report, as a part of its forecasting process. [9] Below is a graph for Dominion Zone Peak Demand Forecast Adjusted for Data Center Growth where the black-dashed line indicated the energy forecasts. [9] The forecast is relevant to reliability of the electrical infrastructure and Virginia dependency on regional states to meet peak consumption. As cited earlier in the report, 60 percent of Virginia’s total electrical energy is transmitted from outside the state.

**Homeowners Association**

Homeowner Associations (HOAs) are nonprofit organizations formed to govern private residential developments. Their responsibilities address several aspects of the community. HOAs have become an integral part of the residential communities because they maintain the value and integrity of a community by eliminating disparities in the provision of public services. HOAs also improve local communities by addressing resident concerns such as safety and security, lack of maintenance of property value and services not provided by the local government [18]. The local governments find HOAs attractive because they provide many governments functions through private organizations. HOAs members pay for exclusive services, which are superior to those provided by the public sector. The first HOA was formed in Boston in 1844, and HOAs have proliferated across the country as one of the fastest growing privatization efforts and housing options. HOA membership has grown tremendously over the two last two decades because they provide valued public services. In 1970, the number of residents living in an HOA was 2.1 million, but by 2012, the number had increased by 61.9 million [18]. The number of HOAs in Virginia is increasing, and they are found in cooperatives and condominiums. The growing popularity of HOAs in Virginia and other states suggest that residents are able and
willing to pay for additional services and amenities. HOA is a cost-effective way to produce large-scale communities and provide local services.

**Laws and Regulations**
Several laws and regulations govern the operations of HOAs. Although HOAs slightly differ from one state to another, they are governed by the same document framework, which contains Bylaws, declaration of covenant, conditions, and restrictions (CC&Rs), Article of Incorporation, rules and regulations [20]. Bylaws are rules that govern the management and administration of HOAs. The Article of Incorporation requires HOAs to be incorporated as a non-profit corporation and file paperwork with the secretary of state’s office before they sell any property. It contains basic information such as HOA’s purposes, name, and location. Individuals who buy a property in the association become members of HOAs, creating a legally binding contract with the HOAs by purchasing in the association [21]. CC&Rs describe requirements and limitations of what a homeowner can do with the property, and seek to preserve, protect and enhance the value of the property in the community [19]. Penalties for violation of the CC&R include fines and suspension of privileges to use facilities and lawsuit. There are also additional legal regulations in the form of case laws and standards set by professional organizations such as a home inspector, architects and engineers [20].

**Formation of HOAs**
HOAs are considered corporate entities, and thus they are formed the same way other corporate entities are incorporated. The process for establishing an HOA varies from one state to another; however, there are general guidelines that should be followed in forming HOA in any state. Many laws and statutes regulate the formation of HOAs, and thus it is important to have expert laws to make the process smooth and avoid legal penalties. The first step is the establishment of a business structure by forming a nonprofit organization. Second, a person seeking to form an HOA must describe how the association will operate and the rules that the homeowners must comply with by creating a covenant, conditions, and restrictions (CC&Rs). The third step is the establishment of a procedure for future modification of the CC&Rs. The next step is developing rules and regulations that make it easy for the community residents to understand CC&Rs. Developers must establish governing documents such as Bylaws and articles of incorporation. These documents outline election of the association leaders, voting guidelines and meeting
frequency. The last step involves election of board members with HOA expertise to run the association.

**HOAs and to Solar Renewable Energy**

HOAs have specific rules regarding the installations of solar photovoltaic systems (PV) and location of solar arrays. HOAs are involved in solar panel installation decisions because modifications of the exterior of a home may affect a community. The association adopts CC&Rs to govern the installation of solar panel and maintain aesthetic standards. It seeks to reduce the soft costs associated with the installation of solar electricity. However, CC&R have created conflict between the individual homeowners and the association over the installation of solar energy devices. Technological advancement and changing lifestyles also contribute to disputes about solar energy between HOAs and homeowners. Modern homeowners look to install a solar panel on their property to produce clean energy, but residents who reside in a community with an HOA must turn to the association for before installation of a solar panel on their properties. Community residents who want to utilize renewable energy may face resistance from restrictive covenants by the HOAs through restrictive CC&Rs that limit or prohibit the use of installation of solar energy devices. Many HOAs restrict installation of solar PV by making rules regarding color, placement, and how far they can extend above the roof. Although HOAs are increasingly becoming aware of the benefits of renewable energy, getting approval is not easy. State laws override CC&Rs and encourage community residents to invest in solar energy as a means of exploiting renewable energy; however, these laws are vague, and thus they do not remedy the problem [18]. CC&Rs not only threaten the utilization of alternative energy at the individual level but also impede efforts to combat climate change.

HOAs appeal to local government and community residents for maintaining community property value and integrity. These associations offer many benefits by providing public sector services while eliminating disparities. The formation and operation of HOAs are highly regulated to ensure a healthy relationship between the association and homeowners. Although HOAs contribute to the development and maintenance of the communities they serve, restrictive CC&Rs have potentially unfavorable outcomes if they limit the utilization of solar electricity in a modern era that values clean technology in the combat of global climate change.
GMU Energy Management

The scope of the project will be George Mason University Fairfax campus and the immediate surrounding areas on the same geographical substation serviced by Dominion Virginia Power. GMU Fairfax would be considered a commercial user for the purposes of the project along with historical residential data from two local sources.

When examining George Mason University short-term power generation usage and costs, the Fairfax campus has seen gradual increases in over the past two years. GMU Fairfax typically has slight dips in usage over the winter break and would be expected with the large break for students from campus and steady usage of power up to and through the summer terms. [18] GMU Fairfax historical data from August 2016 to September 2017, provided by GMU Energy Management, reflected high seasonal shifts during the winter and summer months as depicted below in the graph according the Dominion Virginia Power utility monthly bill. [18] The billing data is over a 14-month period reflecting an average use per day of 262,866 kWh and the average bill at a cost of $467,713.00 over the same period. Based on the winter and summer month peaks from the graph subtracting the highest peaks from the average costs over the 14-month period, we calculated a potential savings of $64,079.39 and $102,271.81 respectively.

The fuel charges, which are “pass through charges,” indicating no profit or loss costs consist of 40 percent of the bill. The remaining 60 percent of the bill comprises demand charges, rider charges, miscellaneous charges, and distribution charges. The complete lists of Dominion’s utility charges are as follows:

Figure 13: Energy Management
Primary Components of Dominion Electricity Bill Base Rates:

**Base Rates**: All construction and operating costs of power places—total costs of providing service to the customer (minus fuel costs). Rates are “frozen” until 2020 via Virginia Law signed in February 2015. [18]

**Fuel Adjustment Clauses**—separate (“pass through charges”) from the base rate covering utility's cost of fuel needed to provide electricity (natural gas, coal, nuclear, biomass). Utility does not get a profit or loss on fuel costs. [18]

**Rate Adjustment Clauses (RAC)**—additional charges that utilities add to electricity bills to include the costs of building new power plants. Clauses did not exit prior to 2007 because prior law covered them under base rates. [18]

**Applicable Riders**: Charges applied to certain rate schedules to recover various costs associated with Dominion Energy’s electric operations and electricity production.

**Demand Charge (kW)**: Largest electrical use or highest “demand” for electricity averaged in any 30-minute period per month measured in kilowatts (kW). Charge is calculated based on cost per kW used.

**Distribution Service**: Charges for the use of local wires, transformers, substations, and other equipment used to deliver electricity to your home or business. This service must be purchased from Dominion Energy Virginia.
Electricity Supply Service (ESS): Charges for the generation and transmission of electricity, including fuel. This service may be purchased from a licensed competitive service provider.

Generation: Charges to produce electricity from Dominion Energy’s power plants.

Transmission: Charges for moving electricity from Dominion Energy’s power plants to substations.

Fuel: Charges associated with the cost for fuel used to produce electricity, including transportation kWh (kilowatt hour): A measurement of electrical energy.

Multiplier: Some meters are programmed to record energy at a slower rate due to the demand needed.

GMU Industrial Users
Buildings account for approximately 75 percent of electrical energy consumption in the United States. [15] To lower the electrical energy usage and peak demand, utilities introduce market-based time-of-use (TOU) pricing models. [15] By connecting on-site renewables and energy battery storage between buildings or residents to sustain a microgrid capable of generation, storage, and sharing electrical energy to balance generation with consumption. [15] This is one potential option for the project where solar PV roof panels are strategically installed to form a microgrid along with a solar PV farm. Upon closer examination of the GMU Fairfax Facilities Energy Footprint from the Five-Year Utility Comparison Report, we identified thirteen buildings that exhibited the highest levels of variability over a 5-year period. [19] Those buildings include: (1) Alan and Sally Merten Hall, (2) Aquia, (3) EagleBank Arena, (4) Nyugen Engineering, (5) Fenwick Library, (6) Krasnow, (7) Recreation Athletic Center (RAC), (8) Robinson Hall, (9) Rogers, (10) Southside Dining, (11) Student Union I, (12) Taylor Hall and (13) the Hub. [19] We take a closer look at each one, in detail, in addition to residential data before entering the cost and gap analysis.

1. Alan and Sally Merten Hall is a 143, 074 square foot area facility named after the GMU’s fifth president and consists of a series of
restaurants, conference rooms, classrooms, and administrative support rooms. The annual electrical utility cost variability from calendar year 2017 has increased 9 percent since 2016 but reflected two years of decreases of 8 percent and 10 percent. However, in 2015, the costs sharply rose to 26 percent from that previous year.

2. Aquia Building is a 55,818-square foot facility and was opened in 2010 at a cost of $24.8 million. The Departments of Criminology, Law, and Society, The Department of Modern and Classical Languages, and the Data Center utilize the facility. The annual electrical utility cost variability for calendar year 2017 to date increased by 12 percent from the previous year but reflected two years of decreased variability in 2015 and 2016 at 2 percent and 7 percent respectively. In 2014, the facility annual electrical utility costs rose 26 percent from 2013.

3. The Eagle Bank Arena (originally the Patriot Center) is a 10,000-seat arena and opened in 1985 and is a 17,000 square feet facility. The annual electrical utility cost variability for calendar year 2017 to date increased by 6 percent from the previous year, 1 percent increase in 2016 from 2015, 8 percent decrease in 2015 from 2014 and 4 percent increase in 2014 from 2013.
4. Long and Kimmy Nguyen Engineering Building opened in 2009 at a cost of $67 million and is a 179,954-square foot facility. The Engineering building consists of office, classroom, labs, and research space. The annual electrical utility cost variability for calendar year 2017 to date increased by 8 percent from the previous year, decreased by 12 percent in 2016 from 2015, 7 percent decrease in 2015 from 2014 and 20 percent increase in 2014 from 2013.

5. Krasnow Institute of Advanced Studies is a 53,441 square feet facility and conducts cognitive research, neuroscience, artificial intelligence, and complex adaptive systems. The annual electrical utility cost variability for calendar year 2017 to date increased by 7 percent from the previous year, increased by 17 percent in 2016 from 2015, decreased by 17 percent decrease in 2015 from 2014 and decreased 6 percent in 2014 from 2013.
6. Recreational Athletic Center (RAC) is a 125,067 square feet facility consisting of three gymnasiums, racquetball courts, squash courts, and two separate fitness galleries of equipment. The annual electrical utility cost variability for calendar year 2017 to date increased by 14 percent from the previous year, decreased by 43 percent in 2016 from 2015, even in 2015 from 2014 and 2 percent increase in 2014 from 2013.

7. Rogers Hall is a fully furnished apartment style facility with full kitchens, shared bathrooms, and dining and living areas for students with approximately 127,049 square feet. The annual electrical utility cost variability for calendar year 2017 to date increased by 8 percent from the previous year, decreased by 9 percent in 2016 from 2015, decrease by 12 in 2015 from 2014 and 24 percent increase in 2014 from 2013.
8. Southside Dining is a $10 million facility cafeteria and is approximately 36,582 square foot of space. The annual electrical utility cost variability for calendar year 2017 to date increased by 8 percent from the previous year, decreased by 9 percent in 2016 from 2015, decrease by 12 in 2015 from 2014 and 24 percent increase in 2014 from 2013.

9. Fenwick Library is the main research library and houses most of the University Libraries' 1.5 million volumes. The facility has approximately 275,811 square feet of space. The annual electrical utility cost variability for calendar year 2017 to date increased by 21 percent from the previous year, a 27 percent increase in 2016 from 2015, decrease by 2 in 2015 from 2014 and 15 percent increase in 2014 from 2013.

10. Student Union Building (SUB) I is George Mason University Student Union Building has offices, conference rooms, restaurants, and administrative support activities for students. The
building is approximately 157,770 square feet of space. The annual electrical utility cost variability for calendar year 2017 to date increased by 6 percent from the previous year, a 11 percent decrease in 2016 from 2015, decrease by 16 percent in 2015 from 2014 and 15 percent increase in 2014 from 2013.

11. The HUB Student Center is a 101,279 square feet facility with meeting rooms, event spaces, post office, and restaurants to support the Mason community. The annual electrical utility cost variability for calendar year 2017 to date increased by 10 percent from the previous year, a 7 percent decrease in 2016 from 2015, decrease by 17 percent in 2015 from 2014 and 18 percent increase in 2014 from 2013.

12. Taylor Hall is a $19 million residential facility completed in August 2015 with approximately 70,516 square feet of space. The annual electrical utility cost variability for calendar year 2017 to date increased by 19 percent from the previous year, a 37 percent increase in 2016 from 2015.
The graph is a summary of the cost variability in percentages from 2013 to 2017 where percentages are captured on the left vertical axis and the facility square footage is on the right vertical axis. Robinson Hall was dropped from the list with the completion of the Peterson Building in 2017. The rationale for each building profile to provide summary of its function as the intent is the installation of PV solar panels or design alternative as an option to stabilize the cost fluctuations over seasonal periods during the year and over time. GMU Fairfax campus would be representative of a commercial user under the rating scheme of Dominion Virginia Power.

**Residential Users**

The project team was able to secure four years of historical residential data representative of a GMU Fairfax resident as a part of the project. Upon examination of the resident electrical utility history, we observed high seasonal trends and variability in their energy use. The average cost (kWh) per month was $0.16 with an average use of 1381 kWh and an average temperature of 54.1-degree Fahrenheit. The graph below tracks the residential history from January 2012 to
December 2016. Furthermore, we believe the peaks, such as the historical commercial user data from GMU Fairfax, opportunities for stabilize the variability over the summer and winter months as indicated on the graph. We also observed a similar pattern in rates versus bills with respect to the basic rates and RACs or riders.

**Figure 16: Energy Consumption**

From a recent 2017 report from Virginia’s Poverty Law Center (VPLC), they found that Dominion’s Energy utility increased 30 percent between 2006 and 2016. Of the billing increases, 42 percent of them were from the Rate Adjustment Clauses (RACs) between 2007

**Figure 17: Single Family User Histogram**
and 2012. [13] The VPLC report also made a clear distinction between Dominion Energy’s rates and bills. As cited above, the report lists three primary components in their analysis of the Dominion electricity bill: Base Rates—costs of all construction and operating costs of power plants, Fuel Adjustment Clauses—utility’s cost of fuel needed to provide electricity, and Rate Adjustment Clauses (RACs) mentioned above, covering the costs of new plants. [13] What appears to be a preliminary observation is that RACs make up to roughly 60% of the commercial user bill and roughly 40% in residential users. The lowest costs are in the category of industrial users. [2] The residential histogram has the frequency on the left vertical axis of energy use (kWh) along the x-axis and the percentages on the right vertical axis. The purpose of the histogram is to visually identify the potential opportunities in savings through stabilization options from renewable solar energy by shifting the right tails in higher energy use to the left side of the x-axis thus reflecting on the graph the trend in percentage savings for the residential user.

**Solar Power Demand and Generation**

![Solar Generation Model](image)

*Figure 18 Solar Generation Model*

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2 Dominion Resources, Inc. 2016 Annual Summary Report
Solar power is a reliable, environmentally friendly, and increasingly affordable source of energy. It is experiencing significant growth across the United States and is changing how and where we produce the electricity that is essential to our modern society. Today’s electricity system suffers from many critical problems related to the environmental and health effects of extracting and burning fossil fuels such as coal and natural gas, and the volatility of fossil fuel prices. The United States’ economic and environmental well-being depends on a strong shift toward electricity generated with fuels that are abundant and reliable, and have a relatively clean environmental footprint. Solar power can generate electricity with no global warming pollution, no other emissions, no fuel costs, and no risks of fuel price rises. Solar is, to a great extent, a good source of renewable energy. Sufficient sunshine across the country can make solar an attractive option in every state. Various options for electricity generation from solar include a wide variety of technologies with different advantages and properties for homeowners, businesses, and utilities. Thanks to many benefits that solar energy offers, the number of commercial solar power plants has been increasing in recent years.

Models
Concentrating solar thermal systems uses optical devices and sun-tracking systems to concentrate a large area of sunlight onto a smaller receiving area. The concentrated solar energy is then used as a heat source for a conventional power plant. A wide range of concentrating technologies exists. The main ones being solar dishes, parabolic troughs, solar power towers, and linear Fresnel reflectors. The primary objective of concentrating solar energy is to generate high temperatures and thus high thermodynamic efficiencies. Parabolic trough systems are the CSP technology that are most commonly used. A parabolic trough includes a linear parabolic mirror that reflects and concentrates the received solar energy onto a tube (receiver) positioned along the focal line [25]. The heat transfer fluid is then pumped through the receiver tube and picks up the heat transferred through the receiver tube walls. The parabolic mirror follows the sun by tracking along a single axis. Linear Fresnel reflectors use various thin mirror strips to concentrate sunlight onto tubes containing heat transfer fluid [25]. Higher concentration can be acquired, and the mirrors are less expensive than parabolic mirrors, but a more complicated tracking mechanism is needed to make the whole process work. The dominant control problems with solar plants are related to control of the thermal variables and sun tracking. Even though control of the sun-tracking mechanisms is usually done in an open-loop mode, the smart grid can be
conceptualized as an extensive cyber-physical system that supports and facilitates remarkably enhanced responsiveness and controllability of highly distributed resources within electric power systems [25]. Control of the thermal variables is primarily done in a closed loop. Solar plants show changing dynamics, nonlinearities, and uncertainties, characteristics that result in detuned performance with classical PID control [25]. Advanced control strategies that can deal with these issues are needed for lower cost per kilowatt-hour generated and for better performance.

**How the Technology Works**

Solar-sourced electricity can be generated either directly using photovoltaic (PV) cells or indirectly by collecting and concentrating the solar power to produce steam, which is then used to drive a turbine to provide the electric power (CSP). The process that solar panels generate energy can be described in four steps as follows: The first step occurs when solar panels collect sunlight. Every solar panel contains something called photovoltaic, or PV, cells. PV cells take light, also known as photons, and turn the light into electricity (or voltage). When sunlight hits the solar panel, PV cells get to work by producing direct current (DC) electricity [26]. The second step occurs when inverters convert the power to usable electricity. An inverter is on the back of each solar panel. It converts DC electricity, which is the unusable kind of electricity, into alternating current (AC) electricity, which is what we need. Then the next step occurs when electricity flows into net meter [26]. AC electricity flows from the solar panels through efficient wires and cables into a net meter. The net meter measures both the power drawn from the grid and the excess power the solar panels are putting back onto the grid.

Finally, after electricity runs through the net meter, the energy generated can power all appliances in residences. If solar panels do not produce enough energy to cover a high energy demand, that should not be difficult problem to solve because the residences are still connected to the power grid, so more energy can automatically be drawn whenever it is needed.

**The Laws Associated with the Technology**

- Noise Control Act: This legislation governs noise control, enacted by Congress in 1972 and amended in 1978. It was initially implemented through regulations issued by the U.S. Environmental Protection Agency (EPA) in the early 1980s. However, the primary responsibility for regulating noise has been delegated to state and local governments. [27]
- Clean Air Act (CAA): This legislation governs the protection of air quality, establishes ambient air quality standards, permit requirements for both stationary and mobile sources, and standards for acid deposition and stratospheric ozone protection. [28]
- Air Commerce and Safety Act: This legislation requiring the Federal Aviation Administration (FAA) to establish standards promoting aircraft safety. Regulations established under this Act require FAA notification prior to the construction of any structure that (1) is located within 20,000 ft. (6,100 m) or less of an existing public or military airport or (2) extends more than 200 ft. above ground level or exceeds specified parameters. [29]

**How It Relates to the Project**

Solar demand and generation have become main concerns of many energy users and suppliers in recent years. Those are important factors that need to be determined properly via simulations to make sure there is an excess amount of energy eventually. Otherwise, it would not be practical to implement the entire model. This project focuses more on residential users. The amount of energy generated by solar panels and the energy demand of those users need to be estimated accurately using appropriate methods so that all requirements of the project are met.

**Battery Storage and Distribution for Solar Panels**

Currently, the world is transiting to the use of renewable sources of energy because of the environmental problems that are associated with the non-renewable sources. Solar energy is, therefore, one of the major sources of such power for the grid. Once the solar energy is produced, it needs to be stored in batteries as a backup to be used when supply fluctuates.

**Models**

There are different battery storage models that are used for the solar power grid. These models include the following: lead acid batteries, metal-air model, lithium ion batteries, flow battery model and sodium sulfur battery. One of the models is the lead acid batteries which are made up of a sponge lead negative electrode plus an anode of lead dioxide. Micro-porous materials separate these two areas and are dipped in aqueous sulfuric acid electrolyte [30]. These are of two types, namely; flooded type and a valve regulate VRLA type. The flooded type uses aqueous sulfuric acid whereby during discharge the anode lead dioxide is converted to lead oxide through a reduction process, which then engages in a reaction with sulfuric acid to produce the lead
sulfate. At the negative electrode side, the lead sponge is oxidized to lead ion and converted to lead sulfate after reacting with sulfuric acid. The VRLA type, on the other hand, uses the same principle as the flooded type but the difference is that they possess a pressure regulating valve and contain an immobilized acid electrolyte [32].

The second model is the lithium-ion batteries. In this model, the cathode (negative) is composed of a lithium metal oxide while the anode consists of the graphite carbon. A lithium salt that is dissolved in organic carbonates is used as an electrolyte [31]. Solar energy charges the battery by causing lithium atoms found in the cathode to be converted into ions, which move towards carbon anode to mix with external electrons [30]. These are stored as lithium atoms in carbon layers where during discharge the entire process is reversed.

The third model is the sodium sulfur battery. This one comprises of a cathode with sodium in molten state while sulfur also in molten form is found at the positive electrode. A wall of a solid beta alumina ceramic electrolyte separates the two. During recharge, process sodium combines with sulfur forming sodium polysulfide [36].

Fourthly, there is the flow battery model which is made up of double electrolyte reservoirs. They also contain an electrochemical cell which has a negative and positive parts plus a separator membrane. The two electrolyte reservoirs are large tanks found outside the electrochemical cell. The electrolyte is pumped through this electrochemical chamber where chemical energy is transformed into electricity [31]. Although the power density as found in in flow-batteries is largely dependent on the electrolyte reaction rates at the cathode and electrodes, both the amount of electrolyte and tank size can affect the energy density [32].

Lastly, there is metal air model, which utilizes commonly available metals such as zinc and aluminum as anodes. When these metals are oxidized they release electrons. The cathodes, on the other hand, are made up of a carbon structure with holes or even a metal mesh that is laced with catalyst. Electrolyte used in this one is a hydroxide which should be in liquid form or perhaps a polymer model [31].

Currently, most solar power systems use lead acid-battery which is also the oldest and store a large capacity for power. However, they contain heavy toxic metal and have a problem of self-discharge. On the other hand, the Li-ion batteries have proved to possess great potential for
future use because of the following: light weight, efficiency, and high-power storage capabilities [31]. The disadvantage of these Li-ion solar power storage batteries is that they are very expensive. The Sodium sulfur batteries have a disadvantage of operating under the intense heat of up to 3000c. Lastly, the flow battery has advantages of long duration power storages and do not undergo self-discharge, however, their maintenance cost is high [30].

**How the Technology Works**

Batteries are used in converting electricity to chemical energy, which can be stored. This process occurs when there is the excess production of energy, and the demand is low. For example, during the day the solar energy production is high which exceeds the demand thus calling for the storage of the solar energy in the chemical energy form. The batteries also have the capability of reversing the stored chemical energy to electrical energy for use when the demand is at peak, and the supply may be low [32].

These batteries are comprised of two terminals namely; the cathode which is usually positively charged and anode, the negatively charged side. These terminals are chemicals preferably metals. In between the anode and cathode, there is an electrolyte, which is a chemical medium [33]. In an event, the battery is connected to the solar power grid system chemical reaction occurs compelling an ion to flow from the cathode to the anode and through the electrolyte. Electrons also attempt to move to cathode, but the electrolyte blocks them. This makes them move through the outside circuit which now generates electricity and when they are exhausted the process stops and resumes when the battery is recharged [33].

**The Laws Associated with Solar Power Battery Technology**

There are various laws that control the storage of solar energy in the United States. These are both federal and state laws, examples include the following:

- **The United States Energy Storage Competitiveness Act of 2007**: This law promotes the development of energy storage technologies through the provision of the Federal grants for research [34].
- **Energy Independence and Security Act of 2007**: This legislation was meant to promote the production and storage of renewable energy and reduce overdependence on nonrenewable sources of energy.
- **Clean Air Act**: This is a federal law that requires air pollution to be controlled in the United States. It is therefore associated with the solar energy battery storage because the technology reduces air pollution by making sure clean energy is constantly supplied to Americans [35].

**How It Relates to the Project**

PV solar farm will generate power as a backup emergency generator. These solar farms can produce more electricity exceeding the power demands during the days with a high intensity of sunlight. The excess solar electricity produced during the sunny days can be stored in a solar battery system to allow the excess electrical energy produced to be stored for later use or when the light intensity is too low for solar panels to generate enough power.

**Microgrid**

A microgrid is an energy system that consists of interconnected loads and distributed energy sources that is capable to operate independently or in parallel with the main power grid. This is to ensure a safe, local, and reliable energy security in addition to providing solutions to consumers in all fields. It is not only beneficial to the consumers but also to the environment as it would lower greenhouse gas in addition to lowering the stress on the distribution and transmission system. The concept of microgrids dates to the industrial revolution. Thomas Edison open his Pearl Street Station in 1882. [37] During this time, there was no standard for a generation-distribution system for electricity. This gave him a lot of room to work with hence he designed it the way he wants as time progressed. Amazingly, Edison’s Manhattan Pearl Street Station is the foundation of today’s microgrid system. However, his microgrid was self-contained and was fired by coal fired steam engine. As with the majority of the microgrids, it was a small system with localized generation and a limited distribution network. Microgrids can therefore be considered as smaller version of the traditional power grid. The picture above is from Maryland’s Aberdeen Proving Ground where microgrid researchers are integrating from multiple
sources for use and storage. Microgrids can generate power, can distribute power, and have controls such as switch gears and voltage regulations. However, they do differ from the traditional electrical grids by enabling a closer proximity in power use and generation as a result increasing transmission reduction and increasing efficiency. In addition, the microgrids can also be integrated with other sources of energy such as solar panel, geothermal, wind power and many more. Microgrids perform better than traditional electrical systems as they enable for self-healing and autonomous operations. In normal usage or at times when the primary power grid fails, a microgrid can work independently isolating its nodes and power loads from the main power grid without affecting its integrity. On the other hand, microgrids coexists with the existing power systems and can therefore feed power back to the larger grid at times of failure or power outages. The main purpose of a microgrid is to provide reliable and sustainable energy when the primary energy source is compromised. It is therefore a stored energy source consisting of large batteries or any other source that can store the energy. The energy therefore can be used by the consumers or other industries. Because it consists of power storage devices, it can work independently or in parallel with the main source of energy with its own controls and voltage separate from the main source of power. [38] However, microgrids needs to be powered to work. A microgrid can be powered by generators, batteries, or even other sources like the solar panels. No matter how the microgrid is fueled or how it is managed, it will still function properly and independently. It therefore is connected to the main grid at a point that maintains the voltage at the same level as the main grid unless the main grid has a problem or it out then the microgrid would disconnect. The main grid and the microgrid are separated by a switch that can function automatically or manually to function as an island. There are various types of microgrids present. Some of the models of microgrids include Customer microgrids or true microgrids. This is the common type of microgrid demonstration available today. They are very easy to imagine as they fit very neatly with the current technology and regulatory structure. It is this type of microgrid that the whole concept of microgrids originated from. The consumer can have a considerable leeway when operating the power system on the side of the meter loosening the restrictions of the nature of the grid. For this reason, a majority of the microgrids are expected to be of this type. The second model of microgrids is the Utility or community microgrids or milli-grids (m-grids). This type of microgrid involves a segment of the regulated grid. They are not very much different from the µgrids. However, they do differ from the business and regulatory model
perspective as they are able to incorporate traditional utility infrastructure. With this feature, the utility regulation comes significantly into play. Any microgrid needs to comply with the existing codes. The third model of microgrids are the Virtual microgrids (vgrids). In this type of microgrid, the grids are situated on different multiple sites but are coordinated in a way that they are presented to the main grid as single entity. Only a few demonstrations of virtual microgrids exist. The system must therefore function as a controlled island or coordinated multiple islands. The next model of microgrids are the Remote power systems (rgrids). These types of microgrids are never connected to the main grid and operate in an island mode at all times; perhaps, due to various economic issues or even geographical locations. This is because they are built in far distance where there is no transmission and distribution infrastructure hence not connected to the utility grid.

**The Laws Associated with the Technology**

There are various laws that control the usage of microgrids in the United States. Some examples are listed below:

- **Environmental Laws - DEP/DEC Permits**: This law has air permitting and emission control requirements [39].
- **Department of Buildings Permit [39]**: Most of construction requires it. In other words, homeowners, builders, or contractors need to obtain a permit before any construction that involves microgrids can take place.

**How It Relates to the Project**

Microgrids are useful control systems that can help distribute energy effectively and efficiently. They are necessary and related to the project in multiple ways. Excess energy storage and distribution are some of the main concerns that our project needs to deal with. Without them, it would be very challenging to distribute energy to different users whose energy demand is higher than the energy supply they have. Thus, microgrids would help our energy-trading process from peers to peers work successfully.

**Smart Meter Technology**

Electricity is used to help power the world and help simplify everyday life. Since being discovered, electricity has been found to be able to be generated and distributed along a grid, or a network. This electricity can be purchased and used by consumers from the power companies
that generate and sell electricity. Currently, many non-renewable resources are being used to generate this electricity and impacting the environment. With constant technological advances, some of the improvements to the current electrical grid could be with improvements in the efficiency and reliability of the grid. A grid that can collect its own energy, convert, and generate that energy into electricity, store and distribute electricity, and keep track of energy use and generation could be referred to as a Micro Grid. The technology in the Microgrid that makes tracking electricity generated, distributed, and used would be referred to as a Smart Meter.

**What Is It**

As technology advances, some ways of improvement can be thought of as reliability and efficiency along the grid. Some of these grid improvements can be in the way electricity is generated and stored, the way it is distributed, and the way it is tracked [40]. With such improvements, the grid can be referred to as a smart grid or Micro Grid, but will be referred to as a Micro Grid for this project [41]. The Micro Grid is a smaller sized grid that can have an approach that is friendlier for the environment by having electricity generated from renewable energy. The Micro Grid can collect renewable energy [42], and storing it for later use [43]. Storing for later use can help make the Micro Grid a more reliable source of electricity as it will be more readily available for the Micro Grid and the renewable energy collected does not have to be used right there and then. Another aspect of the Micro Grid is being able to share or sell electricity that was generated after storing it [42]. The Micro Grid would make you more self-sustainable with the help of the renewable energy, and the remainder would be sold off within the Micro Grid. When referring to the Micro Grid and the electricity tracking, the technology used for measuring is called the Smart Meter. The Smart Meter would be calculating the amount of energy collected and used, as well as collecting the data necessary to help the users save money on paying for electricity [42]. It can be a way of handling the supply and demand of the energy in the Micro Grid, but not limited to it [41].

**Laws Associated with Smart Meter Technology.** As of now, the European Union (EU) has said that about 80% of European Union homes must have a Smart Meter installed by 2020. To go with this, majority of the European Union member states have implemented electricity Smart Metering [40]. As much as Smart Meter programs seem to be a major part of energy policies in many European countries, they are not just for the supply and demand of energy in the grid, but to support other sustainable energy or climate change policies [40]. In the United States, the Energy Policy Act of 2005 supports the
development in a Smart Grid and a Smart Meter. The Act “directs all utilities in the country to consider time-based rate schedule and time-based metering upon the request of customers.” [40]. Also, there happens to be an Act called the American Recovery Act of 2009, which supports the progress of Smart Grid and Smart Grid related technologies and are willing to provide grants for the development.

**How Does It Work**

The technology behind a Micro Grid and mainly, the Smart Meter, can be explained that for every home that is a part of the Micro Grid, there is a Smart Meter that tracks all the power coming in and out of the Micro Grid. This makes the Smart Meter capable of collecting data such as the total power generated from renewable energy, the total power used, and the total power that was stored in the battery. Also, this technology can be used in measuring the amount of needed and used overall by the home. This can help calculate when power is needed, what the peak times are, the amount of unnecessary power used, and where to find a better source of power for the best possible savings. Another way the Micro Grid works is on an “island mode”, in which it is disconnected from the Micro Grid. With certain controls and commands added in, a Micro Grid was able to work on its own and maintain a farm while the owners were away [44]. While there was an instance of a wild fire occurring and while the owners left to seek shelter from the fires, the Micro Grid maintained the irrigation system for 10 days [44].

**How Does It Relate**

The Micro Grid and the Smart Meter are huge parts of the Peer to Peer Energy Exchange project as the Micro Grid can be used for energy exchange and the Smart Meter used as a measuring tool. With residential users collecting and making their own power, there must be some way of measuring how much they use, need, and have. The whole idea of the project is to have a system in which residential users can pay for power from their neighbors that was generated from collecting sunlight on their solar panels in the Micro Grid, so this is a very crucial part of the project and relates very closely.
Gap Analysis

The gap is the ability to use potential excess solar PV energy production and avoid wasted energy produced during daylight hours from residential users to offset peak demand of industrial users to stabilize cost in overall electrical energy costs over time.

Win-Win Analysis: Lower all regulatory restrictions for residential solar PV systems collectively to trade with an industrial user, favorably renewable energy solar market on peer-to-peer energy trading, and continual use of passive renewable energy from residential users to eliminate unutilized wasted solar energy.

Problem and Need Statement

Problem Statement
Residences with solar panels generate electricity during daylight hours when the demand for electricity at the typical residence is at its lowest. In locations without net metering, the excess energy is not taken in by the utility and is wasted into the ground.

Need Statement
There is a need for a P2B energy trading platform to mitigate peak energy demand, lower energy variability, reduce wasted energy, and utilize excess solar PV energy. The system is designed for residences with available excess solar energy, so they can pool their energy generated in daylight hours and trade at their own discretion.

Stakeholder Analysis
Before developing a system, it is necessary to understand the current system and all its different stakeholders that are directly and indirectly involved with the system. The project scope is determined to be within an area of the same energy grid.
Stakeholders are divided into two categories: Primary and Secondary stakeholders. Primary stakeholders are employees, network operators, energy companies, residential users, and commercial users. Secondary stakeholders are regulators and banks.
<table>
<thead>
<tr>
<th>Position</th>
<th>Stakeholders</th>
<th>Objectives</th>
<th>Conflicts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Residential Users</td>
<td>Have a reliable source of energy from producers on the network to power their homes without power outage.</td>
<td>Availability of power at peak demand times and an increase in energy costs.</td>
</tr>
<tr>
<td>Primary</td>
<td>Commercial Users</td>
<td>Have a reliable source of energy from producers on the network to power their businesses without power outage.</td>
<td>Availability of power at peak demand times and an increase in energy costs.</td>
</tr>
<tr>
<td>Primary</td>
<td>Employees</td>
<td>Intellectual capital and labor to operate the energy network.</td>
<td>Increase in efficiency of automation along the network can potentially cause loss of jobs.</td>
</tr>
<tr>
<td>Primary</td>
<td>Network Operators</td>
<td>Provide access to and balance supply and demand of users of the networks.</td>
<td>Conflict with network operators in balancing the needs of conventional energy users meeting peak demand with those residential/commercial end users.</td>
</tr>
<tr>
<td>Primary</td>
<td>Energy Companies</td>
<td>Develop and maintain a profit model to meet peak demand sourcing of the entire network; Lower transactional costs of operating the network.</td>
<td>Safely delivering power to users from different energy sources while minimizing disruption of power as peak demand and energy costs rise. Regulations that were set can restrict business models.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Energy Generators: Produce energy for the network based on consumer demand.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Energy Transmitters: Move electrical energy from the generating site to an electrical substation.</td>
<td></td>
</tr>
</tbody>
</table>
Secondary Regulators

Ensure justified and reasonable rating schemes, terms, and conditions to consumers through regulatory oversight on energy companies and network operators. Ensures safety and regulatory standards for the network.

Provide safety regulations for the energy infrastructure so there are no issues with generation and distribution of power. Regulators set rules the energy companies and businesses must follow.

Secondary Banks

Provide a secure means of conventional energy transactions between users and energy companies. Ensure a profit model to ensure there are no losses from the energy infrastructure.

Uncertainty of return on investment from the energy infrastructure.

**Primary Stakeholders**

**Residential users** expect rate certainty and reasonable costs to meet power consumption needs without outages.

**Industrial users** expect their peak demand of power consumption to maximize efficiency in their business processes at a profit. Commercial end users have tension with any potential power disruptions that affect their essential point of operations or profits.

**Employees** have an interest in maintaining the status quo with respect to how labor requirements are allocated based on consumer peak demand to maintain energy generation and distribution over the network. Employees have tensions with efficiency with improvement to the network potentially resulting from the loss of employment.

**Network operators** have an interest in meeting peak consumer demand over an aging network grid. What this means is that minimizing power outages and expanding capacity to meet those growing needs of the state and regional are in their direct interest in the current system. Network operators have tension amongst other stakeholders to balance the needed upgrades to the infrastructure while still maintaining peak energy consumption to the network.
Energy companies have a direct interest meeting peak demand consumption safely with profit to shareholder and long-term expansion of infrastructure requirements. The tension with energy companies is the strategic investment of a variety of energy sources to minimize disruptions to the ever-growing peak demand.

Secondary Stakeholders

Regulators provide oversight for safety and network infrastructure changes without power grid disruptions.

Banks needs to provide a secure means for customer transaction at a profit. The banking industry has tensions with the uncertainty of energy investment and the impact to the traditional financial model.

The execution of our the project would begin with a developer (investor) interested in financing and building a solar PV housing subdivision along with the local county land and development office who is the regulating body for zoning and permitting.

The State of Virginia would determine if subdivision should be classified as a Utility Substation and may require legislative action. Once approved, the developer hires a builder for the property and at 75% completion point of the subdivision works with residents to draft the Articles of Incorporation establishing the HOA and then the CCR for HOA guidelines. The primary tension (highlighted in RED) would be between HOA and Industrial User in energy trading and the regulators and the developers. The potential resolution of those tensions start at the beginning of the process through public-private partnerships, establishing power purchase agreements and guidelines in the HOA Charter and Covenants, Conditions, and Restrictions (CCR).

For example, if the MEX system were used in Loudoun County, Virginia, “Dillon’s Rule” would apply and states that the County may adopt an ordinance only if the General Assembly in Richmond has clearly granted authority for the local government to make decisions on that topic. According to the Loudoun County Land and Development Office, “the Commonwealth of Virginia has granted the County of Loudoun (and all other Counties in the State) the ability to control land use through several different regulatory instruments - starting with the Comprehensive Plan (an overall policy document, approved by the Board of Supervisors as a guide for future growth) and the Zoning Ordinance (a regulatory document that sets forth the
rules for different zoning districts, in substantial conformance with the Comp Plan), along with other documents.

The Zoning Ordinance (ZO) regulates what land uses can go where and what uses can happen on the land. While the ZO regulates many uses in the different districts, typically utility uses such as the distribution of power to individual customers, telephone, cable television, electricity, gas, water, and the collection of sewage are explicitly exempt from the local ZO regulations. However, the ZO does regulate ‘Utility Substations’ under Section 5-616 of the Revised 1993 ZO.

Under this project scenario of having a subdivision of 250 homes with individual networked solar PV systems, that would trade excess renewable solar energy to an industrial user, Loudoun County would be the regulatory body for the zoning (where the panels are located – i.e., roof-top, stand-alone in yard, etc.), the permitting, and if it were to be considered a Utility Substation, the need for legislative approval (Commission Permit). However, I believe that the major regulatory hurdles would come from the Code of Virginia, and the Virginia Electric Utility Regulation Act” [16].

The potential resolution of tensions associated to industrial users would be receiving a consistent flow of energy that will not be disrupted due to the lack of available excess energy. Resolution of these tensions could be resolved through a series of public-private partnerships and power purchase agreements between HOAs and the utility providers.
Figure 19: Major interactions between stakeholders in the power generation and distribution enterprise.

**Concept-of-Operations**

The Microgrid Energy Exchange (MEX) is a system that allows HOA users collectively negotiate with an industrial user like George Mason University, establishing a power purchase agreement (PPA), and resolve cost structures, billing transactions, and resolution of billing disputes within the microgrid from generated excess renewable solar energy. The concept presumes new construction of smart technology homes with energy efficient appliances and solar PV systems installed by the builder or developer of the property. Residents would pay a flat rate of $225.00 per month for 25 years, regardless of the amount of energy consumed in the home. Residents would agree the specific conditions and guidelines of the HOA in the Covenants, Conditions, and Restrictions (CCR) conditional on the sale of the property. MEX would make suggestions or recommendations for a third party vendor providing microgrid technical solutions.
Each home will require solar PV components installed for generating and trading power. Major components include solar PV panels, arrays, power controller, battery storage systems (connected to a clustered of four houses), smart meters to monitor bi-directional energy use, and power inverters.

![Sequence Diagram](image)

Our sequence diagram in Figure 14 outlines how the proposed process begins. The energy trading platform will be an add-on platform connected via the cloud to the microgrid to collect, monitor, and interact with the main microgrid operator of the HOA. Within the energy-trading platform, the HOA user would access the user platform and search for the available energy in the microgrid battery storage system and passively trade with the industrial user based on the rate structure in the PPA. Residents would pay the flat rate to the HOA. The platform checks for power availability. Once verified, HOA will distribute power to the residents and GMU. The energy trading platform would produce e-receipts to the residents and GMU along with data and predictive analytics on individual residential use, microgrid operations, and to GMU. HOA Users would access the energy trading platform to initiate and confirm energy trades, verify the energy levels in the battery storage systems, confirm power distribution and confirm availability of
funds. Figure 22 below demonstrates the HOA user interactions on the energy trading platform.

Figure 21: P2B Energy Trading Platform

**Graphical User Interface Design**

With the excess energy going to waste a graphical user (GUI) interface was developed to centralize trade for energy and for users with the need for it. The main goal of the GUI is to develop a way to transfer energy and allow payment contracts between consumers and producers. It is designed to be part of the MEX system to offer a more interactive online agreement process to place trades between the users producing energy with solar PV system and the users with the need for excess energy. The platform will have an energy management system that monitors and provides value to utilize excess renewable solar PV energy. The system is designed in which residences with available excess solar energy generated in daylight hours will have flexibility with how they use their energy, and thus can trade the energy based on their set up rates to the consumers. However, this platform is yet to reach its full completion using Excel VBA; thus, a prototype has been initialized. Development begins with coding parts of the platform that provides options for trading including: listing the available energy and setting the price,
browsing available energy, purchasing available energy, and viewing transaction history. The main processes of the system were based from use case models and the sequence diagrams which was designed before building the platform. Two main functions were made as a use case scenario for energy trading, one for the transfer of energy from seller to buyer, and one for the transfer of funds from buyer to seller.

The figure is an overview for the different functions and interactions within the trading platform. The main functions are as follows: ability to set up user profile, monitor energy flow, confirming energy availability, transferring energy, checking account balance, transferring money, and using maintenance and support. Users on both ends will be able to set up a user account. Within the platform, there will also be a feature that allows energy usage monitoring for each user. The information will be provided to each user to help optimize their energy usage and make it more
efficient and reliable. Then, there must be functions that support the trading of energy. Users on both end will be able to see the availability of power before the energy is transferred, and users must be able to check their balances. When the trading occurs, there must be a process which allows the buyer to confirm their account balance to see required funding for trading. There must also be a maintenance and support function in which the system and the components need to be maintained with updates and tests to make sure it is working as planned. The support function is built in case users have issues with any aspect of the system; whether it is inputting their login information, to receiving their money in their account balance or receiving power that they paid for.

Figure above demonstrates the different functions and interactions within the trading platform of how the funds would be transferred. This is broken down from the MEX overview of the system use cases which is a decomposed in functions, to be specific to transferring funds. Users would
be able to set up a profile, monitor energy usage, check personal balances, and transfer money. The account balance would be an interaction with transferring funds as the money would be traded between users. The process is a contract between the buyer to the seller, as the buyer is receiving power from the seller with produced excess energy, in exchange for money. The users can verify available balance and the arrows signifies how funds are transferred from the buyer to the seller.

![Figure 24 MEX System Use Cases (Transfer of Energy)](image)

The figure above shows the different functions and interactions within the trading platform of how the energy would be transferred. The users can check available energy for trading and the arrows signifies how it is transferred from the seller to the buyer. Users will set up a profile, monitor their energy use, and check available power for trading. Both buyers and sellers can
view the available power for sale, and once the buyer agrees to the terms of the trade, the energy is transferred from the seller to the buyer. This process occurs during the same time as the transfer of funds, the buyer would receive what they paid for.

The energy trading platform and the steps necessary for a complete trade. First, the user logs onto the platform and the platform confirms the availability of funds for the buyer and the available energy for trading for the seller. Once it is verified, trade is initiated, and the amount traded is verified by the smart meter. The power distribution is then confirmed, the platform confirms the trade, and an e-receipt is sent to the user.

Figure 25 MEX System Energy Platform
Using VBA and Microsoft Excel, a prototype construct was developed which begins with the user logging onto the platform using their name and login information, then their user profile would be provided with options of: payment options, transaction history, and selecting whether they wish to buy or sell energy. The seller’s page would be shown as providing a way of inputting the available power, at what quantity and the price they wish to trade it at. The buyer’s page would give them options of viewing the available power listings and selecting the appropriate one to fit the buyer’s needs. They would then checkout, thus agreeing to the trade. Once there is a verification process of the available funds and power, the users involved with the trading would receive an E-Confirmation for the trade including a transaction number, information on the users who traded, and when it occurred.

**Requirements**

The requirements for the Peer-to-Business energy trading system was derived from our main purpose of reducing cost of utility for users and allow users to obtain energy during peak demands. Our requirements were also derived from suggestions and recommendations from our engineering staff and faculty members. Our priority was to develop a system which incorporated a network between energy users who have the accessibility and availability to trade in or sell excess energy within the microgrid.
The diagram above is a demonstrates how the Microgrid Energy Exchange(MEX) simulation works. The inputs of the simulation are hourly weather data for every 15th day of each month in 2016 that was obtained from Aviation Weather Center [51], Energy users which are the appliances expected for each household to have including the HVAC system [52], energy generator including 33 solar panels visibility of sunlight, cloud ceiling [53] and energy profile of each appliance which is the probability of each appliance being used every hour of day and its rating [54]; The more frequently a device is used, the higher the probability is. The outputs of the simulation are hourly energy demand, hourly energy supply and hourly excess energy, which is determined by the difference of the amount of energy supplied/generated and the amount of energy needed/consumed.

Decomposed IDEF1 is attached in the appendix.
Microgrid Energy Exchange (MEX) System Requirements

SR 1: MEX shall provide Peer-to-Business energy trading over the microgrid
SR 2: MEX shall provide access to energy based on solar availability
SR 3: MEX shall measure energy demand with 99% accuracy
SR 4: MEX shall measure energy produced with 99% accuracy
SR 5: MEX shall use energy produced to be distributed
SR 6: MEX shall have produced energy stored
SR 7: MEX shall use Smart Meter with 99% accuracy
SR 8: MEX shall create Smart Contracts upon agreement of transaction

Functional Requirements

FR 1: MEX shall allow user to set up user account.
FR 2: MEX shall calculate and keep record of renewable energy generated, stored within the battery, and used.
FR 3: MEX shall allow user to set rates for renewable energy to be traded.
FR 4: MEX shall verify and confirm availability of power available to trade.
FR 5: MEX shall verify and confirm availability of funds in bank account.
FR 6: MEX shall provide confirmation of Smart Contract agreement between prosumer and consumer.
FR 7: MEX shall track power distributed from prosumer to consumer.
FR 8: MEX shall provide consumer with transaction bill upon completion of Smart Contract.
FR 9: MEX shall provide transfer of funds between consumer and prosumer.
FR 10: MEX shall track and record all energy transactions.

Simulation Design

The simulation is designed to evaluate the feasibility of P2P energy trading within a microgrid Energy Exchange (MEX) community. The simulation will aid in evaluating the availability of excess energy and the accessibility for Peer to peer trading based on residential user profile, commercial user and solar energy generation capabilities. The following objectives have been identified for the simulation model.
**Simulation Objectives**

SO1: Identify overall residential and industrial demand

SO2: Identify residential solar generation.

SO3: Identify when supply and demand are the highest and the lowest.

SO4: Identify average supply and demand.

SO5: Identify average excess energy and wasted energy.

SO6: Identify minimum supply to meet demand requirements.

SO7: Identify residential energy demand hourly, daily, monthly, and yearly.

SO8: Identify industrial energy demand for specific building hourly, daily, monthly, and yearly.

SO9: Identify residential solar generation supply hourly, daily, monthly, and yearly.

SO10: Identify months with the highest solar generation.

Provided objectives are to determine excess generation from residential users and whether these excess energies can be utilized to industries.

**Simulation Requirements**

1) **Solar PV Simulation Requirements**

PVR1 Solar PV Simulation shall calculate daily, monthly, and yearly energy generation.

PVR2 Solar PV Simulation shall calculate excess energy amount.

PVR3 Solar PV Simulation shall make at least 100 replications.

PVR4 Solar PV Simulation shall determine generation average and standard deviation.

PVR5 Solar PV Simulation shall determine minimum excess energy to meet residential demand and industrial demand.

2) **Residential Demand Simulation Requirements**

RDS1 Residential Demand Simulation shall record daily, monthly, and yearly energy demand.
RDS2 Residential Demand Simulation shall identify peak hours of energy use.

RDS3 Residential Demand simulation shall make at least 100 replications.

RDS4 Residential Demand simulation shall determine demand average and standard deviation.

3) Industrial Demand Simulation Requirements
IDSR1 Industrial Demand Simulation shall record daily, monthly, and yearly energy demand for GMU engineering building.

IDSR2 Industrial Demand Simulation shall identify variations of energy usage.
### Simulation Inputs, Outputs and Parameters

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Parameters</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appliance List</td>
<td>Watt</td>
<td>Excess Energy kWh</td>
</tr>
<tr>
<td>Probability of Appliance usage</td>
<td>%</td>
<td>Array tilt Degree</td>
</tr>
<tr>
<td>Hourly temperature</td>
<td>Degree</td>
<td>Array Azimuth Degree</td>
</tr>
<tr>
<td></td>
<td>Effciency</td>
<td>Invertor Efficiency %</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hourly Total Energy kWh</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Consumed kWh</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Generated kWh</td>
</tr>
</tbody>
</table>
The table shows the inputs, outputs, and the parameters to the simulation model. The inputs were determined by key components which affect overall kWh usage. The appliance list and its probability affect residential demand for energy; which are randomly generated. Much of the key dataset for the appliances were comprised of common items for a single-resident household. The hourly temperature and annual average solar irradiation based were built for the inputs of solar panels. Lastly, the input known as the history of energy usage is specifically labeled for industries’ past energy usage. In this simulation, we have identified George Mason University engineering building as our source of historical data.

Most of the elements for the parameters were built for solar panels. Each element greatly impacts the energy the panels generate. The tilted angles signify key optimal angles panels must be adjusted to for it to receive maximum efficiency. The table below demonstrates key angles based on month which are obtained from NASA Surface meteorology and solar energy.³

³ https://eosweb.larc.nasa.gov/sse/text/definitions.html

| Lat  | 38.828 | Panel Area | kWh/m² | Panel Yield | % | System Losses | % | Time of Day | hr | Annual Avg solar irradiation kWh/m² | Panel Area m² | History of Energy Usage kWh | Panel Area m² | Panel Area m² | % | System Losses | % | Time of Day | hr |
|------|--------|------------|--------|-------------|---|---------------|---|--------------|----|---------------------------|--------------|---------------------------|--------------|-------------------------|---|---------------|---|--------------|----|----------------|----|
| SSE  | 77.305 | 2.12       | 2.87   | 3.91        | 4.86 | 5.4 | 5.8 | 5.67 | 5 | 4.38 | 3.51 | 2.36 | 1.89 | 3.98            |
| K    |        | 0.46       | 0.47   | 0.49        | 0.49 | 0.48 | 0.5 | 0.5  | 0.48 | 0.51 | 0.53 | 0.48 | 0.46 | 0.49            |
| Diffuse | 0.85   | 1.15       | 1.56   | 2            | 2.34 | 2.46 | 2.38 | 2.12 | 1.68 | 1.21 | 0.91 | 0.76 | 1.62            |
| Direct| 3.48   | 3.87       | 4.39   | 4.69        | 4.72 | 5.07 | 5.03 | 4.58 | 4.76 | 4.84 | 3.74 | 3.28 | 4.37            |
| Tilt 0| 2.1    | 2.79       | 3.87   | 4.83        | 5.37 | 5.75 | 5.63 | 4.98 | 4.31 | 3.48 | 2.33 | 1.88 | 3.95            |
| Tilt 23 | 2.98   | 3.55       | 4.47   | 5.08        | 5.32 | 5.56 | 5.5  | 5.09 | 4.82 | 4.4  | 3.22 | 2.77 | 4.4             |

---

³ https://eosweb.larc.nasa.gov/sse/text/definitions.html
The labels and its meanings are as follows:

**SSE HRZ**

The monthly average amount of the total solar radiation incident on a horizontal surface at the surface of the earth for a given month, averaged for that month over the 22-year period (Jul 1983 - Jun 2005).

**Clearness Index (K)**

The monthly average amount of the total solar radiation incident on a horizontal surface at the surface of the earth divided by the monthly average incoming top-of-atmosphere insolation for a given month, averaged for that month over the 22-year period.

**Diffuse**

The monthly average amount of solar radiation for a given month incident on a horizontal surface at the surface of the earth under all-sky conditions with the direct radiation from the sun's beam blocked by a shadow band or tracking disk, averaged for that month over the 22-year period.

**Direct Normal**

The monthly average amount of direct normal radiation incident on a surface oriented normal to the solar radiation for a given month, averaged for that month over the 22-year period.

**Tilt 0, Latitude-15, Latitude, Latitude+15, 90**

The monthly average amount of the total solar radiation incident on a surface tilted relative to the horizontal and pointed toward the equator for a given month, averaged for that month over the 22-year period (Jul 1983 - Jun 2005). Note that the differences between the Tilt 0 values and the SSE HRZ values are due to approximations in the inputs and time integration inaccuracies when processing the equations and integrating over the "monthly average day" (SSE Methodology). Total solar radiation for each tilt
angle was determined using the RETScreen Isotopic Diffuse Method discussed in SSE Methodology.

**OPT**

The monthly average amount of total solar radiation incident on a surface tilted at the optimum angle relative to the horizontal and pointed toward the equator.

**OPT ANG**

The angle relative to the horizontal for which the monthly averaged total solar radiation is a maximum.

**Units**

- SSE HRZ, Diffuse, Direct Normal, and OPT in kWh/m²/day
- Tilt angles and OPT ANG in degrees
- K is dimensionless

The panel efficiency or panel yield is based upon the solar panel efficiency. Most solar panel efficiency ranges from 15% to 21%. The efficiency of the panels also degrade overtime which averages to roughly 0.6% decrease per year. Better, high-end models such as LG and Panasonic have a 0.4% degrading rate per year. Panel area is measured by size of the panels rather than the number of panels installed. (ex: module efficiency starts with 19.6 with 98% efficiency, and after 2nd year 0.55% annual degradation. By 25 years, module efficiency reduces to 84.8%)

System losses are other miscellaneous components which affects solar generation; which are identified in the table below. Note that the percentage with each subcategory system losses are sample numbers; specific range of the system losses have been identified below as “System Losses Details.”

*Table 4 System Losses*

<table>
<thead>
<tr>
<th>System Losses</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soiling</td>
<td>2.0%</td>
</tr>
<tr>
<td>Shading</td>
<td>3.0%</td>
</tr>
</tbody>
</table>

---

4 https://news.energysage.com/what-are-the-most-efficient-solar-panels-on-the-market/
<table>
<thead>
<tr>
<th>Parameters</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Array tilt</td>
<td>Optimal (South facing)</td>
</tr>
<tr>
<td>Array Azimuth</td>
<td>Optimal (South facing)</td>
</tr>
<tr>
<td>Panel Area</td>
<td>55 meters squared</td>
</tr>
</tbody>
</table>

The last component of the parameter is time of day which affects residential demand, supply, and industrial demand.

As for the output, we want three key components: residential demand, their solar generation, and the GMU engineering building demand.

For the simulation, we have standardized the following parameters.
Once standardized, the simulation will run at least 100 replications.

**Transfer Function**

Three major components were used to determine excess solar energy: residential demand, industrial demand, and residential solar generation. The figure below demonstrates the relationship of the inputs, parameters, and the output; the basis for the probabilistic simulation model. The probability of appliance usage, radiation levels, weather, and historical data are set randomly for the simulation.

The figure above highlights a visual representation of the simulation model with the three major elements mentioned earlier: residential energy demand, solar generation, and industrial energy.
demand. The simulation will help with recording the energy production from residential solar PV system to determine whether there is an available excess energy produced or not.

The figure above shows another visual representation of how the simulation model. Taking the month of July as an example and running the simulation 100 times, the produced graphs are a sample output. As mentioned in the context, the key pattern to the energy usage vs energy generated is that the times when energy used have little to no energy generated while during times when energy demand is low (valley) is when energy generation peaks. The simulation
using the historical data of the engineering building in GMU, shows that there is little variation over the 24-hours.

Equations

**Residential Demand**
The hourly energy demand for all house appliances except the HVAC system is the product of each appliance’s rating and the probability of each one being used every hour of day. Our simulation for energy demand was done based on some assumptions regarding the average rating of each house appliance and how frequently each appliance is used.

**Hourly energy demand for House Appliances = Appliance Rating* Probability usage**

Hourly Energy Demand for HVAC: 

\[
\text{Hourly Energy Demand for HVAC} = (\text{Outside Temperature} - 72^\circ F) \times 0.023 \times 3.5
\]

The total hourly energy demand is the sum of the hourly energy demand for all house appliances and the hourly energy demand for HVAC.

**Total Hourly Energy = Hourly energy demand for House Appliances**

\[+ \text{ Hourly Energy Demand for HVAC} \]

The table below shows a sample list of appliances for a single household. The probability has been set randomly but with implication of time; meaning, there’s higher traffic in energy usage during morning and evening time. In addition, there’s higher traffic in energy usage throughout
the day during weekends, holidays, and emergency situations. For this simulation model, we have set the appliance detail on a weekday to weekday basis.

*Table 5 Appliance List and Probability*
<table>
<thead>
<tr>
<th>Appliance</th>
<th>12:00 AM</th>
<th>3:00 AM</th>
<th>6:00 AM</th>
<th>9:00 AM</th>
<th>12:00 PM</th>
<th>3:00 PM</th>
<th>6:00 PM</th>
<th>9:00 PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>100W light bulb (Incandescent)</td>
<td>0.1</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.9</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>Ceiling Fan</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Clothes Dryer</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.7</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Dishwasher</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.7</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Food Blender</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.5</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>Fridge / Freezer</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Hair Blow dryer</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Inkjet Printer</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.2</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>Iron</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.3</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>Laptop Computer</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.3</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>LED Light Bulb</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.9</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>Microwave</td>
<td>0.001</td>
<td>0.001</td>
<td>0.5</td>
<td>0.5</td>
<td>0.001</td>
<td>0.001</td>
<td>0.5</td>
<td>0.1</td>
</tr>
<tr>
<td>Oven</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.5</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Toaster</td>
<td>0.001</td>
<td>0.001</td>
<td>0.5</td>
<td>0.5</td>
<td>0.001</td>
<td>0.001</td>
<td>0.5</td>
<td>0.1</td>
</tr>
<tr>
<td>Vacuum Cleaner</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Washing Machine</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
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</table>
Using the probability of each appliances, we can then calculate energy usage (in Watts) prediction and record the total. Sample energy usages are demonstrated below.

Table 6 Appliance list and Wattages

<table>
<thead>
<tr>
<th>Appliances</th>
<th>Hourly Consumption (W)</th>
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<tbody>
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</tr>
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</tr>
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<td>Dishwasher</td>
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</tr>
<tr>
<td>Blender</td>
<td>350</td>
</tr>
<tr>
<td>Refrigerator</td>
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</tr>
<tr>
<td>Hair dryer</td>
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</tr>
<tr>
<td>HVAC</td>
<td>3500</td>
</tr>
<tr>
<td>Printer</td>
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</tr>
<tr>
<td>Iron</td>
<td>1000</td>
</tr>
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<td>Internet router</td>
<td>10</td>
</tr>
<tr>
<td>Laptop computer</td>
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</tr>
<tr>
<td>Microwave</td>
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</tr>
<tr>
<td>Oven</td>
<td>2150</td>
</tr>
<tr>
<td>Washing machine</td>
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</tr>
<tr>
<td>Vacuum Cleaner</td>
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</tr>
<tr>
<td>Toaster</td>
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</table>

The average total daily residential demand resulted around 39.5 kW. After determining the average, residential bulk average can be randomly generated with -10% to 10% (below table).
### Table 7 Simulated Residential Demand

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<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
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Supply
The global formula to calculate the energy generated in the output of the PV system is as follows:

\[ E = A \times r \times H \times PR \] \(^5\)

Where, E is the total energy in kWh, A is the total panel area measured in meters squared, r is the solar panel yield or efficiency (%), H is the annual average solar radiation on tilted panels, and PR is the performance ratio or system losses.

For the simulation, we have set A to 55 meters squared, r to 18.5%, H to a historical radiation database,\(^6\) and PR set randomly based on season and time:

**Performance Ratio**

\[ PR = (1 - PR_1)(1 - PR_2) \times \ldots \times (1 - PR_n) \]

*Table 8: Performance Ratio Chart*

<table>
<thead>
<tr>
<th>Performance Ratio</th>
<th>Range</th>
</tr>
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<tbody>
<tr>
<td>PR1: Inverter Losses</td>
<td>6% - 15%</td>
</tr>
<tr>
<td>PR2: Temperature Losses</td>
<td>5% - 15%</td>
</tr>
<tr>
<td>PR3: DC Cable Losses</td>
<td>1% - 3%</td>
</tr>
<tr>
<td>PR4: AC Cable Losses</td>
<td>1% - 3%</td>
</tr>
<tr>
<td>PR5: Shadings</td>
<td>0% - 40%</td>
</tr>
<tr>
<td>PR6: Losses due to shading, dust, snow</td>
<td>0 – 2%</td>
</tr>
<tr>
<td>PR7: Misc.</td>
<td>~ %</td>
</tr>
</tbody>
</table>


### Historical Radiation Database

*Table 9 Radiation Database based on one day, one month measured in Watts*

<table>
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<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
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<td>0</td>
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</tr>
</tbody>
</table>

**Daily Total**: 2251.5 3171.6 3921.2 5684.8 5566.6 6343.4 6379.7 5233.2 4688.7 3399.7 2486.9 1986.7 4258.7 W

The data used to calculate the energy supply, which includes hourly solar radiation and hourly solar generation, were obtained from National Solar Radiation Database. A sample simulation input is found below.
Table 10 Sample Solar Generation Input Database

<table>
<thead>
<tr>
<th>Global formula : ( E = A \times r \times H \times PR )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E = ) Energy ( (kWh) )</td>
</tr>
<tr>
<td>( A = ) Total solar panel Area ( (m^2) )</td>
</tr>
<tr>
<td>( r = ) solar panel yield (%)</td>
</tr>
<tr>
<td>( H = ) Annual average irradiation on tilted panels (shadings not included)</td>
</tr>
<tr>
<td>( PR = ) Performance ratio, coefficient for losses (range between 0.9 and 0.5, default value = 0.75)</td>
</tr>
</tbody>
</table>

Total power of the system 54.0 kWp

Losses details (depend of site, technology, and sizing of the system)
- Inverter losses (4% to 10%)
- Temperature losses (5% to 20%)
- DC cables losses (1 to 3%)
- AC cables losses (1 to 3%)
- Shadings 0% to 40% (depends on site)
- Losses weak irradiation (3% to 7%)
- Losses due to dust, snow... (2%)
- Other Losses 21%

Simulation Results
This section will discuss the results of the simulation models. The simulation was done using Microsoft Excel and VBA. Two simulations were used to model a typical Residential energy consumption demand and energy supply for one day. A third simulation was used to determine GMU energy demand specifically the Engineering Building and finally replicating the simulation 100 times. Simulation VBA coding attached in the appendix.

| number of homes | 255 | number of reps | 10 |

| Residential Demand | | Residential Generation | | Excess |
|---------------------|-----------------|------------------------|----------------|
| 12081.40 | 26.41 | 9170.38 | 25.17 | 4034.20 | 17.14 |

Figure 29 Simulation Screenshot
Utility Analysis

The utility analysis considered the following attributes when examining the potential benefits of a P2B energy trading microgrid system for solar PV residential users: (1) Pay Less in kWh (0.5), (2) Avoid Increasing Energy Costs (0.1), (3) Revenue from Solar PV Production (0.5), (4) Reduce Losses in Dollars per kWh (0.5), Energy Independence (0.1), and Reduce Seasonal shifts (0.3) cited in Figure 13. When comparing the option of ‘Do Nothing’ to the implementation of the MEX system when 100 residents exercise status quo of paying their monthly energy bills at a historical annual increase of 3.2% resulted on zero utility and no cost savings. If the microgrid energy trading system is installed and used by the same 100 residents, the overall savings over a 25-year period is estimated $9.3M with a 0.8 utility.

The business case analysis provides access to the energy trading platform for a monthly rate of $5,000 and 2 cent per kWh per trade between residential subdivisions and an industrial user. With an initial investment of $30,000 and annual operating costs estimated at $80,000, MEX breaks even in the first year with five and ten-year profit projections of $720,000 and $1,500,000 respectively, and a return of investment of 64.56% in Figure 12. The breakdowns of initial costs are computer programmer contract for $50.00 per hour for 120 days (5 day work week) for developing the graphical user interface and platform to host on Amazon Web Services estimated at $500 per month. The remaining costs are part-time staff, office space, and marketing/advertising.
Detailed list of utility analysis is attached in the appendix.
Business Case

Business Plan

MEX plans to generate profit from a monthly access fee from HOAs to the energy trading platform graphical user interface and per kWh transactional charges for each trade. HOA users will have the option of trade transactions based on available stored renewable solar energy in their battery energy system. The Advanced Metering Infrastructure and the Energy Management System will provide real-data analysis on their energy consumption and amount of energy users are willing to exchange with an industrial user.

The sales projections are based on solar projections forecasts from GTM Research for the Commonwealth of Virginia with a labor forecast in solar installation of 50,000 jobs [12]. Currently, MEX has no direct competitors, and the system is positioned ahead of the market demand for this unique, renewable energy solution. The MEX system provides potential business market applications for any large residential subdivisions greater than 200 or more houses adjacent to any hospital, university, high school campus, data center, or small shopping center with the ability to utilize power purchase agreements (PPA) to trade renewable solar energy. We expect an average market growth rate of 10% based on market research and to reach our potential HOA and homebuilder customers through a series of annual conferences and conventions. At this time, we have no direct competitors and we provide microgrid components and access to an energy trading platform with a menu of buying options to generate revenue on each residential energy trade.

The customer value chain, in Figure 12, describes who, from survey market research, are our customers. Based on this research, the results reveal that individuals interested in the MEX system, based on geographical location, would tend to reside in high cost of living areas, high income earners, over the age of 50, are environmentally conscious, and have higher education or advanced degrees [11].
Figure 32 Customer Value Chain

Figure 33 System Business Case Projections
**Business Case for Residential Solar Energy Generators**

Homeowners Associations (HOA) is a primary stakeholder for the microgrid exchange system for residential single-family households in the state of Virginia. The trend of HOAs continues to grow, as the number of HOAs in Virginia is 8,600, representing 1.7M residents, ranking 12th in the nation [5]. The results of the business case analysis and the policy analysis of the legislative environment within Virginia for expansion of renewable solar energy indicates this microgrid system may be ahead of the market with greater potential in other states in the US with more favorable conditions such as state tax incentives, net metering, peer-to-business energy trading, property tax exemptions, tax credits, and solar power rebates [6].

HOAs would charge a flat rate of $225.00 per month from residents and collect 3 cents per kWh, per trade for all excess energy exchanged between the subdivision and the industrial user. HOA pays an monthly access fee of $5,000 per month and allows a 2 cent per kWh per trade for MEX along with an estimated $8,000 per month for operating the microgrid from a third party vendor. The estimated start-up cost for a housing subdivision of 250 houses is $6,300,000 with an annual operating cost of $160,000, breaking even within Year 5 at an $8,000,000 profit and a ten-year profit projection of $39,500,000 with a return of investment of 27.9%. The profit projections over a 25-year period are illustrated in Figure 12 below.

![Figure 34 HOA Business Case Projections](image-url)
Project Plan

Statement of Work
Scope of Work
System model or grid for the P2B energy management is massive. To minimize, and simplify the complexity of the model, the scope of the work for the design of the P2B energy management is within GMU Fairfax campus region.

Period of Performance
The period of performance for the design of the P2B energy trading is about 258 days beginning on August 28, 2017 to May 2018. Unless noted otherwise, all milestones and work will be completed within the proposed time.

Place of Performance
All studies, designs, data allocations, and research will be done at the Fairfax George Mason University campus grounds. In addition, further researches will be held outside of Fairfax grounds such as Washington DC and Maryland grounds. All meetings will be held within George Mason University grounds and through online communication platforms.
Project Schedule

Our schedule is divided to ten higher level categories of Context Analysis, Requirements, Project plan, simulation, testing, Analysis, Project results, Presentations, INCOSE conference and GMU competition. Under each phase, defined tasks are listed with their duration time assigned. Each phase is scheduled based on project briefing deadlines as specific major tasks are required for each briefing. Adjustments will be made continuously to improve our project throughout the span of the academic year. Our entire project is estimated to last 178 days.

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
<th>Predecessors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design FDP Energy Trading Using Blockchains Plan</td>
<td>180 days</td>
<td>Mon 8/28/17</td>
<td>Fri 5/4/18</td>
<td></td>
</tr>
<tr>
<td>1. Content Analysis</td>
<td>15 days</td>
<td>Wed 8/30/17</td>
<td>Tue 9/5/17</td>
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<tr>
<td>1.1. Determine Project Scope</td>
<td>4 days</td>
<td>Wed 8/30/17</td>
<td>Mon 9/4/17</td>
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</tr>
<tr>
<td>1.2. Stakeholder Analysis</td>
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<td>Tue 9/5/17</td>
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<td></td>
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<tr>
<td>1.3. Problem/Need Definition</td>
<td>1 day</td>
<td>Fri 9/8/17</td>
<td>Fri 9/8/17</td>
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<tr>
<td>1.4. Secure CORE Resources</td>
<td>2 days</td>
<td>Mon 9/11/17</td>
<td>Tue 9/12/17</td>
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</tr>
<tr>
<td>1.5. Content Analysis Complete</td>
<td>0 days</td>
<td>Wed 9/13/17</td>
<td>Wed 9/13/17</td>
<td></td>
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<td>2. Requirements</td>
<td>10 days</td>
<td>Fri 9/15/17</td>
<td>Thu 9/21/17</td>
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<td>2.2. System Requirements</td>
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<td>Mon 9/18/17</td>
<td>Fri 9/22/17</td>
<td></td>
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<tr>
<td>2.3. Functional Requirements</td>
<td>3 days</td>
<td>Mon 9/18/17</td>
<td>Wed 9/20/17</td>
<td></td>
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<tr>
<td>2.4. Design Requirements</td>
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<td>Mon 9/18/17</td>
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<td>2.5. Requirements Complete</td>
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<td>Mon 9/25/17</td>
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<td>3. Project Plan</td>
<td>12 days</td>
<td>Fri 9/15/17</td>
<td>Mon 10/2/17</td>
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<td>3.1. Develop Budget</td>
<td>2 days</td>
<td>Fri 9/15/17</td>
<td>Mon 9/18/17</td>
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<td>3.2. Develop Schedule</td>
<td>1 day</td>
<td>Fri 9/15/17</td>
<td>Fri 9/15/17</td>
<td></td>
</tr>
<tr>
<td>3.3. Develop Project Plan</td>
<td>1 day</td>
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<td>Mon 9/18/17</td>
<td></td>
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<tr>
<td>3.4. Develop Statement of Work</td>
<td>2 days</td>
<td>Thu 9/21/17</td>
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<td>4. Simulation</td>
<td>40 days</td>
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<td>4.1. Define Simulation Objectives</td>
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<td>4.2. Develop Simulation Requirements</td>
<td>1 day</td>
<td>Mon 10/9/17</td>
<td>Mon 10/9/17</td>
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<tr>
<td>4.3. Develop Simulation Framework</td>
<td>10 days</td>
<td>Mon 10/9/17</td>
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<td>3 days</td>
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<td>4.3.2. Wind Power Generation Model</td>
<td>3 days</td>
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<td>Thu 10/13/17</td>
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<td>4.3.3. Energy Trading Platform Model</td>
<td>4 days</td>
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<td>4.4. Collect Relevant Data</td>
<td>10 days</td>
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<td>4.5. Enhance Simulation</td>
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<td>5. Testing</td>
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<td>Fri 11/10/17</td>
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<td>5.3. Modify Simulation</td>
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<td>5.4. Output Testing Results</td>
<td>12 days</td>
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<td>5.5. Testing Complete</td>
<td>0 days</td>
<td>Thu 1/11/18</td>
<td>Thu 1/11/18</td>
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<td>6. Analysis</td>
<td>20 days</td>
<td>Mon 1/2/18</td>
<td>Fri 1/26/18</td>
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<td>6.1. Conduct Utility Analysis</td>
<td>10 days</td>
<td>Tue 1/9/18</td>
<td>Mon 1/16/18</td>
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<td>6.2. Conduct Sensitivity Analysis</td>
<td>10 days</td>
<td>Tue 1/9/18</td>
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<td>6.3. Analysis Complete</td>
<td>0 days</td>
<td>Fri 1/26/18</td>
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<td>7. Project Results</td>
<td>20 days</td>
<td>Fri 1/26/18</td>
<td>Thu 2/1/18</td>
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<td>7.1. Conclude Project Results</td>
<td>10 days</td>
<td>Thu 2/1/18</td>
<td>Mon 2/12/18</td>
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<td>7.2. Develop Documentation</td>
<td>10 days</td>
<td>Thu 2/1/18</td>
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<td>7.3. Results Complete</td>
<td>0 days</td>
<td>Tue 3/6/18</td>
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<td>8. Presentations</td>
<td>60 days</td>
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<td>8.1. Faculty Presentations</td>
<td>1 day</td>
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<td>8.5. 6-10 YouTube Video</td>
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<td>Thu 2/8/18</td>
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<td>8.6. Final Source Code</td>
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<td>0 days</td>
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<td>Tue 3/6/18</td>
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</table>
**Budget**
The average national annual salary for an Entry-level Systems Engineer is $77,917. The planned budget consists of labor associated with the systems life cycle. If average hours of work annually are 2080, each member of the team is given an hourly rate of $37.46. Total Budget cost is based on performance of three categories; optimistic with 26 hours/week, most likely with of 39 hours/week and a pessimistic with 52 hours/week. This is based on the completion of the project schedule over the span of two semesters consisting of 178 days. The GMU 2017 Facilities and Administrative Overhead is 52% of the total charge is associated with the project budget. With the consideration of the overhead rate of 52%, the hourly rate is $56.9.

<table>
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<th></th>
<th>Hours</th>
<th>Budget</th>
<th>Overhead</th>
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<td>$77,916.80</td>
<td>$118,433.54</td>
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<tr>
<td><strong>Most Likely</strong></td>
<td>3,120</td>
<td>$116,875.20</td>
<td>$177,650.30</td>
</tr>
<tr>
<td><strong>Pessimistic</strong></td>
<td>4,160</td>
<td>$155,833.60</td>
<td>$236,867.07</td>
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</tbody>
</table>

**Critical Path Analysis**
The critical tasks (highlighted in yellow in the chart below) over the course of the project include the following: Context Analysis, Requirements, System Requirements, Design Requirements, Project Plan, Statement of Work, and Simulation to include the development of the Monte Carlo Simulation of GMU Conventional Energy Production Model, Renewable Energy Sources (Solar and Wind Farms) (Simulink) Model, Grid Battery Storage and Distribution on Smart Grid (Simulink) Model, Energy Trading Platform Model with the Energy Utility Company & Renewable Energy Integration Model. At this point in the project, we are slightly off schedule but have not violated any critical tasks that would cause delays in completing the overall project on-time and on-budget.
Project Earned and Planned Value

The project’s EAC is $208,087.25, ACWP is $15,255.18, and BCWP is $14,536.56. The definitions of each are listed below. The project is roughly $720.00 over budget now. The remaining charts on Cost and Scheduled Variance indicates we are slightly behind project schedule. Cost Performance Index (CPI) and Schedule Performance Index (SPI) graphically depicts the same data which is slightly behind schedule or an unfavorable condition.

**EAC.** Displays the total estimate at completion (EAC). This value represents the aggregate total cost of all actuals over the entire life of the project.

\[ EAC = ACWP + \left( \frac{BAC - BCWP}{CPI} \right) \]

**BCWP.** Displays the system-calculated value of Budgeted Cost of Work Performed (BCWP). The value is calculated and recorded when you baseline a project, or when you update earned value totals. BCWP is also referred to as the earned value (EV). BCWP represents the amount of the budgeted cost (BAC) completed based on performance as measured using the Task EV Calculation method. Calculations are made based on the level at which the calculation is made. BCWP is calculated at the following levels.

Task. BCWP is based on the selected EV calculation method.

**CV.** Displays the system-calculated value of Cost Variance (CV). The CV is the value of what is accomplished to date as opposed to what is spent to date.

\[ CV = BCWP - ACWP \]

**SV.** Displays the system-calculated value of Schedule Variance (SV). The SV is the value of what is scheduled to date as opposed to what is performed to date. A positive value indicates that the work is ahead of the baseline schedule. A negative value indicates that the work is behind the baseline schedule.

\[ SV = BCWP - BCWS \]
**CPI.** Displays the system-calculated value of Cost Performance Index (CPI), which is an efficiency rating for work accomplished. A value equal to or greater than one indicates a favorable condition. A value less than one indicates an unfavorable condition.

\[
CPI = \frac{BCWP}{ACWP}
\]

**SPI.** Displays the system-calculated value of Schedule Performance Index (SPI), which is the ratio of work that is performed to work that is scheduled. A value less than one indicates that the work is behind schedule.

\[
SPI = \frac{BCWP}{BCWS}
\]

**Risk Projections and Mitigation Strategy**

**Risks.** The risks to the project were assessed as the risks above in the chart. There are numerous possible risks to the project including: personal issues, failure to collect data, failure to create a model, failure to properly test, stakeholder conflicts and tensions, weather issues, and school closing. While some of these risks be easily mitigated such as school closing for the day and members doing work at another location, some risks such as failure to collect data can affect the whole timeline of the project. The greater the risk, the higher the number was for the determined risks.

**Mitigation Strategy.** As there are risks to everything, there is also a way to lessen the severity or even avoid the risk entirely. The following mitigation strategies are means of avoiding a risk that can lead to the project being set off course.

**Personal Issues.** With the risk of someone having family issues, or just getting sick, this can pose a threat to the project schedule. There are many possibilities that can distract or draw a group member away from being able to focus on the project. With these possible risks, this can put the group down a person for an undetermined amount of time while on a certain time restricted schedule. As things can unexpectedly occur, group members need to be able to adapt and work from a different environment remotely and communicate amongst each other and fill in for one another if necessary. If there is communication, everything should be able to be as close to the project plan as possible.

**Failure to Collect Data.** The failure to collect the information necessary for the project can set the project back. This could mean the model cannot be created, or even there being an unknown
factor to the system. This can lead to the group not having a full scope of the project and not being able to completely identify the issues. As a means of collecting all the necessary data, the group must search for as many different sources as possible. This will help expand the information that they have available for use.

**Failure to Create a Model.** Creating a model simulation is the biggest risk to the project. Without a proper proof of concept, the project will remain just an idea with no actual proof on how efficient the system really will be. To avoid this issue occurring, the group must understand the complete scope of the project and choose a simulation software they are comfortable with using for this critical part of the project.

**Failure to Properly Test.** With the model being created, the group must know what to do with the simulation they have created. The complete scope of the project is necessary as the group must know how everything works and properly test their simulation, so it can be as realistic as possible. To properly test the simulation, the group must first identify and create a plan to test the simulation and know what to look for.

**Stakeholder Conflict and Tensions.** As the stakeholders are the different parties being affected by the system, the group must be able to avoid any major issues amongst these parties. There cannot be any conflict or tensions between them or this can have a huge impact on the system. The system must the needs and requirements of as many stakeholders as possible. The complete understanding of the concerns of the stakeholders, as well as understanding their needs and requirements will help reach a system that is accepted by all parties. Constant communication will also help, as the stakeholders will be up to date and know what is happening, or if there have been any changes made or need to be done.

**Weather Issues.** With the weather being a source of many issues globally, this makes the group vulnerable to being affected by it. Whether it happens to be a power outage caused by a storm, to a winter storm coming and dropping 3 feet of snow, the group must have a plan. Online communication and assigning work amongst each other will be the best option as group members will not have to step out to meet. The team will be able to communicate from a safe place, or know who is responsible for what so there is no confusion on the assigned work.
School Closing. George Mason University Fairfax Campus occasionally is forced to shut down due to weather, or other issues such as power outage and suspicious objects being found in buildings. These issues can result in the group not being able to meet. Thanks to modern technology, everyone has the capability of being able to be in constant communication. The group could meet in a different location that they agree upon, or also simply work remotely and split up the work.
Appendix

Simulation Coding
Code Executable in Excel file “Solar Energy Generation with rep.xlsm”

Sub ReplicateTrials()
Dim i As Integer, z As Integer
Dim MinRequirementsReal As Worksheet, Simulation As Worksheet

Set MinRequirementsReal = ActiveWorkbook.Sheets("MinRequirementsReal")
Set DailyResidentsDemand = ActiveWorkbook.Sheets("DailyResidentsDemand")
Set Simulation = ActiveWorkbook.Sheets("Simulation")
Set HourlyGenerationReal = ActiveWorkbook.Sheets("HourlyGenerationReal")

'MinRequirementReal.Cells(3, 10) = 1 'number of homes
'
'ResDemand(i) = MinRequirementReal.Cells(26, 3)
'ResGen(i) = MinRequirementReal.Cells(26, 4)
'ResExcess(i) = MinRequirementReal.Cells(26, 5)

Next i

'Find out how to clear values
'(find the bottom number, and delete cells 2 through bottom numb

End Sub
'Put delete here
'find range, and clear
Worksheets("Simulation").Columns(1).ClearContents
Worksheets("Simulation").Columns(2).ClearContents
Worksheets("Simulation").Columns(3).ClearContents

z = Simulation.Cells(1, 10) 'number of replications
'Dim ResDemand(10) As Integer, ResGen(10) As Integer, ResExcess(10) As Integer

For i = 0 To (z - 1)
    MinRequirementsReal.Cells(1, 15) = i 'changes the random variables
    Simulation.Cells(i + 1, 1) = MinRequirementsReal.Cells(26, 3) 'Demand'
    Simulation.Cells(i + 1, 2) = MinRequirementsReal.Cells(26, 4) 'Supply'
    Simulation.Cells(i + 1, 3) = MinRequirementsReal.Cells(26, 5) 'Excess'

    'ResDemand(i) = MinRequirementReal.Cells(26, 3)
'ResGen(i) = MinRequirementReal.Cells(26, 4)
'ResExcess(i) = MinRequirementReal.Cells(26, 5)

Next i

'Find out how to clear values
'(find the bottom number, and delete cells 2 through bottom numb

End Sub

**System IDEF1**
Data Distribution

Figure 35 Residential Demand Normal

Figure 36 Residential Generation Normal
**Utility Analysis**

**Figure 37: Excess Identification Normal**

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC Microgrid System</td>
<td>0.889</td>
</tr>
<tr>
<td>AC Microgrid System</td>
<td>0.218</td>
</tr>
</tbody>
</table>

Preference Set = Installation of a Residential Microgrid System
The top graph shows utility as a function of various system costs and performance metrics, comparing DC Microgrid System and AC Microgrid System.

The bottom graph illustrates the relationship between the percent of weight on energy costs per year measure and utility. It indicates that as the percent of weight increases, utility also increases. Preference Set = Installation of a Residential Microgrid System.
Preference Set = Installation of a Residential Microgrid System
Design P2P Energy | Total System Costs | Energy Cost Per Yr | Network Losses Per Yr | Converter Losses Per Yr
--- | --- | --- | --- | ---
DC Microgrid System | 0.889 | 0.927 | 0.967 | 0.879 | 0.676
AC Microgrid System | 0.218 | 0.049 | 0.299 | 0.011 | 0.789
Weight | 1.000 | 0.340 | 0.270 | 0.240 | 0.150

Preference Set = Installation of a Residential Microgrid System
Goal Member Utilities for AC Microgrid System for Design Peer-to-Peer Energy Trading System Goal

Preference Set = Installation of a Residential Microgrid System

Goal Member Utilities for DC Microgrid System for Design Peer-to-Peer Energy Trading System Goal

Preference Set = Installation of a Residential Microgrid System
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Customer Service Manager


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Other References


