Green Fund Project
Final Report
Samaneh Pazouki
under Supervision of Justin Harrell
Southern Illinois University (SIU), Carbondale, Illinois
6/3/2024

This report may be published on the SIU Sustainability website.

Name of person(s) completing report: Samaneh Pazouki
Identify if the person completing report is a student, faculty, and/or staff: Regular Staff
Department: Engineering Services, Facilities and Energy Management Department, SIU University
Contact Phone and email address: 7753381336 and samaneh.pazouki@siu.edu
Faculty Advisor (if applicable): Justin Harrell
Project Title: Graduate Research Assistant for Campus Climate Action
Project ID #: 23SP104
Award Date: 4/18/2023
Completion Date: 5/31/2024
Total Funds Used: $10,338

Content

A. Climate Action Plan (CAP)

A Climate Action Plan (CAP) is a strategic framework developed by governments, organizations, universities, communities to address and mitigate the impacts of climate change. The primary goal of a CAP is to reduce greenhouse gas (GHG) emissions by 2050 and enhance resilience to climate impacts. CAP includes three scopes:

- Scope 1: It consists of emission produced on/by campus such as emission produced by SIU power plant.
- Scope 2: It consists of emissions resulting from purchased energy such as electricity for the campus.
- Scope 3: It consists of emissions generated off campus as direct result of university activities such as commuting, air travel, electricity transmission and distribution.

A1. Strategies of Energy Demand Reduction of 20 Universities and 10 Organizations in the US

According to our previous studies, energy production produces a large portion of emission in the SIU campus. Hence, one solution is to reduce energy demands of the campus such as electricity, heating, and cooling demand, which is focus of this study. In other words, if we reduce the energy demands of the campus, we need to generate less energy. Therefore, energy demand reduction strategies of 20 universities and 10 organizations are considered in this study. As a result, available energy reduction strategies in the campus are highlighted, and some other strategies are recommended. First, 30% to 60% of the campus energy demands are related to the cooling and heating energy demands. This demonstrates the significance of energy saving on heating and cooling demands. The available strategies of the SIU campus include some buildings automation and scheduling thermostat for (un)occupied hours, standard set points for heating/cooling in occupied hours (70/75), in standby mode (68/77), and in occupied hours (60/80), using (geothermal) heat pumps in three parts of the campus. Some recommended strategies regarding the thermal (cooling/heating) energy demands of the campus include: using solar radiation/heat for heating the building in winter, automation of all buildings by using advanced technologies such as artificial intelligence (AI), using smart thermostat learning from the lifestyle overtime and recommending temperature setting for the rooms/buildings, more geothermal heat pumps in the campus, thermal energy storage (cooling and heating), installing energy meters and energy management systems (EMSs) for all buildings to diagnose the faults and energy loss, equipping smart HVAC with multiple wireless smart sensors for temperature, solar radiation/heat, humidity, and occupancy. Although geothermal is not beneficial for producing electricity, it is a great source for generating and saving heating and cooling energy with typical efficiencies of 300%. Another solution with regard to the energy demand reduction is energy saving by using lighting control strategies. According our research, 20% to 30% energy usage of universities are related to the lighting. One of the best solutions to reduce the lighting usage is to replace the campus's lamps by LEDs and advanced lighting control strategies (e.g., occupancy and daylighting) equipped with advanced sensors which will be elaborated on in section D. These advanced technologies save the energy by 50% to 70% based on our calculations. Some other strategies such as using power strips and energy star appliances and virtualization endeavors by IT as well as incentive/penalty programs and user behavioral solutions are recommended to the campus energy management department in order to reduce the campus's energy demands. Some other strategies should be considered for the fast wire/wireless charging stations of (self-driving) electric vehicles connecting to the campus's electricity feeder.

A2. Summary of Climate Action Plan (CAP) of three leading Universities

In the rest of the project, we studied the energy usage behaviors, produced emission, and goals/strategies of three leading successful universities regarding demand reduction strategies discussed in their CAP report:

- University of Illinois, Urbana-Champaign's CAP report:
  Energy Usage: In Fiscal year 2019 (FY 2019), the campus total energy use was 3 trillion BTU including 38% electricity and 62% heating/cooling/natural gas. The campus total energy source including 75% natural gas for the campus's CHP power plant, 18% purchased electricity, 5% coal for the campus power plant, and 2% wind/solar/biomass. *Emission:* Considering the campus total emission (443,104 MTCO2e), 86% of the campus total emission is as the result of the mentioned energy usage. *Goal:* This university has multiple strategies to reach the goal of carbon-neutrality by 2050. *Strategies:* reduction of the energy use intensity (EUI: KBTU/GSF) by 60% by FY50; the utilization of 140,000 MWh and 150,000 MMBtu/year through solar, wind, nuclear, and biofuel; replacing the coal by geothermal and nuclear reactors; designing/upgrading the steam heating systems to hot water (low temperature systems); energy storages.
- Ohio State University's CAP report:
  Energy use: In FY09, considering the campus total energy use (6,753,572 MMBtu/year), the campus energy resources included 29% grid electricity, 46% natural gas, and 25% transportation. *Emission:* Considering the campus total emission (757,051 MTCO2/year), the 58%, 22%, and 19% of the campus total emission is as the result of utilization of grid electricity, natural gas used for the campus power plant, and transportation/agriculture. 23%, 53%, and 24% of the total emission is related to scope 1, 2, and 3 in sequence. *Goal:* aiming to the carbon neutrality by 2050, the university provides current/future steps by the reduction of energy consumption strategies and the increase of renewable resources and geothermal.

- University of Maryland, Baltimore County's CAP Report: *__Emission:__* In FY18, 35%, 22%, and 43% of the campus emission was as the result of using electricity, gas, and commuting. *__Goal:__* Reducing 20% emission from FY07 to FY18, the university goal is to reduce GHG emission by 100% through some *__strategies:__* such as the replacement of the lamps by LEDs and the increase of 100% renewable resources.

A3. Calculation of Emission for Phase 2 of Climate Action Plan (CAP)

As mentioned, the produced emissions from purchased grid electricity is considered in scope 2. Hence, due to the importance, we calculated the produced emission from purchasing electricity from the grid by considering eGRID (Emissions & Generation Resource Integrated Database) and ICC (Illinois Commerce Commission's Web site). The historical data from FY22 shows that the 30% of emission of scope 2 is related to purchasing grid electricity.

B. Operation & Planning of a Zero-Emission Power Plant (PP) for the SIU Campus by 2050

As it was mentioned in the previous section, one of the largest challenges that poses pressure to energy networks is tremendous amount of energy (electricity/cooling/heating) which are used by the universities. Hence, the energy demand can be significantly reduced. Furthermore, one of the paramount strategies to reduce the GHG emission by 100% by 2050 is to design/upgrade the campus energy systems with advanced technologies such as solar cells, geothermal heat pumps, and electrical/thermal (cooling/heating) energy storages. Thus, a zero-emission power plant is designed/upgraded for the SIU campus by 2050. In the project, we approve the significance of the operation and planning of a zero-emission PP for the campus.

B1. Calculation of Maximum Capacity of Geothermal Heat Pumps (GHPs) for SIU Campus

In this project, we propose a calculation for estimating how much spaces are required for installing geothermal heat pumps based on the available area for the installation and the available budgets limitations.

B2. Calculation of Energy Demand of Each Season in SIU Campus

In this project, we calculate the energy demands of each season, which has been reduced by 50%, based on applying the potential strategies such as replacing the lamps by LEDs. The demands are used in designing the zero-emission power plant for the SIU campus.

B3. Operation and Planning of the PP for the SIU Campus by 2050

Reducing emission from energy demand reduction strategies in one hand and utilization of advanced technologies such as distributed energy resources (DERs) including solar, energy storages, geothermal heat pumps, demand response in smart buildings, and self-driving electric vehicles in other hand can be considered as a solution to achieve zero-emission campus. As it was mentioned in the previous studies, the most produced GHG emission of the universities are as the result of energy usage such as electricity and natural gas. For instance, 144,000 MTCO2 emission from energy usage of electricity (37%), natural gas (6%), and coal (57%) has been reported by SIU university in FY19. Hence, we propose a model of a zero-emission power plant to approve effectiveness of designing/upgrading the energy systems of the SIU campus compared to the current and business as usual (BAU) model and future electrification. In this project, we contribute to integration, operation, and planning of DERs such as solar cells, geothermal heat pumps (GHPs), biomass, electrical/thermal (cooling/heating) energy storages in a zero-emission power plant for SIU campus by 2050. In the current configuration of SIU campus, electricity demand can be supplied by grid electricity and Combined Heat and Power (CHP). The heating demand can be supplied by gas boiler. The cooling demand can be supplied by absorption chiller or electric chillers. However, we optimally operate and design a zero-emission power plant and demonstrate the significance of our design based on the least investment and operation costs as well as zero-emission campus. In this new design, electricity demand can be supplied by renewable-based electricity grid, solar cells, and electrical energy storage. The heat demand can be supplied through GHP, heating storage, and boiler using biomass. The cooling demand can be supplied by GHP, cooling storage, or electric chillers. The simulation is implemented for 4 different scenarios:

- Scenario #1, the simulation is implemented by all available technologies and their maximum capacities.
- Scenario #2, the simulation is implemented by all available technologies. However, the maximum capacities of energy storages are reduced in this scenario.
- Scenario #3, the simulation is implemented by all available technologies. However, the purchased electricity from the electricity grid is increased in this scenario.
- Scenario #4, the simulation is implemented based on current or BAU model.
- Scenario #5, the simulation is implemented based on future electrification of all electric technologies.

Simulation is implemented in a mixed integer linear programming (MILP) model by GAMS Software and through CPLEX solver in less than 0.02 seconds. The PC is equipped by Intel® Core™ i7-8700 CPU @ 3.200GHz, 6 Core(s) CPU and 16 GB RAM. Simulation results demonstrate the best design for the zero-emission power plant for the SIU campus.

- In scenario #1 (base case),

Based on the results, the maximum capacities of solar cells and electrical energy storages are selected. Furthermore, the maximum capacity of renewable-based electricity grid is selected since solar radiation is not available all the time. Boiler and GHP as well as heating storage with its maximum capacity are installed to supply heat load of the campus. Cooling demand is supplied by installation of GHP and cooling energy storage. In this scenario, the total investment cost is $ 58.184 M, and the total operation costs per year is $ 12,778,000.

- In scenario #2 (reduction of energy storage capacities in the planning phase),

Based on the results, investment costs have reduced by 18% and total operation costs are increased by 22% significantly. In this scenario, the maximum capacities of solar cells and electrical energy storages as well as the maximum capacities of renewable-based electricity grid are selected to supply the electricity demand. To supply the heat demand, boiler and GHP as well as maximum capacities of the heat storage are selected. Also, GHP without cooling storage supplies the cooling demand of the campus.

- In scenario #3 (the increase of maximum capacity of the electricity grid by 30% in the planning phase),

Based on the results, the increase of maximum capacity of the electricity grid results in elimination of boiler and reduction of capacity of energy storages. Solar cells and electricity grid are utilized to supply electricity demand of the campus. GHP is installed and utilized to supply heat and cooling demands of the campus. In this scenario, total investment costs and operation costs are reduced by 20% and 44% in sequence compared to the base case. This total and annual operation costs is 44% less than the operation costs of the base case and 78% less than operation costs of the electrification of the campus in case 4. This total and annual operation costs are also 48% less than current/BAU operation costs of the campus. This approves the significance of optimal design and operation of a zero-emission power plant for the SIU campus by 2050.

C. Climate Resiliency Plan of the SIU Campus

In the last decade, climate change dramatically increases intensity and severity of high impact low probability (HILP) events (unpredictable and inevitable) like hurricane, tsunami, tornadoes, wildfires, drought, heat waves, flooding, and sea level rise. The events compromise the reliability and resiliency of systems which require an ability to withstand and reduce the magnitude and/or duration of disruptive events. Although there are no universal definitions, metrics, evaluation, and enhancement methods for the resiliency, based on climate change, the resiliency of systems is defined in terms of anticipation, absorption, adapt to, and quick recovery (prevention, detection, mitigation, and recovery) after the hazardous events. Resiliency events are divided into three states: (i) pre-event (resilient state); (ii) during the event (survivability state); and (iii) post-event (recovery state).

C1. Power System Resiliency (Resiliency's Evaluation and Enhancement Strategies) of SIUC

Definition: In smart grids, system resiliency definition is the ability of power system to return to stable operation point after the HILP events and to supply the critical loads. The existing power system is reliable to abnormal and foreseeable contingencies but not resilient during unexpected and high impact events. Hence, vulnerability of the system should be measured and evaluated based on resiliency metrics to utilize the novel strategies to enhance the resiliency of power systems.

Vulnerabilities: Extreme weather events lead to large blackouts and long outage duration in the United States. According to NERC, severity, duration, and frequency of natural disasters are increasing due to geophysical, meteorological, hydrological, and climatological events. Furthermore, the events change voltage, frequency, dynamic and cause fault currents. It affects the performance of renewable energy resources such as solar cells and wind turbines. Plus, electricity power is dependent on gas infrastructure (39%) surpassing coal usage (30%) according to the EPRI. However, the gas supply/transmission/delivery is vulnerable to severe weather. Due to connection of electricity power systems to communication networks in modern power systems, the communication infrastructure is vulnerable to the HILP events.

Resiliency metrics and evaluations: Metrics are used for evaluation of the system under HILF hazardous events. Resiliency evaluation methods and metrics are key areas of research, however, there is no widely accepted standard in this area yet. While reliability metrics have been standardized and widely adopted, metrics for quantifying resilience have not been standardized by USDHS, USDOE, National labs, FERC, NERC, IEEE PES, EPRI, academia, consultants, and individuals. Another significant challenge is that a system resilient to one type of hazard may not be resilient to another one. Some metrics for consideration of grid resilience's metric development are as follows: cumulative customer-hours of outages, cumulative customer energy demand not served, time to recovery, cost to recovery, costs of grid damages (e.g., repair or replace lines, transformers).

Resiliency enhancement strategies: There are several methods for enhancement of generation, transmission, and distribution power systems; however, power distribution system (AC, DC, Hybrid AC/DC Microgrid) has gained significant attention, which will be elaborated as follows: 1) operation based strategies such as network reconfiguration, conservation voltage reduction, backup generation, microgrid islanding to prevent cascading due to line outage, mobile energy storage, load restoration, optimal switching and optimal dispatchable DER, prediction, security-constrained optimal power flow. 2) planning-based strategies such as redundant transmission/distribution routes, backup generators, remote control switches, optimal location/size of energy storages and renewables, optimal placement of relays, demand response, restoration management, sensors for communication technologies, control systems, sensors for automated distribution switches/sectionalizers/reclosers, unmanned aerial vehicles such as drones equipped with high resolution cameras, priority resiliency enhancement.

C2. A Comprehensive Study for the Resiliency of the SIU Campus

In this project, we have taken steps beyond the impacts of climate change on energy infrastructures of the SIU campus. We have developed our studies on the adverse effects of climate changes on SIU campus's ecosystems, economics, social equity and governance, health and wellness based on the Second Nature approach. Resilience is defined as the capacity of a system or community to endure disruptions, anticipate, prepare for, respond to, and recover from the adverse impacts of climate change. Climate change impacts hydrological events (e.g., flood), climatic events (e.g., high temperature, droughts, and wildfires), and meteorological events (e.g., storms). The goal of climate resilience plan is to analyze the strengths and vulnerabilities of the campus and to develop comprehensive strategies to improve resilience against the impacts of climate change. Climate resilience based on the Second Nature approach refers to the integration of natural processes and ecosystem-based strategies into human-designed systems to enhance climate resilience: The capacity to utilize natural ecosystems for efficient and enduring adaptation, ensuring sustainability in the long run. According to climate change projections (riskfactor.com/city/Carbondale), 21 days will exceed 107°F over three decades, increasing demand for cooling and raising electricity consumption by 14%. This study shows that Carbondale faces a major heat risk. Also, Carbondale has a moderate risk of flooding with a likelihood of over 26% and a moderate risk of wildfire impacting utilities, routes, health, air quality, and economics of region in the coming three decades. Carbondale faces a minor risk of wind from hurricanes, tornadoes, or severe storms damaging utilities, transportation, economics, and health of the region. Plus, Carbondale faces a minor/moderate risk of snow and longer winter affecting agriculture, transportation, and energy consumption if number of days with maximum temperature below 32°F is greater than normal. In order to do analysis, we provide a table which shows the number of days with maximum temperature above 90°F/100°F, number of days with no precipitation, maximum number of consecutive dry days, annual single highest maximum temperature, and number of days with maximum temperature below 32°F as well as average annual total precipitation, number of days per year with precipitation, max number of consecutive wet days, and annual extreme precipitation events (>3 inches) for history and early/mod/late century by considering the increase/decrease of GHG emission. Then, we normalize the available data in the table. Results show that: 1) if we either control or don't control the emission, the number of days above 100°F is significantly increasing, which results in exposing Carbondale at the risk of extreme heat and drought. However, we can significantly reduce the number of consecutive dry days by controlling GHG emission. 2) with the control of emission, average annual total extreme precipitation (>3inch) has decreased by 50% and the number of days with precipitation has increased by 22%. 3) The results show that we can reduce the probability of flooding disasters, compared to extreme heat and drought disasters, when we control and reduce the emission. In other words, we have control on flooding disasters if we can control produced GHG emission. However, extreme heat and drought cannot be significantly controlled by decreasing GHG emissions. As a result, we need other technologies and techniques to reduce the impacts of extreme heat and drought. Furthermore, we should utilize more advanced strategies to prevent and mitigate the adverse effects of extreme heat and drought on Carbondale including SIU. This implies that we need to do more research on climate change impacts on the SIU campus to enhance the campus resiliency. Therefore, we continue our studies on resilient metrics developed by Second Nature approach:

1) social equity and governance: Social equity ensures fair distribution of resources and adaptation measures, while governance involves transparent decision-making processes that prioritize vulnerable communities. Together, they form the foundation for addressing climate change impacts in a just and equitable manner, reducing disparities and fostering resilience among all members of society. Some social and equity resiliency metrics with implementation leads (Office of Equity and Compliance; Diversity and Inclusion office; Student Affairs department) are as follows: community connections and engagement; civic engagement (voter turnout); education level; emergency planning capacities such as coordination between the campus and community in responding to disasters; vulnerable populations; awareness of climate change; crime prevention; institutional engagement (networks participation); income disparity; climate centers.

2) Health and wellness: Health and wellness organizations play a crucial role in addressing the adverse effects of climate change by raising awareness, prioritizing public health, providing support to vulnerable communities, and collaborating with other sectors to develop holistic solutions. Some health and wellness resiliency metrics with their implementation leads (Student Health Services; Counseling and Psychological Services; Environmental Health and Safety) are as follows: rate of asthma; food security; health insurance; access to healthcare; affordable housing; potable water; mental health; access to exercise facilities; emergency healthcare; homeless population.

3) Ecosystem services: Ecosystem services, crucial for human well-being, is to preserve and restore ecosystems and enhance biodiversity despite climate changes. Some resilient metrics for ecosystem services with their implementing leads (Sustainability Office; Environmental Science department; Facilities and Energy Management) are as follows: urban green space, tree canopy, access to outdoor recreation, air quality, protected floodplain, climate-suited vegetation, conservation, coastal buffer, protected watershed.

4) Infrastructure: Climate change poses significant threats to infrastructure, disruption, and economic losses. Strategic resilient planning is imperative to ensure continued functionality to mitigate the adverse impacts and to support long-term sustainability in the face of climate change. Some infrastructure resiliency metrics with their implementing leads (Facilities and Energy Management; Civil Engineering department) are as follows: public transportation availability, communication technologies, energy efficiency, flood resistant buildings, backup energy, dam safety for flooding, resilient energy, access to multi transportation, air conditioning/cooling, heating.

5) Electricity infrastructure: with their implementing leads (Facilities and Energy Management; Electrical Engineering department; Sustainability Office; local utility companies) are as follows: distributed energy resources (DERs); smart microgrids (MGs); transmission & distribution (T&D) power loss; reliability indices assessment and recovery time such as SAIDI (System Average Interruption Duration Index) & SAIFI (System Average Interruption Frequency Index) assessment before/after natural disasters; cooling/heating; artificial intelligence (AI) for predictions and self-healing; grid stability; automation for fault detection.

6) Economic: climate change affects agricultural yields, industries, and so on, which should be addressed by some resilience enhancement strategies to mitigate the economic risks and promote long-term stability. Some resiliency metrics with their implementing leads (Office of the Vice Chancellor for Administration and Finance; Business and Economic Development Center; Career Development Center) are as follows: emergency funds; flood insurance; green fund; diverse economy; adaptation fund (multiple funds); tax incentives; employment; access to credit; financial for emergency planning; investment strategy for sustainability or similar environmental investments. Funding options can be provided by Federal grants, State grants, local government funding, private foundations, public-private partnerships, utility rebate programs, research grants, and alumni donations.

D. Lighting Control Strategies for Energy Saving in the SIU Campus

As mentioned in the previous paragraphs, lighting consumes a large portion of electricity demand, so lighting is one of the best sources of saving energy. Hence, different lighting control strategies can be used for energy saving.

D1. Energy Saving for Outside Lighting through the SIU Campus Lamp Replacement with LEDs

In this project, we have a table including different types of lamps with their numbers and their wattages. Based on ASHRAE, we found the fixture wattage of the lamps. Furthermore, we found their illuminations. From a Google search, we found the equivalent LEDs with the approximate close lumens to the equivalent lamps. The lower wattages of LEDs are recommended to be purchased by Amazon and the higher wattages of LEDs are suggested to be purchased by LEDExpertLighting.com. We calculated the energy consumption from available lamps/LEDs and from future LEDs. For energy consumption calculation (lamps/LEDs), we should use multiplication of their fixture wattages by operation hours by number of operation days by electricity price. Based on energy consumption of available lamps and energy consumption of LEDs, we calculated the energy saving from replacement of available lamps with LEDs 37%. The dynamic payback period of this project is calculated 2.5 years. We have also calculated the benefit to cost of the project for each year.

D2. Different Lighting Control Strategies for Energy Saving in the SIU Campus

In this current project, we calculate energy saving from different lighting control strategies such as vacancy and daylight harvesting in addition to replacement of the available lamps by LEDs in order to have best energy saving at the SIU campus. According to our research, 75% of the lighting strategies are related to daylighting and occupancy sensors compared to other lighting controls methods. Furthermore, according to our research, in the private offices, 38% occupancy sensor, 60% daylight harvesting, 22% multiple switching, and 7.5% manual dimming are used for lighting control strategies. In the open offices, 35% occupancy sensor, 40% daylight harvesting, 16% multilevel switching, and 11% manual dimming are used for lighting control strategies. In classrooms, 55% occupancy sensor, 50% daylight harvesting, and 8% multilevel switching are used for lighting control strategies. The most common technologies for occupancy sensing are passive infrared (PIR), ultrasonic (US), and dual technologies (combination of two aforementioned sensors). Other technologies for occupancy sensors and daylight lighting are under the current study.