Community Resilience with Decentralized and Diversified Energy Systems

URBDP 591 Research Design in Urban Science

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Abstract

Human society is changing with unexpected natural events such as coastal storms, city heat waves, urban flooding and drought. Urbanization and environmental pollution are highly correlated due to improper management of environmental resources and infrastructure systems. Human behavior change needs to address these problems by implementing sustainable and resilient infrastructure to achieve resilient community. Specifically energy infrastructure system will be studied assuming that decentralized and diversified energy systems are enhancing the community resilience by hypothetical deductive method in order to generalize research findings for the universal explanation. Studies on sustainable and resilient infrastructure systems to promote community resilience will encourage the deployment of renewable energy that will promote the resilient community through decision making frameworks.

1. Introduction

1.1. Urbanization and disruptions

Human society is urbanizing rapidly, and more mega cities are emerging. Cities currently occupy 2% of the land on earth to accommodate half of the world's population, while using 75% of world's resources (Girardet 2000). Proper management systems are required, accordingly, to deal with change events such as population growth, creaky infrastructure systems, change in land use and shape, environmental pollution, and climate change. These changes are mainly the result of human activities, which are making society somewhat vulnerable, particularly with limited resources such as minerals, rare metals, fossil fuels and so on, which are expected to run out because of inappropriate management of the resources. There are also increasing disturbances to modern society from climate change and pollution. Human activities such as industrialization without appropriate planning and systematic implementation, result in poor infrastructure systems, environmental pollution, and resource waste. Environmental changes from human activities, including pollution, are now inducing natural disasters associated with climate change. They include but are not limited to coastal storms, city heat waves, urban flooding and drought. Urbanization and environmental pollution are highly correlated because the proper management of resources and infrastructure planning has been missing in urban form until recently. As a result, people suffer from health issues due to environmental pollution, which results from inappropriate management. Those challenges need to be discussed in terms of resilient and sustainable infrastructures to enhance community resilience.

1.2. Infrastructures for community resilience

Human behavior change promoting sustainable use of resources, needs to address urban issues, because human activities contribute to many of the undesirable disturbances described above. In the context of modern society, which is getting more complicated and systemized, human behavior change could be discussed in terms of sustainable and resilient infrastructures. Outdated infrastructure systems have caused waste of energy and pollution, all of which expedite community vulnerability against the unfavorable events. Appropriate infrastructure systems will enhance the effective use of limited resources, reduce environmental pollution, and properly respond to unexpected disasters and failures. Resilient infrastructure systems including systems of water, energy, transportation of material and people, health services and emergency institutions (police and firefighting) are necessary to serve community. Critical infrastructures are essential to human society because they support fundamental economic activity.

Characteristics of resilience are defined as to anticipate, absorb, adapt to and recover (NIAC, 2009) while also characterized as robustness, redundancy, resourcefulness and rapidity in the context of institutional evaluation for measuring the resilience (Bruneau et al. 2003). On the other hand, systematic approaches are required to measure resilience of infrastructure systems, because they are complex and interdependent. Current infrastructure systems, especially those in developing countries, need improvement to meet people's changing needs and situations. They often lack the predictive managing structures that consider environmental impacts and long-run costs. Current infrastructures are often inadequate in response to risks of disasters such as urban flooding and extreme heat waves, because of improper resources and lack of information systems. Furthermore, some regions need to be rehabilitated in terms of the aging infrastructures. Those issues converge on whether there are sustainable and resilient infrastructure systems in place. Among infrastructure sectors, energy would be further studied because energy is getting critical to serve the needs of human activities as the society becomes complex. Reliability of energy supply has been proved to be important especially during the emergency situations where medical services are highly demanded facing the unexpected events.

1.3. Electrical energy system

Climate change and its impact on urban systems are main issues which has raised research questions of how to improve the resilience of the system especially related to energy. Some of researches introduced indices related to resilience for the purpose of analysis, the others created mathematical functions to interpret the current phenomenon and simulated to prove their hypothesis. Energy resilience research is still at its emerging stage that several literatures tried to define energy resilience. First they started to approach to the common definition of resilience: resilience abilities (preparation, absorption, recovery, and adaptation) to ensure sustainability related dimensions (availability, accessibility, affordability, and acceptability). Availability for sustainable dimension and preparation for resilience ability are told to be the most critical (Sharifi et al. 2015). Energy resilience has related areas: infrastructure; land use, geometry and urban morphology; resource management; urban governance; legal and regulation; social and behavior.

Two emerging characteristics for energy resilience were discussed: IES (integrated energy system) and DERs (distributed energy resources). IES is related to interdependency and diversity of systems while DERs is about several renewable energies (Lin et al. 2016). This could be interpreted as decentralized energy systems such as micro-grid. When systems are combined, the complexity becomes characterized and the emergent behavior of the system is hard to be expected. Two measures for energy resilience were introduced: hardware hardening and operational resilience strategies. Hardware hardening happen to be costly and influence only a limited part of the whole system that is less effective. Increasing diversity of energy supply would increase the system resilience. Decentralized energy network has increased due to efficient end-use appliance and low-cost photovoltaic supported by ICT (mobile phone) and virtual financial services. This will enhance the energy accessibility considering the fact that the currently 1.3 billion people lack access to electricity while there are some barriers to mobilize the decentralized energy networks to local level (Alstone el al. 2015). These barriers could be address with aggregation of community connections which will reduce the barrier to grid-based service. One of the barriers is that designing local energy sharing community is unclear. One of the studies (Yamagata et al. 2016) in this regard tried to analyze several algorithms to find the optimal clustering of communities in terms of self-sufficiency, sharing cost, and stability. V2C (vehicle to community) was introduced in the study with PV (photovoltaic) for energy generation and EV (electric vehicle) for energy storage. This energy is shared within the local community clustered. Trade-off between implementation and maintenance cost and electricity self-sufficient was considered in the study, which could be one of examples to design community for community based energy networks. Another study (Shahidehpour et al. 2016) shows controllable and islandable micro-grid systems would improve the resiliency of power grids in extreme conditions. The study introduced 4 indices - K: expected number of line on outage; LOLP: loss of load probability not being supplied; EDNS: expected demand not supplied; and G: difficulty level of grid recovery to figure out the resilience improvement by introducing micro-grids to the power grid system. Governance of energy infrastructure, unlike other studies, was discussed to empathize the need of the polycentric governance as it is critically related to socio-economic actors (Goldthau et al. 2014). It points out it is necessary to research in terms of social science to provide the reliable energy services.

2. Theories to support the research

Characteristics of infrastructure systems (i.e., interdependence and complexity) are significant to understanding resilience because complex modern infrastructure systems are often highly correlated with the vulnerability and robustness of community resilience. It is necessary to approach community resilience in a combination of sectors of infrastructures (i.e., transportation, energy, water, wastewater, telecommunication, etc.) in terms of their complexity and interdependency. The more interconnected infrastructure systems are, the more complex and risky they are in response to disruptions. Cascading effects are inherent to critical infrastructure systems on a whole network when a disruption occurs to a part of the network. For example, damage to an electricity system may affect a water system operated with electric pumps, while water shortage may interrupt electricity generation by influencing cooling systems on the generator. The degree of impact in a disruption may be different depending on the degree of dependency of the systems or the characteristics of system structure. It is known, for instance, that outage duration is much greater for electricity overhead lines than for underground lines, which may affect related infrastructures (Hall, 2012).

Interdependency can be discussed in terms of physical, cyber, geographic, and logical (Rinaldi et al. 2001). Physical interdependence is related to the input and output of different infrastructures being connected, in that physical material and services are interconnected. Cyber interdependence is depending on information from another infrastructure. Geospatial interdependence is about the characteristics of related infrastructures in proximity to each other, thus environmental influence can affect both simultaneously. Logical interdependence includes jurisdictional or regulatory requirements and operational systems. There are several approaches to understand the interdependence of infrastructure systems such as network theory, economic input-output theory, and system dynamics. A quick decision tool needs to be used especially in response to catastrophic events.

2.1. Input-output theory for interdependence

An economic input-output theory or I/O model could address urgent issues because it doesn't require a huge amount of data collection, thus it is cost effective while it gives a rough overview of the effects. Inoperability in the I/O model is defined as a percentage of the system that is unable to accomplish the designed function. The I/O model is structured by economic values of sectors in a country by means of an I/O table, which the member countries are encouraged to publish by international organizations such as United Nations and the Organization for Economic Cooperation and Development (OECD) periodically every 3 – 5 years. There are, however, limitations on this model as an I/O table takes time to be updated while immediate disruptions will cause the static economic situation to move to a dynamic condition. The I/O model is still useful for an approximation purpose rather than detailed analysis. Two case studies (Pulau Bukom refinery fire in Singapore in 2011 and Tohoku earthquake in Japan in 2011) demonstrate I/O model analyses and show the interdependency of the relevant sectors in terms of economic impact and risk analysis (Lin et al. 2017). There is another study about robustness of power and telecommunication infrastructures, which are modeled in terms of resilience. Wang and Reed (2017) claim that interdependent lifeline infrastructure is critical to assess hazard impacts from storms in terms of space and time. An Individual system is modeled with a single degree of freedom model (SDOF) where the I/O model is used to predict future performance. A combined model (power and telecommunication) using the found coefficients with the fragility model and SDOF predicts the restoration after hurricanes. This model could be used to predict performance in future storms. The research recommends to promote micro-grids at the community level, hardening structure of power delivery components, and power generation redundancy to make the systems more resilient against storms because they would increase robustness of the systems. The study also suggests to involve social science to investigate the current resilience of infrastructure from the community perspectives in addition to infrastructure operator perspectives, because social science plays an important role in the integrated resilient modeling.

2.2. Complexity theory for systematic approach

Systematic approaches go along with the characteristics of interdependent infrastructure systems as complexity increases. Modeling and simulation integrating socio-economic, political and physical aspects could be utilized to meet the need for analyzing the complex system. Currently available models, however, seem to lack integration and dynamic characteristics for analysis. A newly developed model or a multi-method modeling framework could be developed in terms of feedback based with temporal and spatial characteristics of the system. A physical sub-system deals with physical structures of infrastructure systems and their relationship to exposure to unfavorable risks and interaction with other systems. An institutional and organizational sub-system, which deals with decision making, policy and management process may affect the physical sub-system of infrastructure. The physical sub-system interacts with the socio-economic sub-system related to human activities, which generates a system dynamic through interacting with other sub-systems. The socio-economic aspect of human activities will again affect institutional and organizational sub-systems of regulation and policy. Each sub-system could be modeled based on the characteristics e.g. an agent based model (ABM) for the institutional sub-system and a system dynamic (SD) modeling method for the socio-economic sub-system. Those sub-systems are then integrated for each scenario simulation and optimized, which could analyze vulnerability of the network. These simulations and optimizations would be followed by multi-objective analysis to find a solution to minimize the environmental impact, and maximize human health and economic value.

Complexity theory would also be referred to for accepting the characteristics of uncertainty in the real world and interactions of entities in the system dynamics. Feedback is an important factor to describe the system dynamics. For example urbanization and development of urban cities have left big impacts on nature such as land use change, bioecological system change and even climate change. These changes has lagged behind the human interactions. This time lags have causes unexpected phenomenon later after the activities. The lagged feedback coming from the nature affected by human activities now is influencing human urban systems. This is one of the important theories to study infrastructures and how the infrastructure systems in the urban form has influenced or is influencing natural systems and the combined human – nature systems related to community resilience. Complexity theory could be applied to risk management since traditional risk analyses fails to account for dynamic change of risks and interaction among risks. They are mostly based on qualitative analysis. System dynamics could be utilized to feature dynamic changes. It is known that DYNAMO or VENSIM software tools employ a feedback basis using internal feedback loops and time delays. Liu and Zeng (2017) shows how risks interact with each other to evaluate risk for investment to renewable energy by overcoming traditional analysis, which lacks a systematic approach toward interaction among risks. A baseline scenario with market, policy and technology risk was established for the study. They found that installed cost reduction makes market risk decrease. Tariff subsidy makes policy risk decrease and technology progress makes technology risk decrease. Policy risk is the main factor to focus on at an early stage and market risk at a later stage. This study shows the characteristics of system dynamics.

2.3. Portfolio theory for diversification effects

Portfolio theory is essential not only from an investment perspective but also from a diversity perspective. Portfolio theory is about promoting more stable states using diversification benefits, which points out that the more diverse a system is, the less risky or vulnerable, thus more resilient the system is. Considering the investment perspective, every asset has its performance of return in terms of a specific time frame. The range of return varies also along with time. The collection of different assets features unique characteristics of the portfolio in investments. There is an optimal option with respect to return and risk or volatility. Having low-correlated different assets together results in less volatility, thus investors can expect their payoff with more certainty, because the diversification benefit reduces portfolio volatility due to the fact that a certain asset is not highly correlated with other assets. For example, when portfolio A is 8% volatility; portfolio B is 7% volatility; and portfolio C is a 50/ 50 weighting of A and B, the volatility of portfolio C should be less than half way between A’s and B’s volatility (i.e., 7.5%) because as long as they are not perfectly correlated, it becomes less volatile.

When systems are combined, the complexity becomes characterized and the emergent behavior of the system is hard to be expected while less correlated energy systems are expected more robust as per the portfolio theory. Increasing diversity of energy supply would increase the system resilience. Renewable energy features decentralization of the energy network with strategies such as mini-grid and off-grid at a small scale. Off-grid energy systems are more resilient in response to disruptions, because a disruption to a part of the network won't affect other parts of the network, as they are separate from each other. Spatial diversity could lessen the effect of such a disruption. Spatial diversity can be addressed with off-grid energy systems because of their tendency to decentralization energy networks. As per International Energy Agency (IEA), 40% of electricity access should be from off-grid sources (Malhotra et al. 2017).

Previous studies mostly focused on single projects, not a portfolio aspect. There has been a lack of systematic assessment. Malhotra et al. (2017) presents, on the other hand, how spatial diversity in a portfolio can reduce investment risks. Unfavorable risk-return profiles and small investment volumes on off-grid projects have been obstacles to off-grid investment, while the potential of aggregation of small-scale renewable energy to investment exists. De-risking of off-grid investment is possible on account of benefits of spatial diversification. The research shows how to attract private investment on off-grid by classification of risks, qualitative analysis of risk correlation, and quantitative estimation of cost and de-risking effects for aggregation of small-scale investments. Market risk could be decreased by creating a portfolio with different geographies or industries against regional disasters, policy change and regional industry. They conducted qualitative analysis of risks and correlations with interviews, then created a quantitative modeling of portfolio diversification effects per jurisdiction and geographic distance using portfolio theory and Levelized Cost of Electricity (LCOE). Risks depending on jurisdictions, are market, permits, technology sourcing, financing, and currency risks while risks on both jurisdictions and geography, are grid extension, social acceptance, payment and credit, and sovereign risks. Risks independent of spatial diversity, are labor input risks. They found the contributions of individual risks to the cost and LCOE, then compared them to diesel-based mini-grids. They point out the benefits of aggregation of mini-grid investments, while considering that high transaction cost should be justified by larger investment scales through project aggregation. Similar studies could be conducted in terms of diversification across technologies, business models, and developers. Trade-off between risk diversification and increased transaction cost should be further studied.

3. Research questions

Here are the questions that must be addressed in terms of resilient energy infrastructure: how can we improve community resilience in terms of reliable energy supply? Is there any technical improvements which could be utilized to increase energy reliability? With the current available resources and technologies, can we improve energy sustainability in response to the uncertain events?

3.1. Goals and outcomes

This research chose community resilience in terms of energy systems as an area of research, because my practical experiences in the several countries such as Philippines and the UAE (United Arab Emirates) gave me an intuition about the research. Having lived in these countries I realized the challenges depending on the geographical area could be different. There are also differences in the availability of technical and financial resources; socio-economic, physical and political situations; institutional and organizational processes; and quality standards and design practices. Developing countries in general, such as the Philippines are comparably more vulnerable: their lack of a robust electricity distribution system results in regular blackouts; frequently congested roads delay transportation of material and people; lack of sanitation systems cause contaminated water and costal pollution; and air pollution from automobiles causes respiratory sickness. Poor construction practices also add to the vulnerability of communities. For example, most of the houses in coastal areas of the Philippines were destroyed or damaged during the super-typhoon in 2013 because they were not designed to resist typhoons and were not constructed properly. While regulation of quality assurance or design codes should be in place, it is not a common practice in the Philippines to involve 3rd parties to monitor quality assurance in the construction process. The inspection party should be involved to ensure construction quality while being independent from both contractor and client. Those different challenges of countries, depending on the geographical, environmental, social and political differences make the response to disruptions more complex.

Studying resilient community will help to define the problems and find the solutions to improve the current energy systems, which will enhance community resilience. The developed energy systems should have these characteristics: environmentally based, adaptable, flexible, resilient, integrally systematic, and equitable to the public, which are found in resilient and sustainable infrastructures.

3.2. Hypothesis

Decentralization of energy production and supply will play an important role to resilient community as it would be more robust in response to disruptions. Centralized energy production may contribute to vulnerability of the current urban form as most of subsystems of human activities are relying on the sole energy production. The more dependent to a sole energy production, the more vulnerable a system would be facing interruptions. Self-sufficient energy system or decentralized energy production will increase the resilience of human societies and communities. Energy diversity, which is a similar concept of biological diversity, would keep the system healthier and more stable. Energy diversity could be discussed with portfolio theory in that diversification effect is the main characteristic which lessens the volatility or risk of investment by having less correlated assets in the package. Similarly, energy diversity, in the context of resilient community with diverse energy production, would reduce the risk of human society thus, enhance the stable built environment by providing reliable energy supply. Homogeneous and a sole energy production system not only adversely affects communities in terms of reliable energy supply but also harms the social and environmental value of the built environment. The purpose of research is to study the relationship of energy diversity and decentralization with community resilience, which could be measured in reliable energy supply.

4. Methodologies

To find out the relationship between community resilience and decentralized and diversified energy systems, two different scales of studies will be performed. For a large scale, it would be national or city level to approach the resilience of energy systems. A small scale would be applied more on the community basis specifically employing individual characteristics of buildings.

4.1. Large scale

To measure the energy resilience in terms of geographical region, state level data was collected including power plants, electric power transmission lines and electric substations. In the US there are 8,391 power plants in 10 different kinds, 66,617 grouped power transmission lines and 56,909 electricity substations all around the nation. Power plants, substations and transmission lines are highly correlated in terms of geographical position because they are connected each other composing a big electrical network. That means there are cascading impacts that a part of the network failure will affect the other parts of the network.

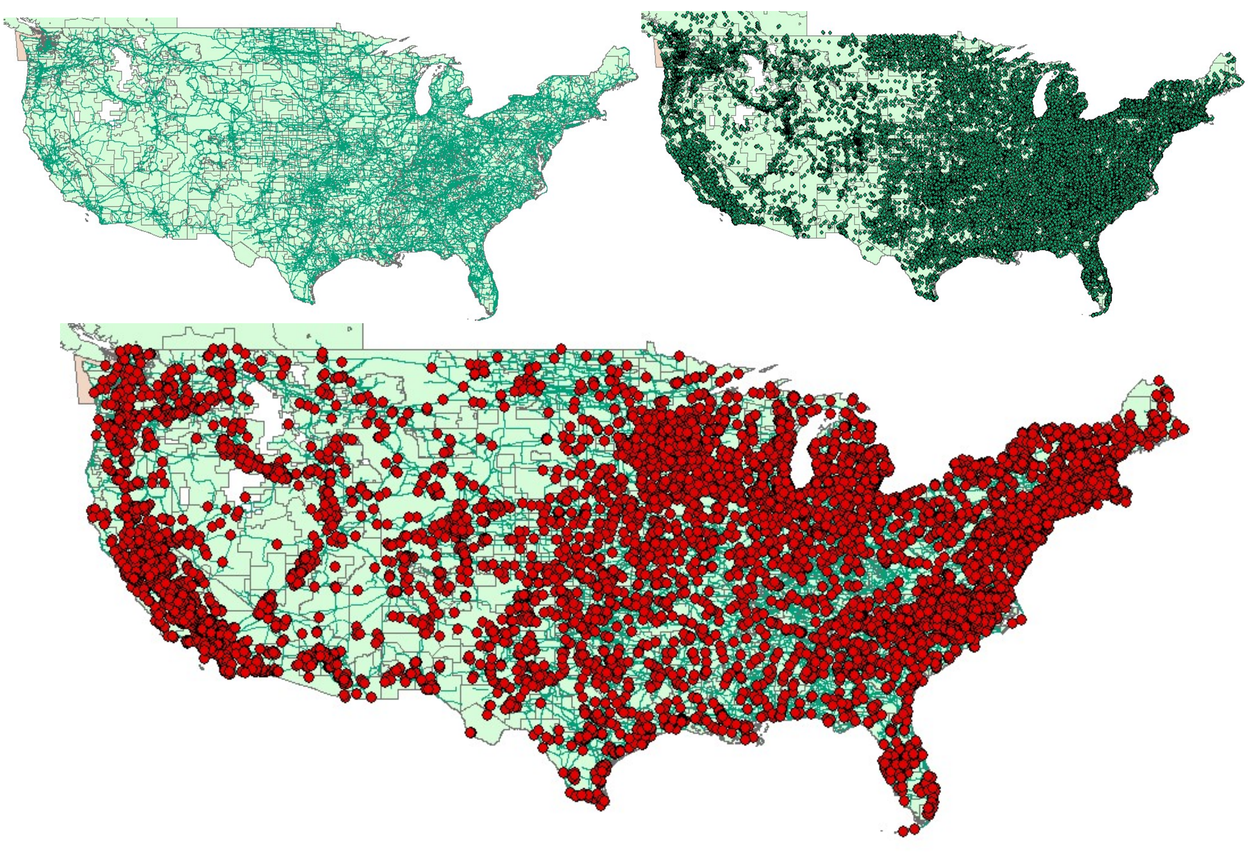

Figure 1 Power transmission lines, power substations and power plants in the US (upper left, upper right, bottom)
(Note: Alaska and islands are excluded in the figures due to the space)

Historic outage data was collected but lacks specific location points such as longitude and latitude. Because of this, outage variable was counted based on a state level. There has been 738 outage events all over the country from 2013 to 2017. Man-made outages (i.e., attack, vandalism and sabotage) were considered to be removed among the 738 outages assuming that states with more population would have more man-made outages, thus the study focusing on resilience against natural events would become mixed up with other factor. For a while, the total outage would be kept without any drop-outs. When it comes to the number of outage per state, California has the highest number of 65 outages followed by Texas of 56 outages. There should be factors why these states have more frequency of outages. The reasons could be higher population, unfavorable weather condition, higher power production capacity, etc. These factors would be the keys to study the resilience of energy systems. While each state has different power production capacities, Texas has the highest electricity production capacity of 122,514.1 MW as of Oct. 2017 followed by California and Florida. Figure 2 shows that California and Texas are the states having the largest electricity power production capacity.

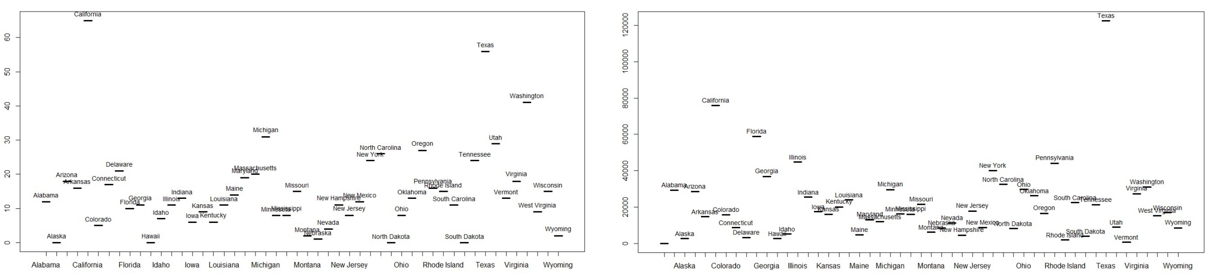

Figure 2 Total number of outages and electricity production capacity (unit: MW) per state in the US (2013 – 2017)

Outage frequencies of states in the US are skewed to the right compared to a normal distribution.

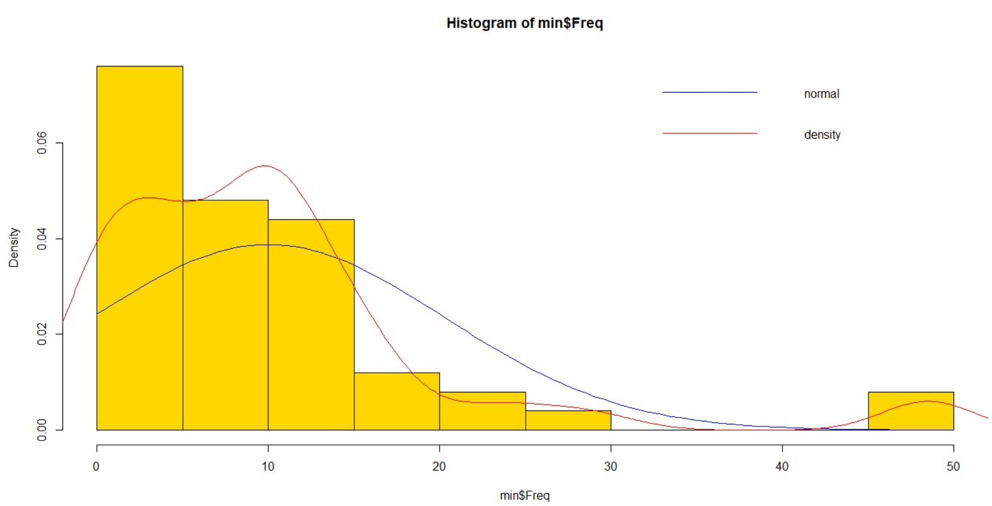

Figure 3 Outage frequencies of states in the US

There might be a correlation between power production capacity and outage frequency for states. Figure 3 confirms that they are correlated. Those states lie under the red line in figure

3 could be considered less efficient than those that lie above the line. This is because those that lie above the line have less outages based on the same amount of the power production capacity. Texas and Florida are the one of those states that are efficient or having less outages comparatively in this regard.

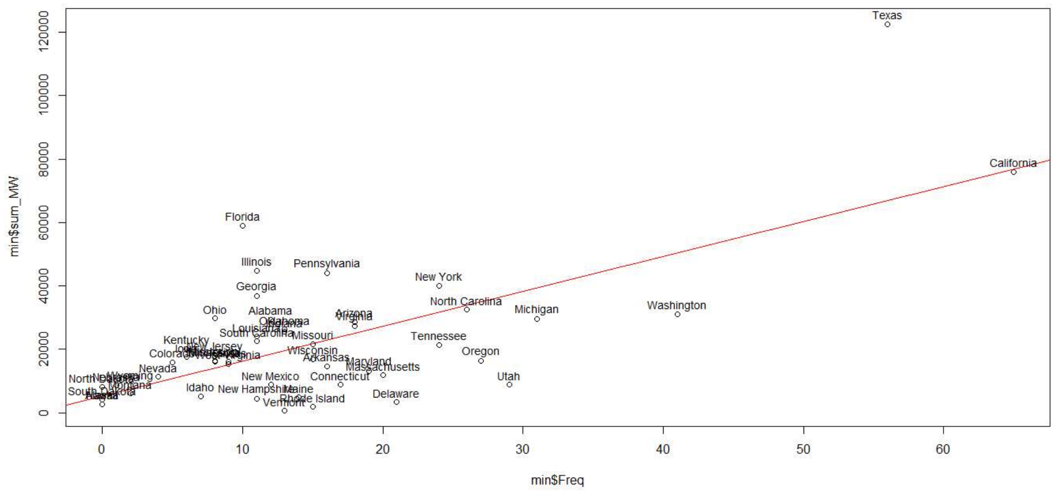

Figure 4 Correlation plot (Y axis: power production capacity, X axis: outage frequency)

There is another assumption that a state that has more portion of renewable energy plants and less fossil fuel based plants, would be more resilient that means having less outages. Most portion of power plants are fossil fuel based such as natural gas and coal. On the other hand renewable energy plants (solar, geothermal, biomass, etc.) comprise a small portion of the total power production capacity in the US. Power plants have different types such as hydro, gas, coal, nuclear, petroleum, biomass, geothermal, pumped storage, solar, and wind. The highest power production in the US is from natural gas as below.

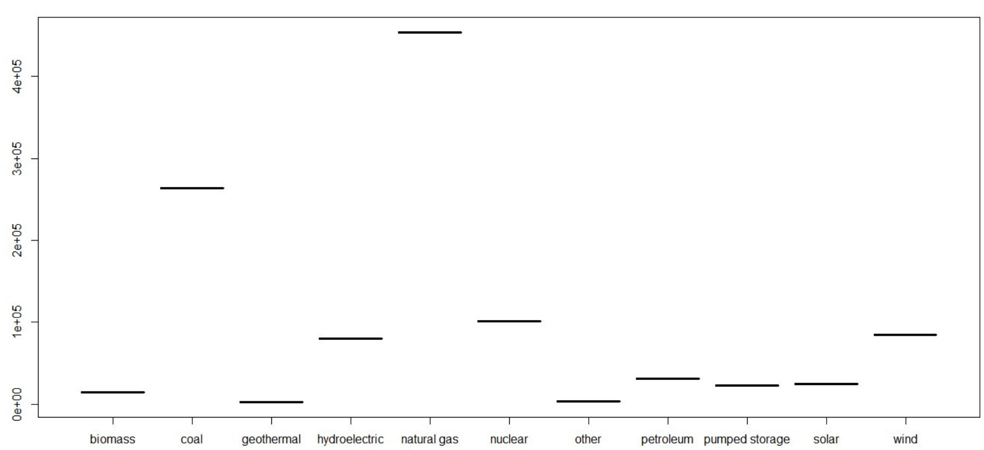

Figure 5 Total power production capacity (in MW) in the US per technology

To verify the hypothesis that energy resilience is related to decentralized and diversified energy system, each respective variable was constructed. Decentralization of energy systems would be quite related to the number of plants and the total capacity of electricity production each state. If there are more power plants producing electricity of a certain amount, it could be considered that there are more distributed power plants spread in the state to serve the same amount of power demand compared to the state with less power plants for the same amount of electricity demand. Here, decentralization index (DCI) per state is described by the sum of the number of plants divided by the sum of power production capacity.

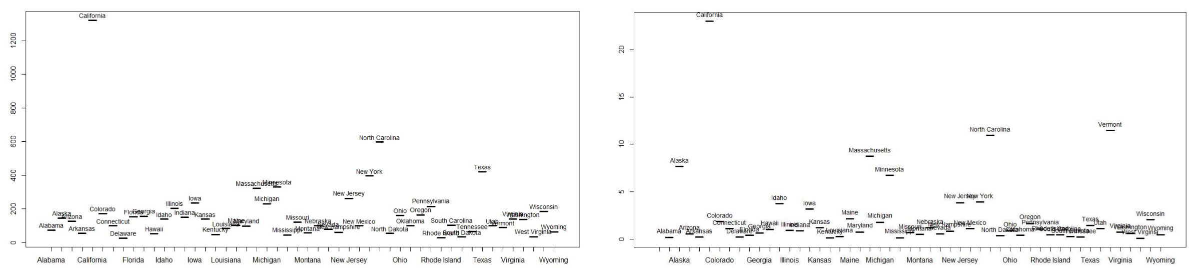

Figure 6 Number of power plants and decentralization index (DCI) per state

Diversification would be connected to the variation among electricity production capacities of a certain type of plant. It means that if the sum of power production is biased to a few power technologies or plants then the variation become larger so it would indicate that the state is less diverse in its energy system. Diversification index (DVI) is described by the square of the sum of power capacity divided by variation factor and variation factor would be calculated by the sum of the square of the sum of power capacity per technology.

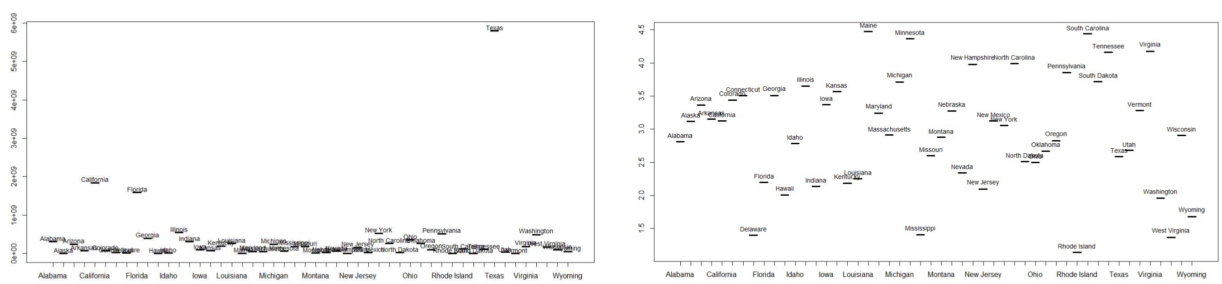

Figure 7 Electricity production capacity variation and diversification index (DVI) per state

By constructing the variables including these two indices, this study can conduct tests to verify the relationship between energy resilience and diversified and decentralized energy systems in terms of state level in the US. It is found that outage frequency increases when a state has more power plants and higher variation factor (i.e., biased power production which is concentrated on a few technologies). Resilience indices (DVI and DCI) are negatively correlated with the outage frequency that means these indices are exactly telling that outage frequencies would be less when a state has energy systems more decentralized and diversified although the p-values of these two indices are not significant in the test model.

Table 1 Energy resilience statistical test

Description	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	7.79E+00	4.56E+00	1.708	0.09458
DVI	-2.21E-01	1.52E+00	-0.145	0.88503
Number of plant	4.16E-02	1.41E-02	2.948	0.00505
Variance factor	5.32E-09	1.79E-09	2.975	0.0047
DCI	-4.69E-01	6.35E-01	-0.738	0.46464
Number of observations = 50				
Adjust R squared = 0.5549				

(Note: DCI, Diversification Index; DVI, Decentralization Index)

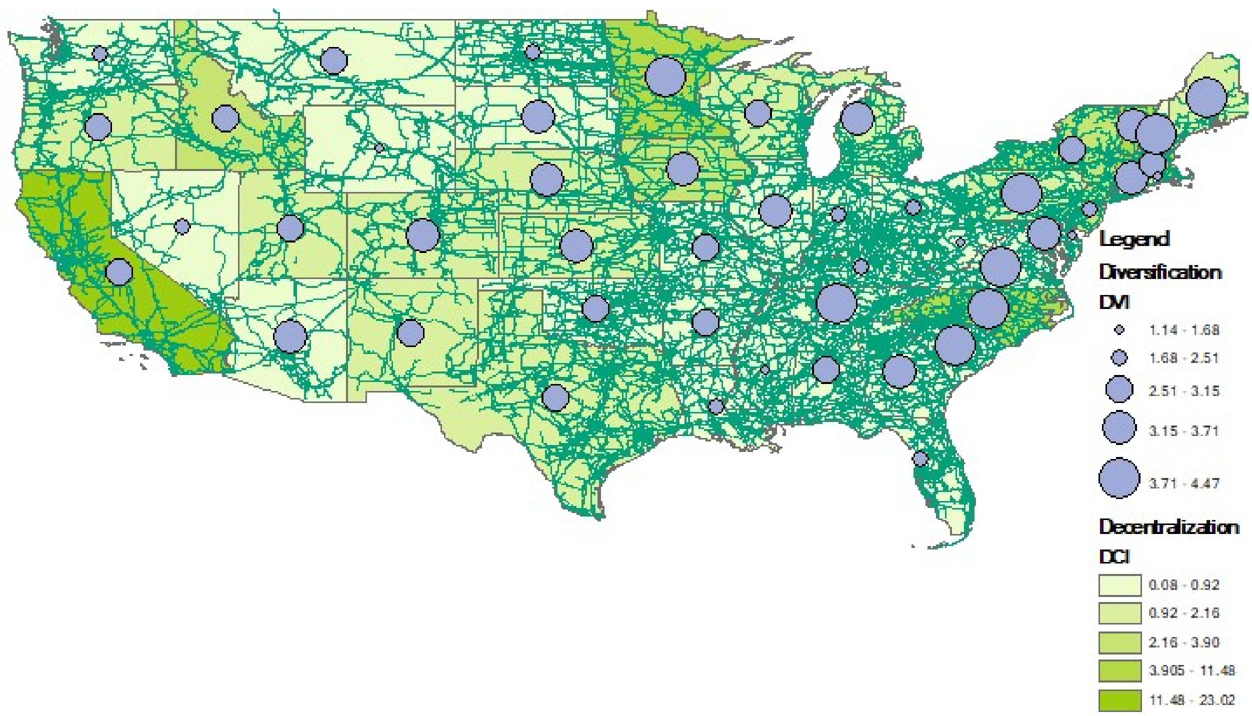

Figure 8 Resilience indices of states

There are trade-offs between resilient indices that having higher diversification index doesn't mean higher decentralization and vice versa. It also applies to the relationship between resilient indices and less desirable predictors (i.e., the number of power plants and variation factor). Interestingly, California has higher resilience indices while having higher undesirable predictors, which are highly correlated with the frequency of outages. There might be other factors influencing this phenomenon. For example California has larger population and higher population density that means it would be possible to have more power plants or more decentralized power sources to serve the population. In this case, while desirable factors (i.e., decentralized and diversified energy system) increase, undesirable factors such as the number of power plants, increase and biased power production structure having a few energy technologies could happen at the same time.

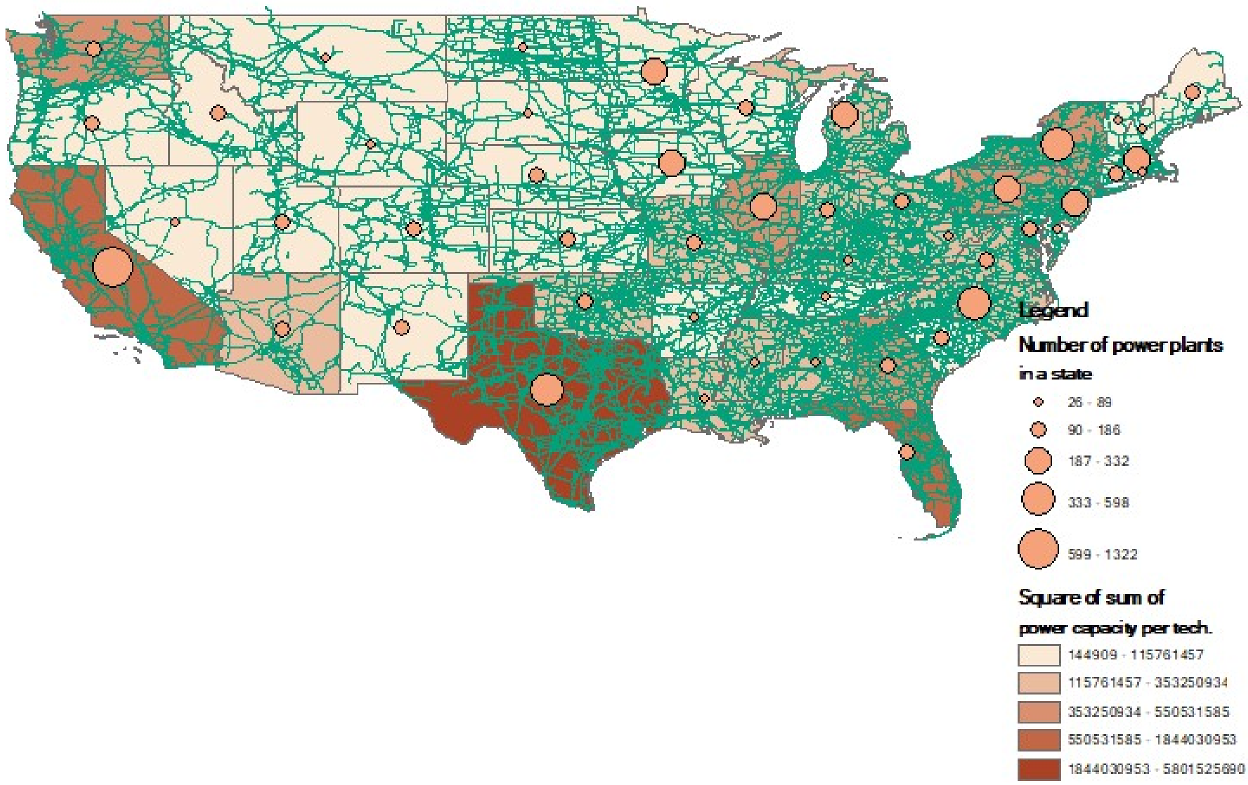

Figure 9 Less desirable predictors to outages

This study shows how resilience for energy systems could be defined with the concept of diversity and self-sufficient theories. Two resilience indices were defined and tested to the real world in terms of frequency of outages in the US from 2013 to 2017. The study confirms the hypothesis that resilient characteristics are correlated with diversified and decentralized energy systems and a prediction model of outage frequency on a state basis was constructed. For further study, each outage event should be mapped in a specific location with longitude and latitude data to figure out the geographical feature on the energy resilience. The study will go forward in this direction for the large scale studies in resilient energy systems.

4.2. Small scale

Different building types have different energy demand and consumption. Commercial communities such as UW (University of Washington) have different types of buildings (dormitory, restaurant, library, hospital, gym etc.) so diversification effect would expect to be essential depending upon the building types. Portfolio theory will be employed to find the optimal composition of buildings in energy system which may result in better resilience in the community (i.e., UW) with highest cost saving though PV involvement by mixing up building types. For commercial solar system occupancy/ ownership structure of buildings should be considered as well as widely varying retail rate tariffs, local utility rate (i.e., the main driver of discrepancy as variation in retail rates is a stronger driver of breakeven prices than is variation in building load or solar generation profiles) while it is known that electricity in Washington is comparatively lower.

Finance options such as direct cash, loan and PPA (power purchase agreement, 3rd party or financial entity owns the solar, building owner or host will benefit energy saving) are also another essential factors to consider. Net-metering regulation and charge options (i.e., energy charge, fixed charge and demand charge) have influenced the system integrity because, for example, demand charge (cost driver is peak load) accounts for 30 to 70% of electricity bill in California. Storage options can supplement the system improvement in resilience. Building types can be divided into 3 categories based on breakeven prices.

- Highest breakeven price: small offices, warehouses, and schools
- Medium: retail establishments, medium and large offices, quick-service restaurants, outpatient medical facilities, and supermarkets
- Lowest: hotels, hospitals, and full service restaurant

Electricity demand of each building in the community (e.g., University of Washington) could be estimated and an optimal portfolio (i.e., higher demand and less volatility) of buildings can be found since UW has different types of buildings. This is a process of selecting buildings (assets) in terms of demand side energy profile per each building using ARIMA (autoregressive integrated moving average) time series model based on historic data. For supply side of electricity, prediction of PV production is quite stable with a certain peak production trend. Considering energy charge and demand charge, lessening the demand through PV involvement with optimal groups of buildings would yield the highest savings of electricity bill. Furthermore, battery involvement in the system network will make the system more flexible allowing to store surplus electricity because battery acts like a tool for peak shaving and load management with DC (direct current) during normal operation and emergency backup for the system resiliency with AC (alternating current) during urgent situations. Cost of batteries in the system needs to be compared to the cost of having grid energy depending on the net- metering regulation in Washington. The study could be performed in different scenarios: cash, loan, PPA.

This research is to study the relationship of energy diversity and decentralization with community resilience, which could be measured in reliable energy supply. In detail, mixing up with independent variables (ID) such as different type of buildings, solar PV, and battery, the dependent variable (DV), resilient electricity supply would be estimated by electricity cost saving. Composing of different types of buildings at UW represents diversity and energy decentralization would be shown by the involvement of solar PV to buildings to compare with electricity grid supply. Since time series models are going to estimate the demand and supply side of electricity, longitudinal sampling design would be implemented. Recent data for electricity bill of each building in this regard will be available since buildings at UW may have the histories of electricity consumption for the past months or years. Production of electricity from solar PV would be simulated using software or examples of similar types because the real installation of PV is not plausible.

Verification of energy demand per every hour a day and the peak demand load for all the studied building at UW may be necessary to figure out how PV system can alleviate the demand thus, lessen the demand charge. Medical building or hospitals at UW have different energy consumption behavior (i.e., comparatively higher energy consumption at night time) thus, including them as well as restaurant type buildings at UW, will diversify the energy demand and lessen the risk accordingly. Financial options for commercial solar (i.e., UW) could be studied if applicable and compare each option with scenarios to find the best options (i.e., cash, loan, and PPA). Net-metering regulation in WA could be studied and may be applied to the study to lessen the risk or benefit project. Storage option such as EV (electric vehicle) at UW could be coupled with PV system in addition to other battery options to increase the resilience of energy production.

Life cycle assessment (LCA) of energy system is essential to analyze environmental impacts. It includes the whole cycle of resource extraction, distribution and movement, which is tracked down to verify the total impact of the system. LCA could find the best option to analyze greenhouse gases (GHG), water and energy use or an option with cost effectiveness (e.g., comparison of options among solar PV, geothermal and wind energy resources). It may include the relevant system construction and operation in consideration of human health cost, valuation of wellness and environmental impacts. Policy makers can take advantage of the assessment in terms of environmental impacts to make decisions for appropriate management policies.

5. Conclusion

Climate change recently has caused several interruption to human society. It seems not as significant as natural disasters or huge accidents from a temporary perspective, but in fact, it has severe potentials in a long run. Natural disasters these days are results from climate change as well. In addition to climate change, accidents and pollutions are increasing in accordance with urbanization with complex and interdependent systems developed to meet the needs of human activities. These events uncover vulnerability of the current urban systems and demand for resilient communities where people could maintain the basic integrity of social systems with unexpected interruptions such as natural disasters. Water, energy and foods are examples required to keep supplied in the unfavorable events to sustain the urban systems. Energy is getting critical to serve the needs of human activities as the society becomes complex. Reliability of energy supply has been proved to be important especially during the emergency situations where medical services are highly demanded facing the unexpected events. Community resilience should be addressed with sustainable and resilient infrastructures, especially energy system, which will cause human behavior changes with the effective system structures. This study will prove that decentralization and diversification of energy sources are more related to resilient community. Renewable energy deployment, which tackles climate change, after all, can be expedited in consideration of interdependence, decentralization characteristics of off-grid networks, and geospatial analysis. The research concerning sustainable and resilient infrastructure systems to promote community resilience, will encourage the deployment of renewable energy to find the best option in current situation through decision supporting tools.

5.1. Limitations

In case of a large scale research, financial saving in electricity bill might be hard to see as a measure of energy resilience. Cost saving, however, can be considered as one of ways to improve resilience in energy system because it means that the system is optimizing the current condition and getting improved with efficiency. Their might be a big upfront cost for employing solar panels and batteries compared to the savings in electricity bill in a short time. TVM (time value of money) will play a role that in a certain period (breakeven point), there would be savings over the upfront cost in a long run.

Also there are certain limitations that currently this research doesn't take into consideration of the dynamics of human factors but more into generalized and assumed predictions of human behavior according to energy system's characteristics. But at least this is the start point to understand the real world and have the research to move forward to deal with the social science and human interacted complex systems in the process of expanding studies.

5.2. Contributions

The final goal of this research is to make communities more resilient against undesirable challenges and events due to the natural disasters and climate change by deploying sustainable and resilient infrastructures especially energy system. This study will promote renewable energy by enhancing and diversifying distributed renewable energy sources rather than only relying on one type of energy sources (e.g., centralized fossil fuel power system). Renewable energy deployment would tackle the unfavorable issues of climate change, because it has less impact on the environment while producing energy that human beings need. With the fact that energy sector produces almost 40% of Greenhouse Gasses (GHG) (IEA and World Bank, 2015), promoting renewable energy will lessen the production of GHG and after all, energy systems will become green supporting community resilience.

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