VALUING CLIMATE RESILIENCE IN ONTARIO'S ELECTRICAL GRID

2019 GUIDEBOOK
FOR THE ONTARIO MINISTRY OF ENERGY, NORTHERN DEVELOPMENT & MINES

munk school
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Executive Summary

Climate change is exacerbating the frequency and intensity of severe weather in Ontario, causing costly interruptions to the steady power supply that fuels our society today. Therefore, Ontario's electrical utilities are faced with new risks that require building a resilient system that can detach from the major electrical grid and operate during and even after a power outage. Basic reliability measures, which cover expected outages under normal conditions are increasingly insufficient in characterizing future electrical outages from natural disasters caused by climate change and that utilities must effectively plan for. However, energy utilities are less likely to invest in climate resilient technologies because there is no standardized method for valuing their benefits.

This study defines resilience as the ability of an electrical grid to withstand low probability, high-consequence severe weather events and recover from them in a relatively short period of time. The value of resilience is the value of the damages that can be avoided or prevented. By estimating the value of these avoided costs, we are able to determine how much investment in resilient infrastructure is justified.

This 2019 Guidebook for the Ontario Ministry of Energy addresses the overarching question: **How can Ontario value climate resilience to facilitate cost-effective planning and incentivize smarter investments in the electrical grid?**

Specifically, this guidebook offers the Ontario Ministry of Energy a two-pronged framework for valuing resilience in the electrical grid:

1. A general set of resilience indicators and an easily adaptable cost-benefit analysis framework that employs resilience indicators (Net Present Value)
2. A resilience valuation process that offers a step-by-step guide to engage relevant stakeholders and prioritize investments that can work for the Ontario province

As an additional recommendation, this guidebook offers parameters for the Ontario Ministry of Energy to consider a province-wide funding program to encourage the first initial investments in resilient electrical grid technologies in Ontario. Coined *ResilientON*, this funding program may offer a way to build practical experience and engage in knowledge-building so that utilities, building owners, and developers could gain confidence to invest in resilient grid technologies.

Part One: Introduction

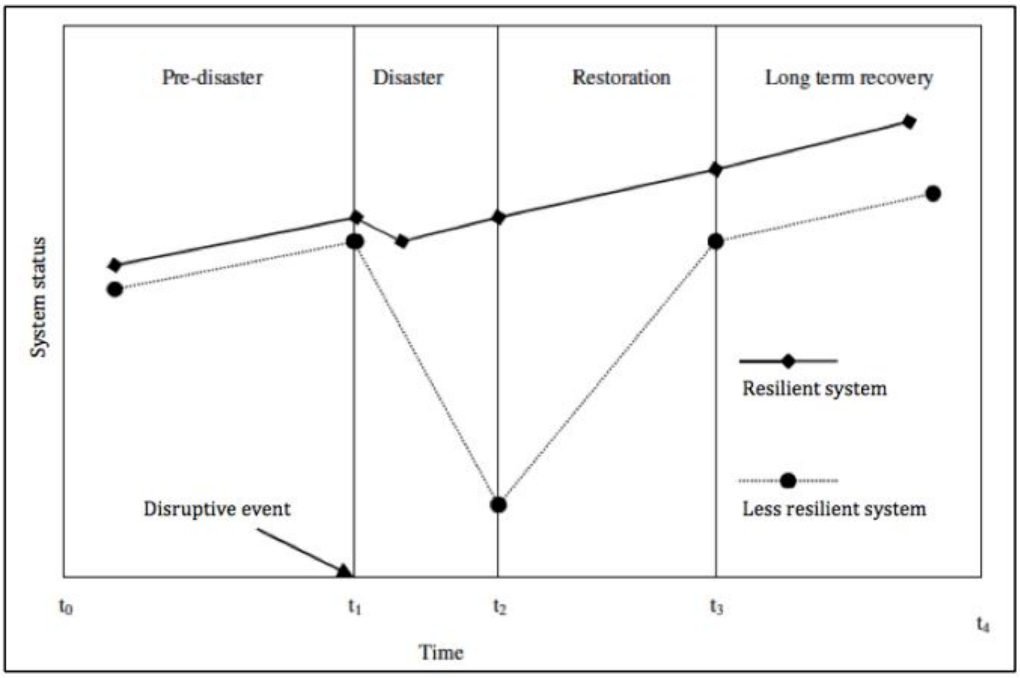
1.1 Climate Change in Ontario and Why Electrical Grid Resilience is Crucial

As a direct result of the anthropogenic climate change, increasing frequency and intensity in severe weather has exposed adverse outcomes in critical energy distribution infrastructures, leaving millions of Ontarian citizens without steady power supply and costing our province billions of dollars. (Singh, Roy et al. 6). In Ontario, power outages caused by extreme weather events, such as ice and wind storms, flooding and hurricanes, present new risks for electrical utilities as well as the communities, businesses and end-users they serve. For instance, the ice storm of December 2013 marked the longest blackout of its kind in Ontario that spread across Southern and Northern Ontario and Windsor-Ottawa corridor in the past decade. In Toronto only, the incident reported more than 300,000 Toronto hydro customers without power or heat. Toronto's Sunnybrook Hospital even needed to discharge six new-born babies from its Neonatal Intensive Care Unit (NICU) due to the power interruption. (Blackwell). Hydro One, which serves mostly rural areas of Ontario, also reported more than 130,000 power outages as a result of the severe ice storm. (Centre for Urban Energy).

More importantly, the increasing frequency and intensity of severe weather pose threats to the current energy system in Ontario, especially on the operation of electrical grids in Ontario. The electrical grids operate daily and consist of high-voltage transmission lines, local distribution systems, and power management and control systems. A more resilient electrical grid is one that is better able to sustain and recover from blackouts caused by climate-related extreme events. (US Department of Energy 5; Vugrin, Castillo and Silva-Monroy 8). Increasingly, Ontario's households, businesses, schools, hospitals and emergency shelters will need to reply on resilient electrical grids that would generate, transmit and distribute power during and after power outages. The benefits of increased grid resilience will include the avoided public and private cost of these power outages, leading to greater efficiencies in energy use, and protecting families and businesses in Ontario.

1.2 What is Resilience vs Reliability?

Figure 1: A Resilient Versus Less Resilient System



Source: US Department of Homeland Security

In this guidebook, we define “resilience” as the ability of an electrical grid to withstand extreme events and recover from them in a relatively short period of time. (USDOE 8). Resilience approaches emphasize the concept that if disruptive events occur regularly, the electricity system should be designed to bounce back quicker and stronger, because the impact of the disruptive events is less. (See Figure 1). Resilience measures would include outage information when low-probability high-consequence events such as hurricanes, windstorms or flooding. In contrast to the definition of “resilience”, “reliability” measures how much time an energy resource is down and unavailable. (Chittum, 11-3). Reliability takes high-probability, low-consequence events into consideration, and measures expected outages that could occur under normal conditions. However, as the hazard landscape is changing, reliability measures are not deemed sufficient on their own to effectively plan for the emerging climate-related disasters. (Clark-Ginsberg 2; Vugrin, Castillo and Silva-Monroy 8).

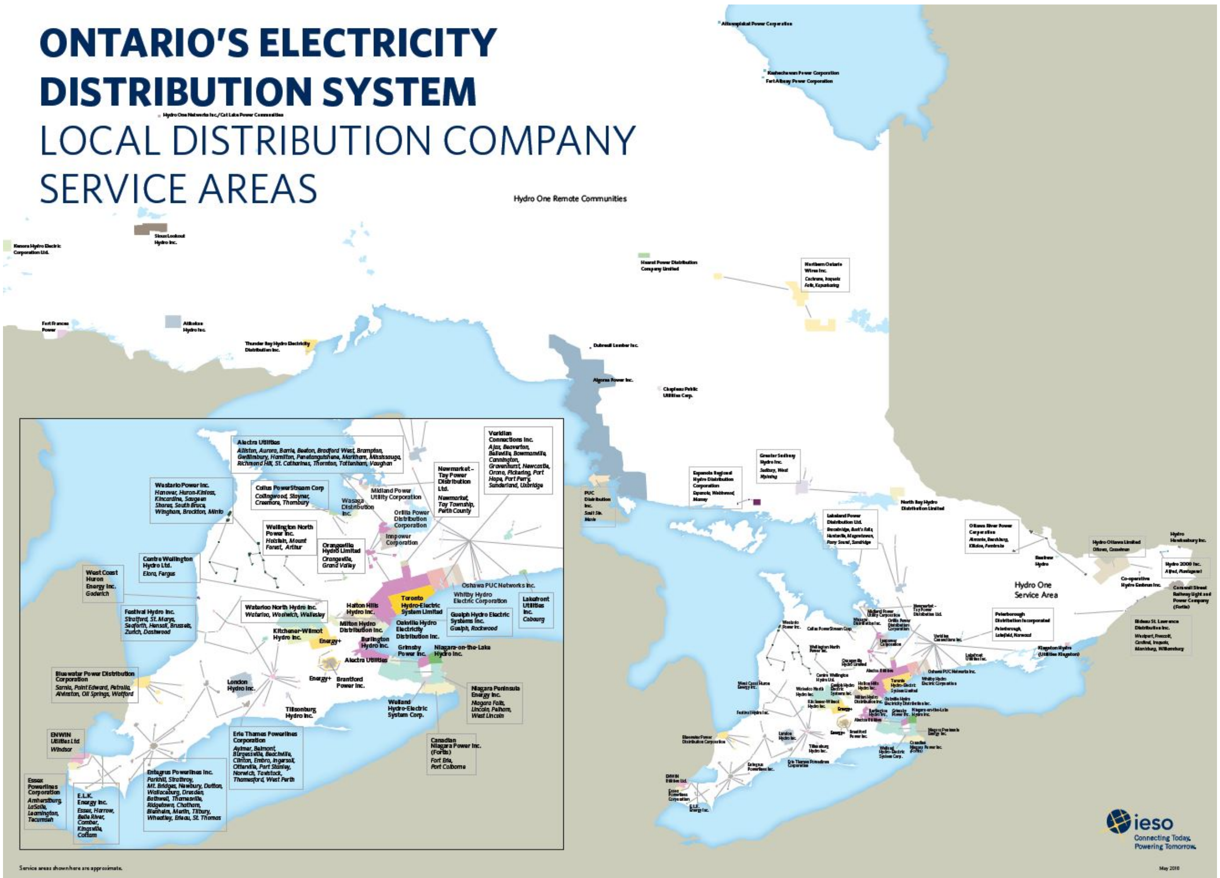
1.3 Valuing Climate Resilience and its Importance for Ontario

This guidebook identifies the valuation of resilience as an estimation of the value of the damages that can be avoided or prevented in case of extreme weather events. By valuing resilience, we can assign a monetary or non-monetary quantitative value to the benefits accrued by using resilient infrastructure, and can thus, avoid costs incurred in using non-resilient infrastructure during power outages. By estimating the value of these avoided costs, we can determine how much investment in resilient infrastructure is justified. (Jeffers et al. 12).

Indicators are an important tool used to measure changes in the electrical grids' state, operations and their impact on end-users, before and after major disruptions caused by severe weather. (Singh, Roy et al. 10). However, currently, Ontario lacks a standardized set of indicators that can be used to value climate resilience. If there are no standardized indicators to account for resilience in cost-benefit analyses, energy utilities and other stakeholders in Ontario may be less likely to identify and prioritize investments in resilience-focused grid technologies.

1.4 Overview of Ontario's Electricity Sector and Key Stakeholders

Figure 2: 68 Local Distribution Companies in Ontario's Electricity Distribution System
Source: IESO



The electricity market in Ontario is a massive and complex system involving many public and private actors. Some of the major groups of actors include Generators; Transmitters; Electricity Distributors; Alternative Suppliers; Electricity Consumers; the Independent Electricity System Operator (IESO); The Ontario Energy Board (OEB); The Ontario Power Authority (OPA); The Ontario Power Generation (OPG); the Electrical Safety Authority (ESA) and the Ontario Ministry of Energy. (van Stee). The Ontario Ministry of Energy manages the entire province's electricity network. In Ontario, there are currently approximately 68 local distribution companies that are responsible for distributing power from transmission lines to their designated service territories. (IESO, See Figure 2). The OEB is responsible for raising electricity prices based on increased costs from the OPG nuclear and hydroelectric power plants, renewable energy generation system expenses and cost recoveries. (Solarshare Bonds).

1.5 Past Actions on Ensuring Resilience in the Ontario's Electrical Grids

Ontario has succeeded in replacing coal-fired electricity with nuclear, renewables, conservation and natural gas. (van Stee). With reduced greenhouse gas emissions and improved electricity grid capacity and resilience, Ontario hosts a much greener, reliable, albeit an expensive system that follows low-carbon solutions to improve resilience. (Environmental Commissioner of Ontario 59). Additionally, Ontario's Long-Term Energy Plan (LTEP) has drawn attention to the importance and potential of Electric Vehicle (EV) batteries in delivering electricity to facilities during a short-term power outage or redirecting it to a grid to be reserved for peak hours. (32). In the future, OPG aims for projects to meet time and cost estimates and remain diligent until benefits are realized in the long-run.

Part Two: Existing Frameworks and Best Practices of Valuing Resilience in the US

2.1 Indicators for Valuing Resilience in Electrical Grids

Using indicators as a tool to measure systemic changes and impact is integral to the process of valuing resilience. A refined set of indicators would facilitate stronger estimates for damage costs and more precise valuations for resilience that can be further used to incentivize smarter investments in resilient electrical-grid systems. Some of the best practices and literature that were reviewed identified key prerequisites for an ideal indicator for resilience:

1. Context: An ideal indicator should be specified in the context of low-probability, high-consequence potential disruptions, this context will help these indicators to be distinguished from reliability indicators.

2. Performance-based: Indicator should be based on the performance of power systems, instead of depending on the characteristics of the power systems alone. This will help the indicators to maximize response and recovery activities, planning and investment efforts.

3. Consequences: An indicator should be able to quantify the consequence of a grid disruption, or be measured on community impact, as underlined in the guidebook.

4. Prioritization: An indicator should be useful to detect which hazards require planning and at what level and preparation, investment and response actions, etc. This would help utilities make stronger rate cases and grant applications.

5. Forward-looking: Indicator should be focused on “planning for the future”

6. Modeling and simulation: Given that resilience analysis revolves around low-frequency events, sufficient historical evidence or statistic is likely to be missing. Hence an ideal indicator must be flexible to include data from modelling and simulation activities that explore postulated scenarios.

7.Consistency: Although this could be a potential challenge, an ideal indicator would allow for consistent comparisons between investment options, mitigation and hazard prioritization cases.

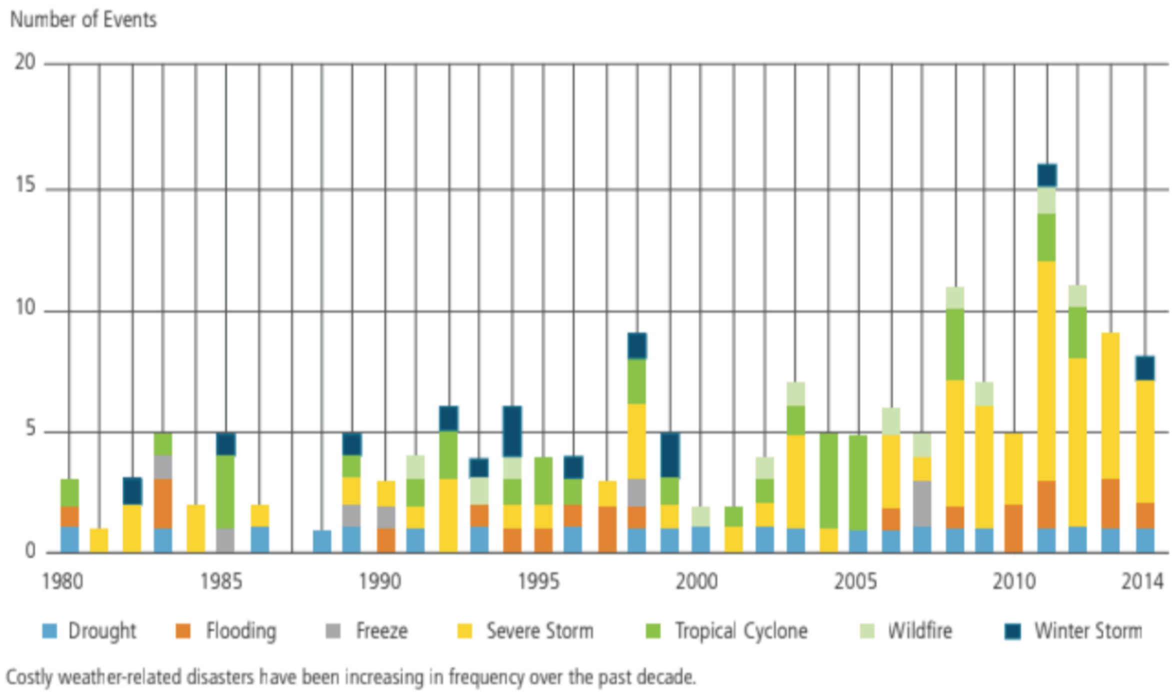
8. Uncertainty: An ideal resilience indicator must consider the inherent uncertainties that accompany response and planning processes. Some of these uncertainties could include conditions of disruptions (frequency, speeds, etc.), grid damage, time required for response, etc.

The jurisdictional scan highlighted sector-specific indicators that were included in the resilience analysis framework. These indicators were both quantitative and qualitative as well as economic and social in nature. They helped estimate the benefits of investing in resilient infrastructure, versus having to bear the damage caused by not adapting to climate change. (US Department of Energy 24). In choosing these indicators for Ontario, it is critical to characterize these based on how they best align with the main objectives and capacities of the Ontario government.

2.2 The United States as Leader in Addressing Extreme Weather

From reviewing the literature on valuing resilience in electrical grids, three best practices were derived from the United States (US) namely New York, Louisiana and California. Why focus on the US? The US has one of the most advanced energy systems in the world. However, Severe weather is the leading source of electric grid disturbances in the US, causing devastating losses. As seen in Figure 3 between 2003 and 2013, an estimated 679 widespread power outages occurred due to severe weather, costing the US economy $18 billion to $33 billion each year. The risk of severe weather in the US is rising. For instance, the number of electricity substations on the Gulf Coast exposed to inundation caused by category 1 storms is projected to increase from 225 to 337 by 2030 due to sea-level rise. As a result, the US Federal Government has made ensuring that electrical infrastructures are resilient a national priority. In the Quadrennial Report, the US Federal Government recommended the Department of Energy in collaboration with the Department of Homeland Security and interested infrastructure stakeholders to develop common analytical frameworks, tools, metrics, and data to assess resilience, reliability, safety and security of energy infrastructures (Quadrennial Energy Review S-10). Incidences of severe weather affecting New York, Louisiana and California, including Hurricane Katrina and Superstorm Sandy have incentivized these states to developed notable best practices on valuing resilience in their electrical grids.

Figure 3: Billion-Dollar Disaster Event Types by Year



Source: Quadrennial Energy Review 2015

2.2.1 Anaheim, California

As a pilot project, the US Department of Energy's National Renewable Energy Laboratory (NREL) explored the impact of resilience on the economics of solar photovoltaic systems (PV) combined with battery energy storage to provide backup power during electric grid outages in Anaheim, California.

Developers and building owners are exploring PV and storage as viable options for augmenting or replacing traditional standby generators as the costs of solar and battery storage technologies are declining (NREL 2). Determining the expected utility bill savings and potential for revenue generation during normal grid operation of a PV and battery energy storage system can be straightforward. Yet, PV and storage technologies provide backup power and thus also create value by allowing businesses to stay open, residents to shelter in place and prevent losses of life by powering hospitals and emergency shelters. In this case, NREL values resilience in terms of the avoided cost of a grid outage through NPV. The expected cost of the loss of businesses or liability incurred because of lack of power is used as a proxy for the value of resilience. Approximate cost of outages for various customer types from 30 utility customer surveys are used (NREL 2). Building owners and investors are often unsure how to value this lost power anticipated during an outage (which is the resilience benefit) and thus is typically unaccounted for when evaluating the cost-effectiveness of a potential building project.

NREL's pilot project in Anaheim, California found that accounting for the cost of electric grid power outages can make PV and energy storage systems economical in cases where it might not appear to be through traditional cost-benefit calculations (NREL 2). This was found by incorporating the avoided cost of a grid outage into the economics of determining cost-optimal system sizing for three different buildings. For each building type, two scenarios were explored: 1) placing no value on resilience 2) values resilience in dollars lost per hour of outage. For each scenario, a solar and energy storage system was designed to maximize economic benefit during a system lifetime of 20 years measured in terms of the net present value of the system (NPV). NPV is the difference between the benefits and the costs of the project in today's dollars.

As shown in Table 1, a combined PV and storage system was already economical for a large office building, but accounting for resilience (the cost of outages) increases the optimal PV size by 35% and added a 271-kWh battery energy storage system economical (NREL 4). Note this study did not include the cost of islanding which could add 10%-15% to the costs and the analysis only considers electricity needs for the buildings and ignores other mitigation measures that impact a buildings ability to become more resilient i.e. thermal loads, energy efficiency, etc.

Table 1: Large Office

Value on Resiliency	Assigned Value of Resiliency ($/hour)	PV Size (kW)	Battery Capacity (kWh)	Net Present Value ($)
No	$0	961	0	$111, 000
Yes	$14, 365	1, 304	271	$289, 060

Source: NREL

2.2.2 New Orleans, Louisiana

In New Orleans, the most prominent environmental shocks come in the form of severe storms or hurricanes and flooding events. The impacts from these events are exacerbated by the presence of cumulative physical stresses, like land subsidence and coastal wetland loss, and social stresses, like poor economic, educational, and health outcomes among vulnerable populations. In 2005, Hurricane Katrina caused devastating losses to New Orleans and surrounding communities. Challenges faced by the city due to the widespread flooding during the hurricane and its aftermath were exacerbated by power outages, and New Orleans recognizes that enhancing the resilience of its power grid infrastructure is essential to improving the overall resilience of its community.

Under the direction of the US Department of Energy, Sandia National Laboratories (Sandia) and Los Alamos National Laboratory (Los Alamos) developed “Resilience Planning Process” – a framework to help a jurisdiction identify shocks and stresses related to climate change, select relevant indicators to value climate resiliency and develop options for grid modernization. Working collaboratively with the local governments, electric utilities and other stakeholders, this model was implemented in New Orleans and became the first of its kind to address grid investments aimed at minimizing extreme consequences to the community in the U.S. New Orleans' classified its resilience indicators into two categories, community measures and economic measures. Each measure includes three indicators: Community measures include number of people without necessary services, lives at risk and net population change; and economic measures include GDP, change in capital wealth and business interruption costs.

New Orleans' "Resilience Planning Process" is a stakeholder-driven, iterative and designed to work within stakeholders' existing processes. The Process comprises of four steps: 1) Identification of shocks, stresses and key infrastructures; 2) Selection of assessment methods and data collection; 3) Assessment of infrastructure performance under shocks and stresses; and 4) Assessment of resilience enhancing investments. (Detailed description can be found in Appendix A). After the results from these four steps were shared with stakeholders, New Orleans identified enhancing advanced microgrids as the solution for grid modernization. Advanced microgrids utilize automated controls to tie together a collection of facilities in a service territory using one or more points of switching devices that segregate the microgrids from the electricity distribution system during power outages. (Jeffers et al. 11-26).

2.2.3 New York

New York, more than other states in the nation, has identified building resiliency as a key driver within the overhaul of its energy regulatory framework, *Reforming the Energy Vision (REV)*. The NY Prize is administered by NY State Energy Research & Development Authority (NYSERDA) and the Governor's Office of Storm Recovery and is one of the main programs of REV to encourage investment in highly resilient electrical infrastructure. Specifically, the NY Prize is the first competitive program in the US aimed to fund the development of resilient microgrids, most of which are anchored by CHP (Combined Heat and Power systems) (NYSERDA NY Prize). The competition is open to communities across NY state. Teams must include the local electrical distribution company and more than 1 entity that will benefit from the microgrid— participants included fire-stations, wastewater treatment plants, shelters, schools and police departments. To receive funding, microgrids must be able to fully island (or disconnect) from the traditional grid and black start (to turn on without any outside power supply) (Chittum&Relf 26).

NY Prize offers support to applicants over 3 stages. For Stage 1, feasibility studies, applicants address certain issues such as site constraints and opportunities, commercial and financial feasibility assessments, net project benefit analysis, etc. The NY Prize Selection Committee approved up to $100 000 in funding for 83 feasibility studies across New York State in 2015. Stage 2 is the detailed design phase where applicants are expected to conduct detailed assessments of the technical design and system configuration, assess regulatory and environmental suitability, and develop formal commercial terms/contractual relationships between project participants. Finally, Stage 3, Project Build-Out evaluates overall cost and benefits of the project, its contribution to public need, and conduct post-operational monitoring (NYSERDA NY Prize).

NY Prize offers a range of tools and information on its website including its own cost-benefit analysis framework for microgrids. Costs and benefits reflect the sector-specific impacts of outages and includes many different reliability and resiliency indicators that characterize how much an outage would impact a certain facility. Table 2 shows a sample set of indicators incorporated into the cost-benefit tests delineated by the NY Prize program specifically for the value of a hospital staying online rather than failing and requiring critically ill patients to receive care elsewhere. NY Prize applicants can add and adjust the metrics based on their project and location (Chittum and Relf 27).

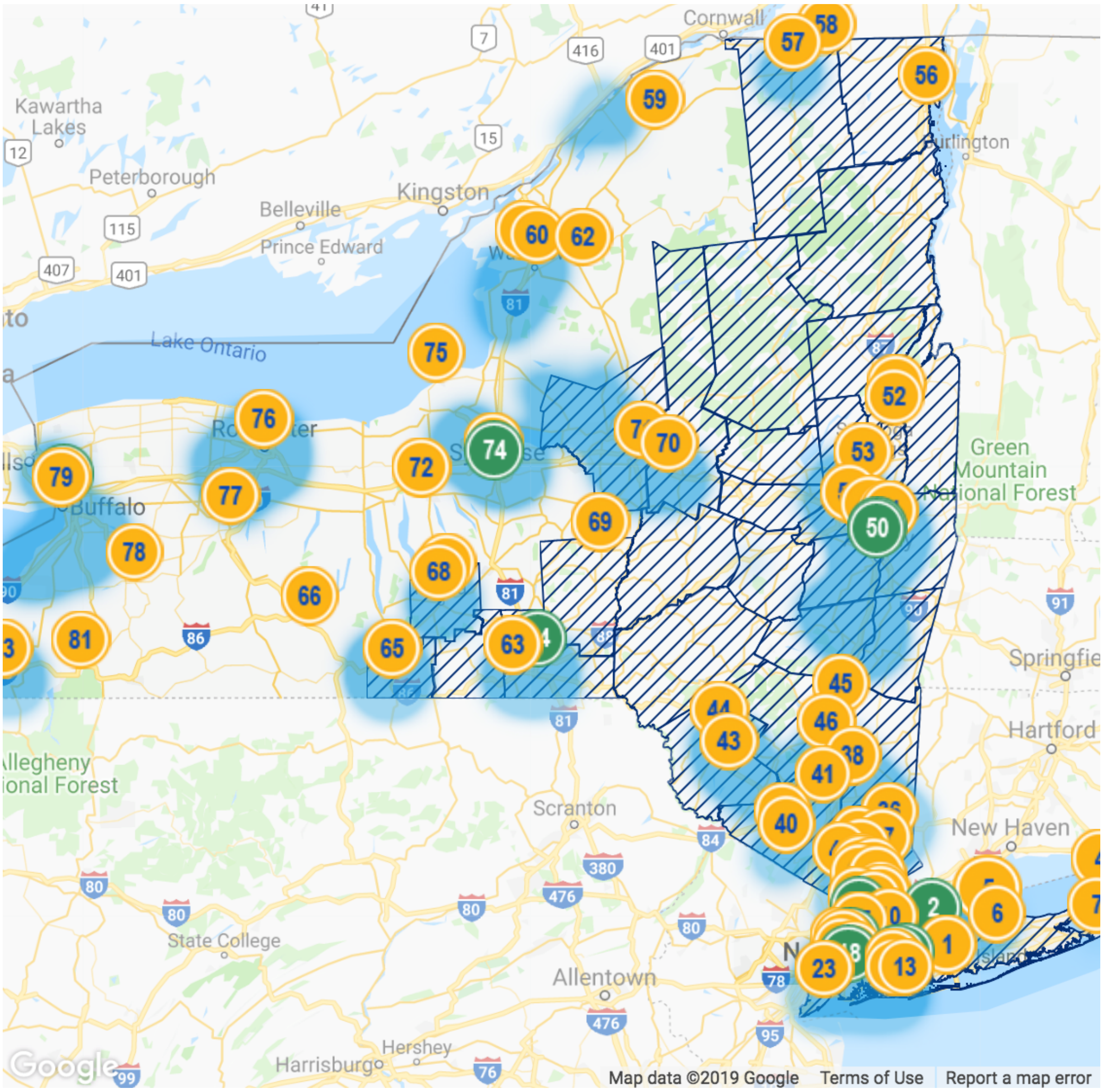
Table 2: Selected resiliency indicators considered in NY Prize program for a hospital

Indicator	Indicator Type	Exemplary Value
Likelihood of backup generation failure	Percentage	15%
Annual emergency department (ED) visits per capita	ED visits/person	0.40
Increase in ED visits during a natural disaster	Percentage	25%
Cost of time	2007 dollars per hour	$28.11
Cost of mileage	2008 dollars per mile	$0.51
Number of people per trip	People/trip	2
Death rates per capital from acute myocardial infarction (AMI)	Deaths/person/year	0.000509
Death rates per capita from unintentional injuries	Deaths/person/year	0.000397
Increase in number of deaths due to a one-mile increase in distance (due to AMI)	Percentage	6.04%
Value of a statistical life	2008 dollars	5 800 000

Source: ACEEE

In addition to a cost-benefit framework that incorporates resilience valuation, the NY Prize also highlights certain geographical areas called *opportunity zones* that would be well served by microgrid deployment due to the presence of constrained distribution system infrastructure. Data on distribution system components are collected from utilities. Figure 4 shows an image of an interactive map provided on their website where the blue areas indicate opportunity zones and the striped areas represent declared storm affected counties (Chittum&Relf 27).

Figure 4: New York Prize Opportunity Zones



Source: NYSERDA, NY Prize

Part Three: Recommended Next-Steps for Valuing Resilience in Ontario

Recommendation #1: Resilience Indicators and Net Present Value

3.1.1 Indicators

Indicators are important not only to measure the changes in an electrical grid system's performance in the event of an outage, but also to measure the impact of an outage on utilities and end-users. (USDOE 63). Indicators help utilities address the following stages of change (Roege et al. 249-256):

- Plan/Prepare: Plan, invest or prepare to equip self with services and assets available, accessible and functioning in the event of a disruptive event
- Absorb: Maintain the functioning of most critical assets and availability of critical services while evading or fighting the disruption.
- Recover: Restore and reset all functions and service availabilities to their initial pre-event functionalities
- Adapt: Using lessons from the event, alter programs, reconfigure the system, train or equip personnel and balance investment, recovery and damage costs to avoid future disruptions.

By assigning a monetary or non-monetary value to these changes and impacts, utilities can use these indicators to estimate the potential cost of damage on services dependent on electricity and avoid these damage costs by implementing resilient technology or processes in their grid systems. Currently in Ontario, utilities don't have a standardized set of indicators that can be used to value resilience. Recognizing this gap in Ontario, the report highlights some important indicators that must be considered to value resilience by all utilities in Ontario (See Table 3). These indicators are general and flexible enough to be applied across any type of infrastructure in Ontario.

Table 3: Recommended set of general resilience indicators

Indicator Bucket	Proposed Indicators	Calculation and Explanation
Critical Impact	Key public health and safety services without power (police, fire, ambulance)	Calculated by examining the number of fire, police or emergency medical services that were unable to operate because of Storm A for X number of hours
	Critical facilities without power after backup fails (control centres, hospital buildings, emergency shelters, old age homes, etc.)	Facilities restored in X hours, additional facilities restored in Y hours, the last facilities restored in Z hours
	Critical customers' lives at risk	Vulnerable population at risk during outage
	Total customers' lives at risk	Total customer lives that would be disrupted
	Total death toll	Total morbidity toll caused by an outage
	Displaced people	People who were evacuated
Economic Impact	Key industries affected	Hospitals or manufacturing or services facilities or schools out of power
	Back-up power for unaffected industries	Facilities from different sectors that have adequate backup for X number of hours
	Population without services	Total number of end-users that will be left without power
	Average business interruption costs in dollars	Total loss in business due to outage
	Loss of assets and perishables in dollars	Total loss in owned assets and perishables due to outage, including cost of insurance coverage
	Cumulative customer-hours not served	Customers that have not received backup since the outage
	Likelihood of backup generation failure	Probability of backup failure

Recovery Impact	Total cost of short-/long-term recovery measured in dollars	Effectiveness and speed of restoration effort profile, e.g., total customers restored in X hours, additional customers restored in Y hours
	Total labour hours required for recovery services	
	Average cost of equipment required for recovery	

3.1.2 Ontario

Ontario is not only a manufacturing powerhouse but hosts one of the largest service industries in the world, employing over 79% of the province's workforce. (Government of Ontario). Having said that, it is imperative for utilities in Ontario to start considering these indicators to ensure that they are "safe fail". Utilities should be sensitive of the fact that these indicators may differ based on industry. Table 4 is a chart examining how an indicator list for valuing resilience - specifically for utilities in the manufacturing industry in Ontario, would look like.

Table 4: Sample resilience indicators for Ontario manufacturing industry

Indicator	Explanation
Staff lives at risk	The total staff lives at risk in the event of a storm - including vulnerable population in the facility
Total customers' lives at risk	The total customers' lives at risk in the facility during outage
Total deaths in the facility	Total morbidity toll caused by an outage
Capacity of back-up power	Number of hours that backup can be used to power the facility

Average business interruption costs in dollars	Total loss in business during and after outage
Loss of assets and perishables in dollars	Total loss in owned assets and perishables due to outage, including cost of insurance coverage
Cumulative customer-hours not served	Percentage of customers that have not received backup since the outage
Likelihood of backup generation failure	Probability of backup failure
Total cost of short-/long-term recovery measured in dollars	Cost of restoring the main phases of the facility restored in X hours, additional phases restored in Y hours, the last phase restored in Z hours
Total labour hours required for recovery services	Total labour hours of recovery services
Average cost of equipment required for recovery	Total cost of equipment required for recovery

During the 2003 blackout episode in Ontario, six of the tiniest patients in the neonatal care unit of Toronto's Sunnybrook Hospital succumbed to the absence of electricity. It is therefore, even more crucial for utilities in the Healthcare sector to accommodate resilience in their cost-benefit analyses. Table 5 highlights proposed indicators for utilities in the healthcare industry in Ontario.

Table 5: Sample resilience indicators for Ontario healthcare industry

Indicator	**Explanation**
Hospital staff at risk	Total staff lives at risk in the event of a storm

General patients and visitors at risk	Total patients and visitors at risk in the facility during an outage
Critical patients at risk	Critical and emergency care patients that cannot be evacuated easily
Total deaths in the facility	Total morbidity toll caused by an outage
Capacity of back-up power	Number of hours that backup can be used to power the emergency/critical units as well as general wards in the hospital
Loss of clinical and general perishables	Total loss in clinical and general perishables due to outage
Loss of assets and equipment	Damage cost of hospital equipment due to disruptions
Cumulative patient-hours not served	Patients that have not received treatment since the outage
Likelihood of backup generation failure	Probability of backup failure in the hospital during outage
Total cost of short-/long-term recovery measured in dollars	Cost of restoring the critical units of the hospital in X hours, additional phases restored in Y hours, the last phase restored in Z hours
Total labour hours required for recovery services	Total labour hours required for recovery and evacuation services
Average cost of equipment required for recovery	Total cost of equipment required for recovery

3.1.3 Appending Indicators into the Cost-Benefit Analysis

Resilience indicators need to cater to low-probability high-consequence events. (Chittum and Relf 4). When the grid goes down, be it for five minutes or five days, the critical economic impact to different facilities can vary substantially. Thus, the willingness of consumers to pay to mitigate that risk will vary as well.

1. Probabilities

Although there is no standard method for using these indicators in the valuation process, general valuation of resiliency is measured in terms of probability of potential consequences - the probability of an outage occurrence, probability that the system would be equipped to withstand these disruptions, probabilities of economic losses, lives at risk and added operating costs in recovery efforts during and after an outage. (Chittum 3). For example, utilities could use the recommended indicators for further calculating and comparing scenarios:

A. Probable downtime associated with relying on a regular grid = (Probability that X type of event will happen in location Y) × (Probability that X type of event will cause downtime) × (Estimated length of downtime)

B. Probable downtime associated with resilient grid = (Probability that X type of event will happen in location Y) × (Probability that X type of event will cause downtime with resilient infrastructure in place) × (Estimated length of downtime with resilient infrastructure)

For example, utilities in low-lying areas in Ontario such as Burlington or Ashbridge's Bay might have estimates of the probability of being flooded at least one day in a year. (Blackwell). Based on past experiences, they would be able to estimate the impact of a flood on their production. If they compared the two scenarios, they may find that with existing infrastructure, floods impacted 36 hours of production, however if they invested in resilient infrastructure such as Combined Heat and Power (CHP) or Distributed Energy Resources (DER), floods resulted in 8 hours of lost production. Utilities could then use these estimates to predict lost revenue due to lost production and determine relative risks in each scenario. However only calculating a probability of an outage is not enough to value resilience. It is important to assign a monetary or non-monetary value to these probabilities in order to determine how and why utilities must invest in mitigation technologies.

2. Net Present Value (NPV)

Net Present Value is an evaluation method used to determine the overall value of an investment. (Woodroof). The NPV represents the value in today's dollars of all future cash flows or returns on investment. The value of money received today is generally worth more (assuming that interest is earned) than money received in the future. Thus, any return on investment in the future must be "discounted" to estimate its Present Value. NPV is useful to measure where resilience is valued in terms of avoided cost of grid outage. For example, utilities can use the expected cost of the loss of business or the liability incurred because of the lack of power as a proxy for the value of resilience. The lifetime economic benefit, measured in terms of a NPV will produce the difference between the benefits and the costs of the investment, in today's dollars. An investment which yields a negative NPV indicates that it would cost more to install and maintain resilient infrastructure than the savings realized throughout time, in today's dollars. And a system with a positive NPV indicates that it would be less expensive to build and operate the resilient system than to continue normal operations without it, when the future return on investment is discounted to today's value of money.

NPV calculations require:

- The annual savings amount
- Total investment made
- Interest earned over time

After discounting returns on investment in today's value, we derive a Present Value for the return on investment using option A (CHP, for example), and a Present Value for the return on investment using option B (existing). The difference between these Present Values will present us with the Net Present Value of an investment. The greater the NPV for option A, the more the investment is worth to the utility, and the higher the value of resilience. A negative NPV means that the investment on option A will simply detract value from the utility over time, in which case the utility is less incentivized to value resilience in its planning.

Recommendation #2: Ontario Resilience Valuation Process

To effectively employ the indicators to account for resilience in cost-benefit analyses, we recommend the Ontario Ministry of Energy to develop an “Ontario Resilience Valuation Process” - a resilience analysis and valuation process that engages different stakeholders as well as meaningfully applies these indicators to identify and prioritize resilience- enhancing policies and investments. Modelled after the “Resilience Planning Process” led by Sandia and Los Alamos, the proposed “Ontario Resilience Valuation Process” (Figure 5) is a stakeholder-driven, which aims to streamline various stages for the Ontario Ministry of Energy to collaborate with distinct stakeholders on valuing climate resilience. At the end of the process, stakeholders will be able to select a range of indicators to measure resilience and identify potential resilience-enhancing solutions in Ontario.

Figure 5: 5 Steps of Proposed "Ontario Resilience Valuation Process"

This proposed process is cyclical and requires constant and consistent stakeholder interaction throughout each stage. Ontario Ministry of Energy, as the main stakeholder of this Resilience Valuation Process, plays a key role in creating and adjusting the valuation framework, disseminating information and establishing collaborations among authorities across different jurisdictional levels. Ontario Energy Board (OEB), ideally, will work closely with the Ministry on overseeing local distribution companies in data collection and performance assessment. Additionally, this process also involves stakeholders from each electricity service territory, which include subject matter expertise and representatives from local distribution companies and municipalities. Ideally, this proposed Resilience Valuation Process is expected to receive feedbacks and data from approximately 68 utilities and 444 municipalities in Ontario.

The proposed "Ontario Resilience Valuation Process" consists of five steps:

Step 1 – Identification of Shocks and Stresses and Key Infrastructures

As the first step in this process, the most primary threats and infrastructures of concerns can be identified with coordination and feedback from different local distribution companies or utilities, along with expertise and representatives from various municipalities across Ontario. For Ontario, heatwaves, ice and wind storms, and flooding are of highest concern. (Ontario Ministry of the Environment, Conservation and Parks 6). However, these climate-related shocks and stresses vary among different service territories in the province, where individual electric utilities face different threats to be resilient. This step can allow stakeholders to address their resilience goals and form design basis threat for selection of potential grid resilience improvement.

Step 2 – Selection of Assessment Methods and Data Collection

Once the resilience analysis problem for local utilities has been defined, the analysis team, along with the support from municipalities and the province, can select a set of indicators from 1) critical impact, 2) economic impact and 3) recovery impact, which we identified in the guidebook, to value resilience of the province to identified shocks and stresses. In the meantime, data collection and assessment method determination should be performed in parallel.

Step 3 – Assessment of Infrastructure Performance under Shocks and Stresses

After we have determined the assessment methods and collected data, the third step calls for assessing the performance of key facilities of concern subject to climate-related extreme events, in coordination with subject-matter experts such as the owners and operators of different infrastructures. In Ontario, key facilities include manufacturing plants, hospitals, schools and universities, emergency shelters, office buildings, shopping centre, mining facilities, wastewater services, public-safety services (police and fire) and residential buildings. (Government of Ontario).

Step 4 – Assessment of Regional Performance

The fourth step zooms out to the overall impact of the shocks and stresses on the performance of individual service territories. The analysis team should work collaboratively with experts from local utilities and select a smaller set of indicators characterized by different regions across Ontario. In this step, a service territory is defined as an area serviced by a single local distribution company in Ontario.

Step 5 – Assessment of Resilience Enhancing Investments

After the regional performance assessment is shared with the Ministry of Energy, OEB and other stakeholders, options for improving resilient-focused grid technologies will be discussed and incorporated on the provincial level. For example, New Orleans narrowed down to three different investment options:1) enhancing advanced microgrids; 2) improving the flexibility and automation of the electricity distribution system; and 3) provision of localized building-tied backup generators. (Jeffers et al. 20-21). Please refer to Appendix A for a detailed description of these three options.

Recommendation #3: ResilientON Funding Program

Considering the above recommended set of indicators and valuation process as a starting point, Ontario will eventually develop an efficient analytic process for valuing resilience in the electrical grid. Yet, it will likely take practical experience and knowledge building for utilities, building owners, and developers to gain enough confidence to invest in resilient grid technologies. Therefore, the Ontario Ministry of Energy may consider taking lead on creating a province-wide funding program to encourage the first initial investments in resilient electrical grid technologies in Ontario, similar to the NY Prize.

Over recent years, Ontario has been focused on taking its first steps to a low-carbon electricity system. As a result, electricity prices have gone up and are expected to rise further, posing a challenge for future governments to justify making long-term investments especially into a ResilientON funding program to address avoided weather storms and disasters. Therefore, Ontario may choose to tap into the resourcefulness and creativity of our thriving private sector. For instance, the Ontario Ministry of Energy may partner with one of Canada's top banks to offer innovative financing solutions for Ontario's first cutting-edge electrical grid resilience projects planned through the ResilientON Funding Program. Resilient electrical grids could be an exciting addition to a bank's portfolio of energy projects. Forming a financing structure for these pilot projects could also encourage standardization and scaling of portfolios which could lead to greater private market participation and ultimately less expensive and more resilient electricity opportunities in Ontario.

Similar to the NY Prize, the Ministry of Energy may receive data from Environment Canada and Ontario utilities to highlight target zones— municipalities that are most prone to severe weather and host critical infrastructure that with constrained distribution infrastructures and thus would benefit most from funding. Teams must include the local electrical distribution system and at least two facilities that would benefit from a resilient electrical grid. Applicants must successfully undergo two phases to receive funding: Feasibility Studies and Design (Stage 1) and Project Build-Out and Post-Operational Monitoring (Stage 2). The Ministry of Energy and other stakeholders involved may choose to create a ResilientON webpage to outline target zones, information on the funding program and an online application package including an NPV cost-benefit analysis test, examples of resilience indicators and suggested resilience valuation process for all stakeholders.

Ontario can expect a number of benefits from a ResilientON funding program and resulting deployment and monitoring of such projects. Primarily, a ResilientON program would enable technological, operational and business models that will reduce costs of building resilient grids further. For instance, these pilot projects could inform whether resilient grids are most efficiently implemented by building owners or developers (before the meter) or utilities (behind the meter). Stage 3 of the project build-out and post-operational monitoring will encourage the collection of practical feedback to fuel further conversations around resilient electrical grids. Overall, ResilientON would spur innovation and community partnerships between utilities, local governments and the private sector, initiating a provincial movement to climate resilience. Therefore, electrical utilities, building owners and developers who may not have considered resilient technologies may be encouraged to start evaluating its benefits, influencing a chain of impact.

Part Four: Feasibility and Things to Consider

None of the above-mentioned methods, processes or schemes would be complete without highlighting the existing gaps in the Ontario electricity network, and without diligent efforts from stakeholders to recognize or address these gaps.

4.1 Complex Stakeholder Relations

The electricity market in Ontario has shifted its focus from mitigation to adaptation. However, what the Ministry must consider is that with increasing electricity prices, utilities and end-users are looking to reduce their electricity costs. To make this instrument as accessible and attractive, the Ministry will have to promote resilience with the right rationale. Despite the complex framework, the Ontario Ministry of Energy has the capacity to overcome constitutional restrictions if any and information asymmetry to ensure that there are no absolute roadblocks.

4.2 Potential for Locational Value

The Ontario Ministry of Ontario could consider the potential of investing further in Distributed Energy Resources (DERs), which has created upcoming options for key electricity services as alternatives to transmission or distribution network investments. Rooftop solar photovoltaics (PVs) have the highest profile of DERs. What sets aside DERs is their ability to deploy power closer to the location of electricity consumption which could be inaccessible to alternative centralized resources. This ability is crucial as the changing value of some electricity services changes with the location of provision. The distributed and modular nature of DERs allow them to provide these services at locations in power grids where they are most valuable. If sited at the right locations and operated at the right times, DERs can deliver higher locational value than its counterparts. However, Ontario would have to grapple with the rising costs of the DERs also on a per-unit basis because of economies of unit scale.

The increasing proliferation of DERs deserves additional policy and regulatory support from the Ministry of Ontario, above and beyond generalized support for low-carbon energy technologies. Ontario must seek inspiration from many jurisdictions in the US, which provide robust policy and regulatory support to DERs that puts them at an advantage relative to its centralized competitors. For example, net-metering policies and favorable taxation policies provide significantly more support for distributed than centralized solar, despite its rising costs. (Burger et al.)

4.3 Cost-Effectiveness

The primary conundrum for the Ministry to be able to resolve is to manage complex stakeholders and address the challenges associated to valuing resilience in a resource-constrained setting. A provincial cost-effectiveness study team can help decide which interventions or solutions offer the best value for money. Although it may seem like a simplification of reality, using methods such as NPV, processes such as the Resilience Assessment Process and further, through Innovative incentivization schemes, the Ministry can leverage this guidebook to accommodate existing resources and refining existing interventions to spur a fresh conversation around valuing resilience in a cost-effective and resource-efficient manner.

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Appendix A:

Jurisdictional Scan: Valuing Resilience in New Orleans, Louisiana

1. New Orleans' Climate Resilience Challenge

In New Orleans, the most prominent environmental shocks come in the form of severe storms or hurricanes and flooding events. The impacts from these events are only exacerbated by the presence of cumulative physical stresses, like land subsidence and coastal wetland loss, and social stresses, like poor economic, educational, and health outcomes among vulnerable populations.

2. Rationale: A Grid Modernization Approach for Community Resilience

The electric grid is central to the web of interconnected systems that must operate resiliently to serve communities during times of extreme disruption. Challenges faced by the city due to the widespread flooding during the hurricane and its aftermath were exacerbated by power outages, New Orleans recognizes that enhancing the resilience of its power grid infrastructure is essential to improving the overall resilience of its community. Investments in modern grid technologies, such as advanced microgrids and automated fault isolation and recovery, can substantially decrease this impact to society.

3. New Orleans' Resilience Goal

Providing citizens in New Orleans with critical infrastructure services as quickly as possible – to decrease both the number of citizens expected to be disrupted, as well as the duration of those disruptions. In a planning context, this metric would be projected over a planning horizon for multiple services, such as electric power, water, food, and emergency medical services.

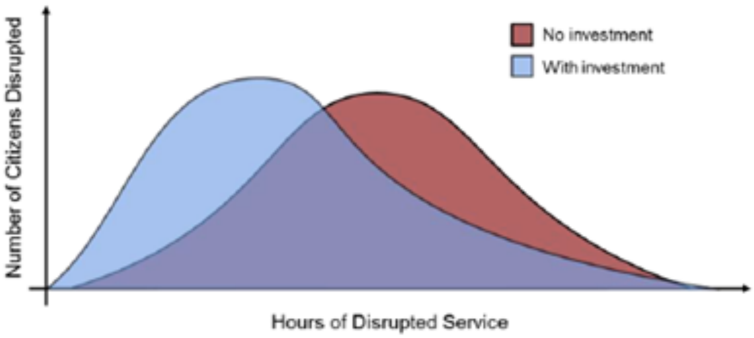

Figure A1 - Suggested metric formulation to measure the impact of resilience investments by New Orleans. Because of existing capability gaps, the percentage of infrastructure assets with reliable backup power was used as a proxy metric.

4. New Orleans' Classification of Resilience Metrics

Measurement Classification	Common Examples

Community Measures	Number of People Without Necessary Services
	Lives at Risk
	Net Population Change
Economic Measures	Gross Municipal Product Loss
	Change in Capital Wealth
	Business Interruption Costs

Figure A2 – New Orleans' Classification of Community Resilience Metrics

5. Identified Science and Technology Gaps When Measuring Infrastructure Resilience

Capability Gap	Description
Projection of future threats	Because of the rare nature of extreme events, characterizing the likely events that will occur over the next 30 years involves significant uncertainty.
Projection of population needs	In many extreme events, significant portions of the population are displaced. Understanding the probable location and the needs of this displaced population remains a challenging exercise.
Interdependent infrastructure performance estimation	Impacts to power-dependent infrastructures, such as communications and natural gas, can feed back to cause larger or longer power outages. These dynamics are not well modeled in existing tools.
Consequence estimation	The economic and societal value of improved infrastructure resilience is dependent on understanding the total consequence of disruptions to infrastructure services. Some of these consequences extend many years after the initial event and are difficult to attribute precisely.

Figure A3 - Gaps in the capability of the urban infrastructure resilience community to project performance-based resilience metrics

6. Implementation of New Orleans' Resilience Planning Process for Grid Modernization Investments

New Orleans' Resilience Planning Process is stakeholder-driven, iterative, and designed to work within stakeholders' existing processes.

***Step 1 – Identification of primary threats and infrastructures of concern*:** By concentrating on a reasonable worst consequence scenario, this step aims to address the resilience goals of city planners, as well as form the design basis threat for selection of potential grid resilience improvement. For New Orleans, hurricanes and severe storms accompanied by large rainfall totals are the threat of highest concern.
Step 2 – Selection of Assessment and Data collection: The analysis team worked with project partners to identify data and tools already in use for infrastructure resilience planning in New Orleans.

Step 3 - *Assessment of Infrastructure Performance Under Shocks and Stresses*: This assessment involves analysis of three factors: 1) Wind and Inundation Impacts - simulation-driven analysis of hurricanes); 2) Electric Power Resilience Assessment – to provide a baseline for the potential benefits of grid modernization options targeted at improving community resilience; 3) Mapping Grid Resilience to Infrastructure Services - Resilience metric chosen by New Orleans – the percentage of infrastructures with sufficient backup power – focuses on lifeline infrastructure services and the ability to support critical needs of the community.

Step 4 – Specification of Grid Improvements for Community Resilience: New Orleans narrowed down to three different investment options:1) advanced microgrids, which utilize automated controls to tie together a collection of facilities in a service territory using one or more points of switching devices that segregate the microgrids from the electricity system during power outages; 2) improving the flexibility and automation of the electricity distribution system that can have faster control over distribution switching and reconfiguration; and 3) provision of localized building-tied backup generators which are able to supply power to a facility to enable operation of critical functions during utility outages. New Orleans identified microgrids as the final grid modernization solution.

7. Lessons Learned from New Orleans' Grid Modernization Approach for Resilience

- Performance-based, consequence-focused resilience metrics should be used throughout to track resilience improvements
- It is important for regulators (the government) to establish goals, incentives, streamlined process requirements, and appropriate cost recovery mechanisms so that utilities may be rewarded for resilience investments that benefit their communities.