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INPUT PAPER

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THE USE OF DIRECT CURRENT VOLTAGE SYSTEMS TO INCREASE A CITY'S RESILIENCE AND REDUCE THE VULNERABILITY OF ECONOMIC ACTIVITY FROM A DISASTER

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EXECUTIVE SUMMARY

Purpose:

The overarching purpose of this paper is to address the challenges facing the implementation of the Hyogo Framework for Action 2005-2015 in a holistic way. The emphasis will be on Thematic Research Area 8, which concentrates on what can be done to mitigate the adverse economic effects of a disaster. The electrical system is seen as pivotal to many economic aspects of disaster risk reduction (DRR). The objective of this paper is to show how distributed electricity systems, coupled with direct current (DC) voltage offer a solution to increasing resilience against the effects of a disaster, thus reducing the impact on both the economy and the people who facilitate its smooth operation.

Design/methodology/approach:

This paper looks at the lifeblood of any modern economic system as being the electricity needed to operate most functions of economic activity. Economic activity requires a workforce and consumers, therefore this research will look at the economic system as being a socio-technical system. The whole economic value chain is the technical system and the workforce and consumers are the social system. Electricity underpins the functionality of the whole socio-technical system. Data from case study literature is used to build a picture of how both people and economic activity are impacted by the loss of electricity. Diagrams will be made of the different subsets of the economic activity that will be adversely affected by the loss of electricity, and of the subsets that surround the wellbeing of the workforce that will enable them to continue working.

Findings:

There is a gap in the resilience literature with regard to the importance of electricity to DRR. Some literature, especially that about the loss of electricity to intensive care units in hospitals, has focused on educating clinicians as to how to overcome such challenges, but only offers limited solutions. It was found that by analysing information about the effects of a disaster from the point of view of reconstruction and rehabilitation programmes, it is possible to gain a clearer picture of some of the higher–order aspects of a disaster that were affected due to the loss of electricity, but not the actual details for each loss factor. This therefore only gives us higher order socio-technical implications.

Social implications

For the workforce to be able to work they must be able to sustain a reasonable level of living standard. For this to happen, all support activities that enable this must be able to function. These support activities may include; a operational home to live in, a school for the children, a functioning healthcare system, and functioning public services- including utilities. All these support activities require electricity to function. The social impact of the loss of electricity include; forced relocation, loss of functionality of all public services, breakdown in law and order, loss of job and therefore means of income, breakup of communities and relationships,

and a longer time to get back to pre-disaster living standards, all of which exacerbate the psychological trauma on individuals and families. By having to move from their community and/or having their means of financial income disrupted, the local economy will lose a proportion of its customers and therefore its income.

Technical and economic implications

The supply chain for economic activity should be looked at as the provision of the products or services from raw materials to consumption. Economic activities should therefore include, procurements of raw materials, excluding workforce skills, production, transportation, wholesaling, retailing, and consumption. At each stage there may be the need for storage, and when it comes to perishables freezing or refrigeration. All these activities require electricity, the loss of which, even in any part of the economic value chain can increase the vulnerability of the whole chain.

Originality and value

Although the importance of the continuation of the electric system in times of disaster is known, this research has been first to focus on the electrical system as being pivotal to the economic impact of a disaster. Based on work carried out during this research which indicated that there is a gap in the DRR literature, some case studies have been used to understand the negative economic impacts of the loss of electricity. They focused on subjects like, post disaster reconstruction and what anesthesiologist should know about healthcare in blackout situations, which are not subjects about electricity. By highlighting the importance of electricity in DRR, it is hoped that this will increase awareness among all DRR professionals that more emphasis should be placed on gathering data, and working towards a more robust electrical system. Distributed energy systems, lead to energy independence, which leads to energy security and untimely to a more disaster resilient society.

1. Background

In 2005 the Hyogo Framework for Action (HFA) 2005-2015 (UN, 2005) was adopted as a guide to help deal with Disaster Risk Reduction (DRR). In 2009, 2011 and 2013 Global Risk Assessment Reports (GRA) on DRR were produced as a means to assess the progress of the HFA and to bring DRR ideas up to date. This paper is a response to the call for further discussion towards the GRA to be published in 2015. The overarching purpose of this paper is to address the challenges facing the implementation of the HFA in a holistic way. The emphasis will be on Thematic Research Area 8, which concentrates on what can be done to mitigate the adverse economic effects of a disaster. In the literature electricity can be mistakenly looked at as being one aspect of DRR like water, health, or any other input function to the DRR equation. This paper will focus on the electrical system as being pivotal to many economic aspects of disaster risk reduction (DRR). Its objective is to show how distributed electricity systems, coupled with direct current (DC) voltage, offers a solution to increasing resilience against the effects of a disaster, thus reducing the impact on both the economy and the people who facilitate its smooth operation.

When a situation occurs it only turns into a disaster when its' impact becomes widespread to the point that the normal means of dealing with the situation cannot cope. In a case where there is widespread damage to the built environment like the 2010 earthquake in Haiti, the use of a decentralised electricity system becomes superseded by the fact that the infrastructure has become unusable. Therefore the solutions in this paper cannot be seen as a panacea for all disaster scenarios, it is but one major tool in the DRR arsenal. In the case where the infrastructure of the built environment is intact, then all the advantages of a decentralised DC electrical system will become manifest.

2. Introduction

2.1. Objectives of this paper

In the lifecycle of disaster management there are three stages. The first stage is mitigation against future disasters, then resilience to the disaster in progress, and finally post disaster recovery. At each stage many actions can be put in place to reduce the risk, mitigate against harm, and to speedup post disaster recovery. This research recognises how important it is to focus on the role that the electrical system plays in <u>all aspects</u> of DRR. Electricity permeates all five of the Priorities for Action as states in clause 14 of the Hyogo Framework for Action (HFA),(UN, 2005). The overarching purpose is to put the electrical system in the forefront of addressing the challenges facing the implementation of the HFA.

This paper is a response to the call for further discussion towards the Global Risk Assessment 2015 report (GRA), which will be the third such report that looks at the progress and possibilities for new actions towards implementing the HFA. The emphasis will be on Thematic Research Area 8, which concentrates on what risk reduction actions can be put in place to mitigate the adverse economic effects of a disaster. There are three main sectors in an economy, these are industrial, agriculture and service sectors, in each sector the value chain has three aspects, production, distribution and consumption (UNISDR, 2013 Chapter 10). To operate a successful value chain a workforce is needed. Their economic output is products and services for the consumption by humanity. Therefore when looking at ways to reduce disaster risk to an economy, the people must be integral to the plan, for without the people there is no economy.

One aspect that facilitates the availability of the workforce for work and the means for a successful value chain is the availability of electricity. In the literature electricity can be mistakenly looked at as only being one aspect of DRR like water, health, or any other input function to the DRR equation. This paper will focus on the electrical system as being pivotal to many economic aspects of DRR. Its' objective is to show how distributed electricity systems, that operate using direct current (DC) voltage, offers a solution to increasing economic resilience, and thus reducing the impact on both the economy and the people who facilitate its smooth operation. See Kinn (2011) for proposed details for the DC elctrcial system of the automenous house of the future. See Box 1.1 for further discussion about the advantages of DC voltage.

2.2. Multiple failure chains due to the centralised system

Almost all electricity generation systems are centralised, with consumers accessing the system via a national grid. Therefore any failure in the national grid system can have far reaching indirect consequences at a very long distance from the actual point of failure, I.e. a failure chain can ensue. "*A **failure chain** is a set of linked failures spanning critical assets in multiple infrastructure systems in the city. As an example – loss of an electricity substation may stop a water treatment plant from functioning; this may stop a hospital from functioning; and this in turn may mean that much of the city's kidney dialysis capability (say) is lost. This failure chain would therefore span energy, water and healthcare systems*." (UNISDR., IBM., & AECOM., 2014). As the urban population grows an electrical failure will have increasing and more devastating secondary impacts on the daily lives of more and more people.

2.3. Importance of electricity in the urban setting

Currently, about half the world population lives in urban areas, and it is estimated that by 2050 the global urban population is expected to approach 6.4 billion, (Gea, 2012 Section 5.2.2). This makes the robustness of the urban electricity system and the continuation of electricity supply, critical to the future resilience of cities, to the continuation of the standard of living of the population and to the economic wellbeing of society.

Electricity is the lifeblood of all modern societies, yet its continual flow is taken for granted. It is only when there is a power cut that we start to appreciate and realise how dependent our daily living standards are on the continuity of its supply. This research is interested in how to make the electrical system more robust. However to do this the vulnerability of the system, and how a long term blackout affects the living standards of the population must be known. The only way to record and assess how the lack of electricity effects the daily lives of a city's inhabitancy would be to turn the electrify off, and record how the living standards of the whole society are affected by the lack of electricity. However this is not acceptable, but in times of a national disaster when there is a sudden and long term loss of electric power, it is possible to record the multiple failure chains that occur due to the blackout, and to all aspects of how people's lives are affected. From this understanding it is possible to identify what aspects of modern living are affected by the loss of electricity and work towards mitigation solutions. To this end many papers are direct to what is coined 'resilient cities' projects around the world, and the United Nations Office for Disaster Risk Reduction has a global reach in coordinating, campaigning, advocating and informing on the International Strategy for Disaster Reduction, (UNISDR, 2014).

Although disaster risk reduction is of major international concern, many disasters when triggered, cannot be controlled. However people have the ability to predict, reduce risk, and manage the response and recovery phase in the lifecycle of a disaster. Much valuable work is carried out into the resilience of the structures in the built environment, and to mitigate the effects on the inhabitants when disaster strikes. In the twenty first century a way to measure living standard is the degree of accessibility to electricity. When a disaster cuts the supply, then not only is the living standard of the local inhabitants reduced, but the rescue effort is hampered especially in the initial post disaster phase. What is proposed by the author is to use electricity as a means to mitigate the human suffering associated with post disaster recovery.

This paper looks at the life force of any modern economic system as being the electricity needed to operate most functions of economic activity. Economic activity requires a workforce, consumers, and rescue workers therefore this research will look at the economic system as being a socio-technical system. The activities of the whole economic value chain, is the technical system and the workforce and consumers are the social system. It is obvious that a disaster causes damage to economic activity. To formulate a resilience plan we have to identify the root causes as well as the whole failure chain of any economic effects. By categorising the damage caused to a major city from a disaster, it will be possible to understand the important role played by electricity in all aspects of the city's resilience. How the subject of electricity is dealt with in the resilience literature is shown in Section 3. Case studies from the literature are presented in section 4. The ramifications and discussion is in section 5 and the conclusions and further work is in section 5

Box 1.1 Advantages of supply and consumption of direct current voltage DC voltage

At this time the supply and consumption of electricity to the built environment is in the form of alternating current (AC) voltage and has been since the race between Edison and Westinghouse was won by AC voltage. For some of the history see Kinn (2011b pp. 11-12). The use of AC voltage provides a locked-in, stable and mature electrical system. However for some specialised loads, DC voltage is still in use. For example it was only in 2007 that the last DC supply line was cut by the ConEddison company in New York, after which the DC loads (elevators) were supplied from the AC network via a transformer (Lowenstein, 2008). Since the advent of the silicon chip and the development of power electronics (Meindl, 1997), the loads using electricity have developed from purely electrical to electronic applications. This means that more and more loads actually consume DC electricity, even though they are supplied by AC. This is either via an external (black) power adapter, or where internal AC-to-DC transformers are used, it is situated somewhere in the appliance and can be found where the casing feels hotter. Transformers are lossy and depending on their design and cost, operate at efficiencies of between 25% and 90%. (Reeder, 2002: 4). An important niche environment where DC appliances are used is in the leisure industry where the electrical supply is from 12V (car) batteries. However the range of products available while increasing, is limited (RoadPro, 2013), compared to the amount of off-the-shelf AC powered household appliances.
When DC micro-generators are used, the expensive inverter which is now used when supplying the AC electrical environment, will not be needed. Also in the all DC electrical environment, all appliances/loads will operate and therefore consume DC electricity. As the electricity consumed is DC voltage, there will be the advantage of the elimination of the ubiquitous AC transformers in each appliance, which can be up to 25 per household (Reeder, 2002, p.7). Eliminating the transformers reduces the amount of energy lost in multiple conversions and therefore for a given peak load requirement, smaller DC micro generators will be needed, and therefore the cost for the system will be smaller (M.C. Kinn, 2011a, p.109). Or for the same outlay a larger DC micro-generation system can be installed thus increasing the energy supply.

DC electrical applications have less parts then their AC equivalence, therefore their mean-time-to-failure is lower, and in operation DC motors, fans, compressors, etc. are much quieter (M.C. Kinn, 2011a, pp.113-114). By eliminating transformers, and increasing appliances' mean-time-to-failure and their life cycle carbon footprint should be smaller than that of an AC equivalent application. Another advantage of DC only appliances is, their physical size is smaller and therefore the amount of materials needed to manufacture them is less. Furthermore one only has to look at the iterations of the mobile phone over the last thirty years to see, that as the power electronics have miniaturised, the battery size has drastically shrunk, which implies that the actual energy needed to run power electronic devices is reducing. One very important outcome of the transition to the distributed supply and consumption of DC voltage electricity, will be a provision of a higher level of energy independence with security.

3. Electricity in the resilience literature

If distributed DC electricity is to be used to increase the resilience of economic activities, then we have to identify the root causes as well as the whole failure chain of the economic effects caused by widespread blackouts. The goal of the literature search was to find information about how economic activity was impacted by disasters. The Global Energy Assessment (GEA) report (2012) was the first document used in the initial stages when trying to understand the effects of the lack of electricity have on the built environment. This report is like an encyclopaedia for anyone interested in understanding how energy impacts humanity. The many hundreds of citations in this report became the catalyst for the beginning of our research into how electricity or the lack of it, affects the people on this planet.

The GEA 2012 led to the first literature search which was to find citations that would help build a picture of the importance of electricity in the built environment. However as more and more papers were read it became apparent the lack of mention of any correlation between the subject-matter under discussion and electricity. This is not a criticism, as one would not usually expect researchers from the Humanities or from the Social Sciences to focus on electricity which is seen as an engineering subject matter. However what this literature search did, was to help build a picture of the different subject areas involved with disaster management and resilience. Some of the different subject areas are as follows; logistics, human geography, sociological and psychological effects, flooding, healthcare, heating and lighting, post disaster reconstruction, economic effects, and resilience of the built environment. Each discipline highlighted important questions about the difference electricity may have made to the outcome of the disaster, but provided little evidence of the direct effects of the loss of electricity that could have been used to understand how a distributed DC system would help reduce the impact of the disaster.

The data we were looking for was, for example, statistics about how many houses, schools, shops, health facilities, public building, etc. were non-functional due to physical destruction, and how many were non usable due to the loss of electricity. Aggregated values like the total number of building etc. that lost electric power, tells us nothing about what difference a distributed electrical system would have made, or knowing that five months after the disaster many shops had not reopened (DRAP, 2012), tells us nothing about why this has happened and whether a distributed electrical system would have negated this situation.

It was hard to find specific details on the direct impact of power outages on the usability of the built environment, or on the living standards and conditions of the survivors. This lead to the question: 'to what extent is electricity recognised by the academic community as being central to disaster resilience'? To answer the question, 'is there a gap in the resilience literature?; a second wide-ranging literature search was carried out to see how prominent electricity was in the disaster literature. The search consisted of 6920 citations, (Kinn, 2014). It was concluded that there is a gap in the resilience literature with regard to the importance of electricity as being pivotal to DRR. Some literature, especially that about the loss of electricity to intensive care units, had focused on educating clinicians as to how to overcome such challenges, but only offered limited solutions.

To understand how crucial and central the continuation of the electricity supply is to the standard of living of people caught up in a disaster zone, it is important to know how a city is impacted by a large scale disaster. The problem is that almost all the academic papers found did not focus of the electrical system. Those that do are looking through the lens of their particular discipline with the loss of electricity being minor to their research. Therefore although these citations do not specifically focus on the impacts of electricity, many of the papers that look at aspects such as; logistics, human geography, sociological and psychological effects, flooding, healthcare, heating and lighting, post disaster reconstruction, economic effects, and resilience of the built environment, have useful information that can be used to understand how a city and its inhabitants are impacted by the loss of electricity.

To highlight the central importance of electricity to resilience in the built environment, the consequences of the damage caused to the electrical system on a large modern city due to a major disaster has to be characterised. To do this data from a case study about the wide ranging reconstruction program implemented after Hurricane Sandy that struck the New York area in 2012 was used. Also used was data from a case study of how the largest trauma centre in Houston Texas was affected by Tropical Storm Alison that struck in 2001.

4. Case Studies Hurricane Sandy and Tropical Storm Alison

Using Case studies to understand how the built environment is impacted by a major disaster will help us understand what aspects of the disaster have an economic impact.

4.1. Introduction to Case Studies

The criteria for the case we wished to study had to have a unique set of specific circumstances, these were; a large scale urban disaster, one where the geographical loss of electricity was far larger than the area of physical destruction, available data about direct physical destruction and direct effects of electricity, and data about secondary failure chains caused by electricity or the lack thereof. We were not able to identify any papers that described these circumstances and had as their focal point electricity. However we were able to find literature that focused on other aspects, from which important information about the electricity could be gleaned.

Hurricane Sandy (Sandy) was chosen as our main case study, due to it uniquely filling many of the above criteria. Hurricane Katrina was also looked at, but we were not able to find data about the specific effects of the power outages had on the city of New Orleans. Also where there has been mass destruction of the built environment, like that from Hurricane Katrina or Typhoon Haiyan, it is more difficult to ascertain the secondary impact associated with the loss of electrical power. In contrast to Hurricane Katrina that caused initial mass migration and longer term displacement, with Sandy, the amount of people not able to come back into their homes and businesses, post disaster was small. Also the data, that shows how Sandy affected electricity, was readily available in a report, whereas for Katrina and other major disasters, less is known about the impact of the loss of electricity.

Data about Hurricane Sandy that took place in 2012, came from a report entitled 'The City of New York Community Development Block Grant – Disaster Recovery (CDBG-DR) Action Plan Incorporating Amendments 1-4' (DRAP, 2012). In this paper it will just be called DRAP (Disaster Recovery Action Plan). Throughout this paper the wording taken directly from the DRAP will be in italics, with reference made to the page numbers where the extract came from. The second important case study focuses on an intensive care unit at a hospital that lost electrical power due to Tropical Storm Alison in 2001.

Data from case study literature was used to build a picture of how both economic activity and people are impacted by the loss of electricity. This data was used to build the diagrams of the different subsets of the economic activity that will be adversely affected by the loss of electricity, and of the subsets that surround the wellbeing of the workforce that will enable them to continue working. See section 5 Discussion.

4.2. Impacts of power cuts due to a citywide disaster

To characterise the impact of the loss of electricity on the city, the functionality of the city has been broken up into sectors and the direct and indirect impacts noted.

4.2.1. Housing

The DRAP divides residential housing into properties owned by the New York City Housing Authority (NYCHA) and privately owned properties. What is important to notice is that many of the NYCHA buildings are large multi-occupancy. It is unusual for a building with less than three floors to have an elevator, so if "*402 buildings lost power, elevator and compactor service*" it can be assumed that, in the worst case the water damage in these buildings would have been in the basement and ground floor. Therefore it can be concluded that the impact to the domestic living conditions for tens of thousands of residents living above the water damaged apartments, was greatly affected by the secondary effect of the loss of electricity and not by the direct effect of the hurricane. Box 1.2 shows the damage statistics for the NYCHA public housing.

Box 1.2 Damage statistics for the *NYCHA* public housing (Source DRAP)

"While none of the NYCHA buildings sustained permanent structural damage due to the storm, many buildings' systems – essential for supporting the living conditions for tens of thousands of New Yorkers served by NYCHA – were significantly impacted.
Over 400 buildings in Brooklyn, Queens, and Manhattan, with 35,000 residential units housing roughly 80,000 residents, were affected significantly by Sandy. Of the over 400 buildings, 402 lost power, and with it, elevator and compactor service. 386 buildings lost heat and hot water.
In Coney Island, 42 buildings – home to 8,882 residents – were impacted.
In the Rockaways, 60 buildings – home to 10,100 residents – were impacted.
In Red Hook, 32 buildings – home to 6,173 residents – were impacted.
In Manhattan, 176 buildings – home to 41,513 residents – were impacted.
NYCHA developments in Coney Island were especially impacted because those buildings sustained substantial sand and saltwater infiltration. The systems damage in other developments was due mostly to flooding. An additional 356 NYCHA buildings at 97 developments in all five boroughs sustained moderate damage, mostly due to wind damage on roofs and facades". (Page 36)

" ..major impacts to the residents of NYCHA's Red Hook Houses who were without power, heat, and running water for 1-3 weeks following the storm. On a positive note, new waterfront residential developments fared quite well." (Page 82)

The size of the Red Hook housing complex with its 6173 residents is that of a small town, and not having power, heat and water for up to three weeks would have severely impacted the living standards not only of all the residence but also on those who had to negotiate the flood water to help them. What is known is that *"While none of the NYCHA buildings sustained permanent structural damage due to the storm, many buildings' systems – essential for supporting* *the living conditions for tens of thousands of New Yorkers served by NYCHA – were significantly impacted.".* However what is not known is the extent of the number of residences impacted due to water encroachment and those indirectly impacted due to the loss of electricity.

4.2.2. Healthcare

The direct effect on the healthcare of New York residence was on three levels. The first was the direct danger to life due to the power cut, such as residents at home and patients in two major hospitals, that required the use of electrically operated life sustaining equipment, who were severely impacted by the loss of power. Secondly, people who were in need of medications and could not get out of their residence and required public assistance to receive their medication. Thirdly new patients who were in need of medical assistance who had to travel to further facilities for assistance. Set out in Box 1.3 are extracts that show the full extent of how the loss of electricity directly impacted the healthcare of New Yorkers.

Box 1.3 How the loss of electricity effected the New York health system (Source DRAP)

"To provide basic primary care in affected communities, the City brought temporary mobile healthcare services to areas with extensive power outages and incorporated health referrals in door-to-door outreach. Eleven mobile medical vans offered basic primary care and prescriptions to adults and children in rotating areas in the Rockaways, Brooklyn, and Staten Island based on community needs; these vans served on average more than 40 visits each day. By January 14 more than 600 people had received medical care from the National Guard at their homes and another 1,100 received follow-up care from the Visiting Nurse Service." (Page 7)

"Mayor's Office for People with Disabilities (MOPD): People with disabilities faced unique difficulties as a result of Hurricane Sandy, particularly if they lived within Zone A and faced mandatory evacuation. Those who lost power in other zones faced their own New York City CDBG-DR Action Plan challenges, including being trapped in their apartments with no elevator access; being unable to power life sustaining equipment; and dealing with shortages of food, durable medical equipment, and medication. In particular, those in need of dialysis found it very difficult to get treatment because sites were closed and transportation was not available." (Page 94)

"As mentioned earlier, the damage, flooding, and power disruptions resulting from Hurricane Sandy forced to evacuate and temporarily close two of the City's public hospital facilities, Bellevue Hospital (a crucial level-one trauma center) and Coney Island Hospital, and to divert patients from the Coler-Goldwater Specialty Hospital and Nursing Facility. These closures, as well as damage to other HHC facilities, forced the displacement of hospital medical and support staff.

After the evacuations, Coney Island Hospital and Bellevue worked to reopen rapidly, and there was a four month process to fully restore services at Bellevue and partially restore services at Coney Island Hospital. During that four month period, inpatient (and most of the outpatient) services were not being provided at these hospitals. Medical employees were redeployed throughout HHC in order to avoid staff attrition which would have delayed the eventual reopening. In addition, non-medical staff were maintained to assist with the response and recovery of the closed facilities. Further, other expenses, such as contract payments to affiliated medical schools that provide physicians services such as New York University Medical School and Mount Sinai, continued. Most of these costs were not supported by additional revenue in the facilities to which they were redeployed, since patients were largely redirected to non-HHC facilities such as Beth Israel. Therefore the closed hospitals were cut off from Medicaid, Medicare, and commercial insurance. If necessary, the City will seek a waiver to recover these expenses incurred to maintain operational readiness." (Page 103)

The questions that cannot be answered from the DARP are; what were the direct technical issues at the hospitals that caused the electricity system to fail? And what technical issues delayed the reconnection of the electric system? Knowing the answers would help to provide a more resilient system during the reconstruction phase of the disaster.

There is also some data from tropical storm Allison, which in 2001 caused to total meltdown of functionality at the Memorial Hermann Hospital in Houston Texas, which was closed for 38 days. A paper by Nates (Nates, 2004) gives a rare insight into the impact of the loss of electrical power to the level 1 trauma hospital. Below is a summary of what happened.

> *« In June 2001, tropical storm Allison caused >3 feet of rainfall and catastrophic flooding in Houston, TX. Memorial Hermann Hospital, one of only two level I trauma centers in the community, lost electrical power, communications systems, running water, and internal transportation. All essential hospital services were rendered nonfunctional. Life-saving equipment such as ventilators, infusion pumps, and monitors became useless. Patients were triaged to other medical facilities based on acuity using ground and air ambulances. No patients died as result of the internal disaster.»*

This description shows how vulnerable healthcare provision is during a blackout. The reason that there were no fatalities was due firstly to backup generators, battery packs and personal mobile phone, and secondly for some patients, it was the dedication of the healthcare professionals who operated manual equipment on shifts, until the patients could be evacuated.

This disaster put the hospitals out of commission for up to four months. The tropical storm was forecast which gave time for contingencies to be put into operation. However there are many instances where unexpected total blackouts occur for only a few hours, and where ICUs have to go into manual mode to keep patient alive through manual means. In the literature between 1992 and 2010 at least 7 instances are documented of total electrical failure, where even the emergency backup system failed. (Carpenter & Robinson, 2010; Fawcett, Blowers, & Wilson, 2001; Maxwell & Oneil, 1993; Mitchell, 2001; Ohara, 1993; Ohara & Higgins, 1992) The only solution provided by these papers is for better maintained emergency generators and the use of more battery powered devices including lighting.

4.2.3. When water meets electricity

The utility companies in the United States have contingency plans to cut all power to areas where flooding is expected. This is done to prevent water coming into contact with high voltage electricity. If this were to happen, then besides causing damage to the electrical infrastructure, there can be a catastrophic secondary consequence of fire.

> *« Fires also hit a few areas, most severely in Breezy Point where 126 homes burned down and another 22 were seriously damaged. » (DARP Page 94)*

According to the New York 1 News;

« Fire Commissioner Salvatore Cassano said rising sea water made its way into electrical systems at a home at 173 Ocean Avenue. » (NY1. News)

The incident shows vulnerability in the centralised electricity system. In the USA, in contrast to most of Europe many of the houses are made from wood and are bungalows. What happened was, as the water encroached into the Breezy Point neighbourhood, it came in contact with electricity and caused a fire. This fire began to spread from house to house and as the roads were under water the fire-fighters were unable to get their apparatus near the burning properties. They had to use boats to rescue people form building that were on fire. In this incident houses were completely destroyed by what essentially was the secondary effect of the electrical fire.

This incident although caused by electricity, the news focus has been on the fire and since there was prior warning of possible tidal surges, the question asked was "why wasn't the electricity to the whole area cut by the service provider?". However little has been reported about what can be done to change the electrical system to mitigate against flood water coming into contact with high voltage systems and causing damage and huge fires. This fire shows what can happen when a sudden incident takes place and the authorities do not have the time to react by cutting the power to the whole area.

4.2.4. Law and order and some social aspects

The loss of electric power which results in the electrical equipment not being able to operate is a direct impact. However the loss of the functionality of the equipment provides a secondary effect and may actually have a chain reaction effect that leads to secondary public safety, sociological and economic impacts.

Set out below were some of the multi-agency solutions that employed a huge amount of manpower to deal with the secondary law and order and social consequences of the loss of electricity;

« •Enforcement activities including residential and commercial anti-looting patrols, focusing on key neighborhoods around the City that were without power;
•Regulating traffic, and monitoring citywide gas distribution;
• During the citywide gas shortage officers were posted at open gas stations throughout the City;
• Neighborhood patrols and door-to-door checks on residents in the public housing facilities which lost water and electricity;
• Traffic Enforcement Agents worked overtime to direct traffic in the neighborhoods without power throughout the duration of the power loss. » (DARP Page 102)

From the solutions provided one can imagine what societal breakdowns could have happened if the city authorities were unable to implement their disaster contingency plan. For example during a power cut the traffic lights do not work. If we exclude the deployment of skilled traffic officers, within a short time gridlock could have occur. This produces delays in people's journeys, in the emergency services getting to where they are need to be, etc. Gridlock and delays are ingredients for road rage, which in extreme cases can lead to grievous body harm and even death. A shortage of petrol can lead to civil unrest and it is therefore presumed that the officers posted at the open gas stations were there to keep the peace. What is not known is why many gas stations were closed, and to what extent this was due to the need for electricity to operate the pumps, till, lighting etc. in the gas stations. What is known, is that there was,

> *«..a three-week citywide gas shortage. » (DARP Page 104)"*

4.2.5. Drinking and waste water

The role of electricity plays in in providing drinking water and removing waste water is not well understood by the average city resident, and having water on-tap is taken for granted. However due to a prolonged widespread blackout when the tap runs dry and the sewage backs up, it then becomes apparent how crucial electricity is to the movement of water in an urban environment. The extracts in Box 1.4 state that there was damage to the electrical systems which operated part of the city's water system. The DARP is a document that is primarily looking at the damage to the water system through the eyes of the reconstruction plan. What is only known is that the damage to the city's electrical system caused the loss of functionality to the water system. Knowing the exact damage to the electrical systems would help in identifying how a DC system would provide a more robust water system. Some of the damage may have been due to sea water damage that ingrates into the wires and can cause degradation (Sasaki et al., 2012).

Box 1.4 How the loss of electricity effected the New York water system (Source DRAP)

"The New York City Department of Environmental Protection ensured that the City's drinking water remained safe during and after the storm despite the fact that all of the City's water pollution control plants (WPCPs) experienced some degree of damage as a result of Hurricane Sandy. Power was lost at many facilities that compose City's drinking water supply system, including a dam and several reservoir control stations. Power was lost at a number of water supply shafts, and fencing and security equipment was lost at several facilities." (Page 97)

"Of the 14 wastewater treatment plants, 10 were adversely affected by Hurricane Sandy. Most of the damage to wastewater facilities was to electrical systems: substations, motors, control panels, junction boxes and instrumentation. Due to utility power outages, many DEP facilities operated on their emergency generators for up to two weeks. Of the 96 DEP pumping stations, 42 were affected during the storm. Approximately half of the pumping stations failed due to damage from floodwaters, and half due to loss of power supply. The large unmet need to reconstruct and rehabilitate the City's damaged water and wastewater systems are expected to be funded out of future allocations." (Page 116)

"Department of Sanitation (DSNY) documented damage at 61 of its facilities throughout the City. The Department evacuated 14 of its facilities on or before October 29, 2012 and has since returned to all facilities except the Manhattan Community District 1 Garage. The Garage, located directly across the street from the Hudson River, was damaged beyond repair. Operations have been relocated to other facilities pending the completion of construction on the new Manhattan Community Districts 1, 2, and 5 Garage. Severe damage to the electrical cabling at the Brooklyn Community Districts 1 and 4 Garage, as a result of salt water immersion, has forced the facility to resume only limited operations under temporary generator power pending the completion of electrical repair work currently underway. Operations at Department offices located at 44 Beaver Street in Manhattan were displaced for four months following a complete loss of power to the building. Water entered elevator shafts, air conditioning and ventilation units, and electrical switches and New York City CDBG-DR Action Plan transformers and also disabled domestic water pumps, the fire safety system, and air compressors. The Department has recently begun the process of resuming operations at 44 Beaver Street". (Page 112)

4.2.6. Economic activities

«Around 2,275 businesses were impacted. On the Peninsula, a commercial strip along Beach 129th Street was destroyed, more than 50 businesses experienced severe loss from fire and flooding on Rockaway Beach Boulevard from Beach 116th to Beach 100th Streets and more than 40 businesses on Beach 116th Street were seriously flooded. Several businesses were destroyed in Breezy Point and all were affected in Broad Channel. Far Rockaway's main commercial corridor on Mott Avenue experienced less impactful physical damage, but like the rest of the Peninsula the long term power outages led to economic loss. Five months following Sandy, businesses remain closed and of those open, many are struggling to rebuild. » (DARP Page 94)

« .. significant losses to industrial businesses, which often keep their valuable equipment on the ground floor, .. » (DARP Page 82)

It does not state what caused the fire in the businesses on Rockaway Beach Boulevard, so we do not know if electricity was involved like that at Breezy Point. In Mott Avenue the economic impact was directly due to the power outage and not the physical damage of the shops. Very little is known at this time about the extent of direct economic loss across the whole city that was associated with the loss of electricity. This extract is only about one particular area the Peninsula, which after five months was not back to pre-hurricane conditions. There is no mention about the extent of structural damage and why the businesses remained closed. However it is assumed that the loss of power has a lot to do with it.

The direct impact of the loss of electricity can be a cessation of economic activities. This could lead to bankruptcy, loss of jobs for employees, and cause a downward spiral to the whole local when many shops close at the same time. Secondary economic effects can be when the customers and the employees are forced to relocate due to loss of electricity and their unavailability to work and buy goods and services leans to closures. Steps were taken to stop the hospital losing its skilled employees.

> *« Medical employees were redeployed throughout HHC in order to avoid staff attrition which would have delayed the eventual reopening. » (DARP Page 103)*

4.2.7. Communications systems

All communications devices need electricity, either via the mains for batteries, so being able to communicate in times of national crisis is a lifeline for the people and is critical in the process of implementing a Crisis Management Plan. However the electrical system in place today is not robust enough to stand up to the challenge of a national disaster. The DARP states that in Hurricane Sandy affected the ;

> *«Telecommunications networks (power outages and flooding resulted in outages leaving thousands without landline, cable, and mobile service). » (DARP Page 84).*

It is presumed that many people lost their internet connections, including wireless connections.

All but one of the hospital cases cited in section 4.2.2 above testified to the need or a battery operated backup communications system. In all cases the staff relied on their personal cellular phones, to communicate between the staff within the hospital and with the outside world, in some cases until the batteries ran down. Nates (2004) states *that;*

> *«In our case, the personal mobile phones of medical personnel on call became the primary mode of external communication, and messengers on foot maintained internal communication between departments. Walkie-talkies were of limited use owing to the size of the institution. »*

And then goes on to make some very pertinent points,

> *«The interruption of external and internal communications seriously threatens any disaster plan and is in itself a disaster."* He therefore recommends that *"Hospitals*

should have battery-operated internal and external communication systems readily available in the event of a wide-spread disaster and communication outage. »

Increasing resilience by relying on external organisations for communication purposes is a very good idea, and should be rolled out in more places. Nates continues that;

> *« ..in California have led to the development of very well-organized emergency communications system known as Hospital Disaster Support Communication System (HDSCS) in their region (26), and there are other examples at sea (27). The HDSCS is a group of 90 amateur radio operators who provide volunteer backup to 35 institutions in case of internal or external communications failure for any reason in Orange County, CA (28). Since 1980, HDSCS has been involved in 73 communications emergencies, 22% of them serious (e.g., earthquakes, firestorms, floods) »*

In the United Kingdom, analogue telephones operated on a 5 Volt power line powered from the telephone exchange that had DC voltage battery backups in case of power cuts. This meant that power cuts did not affect peoples' ability to communicate in times of blackouts. However now, the UK and much of the developed world are moving to a fully digitised world, where the telephone, Radio and Television can all work over the internet. The problem with is this that in times of power cuts all mass communication services become severed, with the mobile phone only lasting as long as its battery life allows. How will governments or public authorities communicate with people in times of disaster if there is a wider spread prolonged power outage? This problem was highlighted by Akerlund (2000), and seems to perhaps be the elephant in the room to the resilience community, like cyber security was to the smart grid community.

5. Discussion

5.1. Introduction

The goal for Thematic Research Area 8 was to provide solutions to reduce the vulnerability of economic activities from a national disaster. This paper has identified electricity as being a cross-the-board ingredient that affects many strategic functions of all aspects of disaster resilience, including economic activity. To continue economic activity, the resilience of many support activities that may not be part of the value chain for goods and services, must be operational in order for ordinary aspects of economic activity to carry on. Many of these support activities that were gleaned from the case study literature, are not only specific to economic activity but are critical aspects for the smooth running of society. We have therefore looked at the problem of the vulnerability of economic activities in the wider context of the whole socio-technical system which is underpinned by electricity.

5.2. Some economic parameters

In general there are three sectors in an economy, industrial, agricultural and service sectors, each produce and distribute their output for consumption (UNISDR, 2013 Chapter 10). Much of the economic outputs are both produced and consumed by people, and each sector has a similar yet diverse value chain, see Diagram 1.

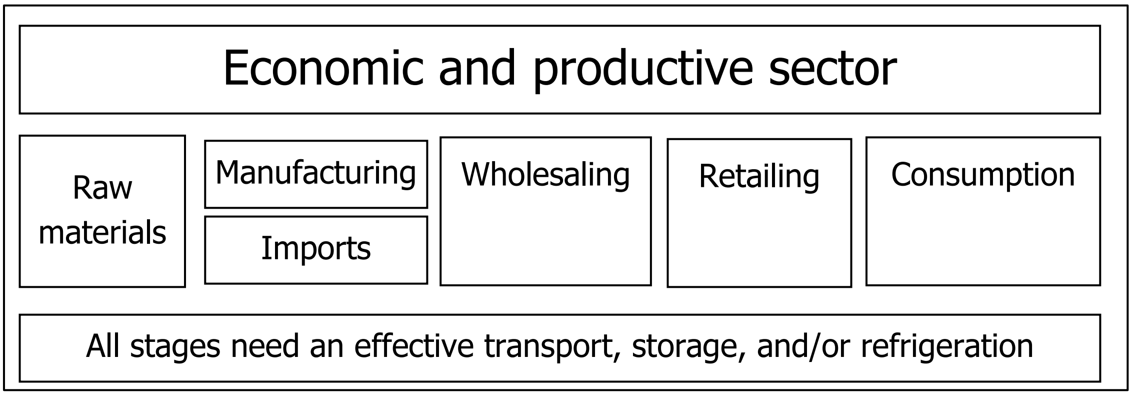

Diagram 1: The economic value chain

All economic activity needs a place of operation, which could be a piece of land, a factory, office, shop etc. It needs a source of raw materials, which in the case of some service industries may be human skills. It needs a means of production, which could be manual or electric tools, heavy machinery or electric instrumentation like a computer. In the case of perishables there is also the need for freezing or refrigeration. For all industries transportation is vital at many key points in the value chain. A thread that holds the whole system together is electricity. Box 1.5 show generalised economic activities.

Box 1.5 Important factors that incorporate economic activity

Economic Sector	Means of Production	Distribution	consumption
Agriculture	Land, seeds, water, machinery, workforce	Transportation, Wholesaling and retailing	Food purchased by Consumers
Industrial	Supply chain of raw materials, factory, machinery and workforce	Transportation, Wholesaling and retailing	Products purchased by Consumers
service	Office, Trained and skilled workforce	Sales and marketing	Services purchased by consumer

5.3. The link between economic activity and electrical energy

The economics of electricity and how its proliferation affects the growth of a country's gross domestic product is a matter of a three way discussion. In section 6.4.2 of the GEA (2012) the research shows that for developing countries the effect energy has on GDP growth is either; a little effect (Wang, 2008), depends of the industrial development of the country, (Soytas, 2006), or it causes GDP growth (Lee, 2005). Whatever the view about the correlation between GPD growth and electricity, by implication, everyone should agree that cutting the energy supply will have a negative impact on every economy. In fact when a power cut occurs, whether due to a technical fault or manmade, whether for a few seconds or a few hours, there will be an associated economic cost (The NextGen Energy Council, 2008). Estimates of such economic costs can be very high for industry, (Balducci, 2002) as well as for domestic customers (Praktiknjo, 2011), there are also the social costs. Work has been carried out to ascertain peoples' willingness to pay a premium to avoid domestic power outages (Carlsson, 2008; Leahy, 2011). The latest scheme is to signup business customers who are willing to either get paid or pay a lower tariff, if they agree that their electricity supplier can balance their supply system by temporarily cutting them off.

5.4. The Socio-technical nature of economic activity

People make products that people consume or use. Therefore the work force is crucial to productivity. We define workforce in two groups, those that are involved in the direct aspects of the economic activity and those that facilitate the smooth running of economic activity. Anyone who works in any aspect of the value chain as shown in Diagram 1, works in the direct aspects of economic activity. It has been shown from the DRAP report that during and just post Hurricane Sandy many people were deployed in what is termed "enforcement" activities. These included, extra patrols in the economic districts to prevent looting, traffic officers to prevent gridlock, many volunteers were needed to help look after the needy with food and medicine, etc. All these people while not producing products were reducing the impact of the disaster on the people.

From the point of view of the economic and productive sector, there are many auxiliary activities that can reduce its effectiveness, one of which is a reduction in manpower. Whatever the size of a disaster, a reduction in the availability of the workforce will create an adverse failure chain in the economic system. Similarly an adverse failure chain around the workforce can reduce or even remove their ability to work. There is a circular symbiotic relationship between people and economic activity. This research therefore approached the problems of economic resilience within the context of a disaster as being a socio-technical system. The social part is that which affect the ability of people to facilitate economic activity, and the technical system as being the whole economic value chain. The underlying linchpin for this whole socio-technical system is electricity, the loss of which adversely affects both the social and the technical aspects of economic activity.

The auxiliary activities that facilitate economic activity are shown in Diagram 2, each of which is a technical subsystem in itself. Diagram 3 shows the activities around the workforce which if they fail can have an adverse effect of their ability to work.

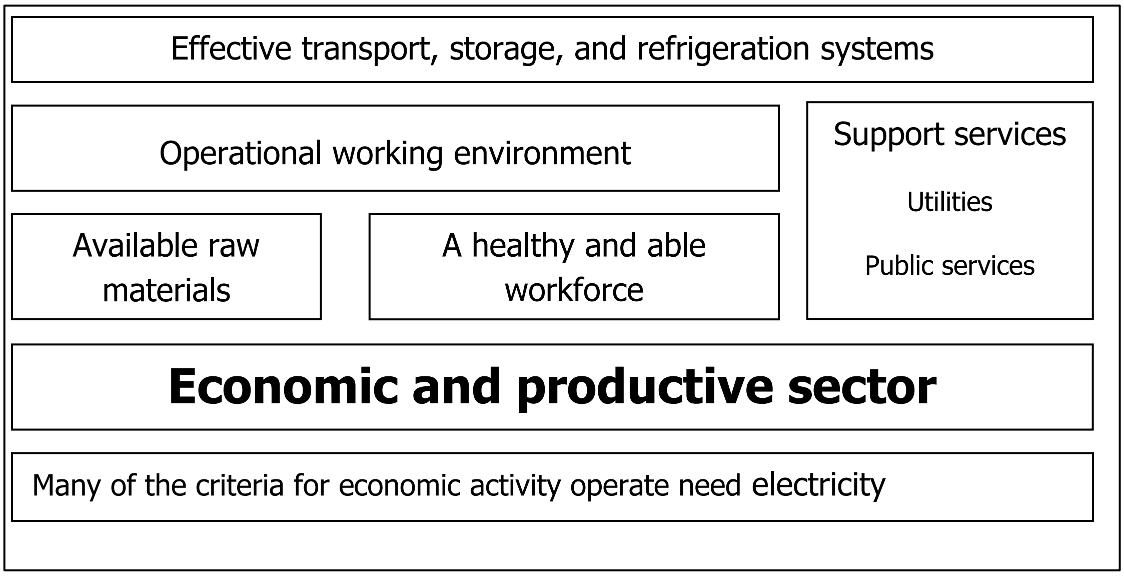

Diagram 2: The auxiliary systems around the economic sector

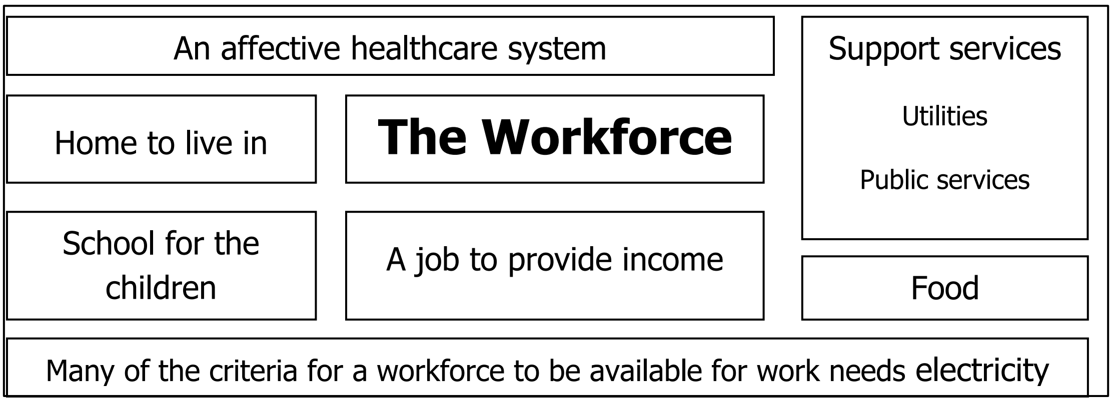

Diagram 3: The auxiliary systems of the social system

5.5. Interrelationship between failure chains and economic activity

For the workforce to be able to function normally post a disaster, all the auxiliary functions that are pivotal for a society to function will have to be operational. This means that people have the basics for human existence, a place to live in and food. Having electricity for lighting, heating and cooking is essential to normal living. If the schools are closed because there is no electricity people may be forced to relocate. Even without relocation, if the schools are closed solely due to not having electricity this could hamper one or more of the parent being able to go back to work. Any dysfunction in the health service that is solely due to the loss of electric power, as highlighted in the case study literature, can have an adverse effect on the ability of people to get back to work, due to their personal or someone in their cares' health needs. The DRAP report highlighted many of the failure chains caused by the loss of electricity. For example the dysfunction of the water services, the traffic and street light, security systems, the city's transport system, communication systems etc. all of which need electricity to function. Economic activities needs these systems to function, so the question that needs to be addressed is, 'in light of the massive economic loss due to a large scale power cut, what can be done to make the electrical system more robust so that the negative economic impact due to a national disaster can be minimised ?'

5.6. Solutions

Centralised electrical systems by their very nature have many points of vulnerability between the points of generation and consumption. Therefore when a disaster affects any one of the critical points in the system, it will cause a blackout in a larger geographical location than where the actual damage occurs. Using village-wide microgrid photovoltaic systems are less vulnerable than centralised systems. However such systems usually only provide a basic living standard that is below that of the developed world.

Current renewable energy systems have the disadvantage that the electricity is generated as direct current voltage (DC) is transformed and distributed as alternating current (AC), and if consumed by electronic devices again changed back into DC voltage. This double transformation introduces energy loss into the system and increases the capital cost of the system. In many disasters only a proportion of the built environment is adversely affected. If the electricity supply to the remaining structures is from autonomous DC voltage systems, then the living standards of those that still have electricity will be maintained.

The solution prescribed by this research is to change the electrical system from a centralised AC voltage system to a distributed DC voltage system. Besides increasing a city's resilience it will also provide in normal times, an electrical system that can provide a high degree of energy independence and energy security for all its' citizens. The question that needs answering is, where there is minimal to no physical damage to the built environment, what would have been the impact from Hurricane Sandy or any national disaster, if there was a distributed electrical system?

When the built environment is rendered uninhabitable the type of electrical system it used is irrelevant to the ability of the inhabitants being able to rebuild their lives. However in all disasters, where the centralised electricity system is damaged and where the built environment is still habitable, then the type of electrical system used becomes very important. Both the case studies mentioned above had very little damage to most of its infrastructure, yet the usability of the homes and hospitals was either reduced, or for a short time had to be evacuated. This shows an inherent vulnerability in the centralised model for the electrical system.

This research therefore prescribes a distributed direct current electrical system to enhance disaster resilience. The DARP recommended the installation of emergency generators, for critical systems. This is the beginning of implementing a decentralised system. However this is only for emergencies and not for day to day usage. This research recommends to go a stage further, and begin to roll out across the whole build environment a distributed DC voltage system. The advantages of using DC have been discussed by Kinn (2011b; 2011) in great detail and are above in Box 1.1. Cheng (2009) as cited form (Bruneau et al., 2003) describes three criteria for infrastructure resilience. A fully DC voltage distributed system will, in a disaster situation, meet these three criteria of resilience. The first criteria is 'a system that has a low probability of failure', in a disaster for those buildings/residences not directly impacted by the disaster their electricity systems should not fail at all as they are 'islanded' systems. This therefore implies that the number of people affected by the blackout is kept to a minimum, thus fulfilling the second criteria of, 'a less-severe negative consequences when failures do occur'. In a conventional centralised electrical system, to reach pre-disaster functionality, the damage to both the centralised infrastructure as well as that to the built environment will have to be repaired. However in a distributed system only the direct damaged to the built environment will have to be repaired, thus meeting the third criteria of 'faster recovery from failure'.

The only solutions provided by the case studies in the healthcare sector were for better maintained emergency generators, and the use of more battery powered devices including lighting. It was shown that in some instances the backup generators either did not come on-line or failed leaving the hospital in total blackout. This tells us that the emergency generator is in fact a centralised system that relies on a single generation and transmission system. The batteries act as a distributed system, however the lifespan of batteries is only good for a few hours. If one considers an incident like Haiti or Typhoon Haiyan , where there was mass destruction of the built environment, and a mass casualty event, then the best reliable method to keep the electricity flowing is a total distributed mesh system, with many generators, and many paths for transmission. Obviously for such a system to be operational the infrastructure of the hospital building must be usable.

The case studies showed that when implementing a resilience strategy against flooding, putting electrical equipment in the basement and ground floor is not a good idea. The physical layout of the building of the Memorial Hermann Hospital is not known, however according to Nates, the emergency generators were on the second floor yet the flood water was able to damage them. Therefore this research recommends that when implementing distributed DC systems, the electrical sub-systems, (multiplexer board, breaker board, voltage controller and meter etc.) should be placed in the loft/roof space, or as high in the property as possible. This adds to the resilience of the property if the water damage affects the ground floor.

When water gets into the electrical system the low voltage should ensure that the circuit breaker activates without a fire hazards. This may mean that with the isolated generators on the roof (Say PVs) the electricity in the upper floors of the building will not be affected. For large apartment blocks like Red Hook, only the residence on the water damaged floors will be affected. This may help in post disaster reconstruction. Sea water causes corrosion to cabling and therefore a more robust sheathing and waterproofing should be implemented. One of the problems in the delays in getting back to normal is the time it takes to restore the energy system, plus the time for the structure to dry out. If each property has a fully functioning electrical system above the water damage line, then the process of pumping water out and drying out could in theory start straight away post facto, using the available on-site electricity.

The DRAP stated that *"..enforcement activities including residential and commercial anti-looting patrols, focusing on key neighborhoods around the City that were without power* (page 89).

If New York had had widespread completely autonomous low powered LEDs street lighting systems, and all theft alarm systems were locally powered, then the need for massive manpower to patrol the streets against ant-social behaviour would have been drastically reduced. For the many patients living above the water line who required electrically operated medical equipment, both in the Hospitals and at home, such a system would have provided them with electricity and would have mitigated all the logistics needed to help them.

5.7. Limitations of the case study data

At this time the data provided by the disaster literature is of aggregated values of a loss factor. Some examples of loss factors are; how many houses were damaged, how many businesses were closed or how many public building were out of commissions. What is not known is the details of each building and why they were rendered non-operational. What is actually needed is the actual consequences of every direct and secondary impact along the whole failure chain due to the loss of electricity. Only from this will it be truly understood the advantages of a decentralised system.

The papers about the healthcare system come from hospital staff on the front line, who reported on first-hand knowledge of the incident. The focus of their papers was not about the resilience of the electrical system, it was about highlighting the need to train anaesthesiologist for emergency events like total loss of electricity power. At this time this research has not found any resilience academics who write about disaster resilience or resilience cities, looking specifically at how electricity affected the incident they are writing about, or planning to mitigate.

While our solution is a distributed direct current system, at this time only an expensive alternating current system exists. There are very few, but growing number, of DC appliance for the home and office, but not enough to provide the plethora of gadgetry available on the market. The use of DC motors and electrical equipment for the light industrial sector are also limited.

6. Conclusions and further work

Many of the problems highlighted by the two case studies could to some extent have been mitigated, by the use of distributed electrical systems in a mesh-network configuration. Changing the system to use direct current voltage will add many more technical advantages and provide energy independence and energy security. A more robust electoral system would reduce the economic impact and increase the availability and ability of the survivors to resume work.

With the data available it is not possible to ascertain the extent of the costs expended in dealing with the disaster that could have been saved had the system been a distributed electrical system. However it is clear that the scale of the New York Disaster Emergency Action Plan would have been much smaller in terms of manpower, time, and would have saved a lot of money.

It is concluded that there is a knowledge gap in the disaster literature with regard to specific details on the direct impact of power outages on, the usability of the build environment, the living standards and conditions of the survivors, and on what changes are need to the electrical system to reduce all impacts of loss of electrical power. Although everyone living through a disaster has first-hand knowledge about how they were affected by the loss of electricity, the research community needs to increase its efforts in firstly understanding the direct and indirect impacts, and secondly providing solutions to increasing the resilience of the electrical system.

The advantages of using decentralised electrical systems have been highlighted, however at this time the used of DC as a main electricity source for the low powered user, needs more research and development as well as new extra-low and low voltage Regulations and Standards, before DC voltage can be rolled out for general usage.

Further research is need to see if a more resilient city, powered by distributed DC systems, would break the negative correlation between disasters and foreign direct investment (UNISDR, 2013 Box 12.2 page 196)

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